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ScienceDirect
Journal of International Money and Finance 26 (2007) 193–212
Journal of International Money and Finance
www.elsevier.com/locate/jimf

What prompts Japan to intervene in the Forex market? A new approach to a reaction function

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Abstract

This paper estimates and analyzes the reaction function of Japanese intervention in the foreign exchange (Forex) markets, using daily Japanese intervention data from April 1, 1991 to December 31, 2002. A theoretical friction model is adopted to describe the intervention as cost-minimizing behavior. An ordered probit model, consistent with the theoretical model, is employed to estimate authorities' reaction function. A noise-to-signal ratio is applied in selecting the optimal cutoff point in estimated ordered probit function. Major findings are as follows: (1) A regime change in June 1995 from small-scale frequent interventions to large-scale infrequent interventions is detected; (2) the optimum cutoff is higher in the first half than the second half.
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JEL classification: F31; E58; G15

Keywords: Central bank intervention; Foreign exchange rates; Ordered probit; Political cost

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doi:10.1016/j.jimonfin.2006.12.001

1. Introduction

The monetary authorities of Japan have intervened in the foreign exchange market more frequently than other G7 countries in, at least, the past 13 years.[1] Between April 1991 and December 2002, the Japanese authorities intervened in the yen/dollar market on 214 days (7% of business days), of which 32 days were in the direction of purchasing the yen and selling the dollar, and 182 days in the opposite direction.[2] The Japanese Ministry of Finance started to disclose the intervention days and amounts from April 1, 1991 to recent months. Ito (2003) analyzed the intervention behavior of the Japanese authorities, describing the institutional aspects and the data as well as making a first attempt of analyzing effectiveness, profits, and a reaction function. This paper, improving significantly over Ito (2003), estimates and analyses the reaction function of the Japanese monetary authorities in deciding when to intervene in the yen/dollar market, using daily intervention data from April 1, 1991 to December 31, 2002. The paper intends to analyze the intervention reaction function without a value or normative judgment.

The often-cited motivation for intervention is to prevent too much appreciation or depreciation, both in terms of a level and a speed of change. Too much appreciation (in a short period time) would harm exporters, while too much depreciation (in a short period time) would harm importers and confidence of financial market in general. To maintain a stable exchange rate that is broadly consistent with fundamentals is an aim of the monetary authorities (see Edison, 1993; Dominguez and Frankel, 1993; Almekinders, 1995; Sarno and Taylor, 2001, 2003 for surveys).

The disclosure of new data in Japan stimulated several detailed studies. Ito (2003) investigated the effectiveness of the intervention, considering various criteria that are derived from possible motivations. He found that interventions before June 1995 were broadly ineffective in moving the exchange rate of the intervention days in the intended direction, while interventions after June 1995 to March 2001 were effective. He also estimated profits, realized income and unrealized capital gains, made by intervention, that amounted to 8.6 trillion yen over the 10 year period. Fatum and Hutchison (2003) investigated the effectiveness of intervention using an event study methodology. They found strong evidence that sterilized intervention influenced the exchange rate. Kearns and Rigobon (2005) estimated the effectiveness of intervention, that is, the impact of interventions on the exchange rate, using Australian and Japanese intervention data. Dominguez (2003) also analyzed the effectiveness of the Japanese intervention and compared to Federal Reserve Bank interventions. Frenkel et al. (2002) used the Japanese disclosed data and estimated the reaction function. Their specification and estimation method are different from ours. Hillebrand and Schnabl (2003) also used the Japanese intervention data and found the effectiveness after 1999. Galati and Melick (2002) analyzed the effectiveness of interventions on market expectations and found some evidence of effectiveness in the mark/dollar and yen/dollar markets.

[1] The intervention decision in Japan is under jurisdiction of the Ministry of Finance. The Bank of Japan acts as an agent for its implementation. The yen for intervention is obtained by issuing short-term government securities (Financial Bills) and listed as the liability in the special budget for intervention, while the acquired dollars are on the asset side of the special budget. See Ito (2003) for details of institutional aspects.

[2] The Japanese Ministry of Finance, under a new Vice Minister of Finance for International Affairs, conducted much more frequent and large-scale interventions from January 2003 to March 2004. The episode of interventions in 2003 and 2004 is analyzed in Ito (2004), but not with the rigor of an ordered probit function.

Ito (2003) estimated a reaction function of the Japanese monetary authorities, using the intervention amounts as the variable to be explained in Ordinary Least Squares (OLS). However, the OLS is not the best framework for the reaction function, since for many days, the intervention amounts are zeros, and the model lacked theoretical foundation.[3] Almekinders and Eijffinger (1996) proposed a theoretical friction model as a framework of the intervention reaction function where intervention was modeled as cost-minimizing behavior of the monetary authorities. This paper extends the Almekinders and Eijffinger paper in several theoretical respects, and then develops an empirical analysis out of the theoretical model. The reaction function of the Japanese authorities was estimated using the Japanese daily data from April 1991 to December 2002. The combination of the following methodological features makes this paper original in the literature of foreign exchange intervention.

First, we extended the Almekinders and Eijffinger paper to allow for conditional and time-varying political cost of intervention with the generalized target exchange rate. It is reasonable to assume that when the political costs for intervention—whether to persuade Minister of Finance in Japan or to get a tacit approval from the United States—are incurred on 1 day, and then they are lowered for the subsequent days. This modification of the model is particularly important in view of the fact that interventions are often autocorrelated, that is, once intervention occurs then another intervention is likely to occur in the following several days.

Second, ordered probit analysis that is consistent with the theoretical model is employed to estimate the authorities' reaction function. What is explained is the intervention indicator (−1, 0, or 1) rather than the actual yen amount of interventions.[4] One might think that using the indicator is inferior to using the actual yen amount. However, this way, we may mitigate the endogeneity problem: how much to intervene will be adjusted within the day depending on the success of intervention that is measured by the exchange rate movement. The right-hand-side variables in the reaction function are those known to the authorities at the dawn of day t.[5] This specification is more precise when the left-side variable is the indicator function than when the left-side variable is intervention amount. How intervention influences the market is evaluated by the authorities hourly, if not continuously, and additional intervention may be carried out if the exchange rate is not moving as intended. Therefore intra-day movement of the exchange rate becomes very relevant for estimating the reaction function with intervention amounts on the left-hand side. Since the intra-day information of intervention is not disclosed, we cannot model this hourly reaction function. With the daily intervention data, the specification with the indicator may avoid this endogeneity problem.

Third, a noise-to-signal ratio is applied in selecting the optimal cutoff point in estimating an ordered probit function. The reaction function can be seen as a prediction of intervention. The literature on assessing prediction of an event has been developed in the financial crisis literature. One strand of the early warning model of currency crises, such as Kaminsky and Reinhart

[3] Interventions were carried out only less than 10% of the business days on average during the sample period. Therefore, for more than 90% of the time, obvious zeros of interventions are not well predicted. A small amount of intervention predictions most of the time turned out to be exactly the forecast errors of opposite signs. In order to rectify this problem, the probit model with a binary choice dependent variable is proposed by Baillie and Osterberg (1997) and Dominguez (1998).

[4] The intervention indicator is set equal to +1 if there was yen-purchasing intervention, −1 if there was yen-selling intervention, and 0 for days in which there was no intervention.

[5] Of course, if the exchange rate moves too quickly within the day, decision to intervene can be made hastily. However, decision to intervene, or at least to be "vigilant," is made in the first hour of the day, consistent with modeling.

(1998), uses a model to predict a crisis and evaluate alternative model specifications by calculating the noise-to-signal ratio. We apply the noise-to-signal ratio method to evaluation of various specifications of the intervention reaction function. In evaluating forecast performance, it is commonly chosen, without a theoretical basis, that the cutoff point is 50% (e.g. Greene, 2000), but the method in this paper allows for selecting optimally the cutoff point by using the noise-to-signal ratio. This is a new insight in the intervention reaction function literature.

Major findings are as follows: First, there was a regime change in June 1995 from small-scale frequent interventions to large-scale infrequent interventions. Second, a tendency of lean-against-the-wind interventions, as opposed to lean-in-the-wind intervention, was more prevalent. Third, the past five-year moving average, rather than one- or three-year moving average, is the relevant long-run target in the mind of policy makers. Fourth, for the short-term consideration, the coefficient of interventions of day before is estimated as significant. Fifth, the first half of the sample period had lower friction costs than the second half of the sample period. Sixth, the optimum cutoff was higher in the first half than the second half. Seventh, the political costs were biased in preference for yen appreciation in the first half while biased in preference for yen depreciation in the post-June 1995.

The rest of the paper is organized as follows. Section 2 gives an overview of the yen/dollar exchange rate movement and intervention incidents from April 1991 to December 2002. Section 3 gives the specification of reaction function derived from a model. Section 4 estimates the model of interventions and analyzes the estimation results. Section 5 evaluates the predictability of interventions. Section 6 concludes the paper.

2. Overview of the yen/dollar movement

In Fig. 1, the yen/dollar movement is shown. The yen fluctuated between 147 yen/dollar (on August 1, 1998) and 80 yen/dollar (on April 19, 1995). From 1991 to April 1995, the yen appreciation trend was observed, followed by the yen depreciation trend from April 1995 to August 1998. The yen appreciated from August 1998 to January 2000, when the yen was

Fig. 1. Yen/dollar exchange rate, April 1991–December 2002, NY close.

just above 100 yen/dollar. The yen depreciated after that, until the yen reached the mid-120s in March 2001.

Fig. 2 shows the monthly-aggregated amounts of interventions. All interventions to purchase the yen were conducted when the yen/dollar rate was higher (yen being more depreciated) than 125 yen, while all interventions to sell yen were conducted when the yen/dollar rate was lower (yen being more appreciated) than 125 yen. The fact that the dollar was bought when it was relatively cheap vis-à-vis the yen, and that the dollar was sold when it was relatively expensive means great profits to the monetary authorities. From April 1991 to December 2002, the realized gains (by purchasing the dollar and selling the matching amount) amounted to 1 trillion yen, and the net interest income (the interest income earned on the accumulated foreign reserves due to interventions minus the interest payments on the yen securities) amounted to 4.9 trillion yen. At the end of December 2002, the accumulated net intervention amounts in terms of the dollars, 225 billion dollars, have the inventory unit price of 108.8 yen/dollar, while the market price was 118.7 yen/dollar, suggesting the unrealized gains of 2.3 trillion yen. The gains suggest that the interventions were rather stabilizing in the notion of Milton Friedman, as argued in Ito (2003).

The intervention size and frequencies greatly changed before and after June 21, 1995, when Dr. Sakakibara became Director General of the International Finance Bureau of Ministry of Finance. Table 1 shows the number of intervention days, the total yen amount of intervention, the average (per day) size of intervention for each year. In the first half of sample (April 1991–June 20, 1995), 165 interventions were conducted, while only 49 interventions were conducted in the second half (June 21, 1995–December 2002) of the sample. The total intervention amount was 8 trillion yen in the first half, while it was 25 trillion yen in the second half. The average intervention size was about 47 billion yen in the first half, but the average size of intervention increased by more than 10 times in the second half of the sample. In summary, the first half was characterized by frequent, small-size interventions, while the second half by infrequent, but large-size interventions.

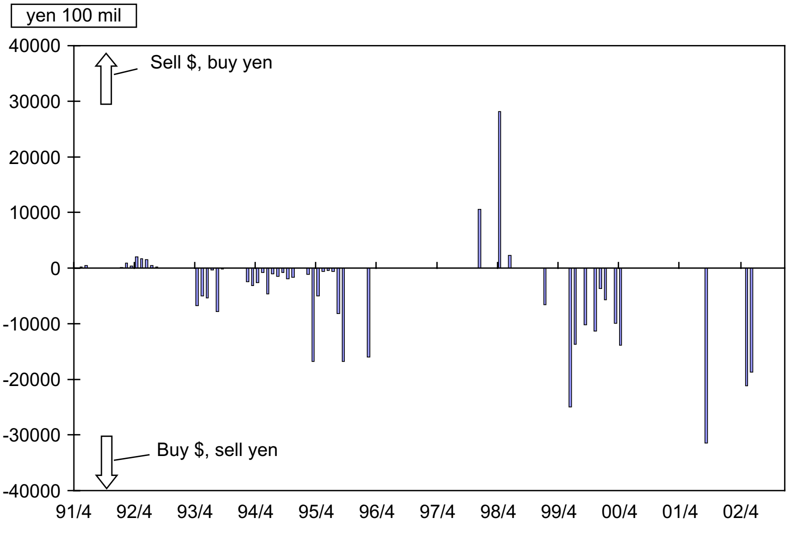

Fig. 2. Amounts of intervention (monthly aggregation).

Table 1
Frequencies of interventions

By fiscal year. Unit = billion yen

FY	Days	Total amounts	Amounts per day	FY	Days	Total amounts	Amounts per day
1991	8	190.9	23.9	1995:2	13	4205.1	323.5
1992	18	582.4	32.4	1996	0	0	0
1993	61	3113.5	51.0	1997	3	1059.1	353.0
1994	69	3299.0	47.8	1998	4	3703.3	925.8
1995:1	9	562.1	62.5	1999	14	7964.6	568.9
				2000	1	1385.4	1385.4
				2001	7	3145.5	449.4
				2002	7	3992.4	570.3
Subtotal 1991–1995:1	165	7747.9	47.0	Subtotal, 1995:2–2002	49	25 455.4	519.5

Source: The Ministry of Finance, home page (www.mof.go.jp/1c021.htm).
Notes: Fiscal year (FY) is from April of year t to end-March of year $t+1$. The first half of 1995, 1995:1, covers the FY 1995 days until June 20, 1995; the second period of 1995, 1995:2, covers the FY 1995 days after June 21, 1995. The 2002 covers only until end-December 2002.

Dr. Sakakibara himself noted the difference, emphasizing that it was a deliberate choice. Talking of interventions by his predecessor, Dr. Sakakibara writes, “The market was accustomed to interventions, because they were too frequent. The interventions were taken as given. Most interventions, including joint interventions, were predictable, so that interventions, even joint ones, had only small, short-term effects, and could not change the sentiment of the market.” (Sakakibara, 2000, p. 119) “[T]he change in intervention philosophy and technique [was introduced]. For this, all I have to do was to make a decision and convince the Vice Minister and the Minister of [its desirability]. For one, the frequency of interventions was reduced substantially, and per-intervention amount was increased, in order to push up the level [of the dollar vis-à-vis the yen]” (Sakakibara, 2000, p. 120).

Words and deeds of Dr. Sakakibara seem to show the deliberate changes in the intervention style in order to change the level of the exchange rate by influencing the expectation of the market. Less frequent, but large-scale each time, interventions were a hallmark of the period from June 1995 to end-2002.[6] In the next section, we rigorously examine the monetary authority’s decision to intervene using an econometric model that takes into account the feature that interventions are infrequent events.

3. Model of infrequent intervention

3.1. Loss function

In most of the papers in the literature, the intervention reaction function is typically assumed rather than derived. An exception is Almekinders and Eijffinger (1996) that derived a reaction

[6] Dr. Sakakibara retired in July 1999. But, his successor, Mr. Kuroda was widely regarded as a person who inherited the same philosophy toward the exchange rate market function and intervention policy. The pattern of intervention by Mr. Kuroda does not show an apparent change from the one by Dr. Sakakibara.

function from the loss function of the monetary authorities.[7] We follow their approach, with more realistic formulation of the target exchange rate and the cost function of intervention. The monetary authorities are assumed to have a loss function that should be minimized using interventions. The loss function is assumed to be

$$\mathrm{Min}_{\mathrm{Int}_t} E[\mathrm{Loss}_t|\Omega_{t-1}] = E\left[\left(s_t - s_t^{\mathrm{T}}\right)^2 \middle| \Omega_{t-1}\right] \tag{1}$$

where s_t denotes the log of the yen/dollar rate at the close of the New York market (time t); s_t^{T} denotes the target of the yen/dollar rate for the monetary authorities at time t; Int_t is the amount of intervention at time t; and Ω_{t-1} denotes the information available to the monetary authorities and market participants at the end of date $t-1$.[8] The specification means that the loss is defined by squared deviation of the actual exchange rate from the target rate at date t. In addition, the monetary authorities are assumed to believe that the exchange rate is a random walk if there is no intervention and the date t intervention has impacts on the actual exchange rate process. The process of exchange rate is as follows:

$$s_t = s_{t-1} + \rho \mathrm{Int}_t + u_t \tag{2}$$

where u_t is a white noise. Effectiveness of intervention on exchange rate implies the negative sign of ρ. For example, the yen-purchasing intervention ($\mathrm{Int}_t > 0$) by the monetary authorities tends to appreciate the yen ($s_t - s_{t-1} < 0$), and then the negative sign of ρ should be obtained.

Minimizing the loss function (1) by choosing Int_t subject to the constraint (2) leads to the following intervention reaction function:

$$\mathrm{Int}_t^* = -\frac{1}{\rho}\left(s_{t-1} - s_t^{\mathrm{T}}\right) \tag{3}$$

where Int_t^* denotes the optimal amount of intervention. The authorities have a target exchange rate that is defined by the weighted average of the past exchange rates. Our conjecture is that at least five elements play an important role in prompting the authorities to intervene: the yen/dollar rate on the previous day, the yen/dollar rate in the previous month (21 business days), the past k-year moving average of the yen/dollar rate for $k = 1, 3, 5$. The past k-year moving average is defined as:

$$s_t^{k\mathrm{M}} = \frac{1}{k260} \sum_{i=0}^{k260-1} s_{t-i}$$

which is plotted in Fig. 3. Note that a year is about 260 business days.

[7] The objective of the Frenkel et al. (2002) paper is similar to ours. The difference is specification and methodology. They have defined the loss function as a weighted sum of the deviation from the target exchange rate and the deviation from the target intervention amount, and applied the model to the Japanese intervention data. The former is simply the moving average or PPP. We think that using the intervention target in the loss function is not convincing. Their paper is not using the friction model, unlike Almekinders and Eijffinger (1996) and this paper. The Frenkel, Pierdzioch, and Stadtmann paper did not check a possible regime change in the middle of the sample period, unlike Ito (2003) or this paper.

[8] The New York close rate, instead of the Tokyo market, is used because Japanese intervention of day t can be carried out in the Tokyo market, European market, or New York market. See Ito (2003) for a detailed time line for this.

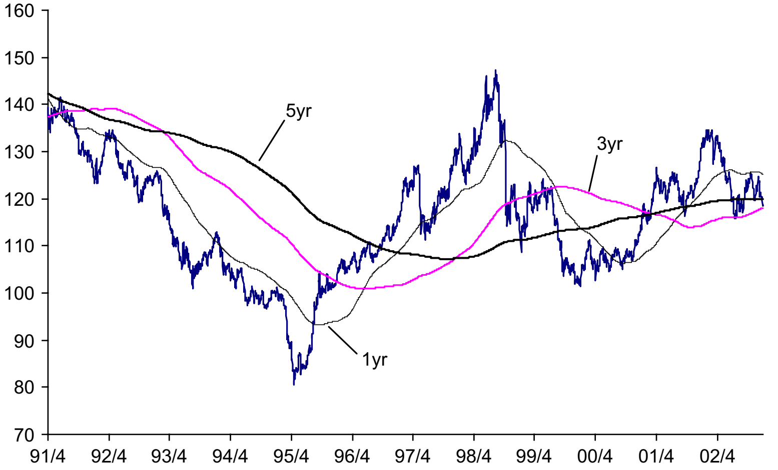

Fig. 3. Past *k*-year moving average of the yen/dollar rate.

Therefore, the target exchange rate is

$$s_t^{\mathrm{T}} = \alpha_1 s_{t-2} + \alpha_2 s_{t-21} + \alpha_3 s_{t-1}^{\mathrm{long}}, \qquad (4)$$

$$s_t^{\mathrm{long}} = c_1 s_t^{\mathrm{1M}} + c_2 s_t^{\mathrm{3M}} + c_3 s_t^{\mathrm{5M}}$$

where $\alpha_1 + \alpha_2 + \alpha_3 = 1$ and $c_1 + c_2 + c_3 = 1$.[9] The form of the target exchange rate is more general than those of Ito and Yabu (2004) and Almekinders and Eijffinger (1996). Ito and Yabu (2004) assumed that the "long-run target," s_t^{long}, is simply the past one-year moving average, i.e., $c_1 = 1$ and $c_2 = c_3 = 0$. However, in fact, it is unknown which moving average is more important as the long-run target in the mind of policy makers. Almekinders and Eijffinger (1996) assumed $\alpha_1 = \alpha_2 = 0$ and $\alpha_3 = 1$ using the past one-week moving average as s_t^{long}. However, α_i has important implications. For example, when the monetary authorities pay greater attention to long-run stability than to other factors, α_3 takes a value close to one. This represents the desire of the monetary authorities for mean reversion. On the other hand, when they attach greater importance to short-run stability than to others, α_1 takes a value close to one. This is the case when a short-run movement (s_{t-2} to s_{t-1}) is to be reversed, or at least to be moderated in speed. Coefficient α_2 represents the medium-term target of the authorities, that is mean reversion to the trend of the past one month. In the case they attach equal importance, each α_i takes 1/3.

Using Eqs. (3) and (4), the optimal intervention can be written as

$$\begin{aligned}\mathrm{Int}_t^* &= \beta_1(s_{t-1} - s_{t-2}) + \beta_2(s_{t-1} - s_{t-21}) + \beta_3\left(s_{t-1} - s_{t-1}^{\mathrm{1M}}\right) \\ &\quad + \beta_4\left(s_{t-1} - s_{t-1}^{\mathrm{3M}}\right) + \beta_5\left(s_{t-1} - s_{t-1}^{\mathrm{5M}}\right) \qquad (5)\end{aligned}$$

where $\beta_1 = -\alpha_1/\rho$, $\beta_2 = -\alpha_2/\rho$, $\beta_j = -\alpha_3 c_{j-2}/\rho$ for $j = 3, 4, 5$. That is, the optimal intervention is a function of five explanatory variables; the change in the yen/dollar rate on day $t-1$; the change

[9] Another approach is to use the PPP rate instead of Eq. (4). However, given the availability of the data in the monthly base, it leads to a sticky target rate in the daily model of intervention.

in the yen/dollar rate in the previous 21 (business) days; the percent deviation of the current (day before) level from the past k-year moving average for $k = 1, 3, 5$. Note that the relationships among parameters are written as follows: $\rho = -1/(\sum_{i=1}^{5} \beta_i)$, $\alpha_1 = \beta_1/(\sum_{i=1}^{5} \beta_i)$, $\alpha_2 = \beta_2/(\sum_{i=1}^{5} \beta_i)$, $\alpha_3 = (\sum_{s=3}^{5} \beta_s)/(\sum_{i=1}^{5} \beta_i)$, $c_j = \beta_{j+2}/(\sum_{i=3}^{5} \beta_i)$, for $j = 1, 2, 3$. This means that once we can estimate β_i, we can identify α_i, c_i, and ρ, respectively. As we will see, however, this is not the case. We cannot estimate β_i but a normalized value of β_i. Therefore, we can identify only α_i and c_i, not ρ.

3.2. Political cost

The specification of intervention (5), when taken literally, implies that intervention should take place almost everyday. This is inconsistent with the fact that interventions were actually carried out only less than 10% of the business days on average. One way to rectify this problem is to model explicitly the political cost for intervention, which is incurred during decision-making process for designing the optimal intervention strategy (see Almekinders and Eijffinger, 1996). Political costs reflect costs of discussion with Minister of Finance of own country and other major countries of intervention currencies. In order to carry out intervention, an explanation to the Minister of Finance, and in some cases to other ministers, including Prime Minister, is necessary and a tacit approval, if not coordinated intervention, of other countries has to be sought after. Political costs are most likely independent of the size of intervention. However, once the approval is secured, then intervention can be carried out in several days in a row, if the situation does not change dramatically.

What is called political cost may also reflect aversion to intervention by those who are in charge of interventions, namely, officials at the Ministry of Finance. Those who believe that the market will have power to restore an equilibrium sooner than later, they find costs to be high, while those who believe that the market can overshoot and get misaligned for a long time tend to find political costs low. Any consideration that is not captured by the specification of the target rate will show up as the political costs.

With the presence of political costs, intervention takes place if and only if benefits of intervention are higher than costs. Usually, political costs are assumed to be a function of intervention at date t. If intervention was carried out the day before, then the political cost is less, because the decision by the Minister was already secured once, so that an additional cost on the day after is much less. Therefore, we assume that political costs are a function of interventions not only at date t but also at date $t-1$. Under this assumption, we can explain why intervention tends to be correlated (once intervened, another intervention is likely to occur the day later). Therefore, a cost function of intervention is defined as follows:

$$C_t = \begin{cases} C_1^{\mathrm{P}} - C_2 I(\mathrm{Int}_{t-1} > 0) & \text{if } \mathrm{Int}_t > 0 \\ C_1^{\mathrm{S}} - C_2 I(\mathrm{Int}_{t-1} < 0) & \text{if } \mathrm{Int}_t < 0 \end{cases} \tag{6}$$

where $C_1^{\mathrm{P}} > 0$, $C_1^{\mathrm{S}} > 0$, and $I(\cdot)$ is the indicator function.[10] The political costs of the yen-purchasing intervention are $C_1^{\mathrm{P}} - C_2 I(\mathrm{Int}_{t-1} > 0)$. On the other hand, the costs of the yen-selling intervention are $C_1^{\mathrm{S}} - C_2 I(\mathrm{Int}_{t-1} < 0)$. For example, $C_2 > 0$ implies that intervention at date $t-1$ reduces political costs of intervention at date t. The opposite situation, $C_2 < 0$, may be possible. Then, intervention at date $t-1$ increases political costs of intervention at date t.

[10] For instance, $I(\mathrm{Int}_{t-1} > 0)$ is 1 if $\mathrm{Int}_{t-1} > 0$ and 0 otherwise.

3.3. Ordered probit

The monetary authorities compare benefits of reducing losses of no intervention to fixed costs of intervention, and carry out interventions only when benefits are higher than costs. Note that the greater the optimal amount of intervention the greater the loss of no intervention. Therefore, once the optimal intervention crosses the thresholds, the monetary authorities intervene in the foreign exchange market. The actual intervention can be written as follows[11]:

$$\text{IInt}_t = \begin{cases} -1 \quad \text{if } \text{Int}_t^* + \varepsilon_t < \mu_1 + \beta_6 I(\text{Int}_{t-1} < 0) \\ 0 \quad \text{if } \mu_1 + \beta_6 I(\text{Int}_{t-1} < 0) < \text{Int}_t^* + \varepsilon_t < \mu_2 - \beta_6 I(\text{Int}_{t-1} > 0) \\ +1 \quad \text{if } \mu_2 - \beta_6 I(\text{Int}_{t-1} > 0) < \text{Int}_t^* + \varepsilon_t \end{cases}, \tag{7}$$

where $\mu_1 < 0$, $\mu_2 > 0$, and $\varepsilon_t \sim \text{i.i.d.} N(0,\sigma^2)$.

Given the observation that the direction of intervention at date t was never different from that of date $t-1$, Eq. (7) can be replaced by the following:

$$\text{IInt}_t = \begin{cases} -1 \quad \text{if } y_t^* < \mu_1 \\ 0 \quad \text{if } \mu_1 < y_t^* < \mu_2 \\ +1 \quad \text{if } \mu_2 < y_t^* \end{cases} \tag{8}$$

where $y_t^* = X_t\beta + \varepsilon_t$ with

$$X_t\beta = \beta_1(s_{t-1} - s_{t-2}) + \beta_2(s_{t-1} - s_{t-21}) + \beta_3\left(s_{t-1} - s_{t-1}^{1\text{M}}\right) + \beta_4\left(s_{t-1} - s_{t-1}^{3\text{M}}\right) + \beta_5\left(s_{t-1} - s_{t-1}^{5\text{M}}\right) + \beta_6 \text{IInt}_{t-1}.$$

This model is considered as an ordered probit model and can be estimated by the maximum likelihood method. However, we can estimate $\beta_i^* = \beta_i/\sigma$ and $\mu_i^* = \mu_i/\sigma$, not β_i and μ_i directly. This means that we can estimate $\alpha_1 = \beta_1^*/(\sum_{i=1}^5 \beta_i^*)$, $\alpha_2 = \beta_2^*/(\sum_{i=1}^5 \beta_i^*)$, $\alpha_3 = (\sum_{s=3}^5 \beta_s^*)/(\sum_{i=1}^5 \beta_i^*)$, $c_j = \beta_{j+2}^*/(\sum_{i=3}^5 \beta_i^*)$ for $j = 1, 2, 3$, but there is no way to identify ρ without additional assumptions. The model can be regarded as a reaction function with a "neutral band" of no intervention.

3.4. Relationship to conventional specification

The conventional reaction function of the monetary authorities, without the neutral band of no-intervention, is presented here for comparison. Let us recall that Ito (2003) defined a reaction function that was conventional in the literature and estimated it. The intervention, either size (amount) of intervention (Int) or the indicator, IInt = (1, 0, or −1), is regressed on the daily exchange rate change, the monthly change, the deviation from a long-run equilibrium, and the intervention of the day before. In the indicator specification, the following regression can be estimated[12]

[11] Notice that we use the indicator function (1, 0, or −1) as the left-hand side variable instead of the actual amount of intervention. As discussed in Section 1, using the indicator function is less problematic in terms of the endogeneity problem.

[12] Ito (2003) used the intervention amount instead of the indicator functions. The long-run target was simply the past one-year moving average. Hence, the following regression was estimated:

$$\text{Int}_t = \theta_0 + \theta_1(s_{t-1} - s_{t-2}) + \theta_2(s_{t-1} - s_{t-21}) + \theta_3\left(s_{t-1} - s_{t-1}^{1\text{M}}\right) + \theta_4 \text{Int}_{t-1} + \omega_t.$$

$$\mathrm{IInt}_t = \phi_0 + \phi_1(s_{t-1} - s_{t-2}) + \phi_2(s_{t-1} - s_{t-21}) + \phi_3\left(s_{t-1} - s_{t-1}^{1M}\right) + \phi_4\left(s_{t-1} - s_{t-1}^{3M}\right) + \phi_5\left(s_{t-1} - s_{t-1}^{5M}\right) + \nu_t. \quad (9)$$

Eq. (9) can be interpreted as a linearlization of the general intervention reaction function (8). Therefore, the conventional regression has a constant term while the ordered probit function has no constant term. Furthermore, ν_t has heteroskedasticity and thus heteroskedasticity-and-autocorrelation-consistent (HAC) standard errors should be used for inference.

4. Estimating a reaction function

4.1. Structural break

Structural changes are suspected from observations of intervention patterns, as described in Section 2. In this section, a structural break for the reaction function is tested first in order to examine whether our observation, supported by Dr. Sakakibara's own assertion, is confirmed by data.

The regression analysis will be conducted to test rigorously the possible break at around the time of June 1995, when Dr. Sakakibara became in charge of intervention. First, the null hypothesis of no break at June 21, 1995, for the ordered probit regression (8), is rejected at the 1% significance. Therefore, our prior of a structural change due to a personnel change is confirmed by the statistical test.

Second, for the linear version (9), $\sup_\tau (F(\tau))$ test, a la Andrews (1993), is conducted to test and search for an unknown break date. The possible structural break dates are the middle 70% of the sample period. Namely the first 15% and the last 15% of dates are excluded from test for structural break.[13] The standard Chow test is conducted to obtain the F-statistic at each break candidate, τ. Fig. 4 shows the sequence of the F-statistics as a function of a single break date. The break dates are on the x-axis and the F-statistics on the y-axis. The single peak of the F-statistic is found to be on April 18, 1995. The break date is two months earlier than the date we identify by the personnel change, June 21. The reason for this deviation is based on the following pattern of intervention during the two-month period between the two dates. Continuous interventions, a hallmark of pre-Sakakibara era, seemed to have ended on April 18. The only intervention after this date before June 21 was May 31. Therefore, according to statistical analysis, the policy switch from frequent interventions to infrequent interventions occurred on April 18.

The largest of the F-statistics is 34.7, which occurs on April 18; this is the $\sup_\tau (F(\tau))$ statistic. The null hypothesis is rejected with 1% significance. Moreover, the F-statistic on June 21, which is 22.5, is also large enough to reject the null of no break with 1% significance. Since we have prior knowledge of regime change due to a personnel change, supported by a memoir of Dr. Sakakibara, we will adopt June 21 as the structural break date. Below, all models are estimated for the entire period, before June 21, 1995 (pre-June 1995), and after June 21, 1995 (post-June 1995).[14]

[13] For the large-sample approximation to the distribution of the $\sup_\tau (F(\tau))$ test to be good, the subsample endpoints should not be close to zero so that 15% trimming is a common choice in practice.

[14] Even if we adopt April 18 as the regime change date, most of the findings comparing the first regime and second regime remain valid.

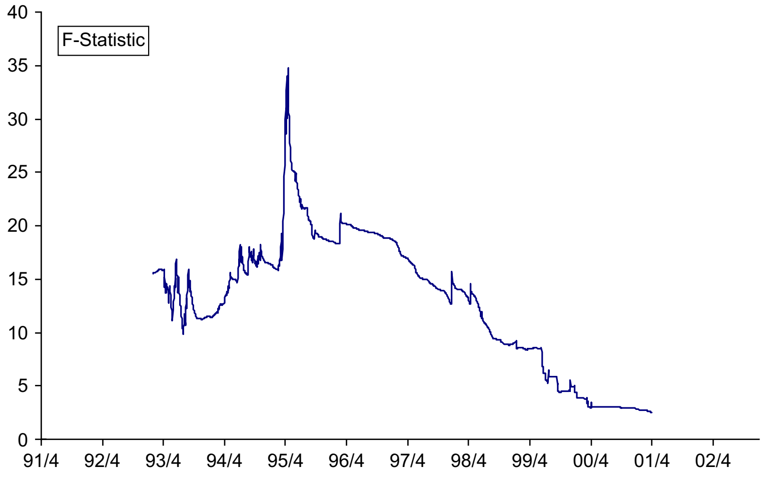

Fig. 4. F-statistics testing for a break in Eq. (9) at different dates.

4.2. Conventional regressions

The conventional reaction function, Eq. (9), is estimated. This is basically an update of the reaction function estimated in Ito (2003), extending the sample period by one year, with a modification of replacing intervention amount (Int) with the intervention indicator (IInt) as a dependent variable.

Results are shown in Table 2. The reaction function gives different estimates and explanatory power in the first half and second half of the sample. Reactions to the previous day changes (ϕ_1), to the medium-term trend (ϕ_2), and to the deviation from the past five-year moving average (ϕ_5) were all much stronger in the first half. Of these, the medium-term trend seemed to

Table 2

Conventional reaction function with no neutral band, OLS

$$\text{IInt}_t = \phi_0 + \phi_1(s_{t-1} - s_{t-2}) + \phi_2(s_{t-1} - s_{t-21}) + \phi_3\left(s_{t-1} - s_{t-1}^{1\text{M}}\right) + \phi_4\left(s_{t-1} - s_{t-1}^{3\text{M}}\right) + \phi_5\left(s_{t-1} - s_{t-1}^{5\text{M}}\right) + \phi_6\text{IInt}_{t-1} + \nu_t$$

	Full sample 91/4/1–02/12/31	First half 91/4/1–95/6/20	Second half 95/6/21–02/12/31
ϕ_0	−0.01 (0.005)**	0.06 (0.02)**	−0.02 (0.005)**
ϕ_1	3.96 (0.82)**	5.45 (1.96)**	2.39 (0.76)**
ϕ_2	0.59 (0.22)**	1.91 (0.62)**	0.17 (0.12)
ϕ_3	0.27 (0.12)*	0.29 (0.70)	0.12 (0.09)
ϕ_4	−0.40 (0.12)**	−0.44 (0.73)	−0.09 (0.09)
ϕ_5	0.53 (0.11)**	0.91 (0.47)*	0.22 (0.09)**
ϕ_6	0.45 (0.04)**	0.44 (0.05)**	0.23 (0.07)**
Adjusted R^2	0.307	0.399	0.085
Observations	3055	1101	1954

Note: HAC standard errors are given in parentheses. ** signifies statistically significant at the 1% level; * at the 5% level of significance. IInt_t is set equal to +1 if there was yen-purchasing intervention, −1 if there was yen-selling intervention, and 0 for days in which there was no intervention. The past k-year moving average is defined as

$$s_t^{k\text{M}} = \frac{1}{k260}\sum_{i=0}^{k260-1} s_{t-i} \quad \text{for } k = 1, 3, 5.$$

have been ignored by the authorities in post-June 1995 period. The coefficient of lagged intervention (ϕ_6) was also found to be significant in both periods, with a larger coefficient in the first period. These results reflect the fact that there were much more frequent interventions in the first half.

The deviation from the past five-year moving average is significant for the first half and second half but coefficients of moving average of one year and three years are not significant. This is consistent with a view that the five-year moving average is the most important as the long-run target in the mind of policy makers.

The explanatory power of the regression was significantly lower in the second half of the sample, but this is consistent with the reputation that Dr. Sakakibara wanted the intervention to be unpredictable. He believed that a surprise intervention would be more effective than a predictable one.

4.3. Ordered probit regressions

Estimates of the ordered probit model are summarized in Table 3. The following six observations stand out. First, a tendency of lean-against-the-wind interventions is confirmed for the daily and medium-term considerations. For the daily reaction, $\beta_1^* > 0$ holds true for the entire, the pre-June 1995, and the post-June 1995 periods. The positive coefficient means that yen appreciation (depreciation) on the day before tends to trigger an intervention to sell (buy, respectively) the yen. There was also a tendency of lean-against-the-wind interventions when there is trend of appreciation (depreciation) in the medium term (preceding 21 days), as $\beta_2^* > 0$ is confirmed for the entire, the pre-June 1995, and the post-June 1995 periods. Namely, if the yen appreciation (depreciation) occurred in the last 21 days, then it is more likely to intervene and sell (buy, respectively) the yen.[15]

Second, the past one-year and the past three-year moving averages seem to be ignored by the authorities for each of the pre-June 1995 and post-June 1995. On the other hand, intervention is more likely to occur when the exchange rate is more deviated from the past five-year moving average for each of the pre-June 1995 and post-June 1995 periods. This implies that the past five-year moving average is the relevant long-run target in the mind of policy makers, i.e., $(c_1, c_2, c_3) = (0, 0, 1)$ with a restriction that non-significant estimates being set to zero.

By construction, the original weights of the three components of the target exchange rate are calculated. Using $\alpha_1 + \alpha_2 + \alpha_3 = 1$, we can calculate each component, $(\alpha_1, \alpha_2, \alpha_3)$. In the pre-June 1995 period, $(\alpha_1, \alpha_2, \alpha_3) = (0.62, 0.22, 0.16)$, while in the post-June 1995 period, $(\alpha_1, \alpha_2, \alpha_3) = (0.74, 0.13, 0.13)$, with a restriction that non-significant estimates being set to zero. In the pre-June 1995 and post-June 1995 periods, the monetary authorities were mindful of the daily, medium-term, and long-term exchange rate movements. Moreover, in the post-June 1995 period, the monetary authorities attached more importance to the daily exchange rate movements.

Third, the coefficient of interventions of day before is estimated as significant, $\beta_6^* > 0$. This implies that the likelihood of interventions does increase if there was an intervention the day before. This reflects the lower political costs of continuous interventions. The result does

[15] Dr. Sakakibara has a reputation of carrying out the lean-in interventions ($\beta_2^* < 0$). The reputation partly comes from own writings. This reputation is not proven by the estimation. For the medium-term (β_2^*), however, lean-against interventions were proved for the post-June 1995, that is, the Sakakibara period.

Table 3
Ordered probit model

$$\mathrm{IInt}_t = \begin{cases} -1 & \text{if } y_t^* < \mu_1 \\ 0 & \text{if } \mu_1 < y_t^* < \mu_2 \\ +1 & \text{if } \mu_2 < y_t^* \end{cases}$$

where $y_t^* = X_t\beta + \varepsilon_t$ with $\varepsilon_t \sim \text{i.i.d.}N(0,\sigma^2)$ and

$$X_t\beta = \beta_1(s_{t-1} - s_{t-2}) + \beta_2(s_{t-1} - s_{t-21}) + \beta_3\left(s_{t-1} - s_{t-1}^{1M}\right) + \beta_4\left(s_{t-1} - s_{t-1}^{3M}\right) + \beta_5\left(s_{t-1} - s_{t-1}^{5M}\right) + \beta_6\mathrm{IInt}_{t-1}$$

	Full sample 91/4/1–02/12/31	First half 91/4/1–95/6/20	Second half 95/6/21–02/12/31
β_1^*	27.09 (5.42)**	25.61 (9.22)**	29.07 (8.40)**
β_2^*	5.23 (1.75)**	9.10 (3.08)*	5.37 (2.17)*
β_3^*	2.64 (1.18)*	−0.65 (4.07)	2.09 (1.58)
β_4^*	−4.16 (1.30)**	−0.99 (4.72)	−1.47 (1.74)
β_5^*	5.24 (0.95)**	6.48 (2.77)**	4.92 (1.53)**
β_6^*	1.71 (0.12)**	1.46 (0.15)**	1.59 (0.23)**
Thresholds			
μ_1^*	−2.25 (0.07)**	−2.79 (0.18)**	−2.31 (0.11)**
μ_2^*	2.50 (0.11)**	1.55 (0.11)**	3.40 (0.21)**
McFadden's R^2	0.362	0.403	0.241
Observations	3055	1101	1954

Note: HAC standard errors are given in parentheses. ** signifies statistically significant at the 1% level; * at the 5% level of significance. IInt_t is set equal to +1 if there was yen-purchasing intervention, −1 if there was yen-selling intervention, and 0 for days in which there was no intervention. The past k-year moving average is defined as

$$s_t^{kM} = \frac{1}{k260}\sum_{i=0}^{k260-1} s_{t-i} \quad \text{for } k = 1,3,5.$$

hold for the entire, pre-1995:06, and post-1995:06 periods. The magnitude of increasing likelihood of intervention is 1.5 and 1.6, respectively.

Fourth, the neutral band of no intervention was estimated to be (−2.8, +1.6) for the first subsample, and (−2.3, +3.4) for the second subsample. That is, the neutral band was much wider in the second half than the first half. The difference in the neutral band gives quite a different prediction on interventions, and this is consistent with casual observations of the frequency of interventions, as shown in Table 1. Figs. 5–7 show the estimated neutral band and the fitted value of the latent variable y^*. For the entire period, Fig. 5 shows the relationship between the neutral band and the fitted value. When estimated separately, Figs. 6 and 7 show the relationship of the two subperiods. With the narrow band in the first half, it was predicted as shown in Fig. 6, that interventions are frequent, while with the wide band in the second half, the frequency of interventions was predicted as low as in Fig. 7.

Fifth, the neutral bands are found to be asymmetric that is the magnitudes of upper band and lower band are different both in the first and second half. It is often said that the Japanese monetary authorities are much more tolerant toward yen depreciation than yen appreciation. One way to test for this asymmetric hypothesis would be to compare the ceiling and floor of the neutral band. In the first period, the band was asymmetric toward the yen appreciation than the yen depreciation, as the band was estimated to be (−2.8, +1.6). On the other hand, in the second period, it was shown that the monetary authorities were much more tolerant toward the yen depreciation than the yen appreciation. This shows that political costs were biased in both periods. Moreover, the political costs were biased in preference for yen appreciation in the first half while biased in preference for yen depreciation in the post-June 1995, the Sakakibara period.

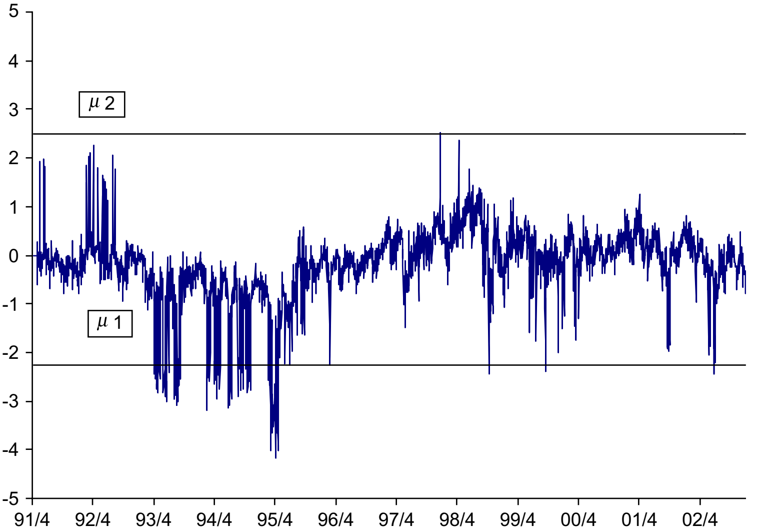

Fig. 5. Neutral band and fitted value of y^*, full sample.

Sixth, although the regression of the second half still has lower explanatory power (McFadden's R^2) than the first half, the difference between the two periods is greatly narrowed in the regression with the neutral band (Table 3) compared to the conventional regression (Table 2). The R^2 increases from 0.085 to 0.241 in the second half. This is due to the fact that the model is rich enough to allow prediction of zero intervention in the model.

4.4. Difference between the two subsamples

It has been established in reviewing the Japanese interventions in the 1990s that the pre-June 1995 period was characterized by frequent, small-scale interventions, while the post-June 1995

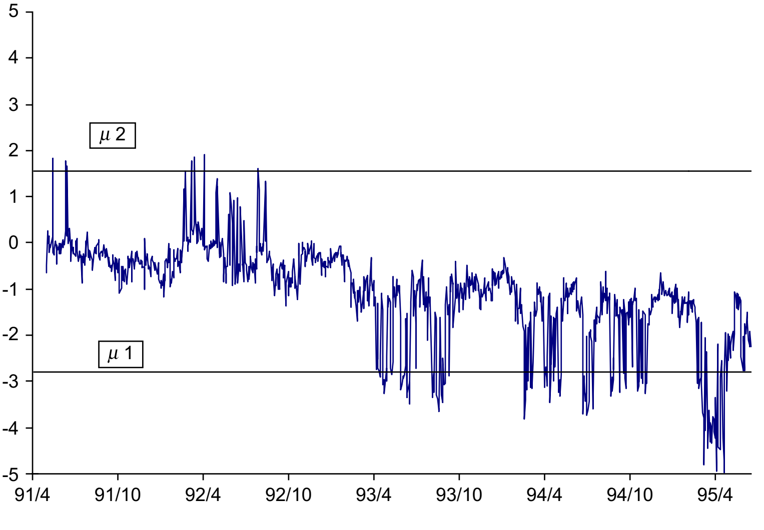

Fig. 6. Neutral band and fitted value of y^*, the first half.

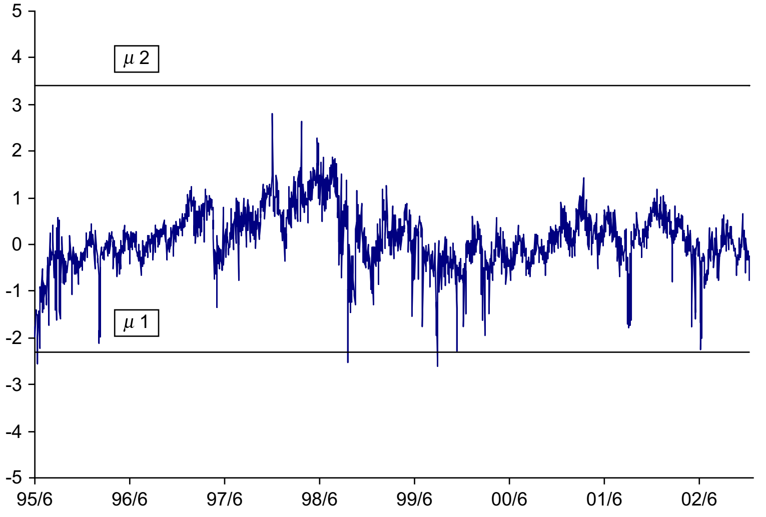

Fig. 7. Neutral band and fitted value of y^*, the second half.

period was characterized by infrequent, large-scale interventions. By the conventional reaction function, a la Ito (2003), showed that the reaction function was estimated badly in the second subsample. Coefficients of the past exchange rate changes and the deviation from an equilibrium level are smaller in the second period than the first period. The smaller estimated coefficients reflect the fact that most of the days, the regressions were fit to predict the zero of the dependent variable. Those who were in charge of interventions in the second period are estimated to be quite insensitive to the exchange rate changes. Infrequent, but large-scale interventions in the second period produced the large forecast errors.

By introducing political costs that lead to a neutral band of no-intervention, it is possible to distinguish whether the monetary authorities of the second period was insensitive to the exchange rate changes—that is the target exchange rate was low—or the political costs were high for some reasons.

Our analysis may suffer from monetary and fiscal policy changes in the sample period.[16] The liquidity trap was discussed in the late 1990s, with a prominent example of Krugman (1998). The zero interest rate policy was adopted in February 1999, lifted in August 2000, only to be re-introduced in March 2001. As Svensson (2001) emphasized, under deflation, depreciation is one of the most effective ways to stimulate the economy and get out of deflation and liquidity trap. Unsterilized intervention is one way to ensure depreciation. Therefore, it is not unreasonable to think that the market participants expected more interventions. This is a valid hypothesis, but it is beyond the scope of our study.

5. Minimizing a surprise or a false alarm?

One way to judge how well the reaction function is tracking the intervention indicator variable is to regard the model as a prediction of intervention, and evaluate the accuracy of

[16] We thank a referee for pointing out the importance of expectations in the environment of deflation and liquidity trap.

prediction. Suppose that an econometrician (or a private-sector market participant) is interested in predicting whether there is intervention on day *t* at the beginning of the Tokyo market, then the probit model can be used for this purpose. The market participant does not like a surprise (i.e., an actual intervention without a warning from a model) or a false alarm (i.e., a model predicts an intervention, which would not take place). The ordered probit model gives the fitted value of probability for intervention. Then, by choosing the cutoff for the indicator in [0, 1], the econometrician can either predict, at the beginning of the Tokyo market, that the intervention will take place or not on that day. If the fitted value of probability exceeds the chosen cutoff value, then an intervention is predicted, while the lower fitted value is ignored for prediction. If the cutoff is too low, then too many interventions are predicted, and most of them will turn out to be false alarms. If the cutoff is too high, then too few interventions are predicted so that actual interventions would take place without the warning call. The task is a well-known problem of balancing minimization of the type one errors vs. the type two errors.

Table 4 summarizes the 2×2 matrix of the prediction and actual interventions: correct prediction, the type one errors, and type two errors. Cell A is the number of days when the signal (warning/prediction) of intervention was issued, and actual intervention was observed. Cell B is the number of days when a warning was issued but turned out to be a false alarm. Cell C is the count of days when actual intervention takes place without a warning by the model. This is the event of surprise intervention. Cell D is the number of days when a model predicts no intervention that turned out to be true.[17]

The currency crisis literature has developed a way to evaluate the so-called early warning model of the crisis (See Kaminsky and Reinhart, 1998 for the seminal work). They have proposed to use the noise-to-signal ratio. Note that $A/(A+C)$ is the ratio of correct signal of the actual intervention (crisis in the early warning literature) days, while $B/(B+D)$ is the ratio of false alarms of the no-intervention days. When a very low cutoff is chosen, then the ratio of correct signals $A/(A+C)$ will increase, but the ratio of false alarm $B/(B+D)$ will increase as well. When a very high cutoff is chosen, the ratio of correct signal decreases, making the signal less reliable in predicting the actual interventions, although the ratio of false alarms would decrease. The noise-to-signal ratio is defined as $[B/(B+D)]/[A/(A+C)]$. The optimal cutoff, as proposed by Kaminsky and Reinhart (1998), is chosen to minimize this ratio. Since $A+C$ and $B+D$ are constant, the optimal cutoff can be chosen to minimize B/A.

Tables 5–7 show the optimal cutoff and the resulting counts in the format of Table 4, for the entire sample, the first half, and the second half, respectively. For the first half, the optimal cutoff was 79%, but the correct signal was issued 29 times out of 165 interventions. The ratio of correct signal was 18%. The false alarm was issued only 6 times out of 936 no-intervention days. The noise ratio was only 0.6%. The noise-to-signal ratio was 3.6%. The intervention was in this sense quite predictable.

For the second half, the optimal cutoff was 28%. With this cutoff, the correct signal was only 7 times out of 49 interventions. The correct signal ratio was about 14%. The false alarm was

[17] We implicitly ignore the possibilities that the probability of the yen-purchasing (selling) intervention is higher than that of the yen-selling (purchasing) intervention, when the yen-selling (purchasing) intervention takes place. In our argument, this case is counted as a correct signal, though it is a noise. However, this is not a problem because these cases do not happen in our data. The monetary authorities always have some economic reasons to intervene in the Forex market so that we do not have a situation in which the econometrician expects the yen-purchasing (selling) intervention when the yen-selling (purchasing) intervention takes place.

Table 4
Conceptual framework: surprise vs. false alarm

	Intervention occurred	No intervention occurred
Signal was issued	A	B
Signal was not issued	C	D
Total	A + C	B + D

Note: Cell A is the number of days when the signal (warning/prediction) of intervention was issued, and actual intervention was observed. Cell B is the number of days when a warning was issued but turned out to be a false alarm. Cell C is the count of days when actual intervention takes place without a warning by the model. This is the event of surprise intervention. Cell D is the number of days when a model predicts no intervention that turned out to be true.

Table 5
Optimal noise-to-signal ratio: full sample

	Intervention	No intervention
Signal was issued	39	7
No signal was issued	175	2834
Total	214	2841

Cutoff: 75%.
Signal: 39/214 = 0.1822.
Noise: 7/2841 = 0.00246.
Noise-to-signal ratio: 0.0135.

Table 6
Optimal noise-to-signal ratio: the first half

	Intervention	No Intervention
Signal was issued	29	6
No signal was issued	136	930
Total	165	936

Cutoff: 79%.
Signal: 29/165 = 0.175.
Noise: 6/936 = 0.0064.
Noise-to-signal ratio: 0.036.

Table 7
Optimal noise-to-signal ratio: the second half

	Intervention	No intervention
Signal was issued	7	18
No signal was issued	42	1887
Total	49	1905

Cutoff: 28%.
Signal: 7/49 = 0.143.
Noise: 18/1905 = 0.0094.
Noise-to-signal ratio: 0.066.

issued 18 times out of 1905 no-intervention days; the noise ratio was 0.9%. The noise-to-signal ratio was 6.6% that is much higher than the first half.

This confirms the conventional wisdom, as documented in Ito (2003) that interventions in the second half of the sample were quite unpredictable, and that was intended by Dr. Sakakibara. It should be noted that the reaction function in this section is of the in-sample prediction type. If the model is seriously used for prediction, the out-of-sample prediction model should be developed. However, it is not straightforward, as both regression and the cutoff point should be optimized everyday. This is left for future research.

6. Conclusion

This paper has proposed and estimated a new model of intervention activities of the Japanese monetary authorities. The reaction function of intervention has been typically estimated with a regular OLS regression. However, the conventional model has a shortcoming of predicting almost always interventions that turned out to be false. The new model is based on a theoretical model of interventions with conditional political costs of intervention. The ordered probit model with a neutral band of no-intervention, is derived from theory, and estimated for the 1991–2002 period. The frequency and size of intervention changed, from frequent, small-size interventions to infrequent, large-size interventions, in June 1995 when Dr. Sakakibara became in charge of intervention policy.

The ordered probit reaction function with a neutral band was estimated for the entire, first half, and second half of the sample. The following points stand out. The interventions were of the lean-against type, in that large changes in the previous days tended to prompt interventions to counter the movement. The authorities tended to intervene when the exchange rate deviated large from a long-term moving average. When there was an intervention a day before, it is more likely, other things being equal, for the authorities to intervene. The neutral band was much wider in the second half than the first half.

The ordered probit function can be viewed as a forecasting model of intervention indicator. When a cutoff level is chosen, the prediction of intervention is generated that may turn out to be true or false. The optimal cutoff level was chosen to minimize the noise-to-signal ratio. The optimal cutoff was higher in the first half than the second half. The noise-to-signal ratio was higher in the second half, as many interventions were surprises. According to the writings of Dr. Sakakibara, this was a deliberate policy of the authorities.

The newly proposed model of interventions is successfully estimated, allowing us to make interpretations that have not been made before. It remains to be a future task to refine the specification, and introduce a concept of out-of-sample forecasts in calculating the noise-to-signal ratio.

Acknowledgements

This paper is drawn from chapter 3 of Tomoyoshi Yabu's Ph.D. Dissertation at Boston University (Yabu, 2005). We thank Naohiko Baba, Graham Elliott, Eli Kollman, Eiji Kurozumi, Kenji Miyazaki, Pierre Perron, Akiko Tamura, and anonymous referees for many helpful comments. We have benefited from comments received from the participants of seminars at Boston University, Japanese Economic Association, MIT, and the Bank of Canada. The first author gratefully acknowledges financial support from Japan Society for the Promotion of Science, Grants-in-aid, Basic Research (A-2-15203008). Needless to say, the authors are solely responsible for any remaining errors. The views and opinions expressed in this paper are those of the authors and do not necessarily reflect those of the Bank of Japan or National Bureau of Economic Research.

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