Modeling Coordinated Foreign Exchange Market Interventions: The Case of the Japanese and U.S. Interventions in the 1990s

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Abstract: During the past thirty years, central banks often intervened in foreign exchange markets. Sometimes they carried out foreign exchange market interventions on a unilateral basis. However, central banks often coordinated their foreign exchange market interventions. We develop a quantitative reaction function model that renders it possible to study the factors that made central banks switch from unilateral to coordinated interventions. We apply our model to the intervention policies of the Japanese monetary authorities and the U.S. Federal Reserve in the yen/U.S. dollar market during the period 1991–2001. To this end, we use recently released official data on the foreign exchange market interventions of the Japanese monetary authorities. JEL no. F31, F33, G14, G15
Keywords: Exchange rates; central bank intervention policy; reaction function; ordered probit model

1 Introduction

During the past thirty years, central banks often intervened in foreign exchange markets in an attempt to influence either the exchange rate level or the exchange rate volatility. While, during some periods, central banks carried out interventions on a unilateral basis, during other periods they coordinated their foreign exchange market activity. The factors that triggered unilateral interventions have extensively been ex-

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plored in the empirical literature. However, relatively little is known about the factors that led central banks to conduct coordinated instead of unilateral foreign exchange market interventions. This paper contributes to fill this gap by developing a quantitative model that allows assessing whether systematic factors exist that, in the past, led central banks to prefer coordinated over unilateral foreign exchange market interventions.

Our paper adds a new aspect to the substantial and rapidly growing empirical literature on foreign exchange market interventions. Papers in this literature usually deal with one of two broad research topics. One topic of research is the effect of foreign exchange market interventions on the level and the volatility of exchange rates.[1] The other major topic of research concerns the motivating factors behind the foreign exchange market interventions of central banks. Generally, these factors are identified upon estimating the reaction functions of central banks.

The reaction function model we develop belongs to the class of qualitative dependent variable models. Such models have often been used in recent analyses to model the response of central banks to economic developments. Significant contributions to the literature using this type of empirical model include, in particular, the studies by Almekinders and Eijffinger (1994, 1996) and Baillie and Osterberg (1997a).[2] The specific qualitative dependent variable model we use is the so-called ordered probit model. This model was adapted by, e.g., Eichengreen et al. (1985) and Davutyan and Parke (1995) to estimate central bank reaction function models, but in the context of explaining the discount rate policy of central banks. In this paper, we apply the ordered probit model to U.S. and Japanese intervention data in order to analyze

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1 As a kind of effectiveness check, some authors analyze whether foreign exchange market intervention is profitable for the central bank. The profitability of intervention is interpreted as evidence that central banks "buy low and sell high" and, thereby, stabilize foreign exchange rates (see, e.g., Leahy 1995; Sjoo and Sweeney 2000). Also, the results of recent research indicate that a close link seems to exist between the profitability of technical trading strategies and central bank intervention activity (Szakmary and Mathur 1997; Neely 1998; Saacke 2002). While LeBaron (1999) emphasizes that it cannot be ruled out that intervention causes the profitability of technical trading strategies, Neely (2002) finds evidence that intervention does not generate technical trading profits.

2 Useful surveys of the earlier empirical literature are presented in Almekinders (1995) and Edison (1993).

the intervention policy of the Japanese monetary authorities (henceforth referred to as JMA) and the U.S. Federal Reserve (Fed) during the 1990s.[3]

Until recently, the JMA did not make publicly available any data on their foreign exchange market interventions. However, this behavior was not unique. In fact, with respect to the largest economies and the most important currencies worldwide, intervention data, until recently, were made available to researchers mainly in the cases of the Fed and the Deutsche Bundesbank.[4] For this reason, the central bank reaction functions presented in the empirical literature, for example by Almekinders and Eijffinger (1994, 1996) and Baillie and Osterberg (1997a), have in general been limited to shed light mainly on the determinants of the intervention activities of the Fed and the Deutsche Bundesbank. By contrast, we make use of the fact that the JMA recently released a comprehensive data set on the interventions in foreign exchange markets it conducted during the period 1991–2001. This release of data on their foreign exchange interventions constitutes a significant change in the information policy of the JMA.

Lacking official intervention data, relatively little effort has been made in the literature to examine the factors behind the intervention activities of the JMA. An exception is the empirical study by Baillie and Osterberg (1997b). These authors had access to official JMA intervention data for the period 1985–1990 in order to study the impact of the interventions of the JMA on the risk premium in the forward exchange market. The study by Ito (2002) is another example for an empirical study using official JMA data to analyze the Japanese foreign exchange market intervention policy. Ito uses the same data set we analyze in this paper. His study differs in two important respects from our study. First,

[3] In Japan, the jurisdiction over decisions on whether or not to intervene in the foreign exchange market rests with the Japanese Ministry of Finance. The Bank of Japan conducts transactions as an agent of the Ministry of Finance. See Ito (2002) for a discussion of the institutional details. As regards U.S. interventions, the U.S. Treasury has the legal authority for intervention. In practice, Treasury consults with the Fed on intervention decisions. Afterwards, the Federal Reserve Bank of New York conducts intervention on behalf of both (see Humpage 1994 and Schwartz 2000).

[4] Recently, official intervention data disseminated by the central banks of Australia (Kim et al. 2000; Kim and Sheen 2002; Neely 2002), Sweden (Sjoo and Sweeney 2000, 2001; Aguilar and Nydahl 2000), Switzerland (Dominguez and Frankel 1993; Fischer and Zurlinden 1999; Neely 2002), and the Netherlands (Fase and Huijser 1994) were used in empirical analyses of foreign exchange market intervention.

Ito focuses his analysis on the effects of the JMA interventions in the 1990s on the level of the yen/U.S. dollar exchange rate. Second, though he also estimates a reaction function for the JMA, his reaction function model is different from the one we develop in this paper. In particular, he does not use the ordered probit model as a tool allowing him the estimation of a central bank reaction function that features coordinated foreign exchange market interventions. The ordered probit model we use in this paper renders it possible to estimate a central bank reaction function model that describes unilateral and coordinated interventions within a unified framework.

Our empirical results suggest that fundamental developments in the yen/U.S. dollar foreign exchange market only had little explanatory power for the decision of the JMA and the Fed to coordinate their intervention activities. Our results indicate that the Fed joined the JMA when intervening in the foreign exchange market more or less on a discretionary basis. This follows from the small marginal effects of both deviations of the yen/U.S. dollar foreign exchange rate from a medium-term or long-term target rate and "disorderly markets" in the form of high exchange rate volatility on the probability of coordinated intervention.

Clearly, these results do not contradict the argument that the main motive behind conducting coordinated interventions had been to make interventions more forceful and credible. Yet, they indicate that the central banks did not believe that the credibility of their interventions was influenced much by economic developments in the foreign exchange market. This suggests that other factors that cannot be easily captured in a quantitative model seem to have played a major role for the coordination of foreign exchange market interventions.

We organize the remainder of this paper as follows. In Section 2, we describe the data set we use in our empirical analyses. In Section 3, we lay out the empirical central bank reaction function model. In Section 4, we motivate the set of variables we use as explanatory variables of the JMA and Fed interventions in the yen/U.S. dollar market. In Section 4, we also present the estimation results we obtain for our reaction function model. In Section 5, we back up our empirical results by providing further evidence on the determinants of unilateral and coordinated interventions. In Section 6, we offer some concluding remarks.

2 The Data

The data set we analyze in this paper contains daily yen/U.S. dollar spot exchange rates and daily data on the foreign exchange market interventions of the JMA and the Fed. We use a recently released data set on the interventions of the JMA in the yen/U.S. dollar foreign exchange market (Japanese Ministry of Finance 2002). The data on Fed interventions are taken from the Federal Reserve Bank.[5] More recent data we collected from the Federal Reserve Bank of New York (2002). In total, our data set covers the period 1991–2001. This sample period includes several episodes of significant foreign exchange market interventions. The data set includes 2,790 days of foreign exchange trading.

Figure 1 shows the development of the yen/U.S. dollar exchange rate for the period 1991–2001 as well as the foreign exchange market interventions conducted by the U.S. Fed and the JMA. The figure shows that the yen appreciated vis-à-vis the U.S. dollar in nominal terms from 1991 until 1995. After the yen/U.S. dollar exchange rate had reached a minimum of 81.07 yen/U.S. dollar in April 1995, the direction of the exchange rate trend reversed and the yen started to depreciate vis-à-vis the U.S. dollar over the subsequent three years. It reached a maximum of 147.11 yen/U.S. dollar in August 1998. The appreciation that took place in 1999 and 2000 was then followed by a depreciation of the yen against the U.S. dollar in 2001.

As regards the foreign exchange market interventions of the Fed and the JMA, Figure 1 provides some evidence that both central banks tried to counter the movements of the yen/U.S. dollar exchange rate. For instance, when the yen tended to appreciate sharply during the period from 1991 to 1995, both central banks frequently stepped into the market in an attempt to purchase U.S. dollars, i.e., to weaken the yen. Note that the scales of the two panels in Figure 1 are different, reflecting that the interventions the Fed conducted during the 1990s were in general smaller than the interventions of the JMA. A closer look at the data reveals that, with only one exception, the Fed intervened in the yen/U.S. dollar market when the JMA did so too. Hence, on such occasions, coordination of interventions can be assumed. In fact, the

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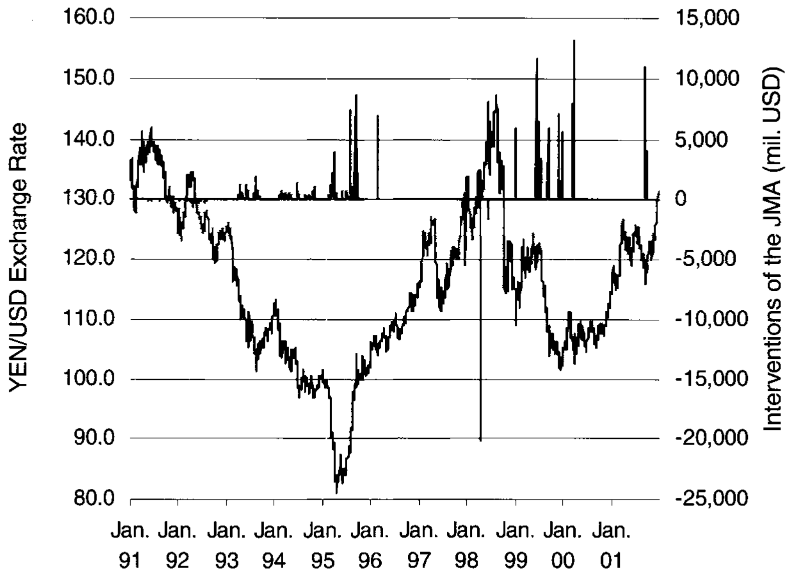
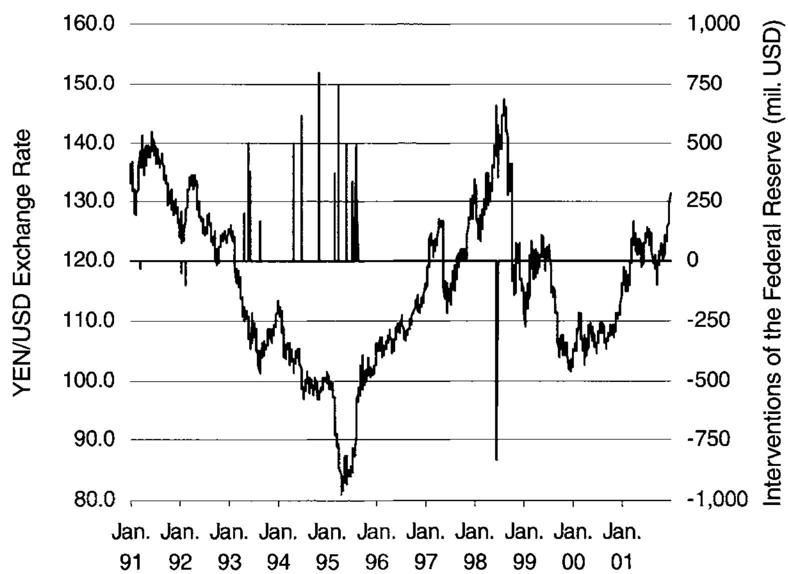
[5] To be more specific, we downloaded a data set providing information regarding Fed interventions during the period 1973–1996 from the internet page of the Federal Reserve Bank of St. Louis. This data set was also used by Neely (1998).

Figure 1: *The Data Used in the Empirical Analysis*





Note: Positive (negative) interventions denote U.S. dollar purchases (sales) of the Fed and the JMA. All interventions are expressed in terms of U.S. dollars.

conditional probability that the JMA intervened whenever the Fed was in the market was 95.7 percent. By contrast, the conditional probability that the Fed intervened on a day when the JMA intervened was only 10.6 percent. On days on which both central banks intervened in the market (22 days), interventions were always in the same direction. These observations suggest that the Fed followed mainly the intervention policy (or intervention requests) of the Japanese monetary authorities.

A more detailed analysis of the foreign exchange market interventions of the JMA and the Fed can be conducted by resorting to the summary statistics that we present in Table 1. We use these summary statistics to study at which exchange rate levels the JMA and the Fed stepped into the yen/U.S. dollar market. This is motivated by the work of Ito (2002), who suggests that the JMA used foreign exchange market interventions in order to stabilize the yen/U.S. dollar exchange rate around an implicit target level of 125 yen/U.S. dollar. To study whether this was indeed the case, we partition the exchange rate series into nonoverlapping equidistant intervals of width 5 yen/U.S. dollar. With this partition in hand, we can compute the cumulated volume of interventions and the number of interventions for each yen/U.S. dollar interval.

With respect to the direction of intervention, a clear picture emerges: All interventions aiming at strengthening the yen – i.e., interventions that involved selling U.S. dollars – occurred when the yen was above the level of 125 yen/U.S. dollar. In line with this behavior, all interventions aiming at weakening the yen – i.e., interventions that involved buying U.S. dollars – took place when the yen was below the exchange rate level of 125 yen/U.S. dollar. This is a first hint that the central bank objective was to stabilize the exchange rate around this level.

Furthermore, Table 1 shows that the JMA intervened more often (208 intervention days) than the Federal Reserve (23 intervention days). Despite this difference in the frequency of intervention, the data reveal that, with respect to the direction of intervention, both central banks always intervened in the same direction.

3 A Quantitative Model of Coordinated Central Bank Interventions

To describe the foreign exchange market intervention policies of the JMA and the Fed, we estimate a central bank reaction function model.

Table 1: *Summary Statistics of JMA and U.S. Fed Foreign Exchange Market Interventions, 1991–2001*

Yen/U.S. dollar exchange rate		Japanese monetary authorities				Federal Reserve			
Higher than ...	... and up to ...	Direction of interventions	Number of intervention days	Sum of amounts ($ mil.)	Average amount per intervention ($ mil.)	Direction of interventions	Number of intervention days	Sum of amounts ($ mil.)	Average amount per intervention ($ mil.)
145	150	$ sales	0	0	0	$ sales	0	0	0
140	145	$ sales	2	299	150	$ sales	0	0	0
135	140	$ sales	3	1,880	627	$ sales	2	863	432
130	135	$ sales	7	3,320	474	$ sales	0	0	0
125	130	$ sales	21	32,130	1,530	$ sales	3	200	67
120	125	$ purchases	3	25,667	8,556	$ purchases	0	0	0
115	120	$ purchases	10	33,058	3,306	$ purchases	0	0	0
110	115	$ purchases	18	12,944	719	$ purchases	1	200	200
105	110	$ purchases	23	33,863	1,472	$ purchases	3	1,066	355
100	105	$ purchases	54	63,421	1,174	$ purchases	4	1,475	369
95	100	$ purchases	35	27,034	772	$ purchases	4	1,900	475
90	95	$ purchases	9	13,338	1,482	$ purchases	2	870	435
85	90	$ purchases	17	17,049	1,003	$ purchases	3	1,333	444
80	85	$ purchases	6	3,900	650	$ purchases	1	500	500
		Total sales	33	37,630	1,140		5	1,063	213
		Total purchases	175	230,273	1,316		18	7,344	408
		Total intervent.	208	267,903	1,288		23	8,407	366
Lowest point of dollar sales			125.025 yen/U.S. dollar on 5-Jan-93				125.025 yen/U.S. dollar on 5-Jan-93		
Highest point of dollar purchases			124.998 yen/U.S. dollar on 14-Jul-92				111.200 yen/U.S. dollar on 27-Apr-93		

The central bank reaction function model we estimate belong to the class of so-called qualitative dependent variable models. The particular qualitative dependent variable model we use is the ordered probit model (see, e.g., Greene 2000: 875–879). This model, which was pioneered by Aitchison and Silvey (1957), is particularly suited to address the question we analyze in this paper because it allows for a simultaneous estimation of the determinants of unilateral and coordinated foreign exchange market interventions.

To set up the ordered probit model, we first introduce a latent continuous variable, S_t^*, that denotes the joint propensity of the JMA and the Fed to intervene in the foreign exchange market. The continuous variable, S_t^* , is defined on the real line and is assumed to depend linearly on an $(m \times 1)$-dimensional vector, $\mathbf{x_t}$, of explanatory variables determining the conditional mean of S_t^* as formalized below:

$$S_t^* = \mathbf{x}_t'\mathbf{b} + \varepsilon_t, \tag{1}$$

where $\mathbf{b}$ denotes a $(m \times 1)$ vector of coefficients and ε_t is a normally distributed error term. To avoid distortions caused by a potential simultaneity bias, we use lagged realizations (i.e., from period $t - 1$) of the explanatory variables in the vector of regressors, $\mathbf{x_t}$, when estimating the ordered probit model.

The motivation to employ the ordered probit model to analyze the coordination of central bank interventions stems from the fact that S_t^* has a continuous state space and is, therefore, in general not observable. To develop an empirically meaningful model, we assume that it is only possible to observe a discrete variable S_t (the foreign exchange market interventions of the JMA and the Fed) that assumes a known numerical value if the unobservable index variable, S_t^*, falls into a certain interval of its state space. The ordered probit model can then be used to link the observable realizations of S_t and the unobservable continuous variable, S_t^*, via the following assignment rule (Campbell et al. 1997: 123):

$$S_t = j \text{ if } S_t^* \epsilon s_j, \quad j = 0, 1, \ldots , N, \tag{2}$$

where the sets s_j form an ordered partition of the state space of S_t^* into j nonoverlapping intervals. In the following analysis, it suffices to set $N = 2$, as this implies that we can subdivide the state space into three disjunct intervals that allow discrimination between no interventions, unilateral JMA or unilateral Fed interventions, and coordinated JMA and Fed interventions. Denoting interventions by I_t and indicating the central bank by a superscript, we assume that the unobservable continuous latent variable, S_t^*, is in interval j whenever the following inequalities hold:

$$S_t = \begin{cases} 2 \text{ if } I_t^{JMA} \neq 0 \text{ and } I_t^{FED} \neq 0 \\ 1 \text{ if } I_t^{JMA} \neq 0 \text{ and } I_t^{FED} = 0 \vee I_t^{JMA} = 0 \text{ and } I_t^{FED} \neq 0 \\ 0 \text{ if } I_t^{JMA} = 0 \text{ and } I_t^{FED} = 0. \end{cases} \tag{3}$$

Equation (3) states that S_t^* is in interval 2 whenever both the JMA and the Fed intervened in the yen/U.S. dollar market. The latent variable, S_t^*, can be found in interval 1 whenever the JMA or the Fed carried out a unilateral intervention. Similarly, the unobservable continuous process assumes a realization belonging to interval 0 if neither the JMA nor the Fed intervened in the yen/U.S. dollar market.

For estimation purposes, we reformulate (3) in terms of the latent variable as follows:

$$S_t = \begin{cases} 0 & \text{if } \quad S_t^* \leq S_1 \\ 1 & \text{if } \quad S_1 < S_t^* \leq S_2 \\ 2 & \text{if } \quad S_2 \leq S_t^*, \end{cases} \tag{4}$$

with S_1 and S_2 being threshold parameters separating the nonoverlapping states, S_j. Given that ε_t is assumed to be normally distributed, the probability that S_t^* can be found in interval j can be written as (see, e.g., Greene 2000: Chapter 19):

$$\begin{aligned} \text{Prob}(S_t = 0) &= \Phi(S_1 - \mathbf{b}'\mathbf{x_t}) \\ \text{Prob}(S_t = 1) &= \Phi(S_2 - \mathbf{b}'\mathbf{x_t}) - \Phi(S_1 - \mathbf{b}'\mathbf{x_t}) \\ \text{Prob}(S_t = 2) &= 1 - \Phi(S_2 - \mathbf{b}'\mathbf{x_t}), \end{aligned} \tag{5}$$

where $\Phi(\cdot)$ denotes the standard normal distribution function. The unknown parameters of the ordered probit model can be estimated efficiently by maximizing the following log-likelihood function (see Aitchison and Silvey 1957; Campbell et al. 1997):

$$LL = \sum_{t=1}^{n} \sum_{j=0}^{2} N_j \ln \text{Prob}(S_t = j), \tag{6}$$

where N_j assumes the value of one if the realization of S_t is in category j and zero else.

4 The Empirical Evidence on Reasons for Central Banks to Intervene

The results reported by Ito (2002) indicate that the JMA had a longerrun exchange rate target of 125 yen/U.S. dollar in mind when intervening in the foreign exchange market. We therefore use the absolute deviation of the yen/U.S. dollar exchange rate from this "implicit target value" as an explanatory variable in our central bank reaction function model:

$$abs\_125_t = |e_t - 125|, \tag{7}$$

where e_t denotes the yen/U.S. dollar exchange rate. Of course, using an exchange rate level of 125 yen/U.S. dollar as a long-run exchange rate target is to some extent somewhat arbitrary. We, therefore, also use, as a robustness check, the purchasing power parity (PPP) value of the yen/U.S. dollar as a long-run exchange rate target. In this case, we use as an explanatory variable in our central bank reaction function model

$$abs\_PPP_t = \left|e_t - e_t^{PPP}\right|. \tag{8}$$

As a further potentially important explanatory variable, we consider the absolute deviation of the daily spot yen/U.S. dollar exchange rate from its moving average. This is based on the notion that a moving average reflects both short-term and medium-term changes in the exchange rate. As discussed by Almekinders and Eijffinger (1996), defining the moving average of the exchange rate as a target variable of the central bank renders it possible to analyze whether the central bank systematically tried to smooth the exchange rate path by adopting a "leaning against the wind" strategy. To take this argument into account, we incorporate the 25-day moving average of the yen/U.S. dollar exchange rate as a short-term to medium-term target variable in our empirical central bank reaction function model. Specifically, we compute the absolute value of the difference between the actual yen/U.S. dollar exchange rate and its moving average:

$$abs\_mov_t = \left|e_t - \frac{1}{25}\sum_{i=0}^{24} e_{t-i}\right|. \tag{9}$$

Several authors have examined whether central bank interventions are triggered by exchange rate volatility.[6] In order to control for the effect

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[6] See, among others, Bonser-Neal and Tanner (1996), Dominguez (1998), and Beine et al. (2002).

of exchange rate volatility on the probability of an unilateral or a coordinated intervention, we include a measure of exchange rate volatility in the vector of regressors of our ordered probit model. We employ in the set of explanatory variables of our reaction function model three alternative measures of exchange rate volatility. Specifically, we include the absolute yen/U.S. dollar returns, the average of the absolute yen/U.S. dollar return over the preceding five trading days, and exchange rate volatility obtained upon estimating a GARCH(1,1) model.

Finally, we take into account that the interventions of the JMA tended to occur in clusters. To control for the fact that the probability of a JMA intervention in period t conditional upon a JMA intervention in period $t-1$ was relatively high, we include the one-period lagged JMA intervention in the vector of explanatory variables.

Equipped with the variables that have generally been used in the international finance literature to explain the foreign exchange market interventions of central banks, we estimate five specifications of our ordered probit model. Estimating alternative specifications of the model allows the robustness of our empirical results to be analyzed. Table 2 summarizes the estimation results for the various specifications of our model. In specification 1, we neglect the influence of exchange rate volatility on the propensity of the JMA and the Fed to intervene in the foreign exchange market. Therefore, the vector of regressors we use to estimate specification 1 of our model only includes the absolute deviation of the yen/U.S. dollar exchange rate from the 125 yen/U.S. dollar target rate, the absolute deviation of the yen/U.S. dollar exchange rate from its moving average, and the lagged JMA interventions. In specification 2, we use the same regressors as in specification 1 but replace the absolute deviation of the yen/U.S. dollar exchange rate from the 125 yen/U.S. dollar target rate with the absolute deviation of the yen/U.S. dollar exchange rate from its PPP value. In specification 3, we extend specification 1 to incorporate two measures of exchange rate volatility: the absolute returns of the yen/U.S. dollar exchange rate and the average of the absolute yen/U.S. dollar returns over the preceding five trading days. In specification 4 of our model, we replace these volatility measures with the conditional yen/U.S. dollar exchange rate volatility obtained from a GARCH(1,1) model. Finally, in specification 5 of our model, we take into consideration that the JMA may have changed their intervention policy during the sample under investigation. As emphasized by Ito (2002), it could be that the intervention strategy of the JMA changed in

Table 2: *Estimation Results for the Ordered Probit Model*

Specification	(1)	(2)	(3)	(4)	(5)
Abs_ 125	0.0274		0.0281	0.0318	0.0399
z-statistic	(6.84)		(6.92)	(7.41)	(5.38)
Abs_ PPP		0.0297			
z-statistic		(7.85)			
Abs_Mov	0.0802	0.0810	0.0964	0.1441	0.2215
z-statistic	(3.52)	(3.51)	(3.56)	(5.00)	(4.45)
abs. ret.			7.2641		−2.5243
z-statistic			(0.89)		(−0.18)
abs. ret. 5			−25.9982		−13.4072
z-statistic			(−1.43)		(−0.41)
GARCH				−7895.89	
z-statistic				(−3.97)	
Lag. int.	1.5434	1.4685	1.5412	1.4974	1.2397
z-statistic	(15.78)	(14.71)	(15.66)	(15.13)	(9.25)
S_1	2.3095	2.3343	2.2521	2.0986	2.2684
z-statistic	(25.35)	(26.05)	(21.93)	(19.39)	(12.60)
S_2	3.6324	3.6788	3.5768	3.4423	3.7479
z-statistic	(26.72)	(26.94)	(24.97)	(23.23)	(16.44)
LR statistic	406.0628	420.8040	408.4888	427.1004	212.2633

Note: The table provides maximum likelihood estimates of the ordered probit model described in Section 3 as well as some diagnostic statistics. The normally distributed *z*-statistic is used to assess the significance of the coefficients of the independent variables. To assess the overall explanatory power of the model, a likelihood ratio (LR) test was computed. To compute the LR test, both the unrestricted model in equation (1) and a model only containing an intercept term were estimated. Taking the difference between the respective log-likelihood functions to compute $LR = -2(LL_{restricted} - LL_{unrestricted})$ yields a test statistic which is χ^2-distributed with degrees of freedom equal to the number of imposed restrictions (Greene 2000).

1995 when a new Director General of the International Finance Bureau was appointed, who claimed to follow a different intervention philosophy based on less frequent but larger interventions. To take this potential change in the intervention strategy of the JMA into consideration, we estimate specification 3 of our model for a subsample covering the period from 1991 to 1995. In all other respects, specification 5 of our model is identical to specification 3.

The estimation results summarized in Table 2 show that the coefficients of the absolute deviation of the yen/U.S. dollar exchange rate from its 125 yen/U.S. dollar rate and the absolute deviation of the yen/U.S. dollar exchange rate from its moving average are significantly different from zero in all five specifications of our model. In contrast, exchange rate volatility seems to have had only a rather moderate impact on the propensity of the JMA and of the Fed to intervene in the foreign exchange market. For instance, the coefficients of the absolute exchange rate returns and the average absolute exchange rate returns over the previous five trading days are insignificant in all specifications of the model in which these measures of exchange rate volatility are included in the vector of regressors. Only the conditional exchange rate volatility from the GARCH(1,1) model is significantly different from zero.[7]

So far, our analysis has not yet focused on the quantitative impact of the various explanatory variables on the probability that S_t^* settles in interval j. Therefore, we report in Table 3 the respective probabilities that $\text{Prob}(S_t = j)$ and the corresponding marginal effects $\partial\text{Prob}(S_t = j)/\partial\mathbf{x}$ for specification 4 of our ordered probit model. The marginal effects allow the identification of the sign and the magnitude of the effect of an infinitesimal variation in the explanatory variables on the probability that S_t^* falls into interval j. In Table 3, we focus on the impact of the absolute deviation of the yen/U.S. dollar exchange rate from its 125 yen/U.S. dollar rate and the absolute deviation of the yen/U.S. dollar exchange rate from its moving average on the probability that the JMA and the Fed conducted unilateral and coordinated interventions.

In the nonlinear ordered probit model, the marginal effect of a change in an independent variable on the dependent variable depends on the value assumed by the independent variable. We, therefore, present in Table 3 marginal effects for two cases: In the first case, the independent variable assumes a value one standard deviation above its sample mean and, in the second case, the independent variable assumes a value one standard deviation below its sample mean. In both cases, we set the other independent variables in the vector of regressors equal to their sample mean.[8] For example, the effect of a marginal change in the absolute deviation of the yen/U.S. dollar exchange rate from 125

[7] When interpreting the significance of the coefficients of the volatility regressors, one should take into consideration that the fact that the "true" exchange rate volatility is unobservable causes an errors-in-variables problem and in general causes the coefficients to be biased toward zero and insignificance.

[8] We neglect the effect of lagged interventions.

Table 3: *Marginal Effects for the Ordered Probit Model*

Variable	State	Probability		Marginal effects	
		$\mu - \sigma$	$\mu + \sigma$	$\mu - \sigma$	$\mu + \sigma$
	0	0.9838	0.9385	−0.0013	−0.0039
Abs_125	1	0.0160	0.0595	0.0013	0.0037
	2	0.0002	0.0019	0.0000	0.0002
	0	0.9808	0.9463	−0.0067	−0.0157
Abs_Mov	1	0.0188	0.0534	0.0066	0.0156
	2	0.0003	0.0003	0.0002	0.0002

Note: Marginal effects are calculated from the results for specification 4 (see Table 2) by setting the explanatory variables equal to their mean. The lagged interventions are set equal to zero. The parameters μ and σ denote the mean and the standard deviations of the absolute deviation of the yen/U.S. dollar exchange rate from its 125 yen/U.S. dollar target value and of the absolute deviation of the yen/U.S. dollar exchange rate from its moving average, respectively.

yen/U.S. on the probability that the JMA and the Fed conducted a coordinated intervention is equal to 0.0002 in specification 4 if the absolute wedge between the actual exchange rate and its "implicit target rate" assumes a numerical value one standard deviation above its sample mean.

The results summarized in Table 3 show that the quantitative impact of deviations of the yen/U.S. dollar exchange rate from its target level had only a negligible impact on the probability that the JMA and the Fed used coordinated rather than unilateral foreign exchange market interventions. Thus, though our model successfully captures the impact of several important explanatory variables on the foreign exchange market interventions of the JMA and the Fed, it also implies that the decision of these central banks to coordinate their interventions can hardly be explained in terms of fundamental developments in the foreign exchange market.

Our results according to which traditional fundamentals can hardly explain the specific coordination behavior between the JMA and the Fed is confirmed by the expectation-prediction table given in Table 4. Expectation-prediction tables are a convenient instrument allowing the fit of a qualitative dependent variable model to be analyzed. The expectation-prediction table given in Table 4 refers to specification 4 of our model. We computed the prediction of the model by picking the

Table 4: *Expectation-Predictions Table*

State	Actual number of counts	Predicted number of counts	Error
0	2,579	2,718	−139
1	187	70	117
2	22	0	22

Note: The table is based on specification (4) of the model presented in Table 2. The actual number of counts gives the number of no-intervention days (state 0), the number of days on which unilateral interventions were conducted by the JMA (state 1), and the number of days on which the JMA and the Fed conducted coordinated interventions (state 2). The predicted number of counts results from classifying the predictions on the basis of the respective maximum predicted probability.

state with the maximum probability among the three for the point estimates. The expectation-prediction table reveals that the model predicts 70 out of 187 unilateral foreign exchange market interventions during the sample period under investigation. Thus, upon using our model, we are quite successful in explaining roughly one-third of the unilateral interventions. In contrast, according to the expectation-prediction table, our model fails to predict the interventions the JMA coordinated with the Fed.[9]

Because our model contains all explanatory variables commonly used to estimate central bank reaction function models (see, e.g., Ito 2002), we conclude that, though these variables have some explanatory power, other factors may have played an additional (and significant) role when the JMA and the Fed decided to coordinate their foreign exchange market interventions. Thus, it is obviously not the same set of economic factors that triggered unilateral and coordinated interventions.

[9] One should not stretch the interpretation of the expectation-prediction table too far. It is well known in the empirical literature that even binary qualitative-dependent variable models with a good fit often fail to produce forecasted probabilities greater than 50 percent. We, therefore, emphasize that the results of the expectation-prediction table do *not* imply that our ordered probit model is completely useless in predicting interventions. In fact, the estimation results summarized in Table 2 clearly show that our ordered probit model does help predicting interventions. The expectation-prediction table, however, indicates that the predicting power of the model mainly applies to unilateral rather than coordinated interventions.

5 A Closer Look at Unilateral and Coordinated Intervention Days

Our empirical results suggest that determinants most commonly used to explain unilateral interventions are not able to explain the coordinated interventions conducted by the JMA and the Fed during the 1990s. However, this neither implies that coordinated interventions occur without reasons nor that that coordinated JMA and Fed interventions occurred completely randomly, independent of the state of the explanatory variables we use in our reaction function model. To analyze this argument in more detail and to gain further insight into the characteristics of the JMA and Fed intervention policies, we study whether the absolute deviation of the yen/U.S. dollar exchange rate from its "implicit target rate" of 125 yen/U.S. dollar was different on days of coordinated interventions as compared to days of unilateral interventions.

Table 5: *Comparing Non-Intervention and Intervention Days*

	No-intervention days (1)	Unilateral intervention by either JMA or Fed but not both (2)	Coordinated intervention by JMA and Fed (3)
Number of observations	2,581	187	22
Mean of ABS_DIF_125	12.48	19.98	23.32
		t-Test	*U*-Test
Null hypothesis (1) = (2)		9.78***	−10.14***
Null hypothesis (2) = (3)		1.29	−1.42
Null hypothesis (1) = (3)		4.35***	−4.39***

Note: The standard *t*-test and the nonparametric Mann–Whitney *U*-Test are used to compare the differences between the arithmetic mean of the absolute deviation of the yen/U.S. dollar exchange rate on non-intervention and intervention days and the mean on days of unilateral and coordinated intervention. *** indicates significance at the 1 percent level. For further details on these tests, see DeGroot (1989).

Table 5 shows the mean of the absolute differences between the exchange rate and the exchange rate level of 125 yen/U.S. dollar as observed on non-intervention days, days when a unilateral intervention occurred, and days when a coordinated intervention took place. The results summarized in Table 5 can be interpreted as follows. On days when no interventions of the Fed or the JMA occurred, the exchange rate deviated from this level on average by about 12 yen. On days when only the JMA conducted foreign exchange market interventions, this difference was on average about 20 yen, i.e., it was higher than on days without any intervention activities. As shown in the lower part of Table 5, the difference between these two mean values is statistically significant. Furthermore, the last column of Table 5 reveals that the exchange rate of the yen vis-à-vis the U.S. dollar deviated from 125 yen/U.S. dollar on average by more than 23 yen on days of coordinated interventions. The difference between the average deviation of the exchange rate from the 125 yen/U.S. dollar level on days of coordinated interventions on the one hand and on days without any interventions on the other hand is also statistically significant. Although the mean is higher on days of coordinated intervention, the difference between the means of unilateral and coordinated intervention days is not statistically different. These results confirm the results of estimating our ordered probit model reported in Section 4. It appears that interventions were conducted on days when the wedge between the actual exchange rate and the "implicit target rate" of 125 yen/U.S. dollar was relatively large. Yet, the results highlighted in Table 5 also suggest that there is no statistically significant difference between the deviations of the exchange rate from its "implicit target rate" on days of unilateral and coordinated interventions. This means that coordinated interventions tended to occur on similar days as unilateral interventions.

We are, thus, led to the conclusion that a significant deviation of the yen/U.S. dollar exchange rate from its "implicit target level" defined by the central banks seems to have been a necessary condition for coordinated interventions. Yet, it was not a sufficient condition for coordinated interventions to occur since not all significant deviations triggered a coordinated intervention of the JMA and the Fed. Given that there were 22 coordinated interventions and 187 unilateral interventions during the period 1991–1999, we further conclude that (i) most of the time significant deviations of the yen/U.S. dollar from its "implicit target value" triggered only unilateral interventions, and (ii) the JMA and the Fed mainly decided on a discretionary basis about coordinated foreign exchange market interventions. This, in turn, suggests that political factors rather than economic factors were the main determinants of coordinated JMA and Fed interventions in the 1990s.

6 Conclusions

The vector of explanatory variables we use in our reaction function model contains the major economic regressors supposed to be of importance for explaining central banks' foreign exchange market intervention policy. Our results clearly show that these variables have some significant explanatory power for explaining the intervention policy of the JMA and the Fed in the 1990s. However, our findings also highlight that these variables do only a poor job in explaining the coordinated interventions of the JMA and Fed implying that the coordination of interventions was driven by different factors than unilateral interventions. In fact, our results suggest that other, more qualitative factors – presumably more political in nature – play a prominent role as explanatory variables for the decision of the JMA and the Fed to coordinate their foreign exchange market interventions.

Of course, it is always difficult to capture such factors in a quantitative central bank reaction function model. For central banks to conduct coordinated interventions, many qualitative factors could play an important role. For example, consultations between two countries, whether held regularly or on a more discretionary basis, could be used to discuss, among other topics, the appropriateness of the exchange rate level and, if found inappropriate, could lead to coordinated activities. In addition, it cannot be excluded that, on occasion, foreign exchange market intervention can be the response of a central bank to market expectations about future negative economic developments, rumors about the objectives of the leadership of a central bank, or statements questioning the reputation, credibility, or decisiveness of a central bank.

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