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Evaluating foreign exchange market intervention: Self-selection, counterfactuals and average treatment effects

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**Evaluating Foreign Exchange Market Intervention:
Self-Selection, Counterfactuals and Average Treatment Effects**

SCCIE Working Paper No. 06-04

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Abstract: Studies of central bank intervention are complicated by the fact that we typically observe intervention only during periods of turbulent exchange markets. Furthermore, entering the market during these particular periods is a conscious “self-selection” choice made by the intervening central bank. We estimate the “counterfactual” exchange rate movements that allow us to determine what would have occurred in the absence of intervention and we introduce the method of propensity score matching to the intervention literature in order to estimate the “average treatment effect” (ATE) of intervention. Specifically, we estimate the ATE for daily Bank of Japan intervention over the January 1999 to March 2004 period. This sample encompasses a remarkable variation in intervention frequencies as well as unprecedented frequent intervention towards the latter part of the period. We find that the effects of intervention vary dramatically and inversely with the frequency of intervention: Intervention is effective over the 1999 to 2002 period, ineffective during 2003 and counterproductive during the first quarter of 2004.

Key words: Foreign Exchange Intervention, Bank of Japan, Self-Selection, Matching Methods.

JEL Classifications: E58, F31, G15.

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1. Introduction

Central banks typically “self-select” to intervene during periods of abnormal exchange rate movements and not when normal market conditions prevail. As a result, we tend to observe intervention and assess its effects only during episodes of market turmoil and not during more tranquil periods. Furthermore, since an exchange rate movement at any given point in time coincides with either intervention or no intervention, we cannot directly observe both what is the exchange rate movement coinciding with intervention and what would have been the “counterfactual”, i.e. what would have been the exchange rate movement if intervention *had not* occurred when the authorities did in fact intervene. Clearly, the counterfactual is not directly observable and, as such, this constitutes a missing data problem. These inherent issues of self-selection and missing data complicate the assessment of the effects of intervention. Following the modern literature on treatment effects (see Imbens, 2004, for a recent survey), we address the issue of self-selection and the missing counterfactual by estimating the “average treatment effect” (ATE) of intervention on the exchange rate. We use a propensity score matching methodology to do so.

The approach taken here to evaluate the effectiveness of intervention, while addressing the aforementioned methodological issues, is to postulate a counterfactual and, in turn, match pairs of observations of exchange rate movements – each pair consisting of an exchange rate movement coinciding with intervention and one that coincides with no intervention - on similar observable characteristics. We consider intervention as a "treatment" and, using matched counterfactuals, investigate the exchange rate movements with and without intervention in otherwise identical circumstances (as far as can be determined by observable market characteristics that lead up to the decision by the central bank to intervene). By using similar

economic circumstances that lead to intervention (similar probabilities of intervention) for “matching up” observations that differ only in whether intervention occurs or not, we are able to address the missing observations and the sample selection bias issues, thereby obtaining more reliable estimates of the effects of intervention.

The focus of our matching analysis is to examine the effects of daily Bank of Japan (BoJ) interventions in the JPY/USD exchange rate market over the January 1999 to March 2004 period. This is a fascinating and unprecedented period in the history of foreign exchange market intervention and fits our methodical framework perfectly. Firstly, the magnitude of intervention was extremely large. Japanese foreign exchange market intervention jumped in 2003, shown in Figure 1, with the BoJ selling JPY 20.2 trillion (USD 177 billion) in exchange for USD - an amount surpassing that of any other country for any given year. Massive intervention operations in support of the USD continued in the first quarter of 2004, during which time the authorities sold another JPY 14.8 trillion (USD 139 billion). Although Japan has been the most active amongst the larger industrial economies in its foreign exchange market operations during the past decade and more, the recent magnitude dwarfs all previous experience. Secondly, there are distinct periods of intervention frequency during this sample period. Fatum and Hutchison (2005) and several others observe that a sharp departure from past BoJ intervention policy began in early 2003 when the frequency of interventions jumped dramatically. BoJ intervention continued in the first quarter of 2004 and, in fact, this quarter stands out with an intervention frequency of 85% of business days. Consistent with the studies by Ito (2003 and 2004) and Kearns and Rigobon (2005), we identify three sub-samples of separate intervention regimes according to, in our case, highly noticeable changes in the BoJ intervention frequency. Formal

tests of reaction function parameter instability across the sub-samples confirm the existence of three separate BoJ intervention regimes.¹

The basic methodology consists of two parts. In the first part, models of the BoJ decision to intervene are estimated separately across the three sub-samples. From the model estimates, the probability of intervention (a propensity score) for each day in the given sample is derived. The sample is then split into a group of days when intervention occurs and a group of days when no intervention occurs. Regardless of whether or not intervention occurs on a given day, there is a uniquely defined intervention probability associated with each day in both groups as well as a realized (day-to-day) change in the JPY/USD exchange rate. In the second part, a matching algorithm – the so-called “nearest neighbor” algorithm where each intervention observation is matched with the no-intervention observation that has the “nearest” propensity score - is implemented and the ATE of intervention on exchange rates is examined using difference-in-means tests.

Focusing on all intervention days and the general issue of effectiveness, the results of the ATE-matching analysis show that the effect of BoJ intervention varies dramatically across the three sub-samples under study: significant effect (in the “right” direction) during the period of infrequent interventions, no significant effect during the period of relatively frequent interventions, and a perverse (“counterproductive”) effect during the period of very frequent interventions. Furthermore, we find a systematic pattern of non-uniform intervention effects across specific types of intervention days, indicating severe structural parameter instability across different intervention regimes. These findings are consistent with the view that infrequent intervention operations may surprise markets and prove an effective policy strategy, while

¹ Despite the evident departure from past intervention policies, there was no official announcement of a policy change in January 2003 or in January 2004. Furthermore, there was no official announcement made when the active BoJ intervention policy ended abruptly on 16 March 2004 and no intervention took place in the remainder of 2004.

frequent intervention operations – even very large scale - are incorporated into market expectations with little or even counterproductive effects.

The rest of the paper is organized as follows. Section 2 describes the BoJ intervention data. Section 3 further discusses the matching methodology and its application to the study of intervention; this section also describes the reaction function estimations necessary for extracting the propensity scores used in the matching. Section 4 presents the results. Section 5 discusses the results in light of other recent intervention papers. Section 6 concludes.

2. Data

The BoJ intervention data is provided by the Japanese Ministry of Finance and consists of official, daily operations in the JPY/USD foreign exchange market. During the period under study, 1 January 1999 to 31 March 2004, all BoJ interventions in the JPY/USD market are sales of JPY against purchases of USD. During this period, the US Federal Reserve was not active in the JPY/USD exchange rate market.

Table 1 shows that during the full sample period, the BoJ intervenes in the JPY/USD exchange rate market on a total of 159 days. On most intervention days the magnitude of intervention is substantial, with purchases of over USD 1,000 million and larger dominating (46 intervention days of less than USD 1,000 million are reported and only 20 intervention days consist of less than USD 250 million).

Table 1 also shows that only 30 of the intervention days occur during the first three years of our sample (between January 1999 and December 2002), 82 intervention days occur during 2003, while a remarkable 47 intervention days occur during the last three months of our sample (between January 2004 and March 2004). The described variation in intervention frequencies

across the three sub-samples suggests that the January 1999 to March 2004 time period encompasses not one but three different intervention regimes.

We follow Ito (2003) and others in using noon New York quotes of the daily JPY/USD exchange rate. The exchange rate data are obtained from the Board of Governors of the Federal Reserve data bank.

3. The Method of Matching

The advantage of the matching method is that it addresses the issue of non-random sample selection.² Furthermore, as a non-parametric statistical method, it avoids the estimation of a time-series model of daily exchange rate changes. This is a further advantage, given the lack of consensus on what is the proper exchange rate model.

The effect of the BoJ intervention on the JPY/USD exchange rate is assessed by matching observations with similar characteristics in terms of intervention propensities (i.e. the likelihood that the BoJ is intervening on a given day), using that one group of observations consists of days when the BoJ intervened (the “treatment” group) while the other group consists of days when the BoJ did not intervene (the “control” group). In turn, the matching of observations allows us to capture the effect of intervention (the “treatment” effect) by measuring the difference in the average JPY/USD exchange rate change between the two groups.

In order to characterize the similarity among observations with and without BoJ intervention, we consider a set of observable variables that can explain the occurrence of BoJ intervention. These variables, described in detail in the next sub-section, are the standard

² See Glick, Guo and Hutchison (2004) for a recent application of the matching method to an analysis of the effects of capital account liberalization on the risk of currency crises. See also Persson (2001) for a very useful exposition of the matching methodology. An excellent textbook treatment is provided by Wooldridge (2002) and a comprehensive recent survey is provided by Imbens (2004).

explanatory variable used when estimating a central bank intervention reaction function. One approach would be to match each intervention observation with a no-intervention observation that has the same observed values of a vector of intervention determinants. This multidimensional matching is, however, difficult to implement given the relatively limited number of intervention observations and, as it turns out, not necessary. Instead, as shown by Rosenbaum and Rubin (1983 and 1985) in a general context, it is sufficient to match according to the one-dimensional probability of an observation being subject to the “treatment”. Therefore, by using the observable intervention determinants for estimating the probability of an intervention occurrence for each day in our sample, the matching is carried out according to the estimated probability of BoJ intervention (the propensity scores).

The nearest neighbor algorithm matches each intervention observation to the no-intervention observation that has the nearest propensity score. After the no-intervention observation is used, it is “returned” to the pool of no-intervention observations. The effect of intervention, i.e. the “treatment” effect, is computed as a simple average of the differences in outcomes across the paired matches.

As a robustness test, we also implement the radius algorithm. The radius algorithm matches each intervention observation to the average of all the no-intervention observations with propensity scores falling within a pre-set radius from the propensity score of the intervention observation. The effect of intervention is again computed as an average of the difference in outcomes, weighted by the number of no-intervention observations used in the construction of each match. Our results are robust to this change in matching algorithm and, therefore, only results based on the nearest neighbor algorithm are presented.

3.1 Propensity Scores: Bank of Japan Reaction Functions

In order to estimate the BoJ intervention reaction function and, in turn, extract the propensity scores, we follow Ito (2004). Ito (2004) extends the friction model developed by Almekinders and Eijffinger (1996) and uses daily data for estimating an ordered probit threshold model of BoJ intervention over the 1991 to 2002 time period. He develops the reaction function model from first principles by assuming that the Japanese monetary authority has a loss function (in exchange rate deviations from a target) that it seeks to minimize by intervening in the foreign exchange rate market. Furthermore, he assumes that the exchange rate is a random walk, and that there are “political costs” associated with intervention. These political costs are independent of the size of intervention and may help explain why intervention tends to be correlated such that intervention on day t is likely to be followed by intervention on day $t+1$.

As explanatory variables, Ito (2004) uses three measures of the past exchange rates (the first lag of the JPY/USD rate, the 21 business day moving average of the JPY/USD rate, and the one-year moving average of the JPY/USD rate) as well as the first lag of a (-1, 0, 1) intervention indicator variable that takes on non-zero values on intervention days only.³ In addition, he employs (potentially asymmetric) threshold values of intervention in order to capture when the costs of intervening are exceeded by the benefits.

As mentioned earlier, all the BoJ interventions that occur during our sample period are sales of JPY against USD purchases. This allows us to use a standard binary choice model, reflecting that there are only two (intervention or no intervention) as opposed to three

³ While Almekinders and Eijffinger (1996) use the intervention amount as their dependent variable, consistent with Baillie and Osterberg (1997), Ito (2004) uses the indicator variable of intervention as his dependent variable in a binary choice modeling framework. He argues that the decision of the monetary authority to intervene or not is more important than the magnitude of intervention.

(intervention purchases of USD, no intervention, and intervention sales of USD) possible BoJ intervention outcomes.

We use a logit model framework and estimate the following regression model:

$$(1) \quad IINT_t = \beta_0 + \beta_1 JPYUSD_{t-1} + \beta_2 TARGET_t + \beta_3 MADAY_t + \beta_4 MAYEAR_t + \beta_5 IINT_{t-1} + \varepsilon_t$$

where IINT is the (0, 1) indicator variable that takes on the value 1 on days when the BoJ intervenes and 0 otherwise, JPYUSD is the first-difference of the log of the JPY/USD exchange rate, TARGET is the first-difference of the log of the JPY/USD deviation from an exchange rate target of 125 JPY/USD, MADAY is the 21-day moving average of the log of the JPY/USD exchange rate and MAYEAR is the one-year moving average of the log of the JPY/USD exchange rate.⁴ In order to take into account the possibility of heteroskedasticity in the error term, ε_t , all our logit model estimations are carried out using White's (1980) heteroskedasticity-consistent (robust) standard errors. The constant term, β_0 , is included to allow for the possibility of a threshold value consistent with the political costs of intervention. As pointed out by Ito (2004), this "conventional" reaction function specification is a linearization of the general friction model of central bank intervention.

The reaction function model is estimated separately across the three sub-samples. The sub-samples are demarked by the striking changes in intervention frequencies.⁵ As noted earlier, despite no official announcement of a policy change in January 2003 when the frequency of

⁴ The variable TARGET is included (and significant) in the reaction function estimations displayed in Ito (2003), but not included in Ito (2004). As it turns out, TARGET is insignificant in all our estimations and, therefore, dropped from the estimations used for extracting the propensity scores.

⁵ This is consistent with Kearns and Rigobon (2005) and Ito (2003 and 2004) who identify June 1995 as a turning point in the BoJ intervention policies of the previous decade due to the noticeable change in the frequency of intervention. Ito (2003) discusses in detail how this policy change coincided with the appointment of a new director (Dr. Sakakibara) of the Ministry of Finance's International Finance Bureau.

intervention jumped to 35% of business days, or in January 2004 when the frequency of intervention jumped even further to 85% of business days, it seems evident that the de-facto intervention policy of the Japanese monetary authority has changed twice during the period under study.

Table 2 shows the resulting reaction function estimation output. For each of the three sub-samples we first estimate a reaction function with all the explanatory variables displayed in equation (1) included. These models are labeled Model 1.1 (Sample 1: January 1999 to December 2002), Model 2.1 (Sample 2: January 2003 to December 2003), and Model 3.1 (Sample 3: January 2004 to March 2004), respectively. A common characteristic of these three models is that the variables TARGET and MAYEAR are insignificant. In addition, the first lag of the variable JPYUSD is insignificant in Model 3.1.

Next, we drop the insignificant explanatory variables and re-estimate the reduced models. These models are labeled Models 1.2, 2.2, and 3.2, respectively. For the first sub-sample, the first lag and the 21-day moving average of the JPY/USD exchange rate are both (highly) significant, as is the first lag of the intervention indicator variable. This is also the case for the second sub-sample. For the third sub-sample, only the first lag of the indicator variable is significant and kept in the model.

The displayed model diagnostics suggest that the three reduced models fare well. The McFadden R^2 is reasonably high for all three models, they all pass the Likelihood Ratio test against the constant only alternative, none of the models are rejected by the Hosmer-Lemeshow test and, lastly, all three models improve the predictive ability against the naïve constant probability model.

We use a standard Wald test (F-test) to assess whether the coefficient estimates of the reduced models are significantly different across the three sub-samples. Table 3 displays the results. Comparing the coefficient estimates across Sample 1 and Sample 2 shows that the estimated parameters are significantly different, with the exception of the lagged intervention variable. While two of the explanatory variables of the Sample 1 model do not belong in the Sample 3 model, we can not reject that the coefficient estimate associated with the lagged intervention variable is the same for these two sub-samples. When comparing the coefficient estimate of the lagged intervention variable across Samples 2 and 3 we reject that the estimated parameter is the same. Overall, the Wald tests show that the estimated reaction function parameters are generally unstable, indicating the existence of three separate intervention regimes.

4. Results

As a preliminary investigation, we test for significant effects of intervention without invoking the matching technique. In order to do so, we use a standard t-test for assessing whether the average exchange rate change across intervention days is significantly different from zero. We do so across the full sample as well as separately across the three easily identified sub-samples.

Table 4 shows that intervention is, on average, effective over the full January 1999 to March 2004 period. Table 5 shows that the effects of intervention vary across the three samples and that the full-sample effectiveness result is driven by the intervention that occurred during the January 1999 to December 2002 sub-period. The idea of uniform effects of intervention across different regimes, therefore, seems questionable and we focus our matching analysis on the sub-samples separately rather than on the full sample.

4.1 Nearest-neighbor matching

Using the cumulative logistic distribution function it is straightforward to extract from the estimated BoJ intervention reaction functions the conditional probability of observing a BoJ intervention on any given day in our sample.⁶ These probabilities constitute the propensity scores necessary for the paired matching of observations. Based on these propensity scores, we employ the nearest-neighbor matching algorithm to evaluate the effect of BoJ intervention (computed as a simple weighted average of the differences in the outcomes across the paired matches). We first focus on all intervention days (ALL) and address the general issue of effectiveness, and we pay particular attention to the results from analyzing separately the three sub-samples. We then compare these effectiveness results to the previously discussed preliminary results obtained from testing for significant effects of intervention on the average exchange rate changes across the intervention days without using matching. Second, we define a “stand alone” (SA) intervention day as a single-day of intervention (i.e. an intervention day neither immediately pre- or succeeded by other intervention days) and, furthermore, we define a “cluster” (CL) of intervention days as two or more intervention days immediately pre- or succeeding each other. We then use the matching methodology to compare the effects of SA interventions with the effects of CL interventions.

⁶ In accordance with the cumulative logistic distribution function, the conditional probability of observing an intervention operation on day t is given by $P(IINT_t = 1) = \frac{e^{X\beta}}{1 + e^{X\beta}}$, where X is the vector of intervention determinants and β is the associated coefficient vector. See, for example, Humpage (1999) for an earlier application of the logit model to the study of intervention.

4.2 The Matching Results: ALL

The result of the matching analysis of all intervention days (ALL) across the full sample is displayed in Table 6. Without taking into account our insight regarding the possibility of different intervention effects associated with different time periods, this result would lead us to believe that intervention has no significant impact on the JPY/USD rate once we correct for the selection bias. As discussed below, it is evident from the analysis of ALL carried out separately across the three sub-samples that this is not the case.

Table 7 shows the effects of BoJ intervention when assessed in accordance with the matching methodology. The row labeled ALL displays the results of the effectiveness analysis when all intervention days are considered (separately across the three sub-samples).

Focusing first on the January 1999 to December 2002 sub-sample, Table 7 shows that BoJ intervention (USD purchase against JPY sale) is associated with an exchange rate movement of the correct sign (USD appreciation vis-à-vis the JPY). The point estimate suggests that an intervention day is, on average, associated with a 0.5% same-day increase in the JPY/USD exchange rate. This finding is significant at the 95% level.

Turning to the January 2003 to December 2003 sub-sample, the displayed point estimate of 0.02% is of the correct sign, but insignificant. This suggests that during 2003, intervention has, on average, no effect on the JPY/USD exchange rate.

Lastly, the effectiveness result based on the January 2004 to March 2004 sub-sample suggests that intervention is associated with a JPY/USD movement of the wrong sign. Specifically, a BoJ intervention (USD purchase) is, on average, associated with a 0.13% decrease in the JPY/USD exchange rate (USD depreciation). This finding is significant at the 90% level and illustrates that intervention may not only be ineffective (as is the case of the 2003 sub-

sample), but even counterproductive. This result is particularly interesting and further discussed in Section 5.

In order to assess the importance of carrying out the matching procedure and the importance of addressing the sample selection issue in the context of an intervention study, we compare the discussed ALL results based on matching (displayed in Table 7) to the previously mentioned ALL results based on no matching (displayed in Table 4).

For the first sub-sample, both approaches yield very similar results. Although the estimated effect of intervention based on no matching is slightly higher (and associated with significance at the 99% level) a standard t-test rejects that the two point estimates are significantly different from each other. This indicates that sample selection plays little or no role during the January 1999 to December 2002 time period and further confirms that BoJ intervention works as intended during this period. For the second sub-sample, the sign of the point estimate changes when the matching methodology is employed. However, regardless of whether we use matching or not, we find no significant effects of intervention during the 2003 time period.

Turning to the third sub-sample, however, it appears that addressing the potential sample selection issue is very important. While assessing the effects of intervention without the use of matching yields a correctly signed and insignificant point estimate, employing the matching procedure yields an incorrectly signed and significant point estimate. This strongly suggests the presence of sample selection in the first quarter of 2004 data. More generally, the comparison across the with and the without matching results seems to indicate that on the one hand sample selection can play a crucial role, and failure to account for sample selection can lead to incorrect conclusions. On the other hand, however, sample selection can play little or no role, in which

case, of course, accounting for sample selection is of little or no importance. In the context of intervention studies, it is, therefore, not clear a-priori if sample selection plays a role or not. We think that further research on when, and to what extent, sample selection matters for the assessment of the effects of intervention is warranted.

4.3 The Matching Results: SA and CL

The rows labeled SA and CL in Table 7 display the results of the matching procedure when the effects of intervention across SA (single-day interventions) and CL (clusters of two or more intervention days in succession) are analyzed separately.

For the January 1999 to December 2002 sub-sample, our findings suggest that the previously described significant effectiveness result in the anticipated direction stem from the SA interventions. In fact, the SA point estimate is of the correct sign, similar in magnitude to the point estimate associated with ALL, and significant at the 95% level. By contrast, the CL interventions have, on average, no significant impact on the JPY/USD exchange rate.

The lack of significant overall effects across the second sub-sample (2003) is repeated when assessing the effects of intervention across single-day interventions and clusters of intervention days separately. Both the SA and the CL point estimates are of the correct sign but insignificant. Consistent with the unusually high BoJ intervention frequency that characterizes the first quarter of 2004, there are no single-day interventions during the third sub-sample. The CL result is, therefore, identical to the previously discussed ALL result.

Before concluding on the SA and CL matching results, we attempt to dissect the impact of CL interventions a bit further. In order to do so we distinguish between the first intervention

day in a cluster (CLFD), the intervention day(s) surrounded by other intervention days (CLMD), and the last intervention day in a cluster (CLLD).

The results are displayed in the rows labeled CLFD, CLMD and CLLD in Table 7. As it turns out, assessing the effects of intervention separately across the three intervention day categories reveal no additional insights in the case of the first and the second sub-sample. In the third sub-sample, the first intervention day in a cluster is significant at the 95% level and, again, of the wrong sign, suggesting that the impact of a cluster of intervention days is primarily due to the first rather than the subsequent intervention days.

In sum, we ascribe the significant results found across the 1999 to 2002 to the impact of single-day intervention operations and the significant results found across the first quarter of 2004 to the impact of the first-day of a string of consecutive intervention operations.⁷

The finding of a systematic pattern of non-uniform intervention effects across specific types of intervention days – across the three sub-samples and even separately within the first and the third sub-samples – further suggests that the assumption of structural parameter stability across different intervention regimes is problematic in general and, in particular, that the assumption of uniform effects across all intervention days is not reasonable.

5. Discussion

In this section, we relate the various effectiveness results to the existing intervention literature and, subsequently, attempt to explain the clearly most striking finding, namely that during the

⁷ From the perspective of the non-BoJ exchange rate market participant, on a given intervention day that does not succeed a previous intervention day there is observational equivalence between a single-day intervention and the first intervention day in a cluster. Therefore, we also pool the single-day interventions with the first intervention day of clusters, denote these as general “first days” (FD), and redo the matching exercise in order to assess the effect across these two types of intervention days. The results are displayed in the row labeled FD in Table 7. Consistent with the previous findings, FD is significant and of the correct sign in the first sub-sample, while it is insignificant in the second sub-sample. Since there are no SA intervention days in the third sample, the effect of FD mirrors, by definition, the effect of the first intervention day of clusters (CLFD).

first quarter of 2004, BoJ intervention is counterproductive rather than effective or merely ineffective.

Focusing on the January 1999 to December 2002 sample, our finding of significant effects in the right direction is consistent with several other studies analyzing BoJ intervention over a similar period. For example, Fatum and Hutchison (2006) find significant support for effectiveness over the April 1991 to December 2000 interval, Kearns and Rigobon (2005) find effectiveness over the April 1991 to June 2002 time period, and Ito (2003) finds effectiveness over the June 1995 to March 2001 period. Furthermore, Dominguez (2003) finds evidence of significant effects in the right direction when focusing on the January 1999 to April 2000 and the September 2001 to June 2002 periods. Interestingly, none of these studies rely on the same empirical technique, yet they arrive at very similar conclusions with respect to effectiveness of BoJ intervention.

Turning to the 2003 sample, we find a complete lack of significant effects of the BoJ interventions. This no-effect result is in itself not too surprising given that several (especially less recent) intervention studies have suggested that intervention is often futile and has little or no detectable impact on exchange rate markets.⁸ It is, however, surprising that what seems to work over the previous 4 years no longer works the following year.

Looking at the first quarter of 2004, the effects of BoJ intervention are once again significant, but this time in the wrong direction. Intervention appears to be counterproductive in the sense that the BoJ efforts to support the USD vis-à-vis the JPY are associated with JPY depreciations. This finding of significant yet counterproductive effects of BoJ intervention is not

⁸ See Dominguez and Frankel (1993), Edison (1993), Humpage (2003) and Sarno and Taylor (2001) for comprehensive surveys of the intervention literature and Neely (2005a) for a critical assessment and a very useful overview of recent studies of intervention. See Galati, Melick and Micu (2005) for a recent study that finds little or no effects of BoJ intervention. The latter study focuses on perceived intervention rather than actual intervention and, therefore, their findings may not be directly comparable to ours.

completely unique, but also found in Ito (2003) when he analyzes effectiveness of BoJ intervention over the April 1991 to June 1995 period. In fact, his regression analysis shows that the counterproductive effects of intervention associated with that particular sample period are significant at the 95% level. Nonetheless, it is a very surprising result, especially since intervention had no effects during the previous year and, as noted earlier, significant effects in the right direction prior to that.

It is particularly striking that intervention is effective during the first sub-sample of infrequent interventions (3% of business days), ineffective during the second sub-sample of more frequent interventions (35% of business days) and, finally, counterproductive during the third sub-sample where the interventions occur at an extremely high frequency (85% of business days). Interestingly, this pattern is repeated in Ito (2003), who finds that intervention during the 1991 to 1995 period characterized by frequent interventions (16% of business days) is ineffective while intervention during the 1995 to 2001 period characterized by infrequent interventions (3% of business days) is effective. Although not a testable hypothesis, given that the three sub-samples of our analysis essentially constitute our three “observations”, it seems very plausible that the dramatic increase in the BoJ intervention frequencies constitute an important element towards understanding why intervention in one direction, in one exchange rate, carried out by one central bank over a total time span of little more than 5 years, turns from effective to ineffective to counterproductive.

In a recent contribution, Kearns and Rigobon (2005) introduce a modeling framework in which structural breaks in intervention regimes are used for identifying the structural parameters of their model. They find that BoJ intervention is effective over the May 1991 to June 2002

period.⁹ As acknowledged in Kearns and Rigobon (2005) and discussed by Neely (2005a and 2005b), the reliability of their findings depends on the validity of the assumption of stable structural parameters across different intervention regimes, including the parameters capturing the effects of intervention (i.e. uniform effects of intervention). The results of this paper suggest that this is not a valid assumption. That the effects of intervention vary dramatically over a relatively short period of time illustrate the problem in assuming stability of structural parameters across different intervention regimes.

The suggested “frequency” explanation seems consistent with the theoretical work by Vitale (1999). He shows that in order for a central bank to achieve the desired effects of sterilized intervention, it is necessary that the goals of intervention are undisclosed and, therefore, that secrecy of intervention is desirable.¹⁰ With intervention frequencies of 35% of business days in 2003 and 85% of business days over the first quarter of 2004 and, importantly, all interventions carried out in the same direction, it is evident to the exchange rate markets what the goals of the intervention is. In addition, it can be argued that the higher the intervention frequency, the stronger the market awareness, thereby making it virtually impossible for the BoJ to carry out secret interventions towards the end of our sample period.

This explanation is also consistent with our finding that the significant results of the 1999 to 2002 period stem from single-day intervention operations and, furthermore, that the significant results of the first quarter of 2004 stem from the first rather than the subsequent intervention days, i.e. when interventions are carried out on consecutive days. This result is in line with work

⁹ Kearns and Rigobon (2005) also examine the effects of Reserve Bank of Australia intervention.

¹⁰ It should be noted, however, that earlier theoretical work by Bhattacharya and Weller (1997) suggests that the central bank should keep its interventions secret only when the intervention objective differs from the fundamental or “true” value of the exchange rate.

by Chaboud and Humpage (2005), Fatum (2002) and Ito (2003), and again points to effectiveness being conditional on the surprise element of intervention.

Another possible component towards explaining the observed counterproductive intervention effect is found in Taylor (2004) and Reitz and Taylor (2006). Their recent work on nonlinearities in the context of the so-called coordination channel suggests that central bank intervention works as intended when the exchange rate is far away from its fundamental value, while counterproductive effects can occur when intervention is carried out during circumstances in which the exchange rate is in close proximity to this value. In keeping with their work, the counterproductive results associated with the first quarter of 2004 may be related to changes in the fundamental value relative to the market value of the JPY/USD exchange.¹¹

Lastly, the theoretical model in Ho (2004) has an interesting implication of potential relevance to our findings. Ho (2004) builds a model of the effects of intervention through signaling, and shows that counterproductive effects can arise not from intervention itself, but from the off-setting effects of sterilization. Interestingly, Fatum and Hutchison (2005) find that BoJ intervention was indeed sterilized across the January 2003 to March 2004 period. Further work is required to assess if, consistent with the analysis of Ho (2004), the effects of sterilization offer a valid part of the explanation for the ineffective as well as the counterproductive effects of BoJ intervention.

6. Conclusion

Foreign exchange market intervention generally occurs during periods of market turmoil, rather than under “normal” conditions, and the central bank makes a conscious choice to enter the

¹¹ The concept of the coordination channel is relatively new and more work is required in order to fully assess the validity of this explanation. Furthermore, a better understanding of what constitutes the fundamental exchange rate value is, of course, crucial.

market during these episodes. The special circumstances surrounding market conditions around the time of intervention operations, self-selection of timing, and the fact that we typically don't observe intervention during tranquil periods complicate the assessment of the effects of intervention. Estimating an appropriate “counterfactual” under these circumstances in order to properly evaluate the effects of intervention on exchange rate movements is a central methodological problem. We address the issue of self-selection and the missing counterfactual by estimating the “average treatment effect” (ATE) of intervention on the exchange rate. We use a propensity score matching methodology to do so.

In our analysis, the exchange rate movement is the “outcome” variable and intervention is the “treatment.” Our propensity score matching compares pairs of observations of exchange rate movements - each pair consisting of an exchange rate movement coinciding with intervention and one that coincides with no intervention - that are similar in observable characteristics (and associated with similar probabilities of intervention). The ATE is the average difference in terms of exchange rate movements across these matched pairs. The focus of our matching analysis is to examine the effects of daily BoJ interventions in the JPY/USD exchange rate market over the January 1999 to March 2004 time period.

As a preliminary investigation, we test for significant effects of intervention on the average exchange rate changes across all the intervention days without invoking the matching technique. We do so across the full sample as well as separately across three sub-samples. Consistent with the existing literature, the sub-samples are identified according to highly noticeable changes in the BoJ intervention frequency. The preliminary results clearly show that the effects of BoJ intervention vary across the three samples and, therefore, that the matching analysis should focus on the sub-samples separately rather than on the full sample.

The results of the matching analysis show that the effects of BoJ intervention vary dramatically across the three sub-samples under study. For the January 1999 to December 2002 time period, the effects are significant and in the right direction. From January to December 2003, the effects are insignificant. During the first quarter of 2004, the effects are significant but in the wrong direction.

The inverse relationship between intervention frequency and effectiveness seems apparent. Intervention is effective during the first sub-sample of infrequent interventions, ineffective during the second sub-sample of more frequent interventions and, finally, counterproductive during the third sub-sample where the interventions occur at an extremely high frequency. In this regard, however, the three sub-samples of our analysis essentially constitute only three “observations”. We are, therefore, unable to test formal hypotheses regarding why intervention is effective in the first sub-sample, ineffective in the next, and counterproductive in the last.

Humpage (2003) points out that the connection between intervention and exchange rates is not always robust across empirical techniques, currencies, and time periods. We are using one particular empirical technique, the nearest neighbor matching methodology, for analyzing the effects of BoJ interventions in the JPY/USD exchange rate, where, furthermore, all of the interventions are associated with USD purchases against sales of JPY. Yet, across the three different time periods we reach completely different conclusions regarding the effects of BoJ intervention. As we have discussed, this suggests that the explanation for the different effects of intervention is to be found in the idiosyncrasies of the three sub-samples, despite the fact that, taken together, they only span a 5-year period.

To find that the effects of intervention vary this dramatically over a relatively short period of time, and appears to vary inversely with the frequency of intervention, are important insights. This should caution studies of intervention from drawing very general conclusions based on analyses of very specific data sets. It also further calls into question the validity of assuming stability of structural parameters across different intervention regimes.

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Table 1 Bank of Japan Intervention, 1 January 1999 – 31 March 2004

Full sample: 1 January 1999 – 31 March 2004

Purchases of USD (million USD)	Number of Days	Cumulated Amount
> 1000	113	443,796
> 500	21	16,613
> 250	5	1,694
> 0	20	2,148
Total	159	464,251

Sample 1: 1 January 1999 – 31 December 2002

Purchases of USD (million USD)	Number of Days	Cumulated Amount
> 1000	28	147,629
> 500	2	1,799
> 250	0	1,694
> 0	0	2,148
Total	30	149,428

Sample 2: 1 January 2003 – 31 December 2003

Purchases of USD (million USD)	Number of Days	Cumulated Amount
> 1000	52	165,101
> 500	11	8,864
> 250	4	1,465
> 0	15	1,671
Total	82	177,101

Sample 3: 1 January 2004 – 31 March 2004

Purchases of USD (million USD)	Number of Days	Cumulated Amount
> 1000	33	131,066
> 500	8	5,950
> 250	1	229
> 0	5	477
Total	47	137,722

NOTES:

- (a) Daily Bank of Japan intervention data obtained from the Japanese Ministry of Finance data bank.
 (b) Daily intervention operations of USD 1000 million or greater: >1000; daily intervention operations of USD 500 million or greater, but less than USD 1000 million: >500; daily intervention operations of USD 250 million or greater, but less than USD 500 million: >250; daily intervention operations of less than USD 250 million: > 0.

Dependent Variable: IINT						
	Sample 1: January 1999 – December 2002		Sample 2: January 2003 – December 2003		Sample 3: January 2004 – March 2004	
	Model 1.1	Model 1.2	Model 2.1	Model 2.2	Model 3.1	Model 3.3
Constant	-4.77*** (0.494)	-4.58*** (0.29)	-2.29*** (0.41)	-2.05*** (0.24)	-19.55 (12.79)	-1.10* (0.58)
JPYUSD(-1)	- 113.30*** (26.94)	- 112.95*** (26.33)	-56.10* (31.59)	-57.24* (31.69)	90.47 (84.27)	n.a.
TARGET	-2.50 (4.74)	n.a.	-4.99 (4.90)	n.a.	-116.15 (94.33)	n.a.
MADAY	-36.19*** (7.30)	-32.62*** (4.87)	-16.28* (10.12)	-18.60** (9.10)	93.02* (52.97)	n.a.
MAYEAR	2.07 (2.98)	n.a.	1.56 (4.08)	n.a.	-10.03 (41.07)	n.a.
IINT(-1)	2.73*** (0.69)	2.73*** (0.70)	2.58*** (0.34)	2.60*** (0.34)	2.57*** (0.75)	3.25*** (0.75)
Total Obs	1040	1040	260	260	64	64
Obs with IINT = 1	30	30	82	82	47	47
McFadden R ²	0.26	0.25	0.28	0.28	0.39	0.32
LR statistic		69.00		90.00		24.02
P(LR)		0.00***		0.00***		0.00***
H-L Statistic		3.77		9.05		8.55
Total Gain		94.40		56.82		60.99
Percent Gain		5.60		43.18		39.01

NOTES:

- (a) * denotes significance at 90%; ** denotes significance at 95%; *** denotes significance at 99%.
- (b) Heteroskedasticity and autocorrelation consistent standard errors in parentheses below the point estimates.
- (c) Logit models are defined in Equation (1) in the text.
- (d) The dependent variable IINT is a (0, 1) indicator variable that takes on the value 1 when the Bank of Japan intervenes and 0 otherwise.
- (e) The independent variables are defined as follows: JPYUSD is the first-difference of the log of the JPY/USD exchange rate; TARGET is the first-difference of the log of the JPY/USD deviation from a target rate of 125 JPY/USD; MADAY is the 21-day moving average of the log of the JPY/USD exchange rate; MAYEAR is the one-year moving average of the log of the JPY/USD exchange rate; (-1) denotes the first lag of a variable.
- (f) n.a. indicates that an independent variable is omitted from the second model due to lack of significance.
- (g) The Likelihood Ratio (LR) statistic tests the overall significance of the estimated model against a constant only alternative. P(LR) shows the p-value of the LR test statistic.
- (h) Hosmer-Lemeshow test statistic for goodness-of-fit based on a $\chi^2(8)$ -distribution. The 95 (90) percent critical value for rejecting the null of a fitting model is 15.51 (13.36).
- (i) The estimated logit models' prediction evaluation is based on expected value calculations: Total Gain captures the percentage point gain/loss of correct predictions when compared to the naïve constant probability model; Percent Gain shows the percent of incorrect predictions according to the naïve model corrected by the estimated model.

Table 3 Wald Tests of Reaction Function Parameter Stability			
	Sample 1	Sample 2	F-Statistic
Constant	-4.58	-2.05	76.63***
JPYUSD(-1)	-112.95	-57.24	4.48**
MADAY	-32.62	-18.60	8.29***
IINT(-1)	2.73	2.60	0.04
	Sample 1	Sample 3	F-Statistic
Constant	-4.58	-1.10	144.90***
JPYUSD(-1)	-112.95	n.a.	n.a.
MADAY	-32.62	n.a.	n.a.
IINT(-1)	2.73	3.25	0.55
	Sample 2	Sample 3	F-Statistic
Constant	-2.05	-1.10	15.85***
JPYUSD(-1)	-57.24	n.a.	n.a.
MADAY	-18.60	n.a.	n.a.
IINT(-1)	2.60	3.25	3.68*

NOTES:

- (a) * denotes significance at 90%; ** denotes significance at 95%; *** denotes significance at 99%.
- (b) The null hypothesis of the Wald test is that a coefficient estimate is the same across two sub-samples (parameter stability); the alternative hypothesis is that they are different (parameter instability).
- (c) The dependent variables are defined in the notes to Table 2. The displayed coefficient estimates are associated with the reduced models described in Table 2 (Model 1.2, Model 2.2, and Model 3.2).

Table 4 Without Matching: Effectiveness of Bank of Japan Intervention	
	Full Sample: 1 January 1999 – 31 March 2004
ALL	0.00107** (0.00524)
Obs with IINT = 1	159

NOTES:

- (a) The table shows the mean of the JPY/USD exchange rate changes on intervention days; significance of whether the mean is different from zero is assessed using a standard t-test.
- (b) * denotes significance at 90%; ** denotes significance at 95%; *** denotes significance at 99%.
- (c) Standard errors in parentheses below the point estimate.
- (d) ALL includes all intervention days; IINT is a (0, 1) indicator variable that takes on the value 1 on days when the Bank of Japan intervenes and 0 otherwise.

Table 5 Without Matching: Effectiveness of Bank of Japan Intervention			
	Sample 1: January 1999 – December 2002	Sample 2: January 2003 – December 2003	Sample 3: January 2004 – March 2004
ALL	0.0065*** (0.0021)	-0.0003 (0.0005)	0.0001 (0.0008)
Obs with IINT = 1	30	82	47

NOTES:

- (a) The table shows the mean of the JPY/USD exchange rate changes on intervention days; significance of whether the mean is different from zero is assessed using a standard t-test.
- (b) * denotes significance at 90%; ** denotes significance at 95%; *** denotes significance at 99%.
- (c) Standard errors in parentheses below the point estimates.
- (d) ALL includes all intervention days; IINT is a (0, 1) indicator variable that takes on the value 1 on days when the Bank of Japan intervenes and 0 otherwise.

Table 6 With Matching: Effectiveness of Bank of Japan Intervention	
Full Sample: 1 January 1999 – 31 March 2004	
ALL	0.00003 (0.04153)
Obs with IINT = 1	159

NOTES:

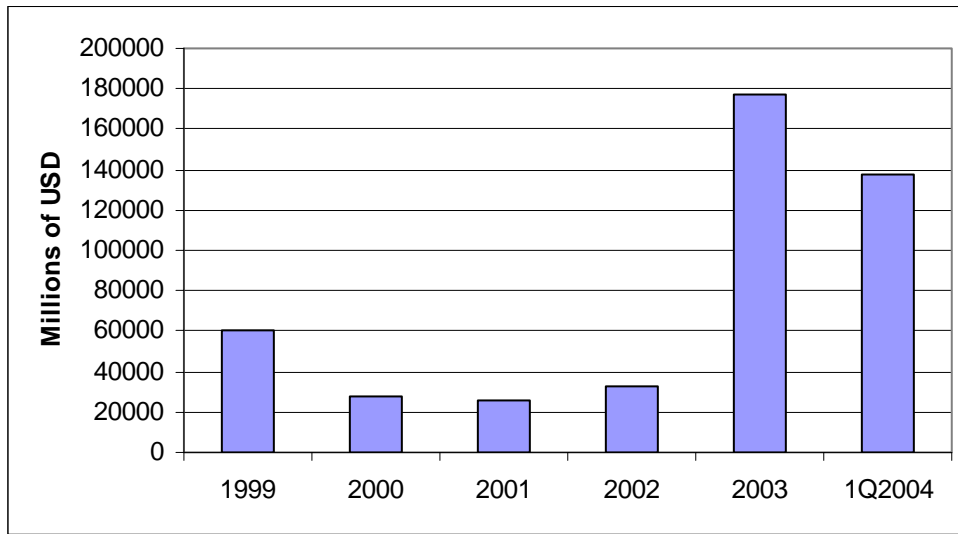
- (a) Matching based on the nearest neighbor algorithm.
- (b) * denotes significance at 90%; ** denotes significance at 95%; *** denotes significance at 99%.
- (c) Standard errors in parentheses below the point estimate.
- (d) ALL includes all intervention days; IINTDUM is a (0, 1) indicator variable that takes on the value 1 on days when the Bank of Japan intervenes and 0 otherwise.

Table 7 With Matching: Effectiveness of Bank of Japan Intervention			
	Sample 1: January 1999 – December 2002	Sample 2: January 2003 – December 2003	Sample 3: January 2004 – March 2004
ALL	0.0051** (0.0022)	0.0002 (0.0007)	-0.0013* (-0.0009)
SA	0.0066** (0.0032)	0.0009 (0.0028)	n.a.
CL	0.0026 (0.0026)	0.0001 (0.0008)	-0.0013* (-0.0009)
CLFD	-0.0015 (-0.0364)	-0.0000 (-0.0019)	-0.0031** (-0.0015)
CLMD	n.a.	-0.0002 (-0.0010)	-0.0010 (-0.0009)
CLLD	0.0013 (0.0030)	0.0010 (0.0015)	-0.0022 (-0.0034)
FD	0.0049* (0.0030)	0.0003 (0.0029)	-0.0031** (-0.0015)
Obs with IINT = 1	30	82	47

NOTES:

- (a) Matching based on the nearest neighbor algorithm.
- (b) * denotes significance at 90%; ** denotes significance at 95%; *** denotes significance at 99%.
- (c) Standard errors in parentheses below the point estimates.
- (d) ALL includes all intervention days; SA includes only “stand alone” intervention days, i.e. intervention days not immediately preceded or succeeded by another intervention day; CL includes all intervention days belonging to clusters, i.e. intervention days immediately preceded or/and succeeded by an intervention day (ALL minus SA); CLFD includes CL intervention days that are not immediately preceded by an intervention day; CLMD includes only CL intervention days that are both immediately preceded and succeeded by other intervention days; CLLD includes only CL intervention days that are not immediately succeeded by another intervention day; FD includes only SA and CLFD intervention days; IINT is a (0, 1) indicator variable that takes on the value 1 on days when the Bank of Japan intervenes and 0 otherwise.
- (e) n.a. indicates that the sample does not include the given type of intervention days.

Figure 1 Bank of Japan Intervention 1999 to 2004



Notes:

- a) Yearly aggregates of daily Bank of Japan intervention in the JPY/USD exchange rate market. The daily intervention data obtained from the Japanese Ministry of Finance data bank.
- b) There has been no Bank of Japan intervention since March 2004.