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The Design of Effective Central Bank Interventions : the yen/dollar case.

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Abstract

This paper explores the effects of the recent interventions of the American Federal Reserve and the Bank of Japan on the level and volatility of the yen/dollar exchange rate. A special attention is devoted to the prominent features affecting the signal conveyed by these interventions. Different GARCH models are estimated, including models with interventions in level or captured by dummies (referring to the signalling effect"). Unilateral interventions of the Bank of Japan exhibit a virtuous effect when expressed in levels but a perverse signalling effect. In order to solve this puzzle, we introduce threshold GARCH models. The results show a clear duality : small unilateral intervention are counterproductive while large and sustained ones influence the foreign exchange market in the desired directions. It is also found that the perverse effect is avoided through coordinated operations.

JEL Classification : F31, E58.

Keywords : Central bank intervention, Signalling channel, Foreign exchange market, Exchange rates.

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The Design of Effective Central Bank Interventions : the yen/dollar case.

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1. Introduction

This paper studies the effectiveness of Central Banks Interventions (CBI) on the yen/dollar exchange rate during the last decade. It is original in two ways : the data set[1] and the econometric strategy. As a result, we obtain strong evidence of CBI effectiveness on the level of the yen/dollar rate. Nevertheless, it has a price, namely, a volatility increase.

The data set includes all dates and amounts of the Japanese and US CBI during the last ten years. The precise dates and amounts of the Bank of Japan's (BOJ) interventions have become public only very recently. They form a valuable source of information.

The econometric strategy we follow is mainly based on a "specific to general" principle. By including one by one the components of the signalling channel into the GARCH regressions, we clearly argue in favor of the dominance of the parsimony criterion.

Globally, the recent literature on CBI on the foreign exchange (forex) market documents poor effectiveness on the level of exchange rates together with a destabilizing impact in terms of conditional volatility. However, the results are far from uniform across the literature. They depend on the period and the currency under study, but also on the econometric specification. A rather exhaustive survey on this matter is provided by Baillie *et al.* (2000).

[1] Ito (2002) also uses the same data and deals with the same issue. Our analysis has been carried out simultaneously and independently.

Concerning the yen/dollar exchange rate, Dominguez (1998) and Baillie and Osterberg (1997a) document a volatility increase following from CBI. Chang and Taylor (1998) confirm this result using high frequency data.

Unfortunately, earlier papers on the relationship between CBI and the yen/dollar rate met the problem of lack of observable interventions. Therefore, they had to deal with sources of information which are inevitably less reliable than direct CBI data. For instance, Baillie and Osterberg (1997a) did not include BoJ interventions in their study, Cai *et al.* (1998) captured the size of these interventions through estimations[2] published in the *Financial Times*, Chang and Taylor (1998) and Galati and Melick (1999) built a data set on Reuters articles, Esaka (2000) used the *Nihon Keizai Shinbun*, Japan's leading daily newspaper. Like Bonser-Neal and Tanner (1996), Beine *et al.* (2002) took advantage of official interventions data provided by the Federal Reserve (Fed) but had to infer the BoJ interventions from the *Wall Street Journal* and/or the *Financial Times* reports.

Another general feature in the literature on CBI concerns the channels through which interventions influence the forex markets. A clear consensus supports that, when interventions do work, it is through a "signalling channel" rather than through a "portfolio channel" (see Popper and Montgomery (2001) for an insightful analysis including, e.g., the puzzling question of CBI secrecy). This point is clearly made by the Fed itself : "Because the Fed's purchase or sales of dollars are small compared with the total volume of dollar trading, they do not shift the balance of supply and demand immediately. Instead, intervention affects the present and future behavior of investors. In this regard, U.S. foreign exchange interventions used as a device to signal a desired exchange rate movement" (Federal Reserve Bank of New York (2000), p.2).

The determinants of the signalling channel have been further investigated. Dominguez (1998) has pointed out that all Central Banks do not have the same credibility or, at least, that intervention signals may not always be credible and unambiguous. Signals coming from weak banks are less effective than those

[2] The estimated values of the interventions in 1998 reported in this paper are : $5 billions on April, 10 and $2 billions on June, 17. Our data base indicates that the dates are correct but these two coordinated interventions have the following respective sizes : $20.32 billions and $1.68 billions. It seems that the undervaluation of the April, 10 intervention comes from the fact that it was thought to be a unilateral Japanese intervention.

delivered by strong banks, like the Fed[3]. Also, coordination among central banks seems to exhibit a positive influence on the market, regardless the amount involved in the intervention (Catte *et al.* (1994) ; Boubel *et al.* (2001)).

Moreover, it appears that CBI are mostly grouped over time. This could indicate that the sustainability of the intervention plays a role in the signalling effect. Finally, the size of the intervention may be of some importance, not *per se*, but rather by indicating to the market the strength of the Central Bank's will. Using an event study approach, Fatum (2000) exhibits that the main factors driving successful interventions are coordination, clustering[4] and large-scale operations.

The existence of specific signalling channels goes apparently in the opposite direction to the overall poor effectiveness of CBI. Actually, there is no formal contradiction between these two pieces of evidence. Indeed, interventions might well include signals which influence the exchange rate in various directions. This may result in an ambiguous impact of CBI identified in a straightforward empirical analysis. Suppose, for instance, that a weak bank intervenes massively on the market. If bank weakness is "bad news" and massive intervention is "good news", then the observed reaction of the market may be close to zero even though both signals do work strongly.

It follows that disentangling the different components of the signal is necessary for drawing any solid conclusion on CBI effectiveness. This is the primary aim of this paper. The identification of the relevant signalling channels will help tackling the lasting big question : Why do Central Banks still intervene on the forex markets (after all, Central Bankers do read the papers on CBI inefficiency)?

Nowadays, Central Banks make real efforts in providing information on their interventions. One can view these efforts as an indirect confirmation of the accuracy of the signalling hypothesis. Indeed, even if secrecy in intervention was once relevant, the disadvantages of such a strategy seems implicitly recognized by Central Banks.

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[3] Actually, the Fed intervenes on the forex markets together with the US Treasury. In what follows, we will make no difference between these two components of the US interventions.

[4] More precisely, "the first day of intervention in an event or cluster of daily intervention is more likely to be successful" (Fatum (2000), p.18).

This paper will investigate the relative sizes of the components of the signalling effects on the yen/dollar rate through a GARCH model including dummy variables. ARCH-GARCH models have become standard in financial econometric studies in general, and in the empirical literature focusing on the impact of CBI in particular .[5]

The use of dummies follows logically from the dominance of the signalling channel. However, previous research on CBI has used a large variety of such variables. In order to get a parsimonious and robust specification, we will carefully examine the empirical results of earlier papers. Then, we will follow a step by step strategy, starting with a very basic GARCH (1,1) model including only significant variables. Potential signalling component of CBI will be sequentially included in the specification of the level equation, while keeping a rather simple structure for the volatility equation.

Section 2 provides descriptive statistics on the CBI included in our data base. Section 3 presents the dynamics of the yen/dollar rate during the period under consideration (1991-2001) and summarizes the motivations for intervention that can be found in the academic literature as well as in Central Bank reports. Section 4 starts with a survey on the GARCH models used in empirical papers on the effectiveness of CBI. Subsequently, we follow a "specific to general" modeling strategy allowing for progressive inclusion of relevant variables. The selection of the "best model" ends the section. Section 5 concludes and suggests new developments.

2. CBI on the yen/dollar rate : Descriptive statistics

We work with first quality data including the precise date and amount of official CBI on the yen/dollar exchange rate, covering the period April 1991-October 2001[6]. The data have been provided directly by the BoJ and the Fed.

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[5] Their main competitor is the implied volatility computed from traded options. Some authors, like Dominguez (1998), do even use both types of volatility measures.

[6] The choice of the sample period is dictated by the availability of the data on official BOJ interventions.

Figure 1 displays the Japanese interventions through time. While there are clearly much more purchases of yens carried by the BoJ, a massive sale of yens took place on the 10th of April, 1998, amounting to 2,620 billions of yens, i.e., more than 20 billions of USD. This is by far an historical record of direct central bank intervention in the foreign exchange market.

The absolute size of BoJ interventions is growing with time much faster than inflation, which is relatively low during the period under consideration. By the end of 1994, the BoJ often relied on massive interventions. Nevertheless, it kept carrying out small interventions like, for instance, in November 1997[7]. Therefore, the data seem compatible with a progressive change in strategy rather than with a clear cut-off between two subperiods.

Japanese CBI exhibit clear patterns of grouped interventions. Indeed, periods of frequent interventions (mid-1992, mid-1993, end-1994, 1995, second half of 1999 and first quarter of 2000) alternate with inactive periods (first quarter of 1993, from second quarter of 1996 until the November 1997, from mid-2000 until the end of the sample period). Besides, isolated interventions are also observed.

Grouped CBI may be seen as a signalling strategy. Indeed, a central bank might decide to split its planned intervention across time in order to influence the market during a longer period. Also, successive interventions allow the bank to react on a daily basis to market movements. However, interventions are generally costly. Therefore in practice, the grouping strategy is easier to conduct with small amounts. In turn, small amounts may lead to less credibility, especially at the beginning of the intervention period. The potential trade-off between size and clustering of CBI will be investigated in the next section.

The most recent observations in our sample seem to indicate that, at least in the BoJ view, amounts matter. Furthermore, recent operations of the BoJ appear still clustered, but in a less systematic way. While central banks' objectives will not be formally investigated here, it is worth pointing out that the year 1998 looks like a turning point in the BoJ intervention strategy, regarding the size and also the clustering strategy.

[7] In November 1997, the BoJ carried out 5 sales of USD, all involving amounts inferior to 400 millions of USD.

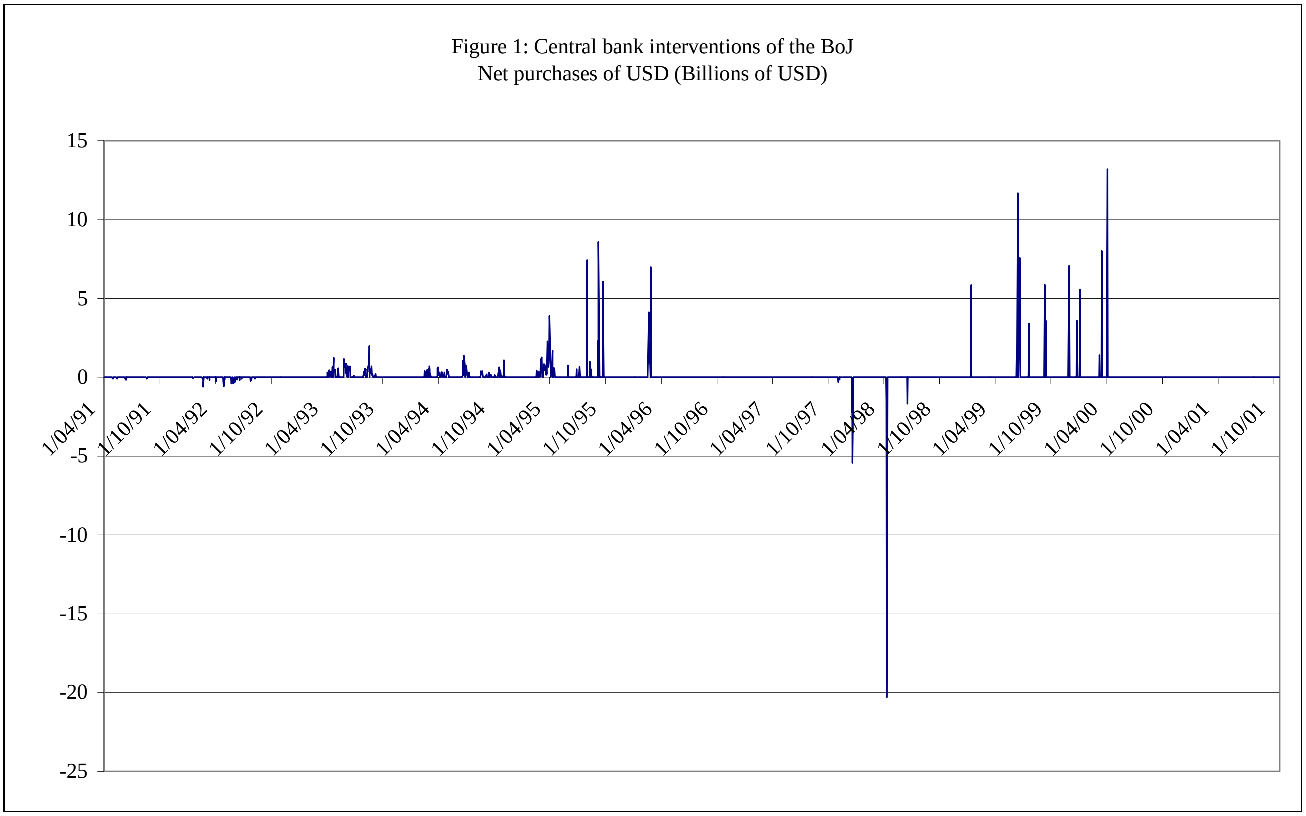


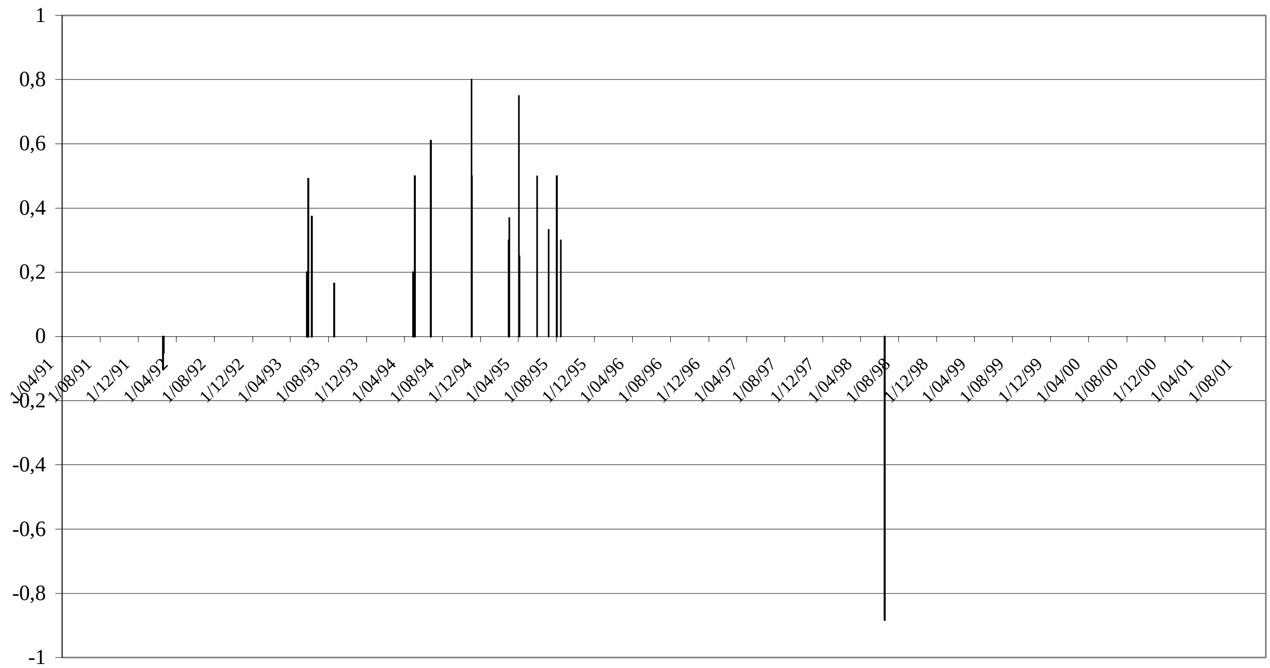
Figure 2 presents the evolution of the Fed's interventions. Note that, due to the magnitude of the data, the scale is different from the one adopted in Figure 1.

The Fed's interventions are concentrated in the first half of the sample period, suggesting that the Fed has dramatically changed its policy regarding forex interventions. After 1995, the only US intervention occurred on the 18th of June, 1998. It was a sale of 883 millions of USD coordinated with the BoJ.

Since only 21 interventions are observed during the period, it is quite difficult to draw conclusions on the size and grouping regularities of the Fed interventions. The small number of occurrences clearly indicates the Fed's reluctance to intervene on the yen/dollar market. [8] Compared to Japan, the US obviously intervened with smaller and less variable amounts.

[8] Humpage (1997) points out the "reluctance to intervene" of US monetary authorities in the nineties.

Figure 2: Central bank intervention of the Fed
Net puchases of USD, billions of USD



The signalling effect of coordination will also be a main focus in the next section. Therefore, at this stage, we adopt a classification of unilateral vs. coordinated CBI, rather than a classification by country. There are several reasons for this choice. First, coordination is indeed a main feature in recent CBI. The central banks themselves confirm that they often coordinate their actions on the forex market. Second, the literature has already emphasized the fact that coordination matters (Catte *et al.*(1994)). Lastly, this classification will reduce the potential multicollinearity problem in the estimations.

Actually, during the last decade, except for a single case, only two types of CBI are observed on the yen/dollar rate : coordinated CBI and unilateral BoJ interventions. The only unilateral intervention of the Fed over the period occurred on the 24th of May, 1993 (the Fed purchased 0.2 billions of USD). We will thus distinguish two types of CBI : unilateral Japanese CBI on one side, coordinated CBI and the only US unilateral CBI on the other side.

Figures 4 and 5 provide the absolute size of the interventions, respectively unilateral from the BoJ and coordinated operations. Coordinated CBI are obtained by summing up US and Japanese interventions occurring the same day and in the same direction.

Coordinated interventions are defined as occurring on the same calendar day, irrespectively of the time discrepancy between Japan and the US. Figure 3 shows the opening hours of the Japanese, European and US markets, expressed in Tokyo local time as our exchange rate quotation refers to the opening price on the Tokyo market.[9] In contrast with European and American markets, there is no overlap between the Japanese and the US markets opening. The New-York market opens up at 10.00 p.m. Tokyo time, five hours after the Tokyo market closure. Central Banks typically intervene during their domestic business hours (Dominguez (1999)). This is consistent with the reported average times of interventions inferred from Reuters time-stamp. On average, the Fed is reported to intervene at GMT 02.57 p.m., while the BoJ intervenes at GMT 03.56 a.m., i.e., around the Japanese lunchtime.

[9] See section 3.1. for further details on the exchange rate quotation.

Figure 3 : Exchange rate markets and opening hours (Tokyo local time)

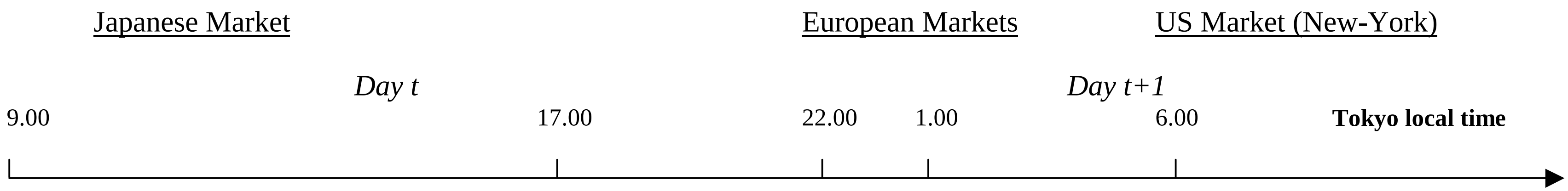


Figure 4: BOJ interventions (absolute amounts)
Billions of USD

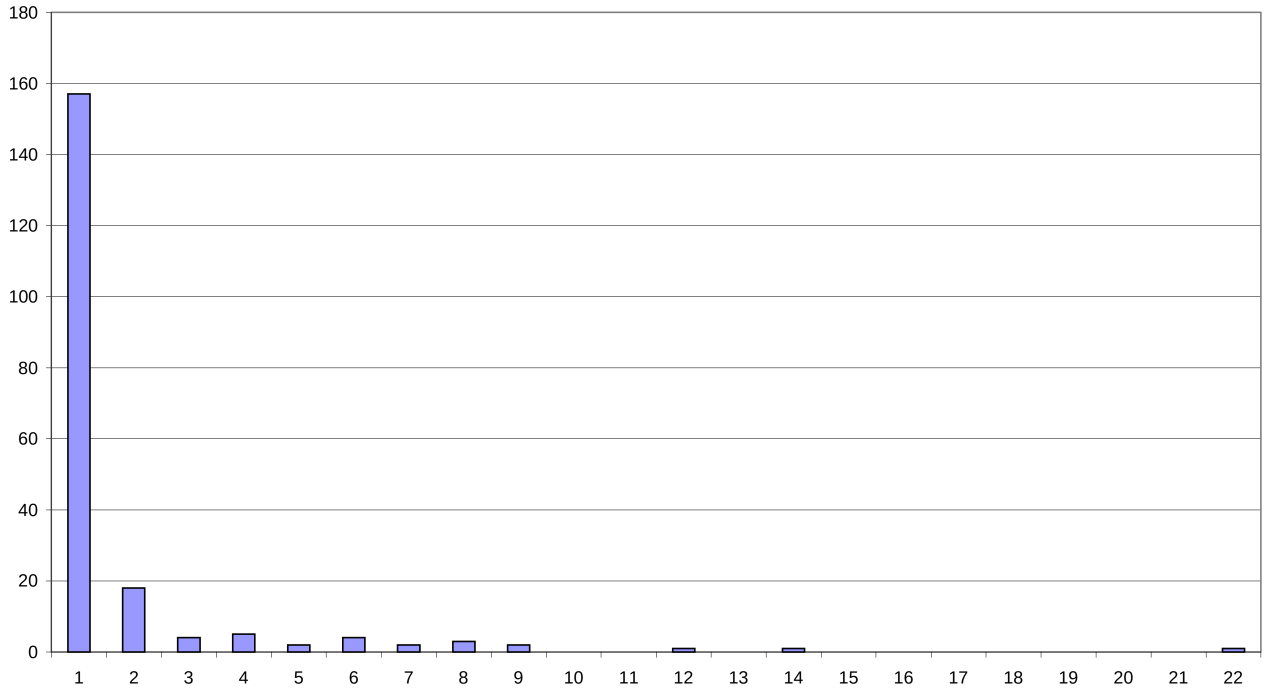
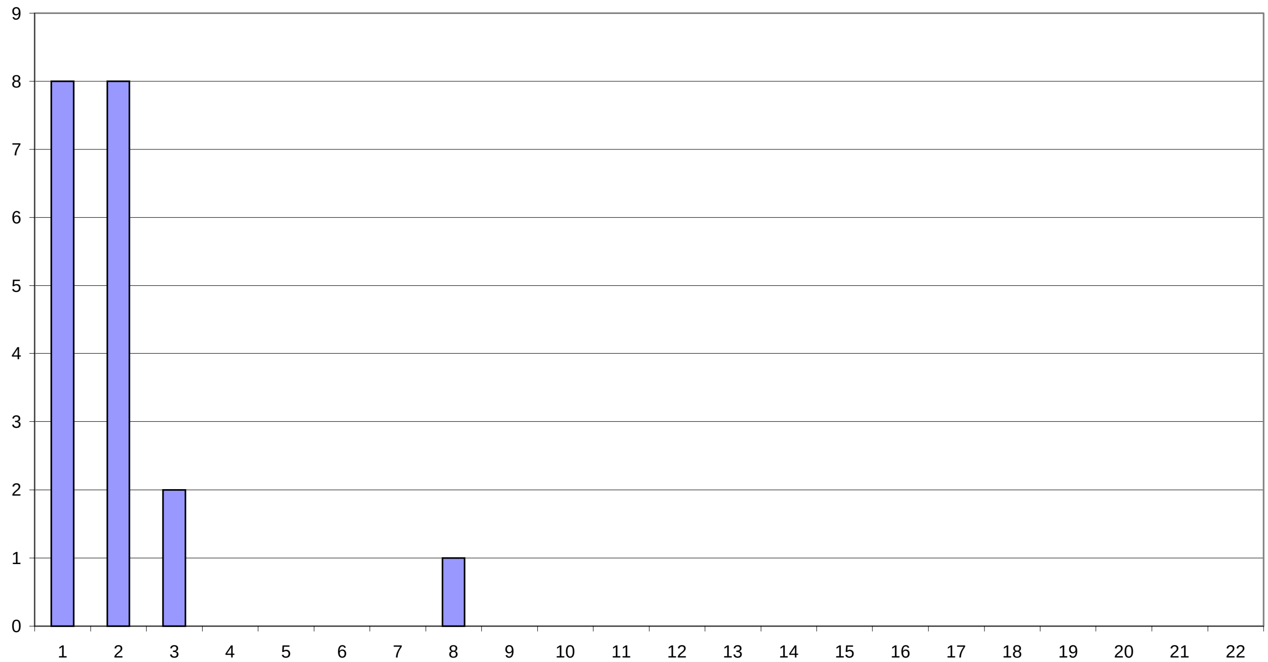


Figure 5: Coordinated interventions BoJ and Fed (absolute amounts)
Billions of USD



At first sight (Fig. 4 and 5), coordinated interventions seem larger on average. However, a formal test of equal mean between the unilateral interventions of the BoJ and the BoJ interventions involved in coordinated interventions is not rejected : the test statistics is equal to 0.054 leading to a p-value of 0.54.[10] This suggests that there is no link between the amount of the intervention and the fact that this intervention is coordinated or not. Table 1 provides descriptive statistics on different kinds of CBI.

Table 1 : Descriptive statistics of central bank interventions (Mia USD)

	Boj	Fed	Co-ordinated	Unilateral BoJ	Co-ordinated BoJ
Number	201	21	20	181	20
Mean	0.79	-0.378	1.16	0.76	0.893
Mean (absolute amount)	1.177	0.269	1.52	1.173	1.143
Standard deviation	2.54	-0.088	1.95	2.60	1.747

[10] The test statistics follows a standard normal distribution under the null hypothesis of equal mean.

3. The yen/dollar rate 1991-2001 : Why did CB intervene ?

3.1. The yen/dollar rate

The data on the yen/dollar exchange rate are collected at 10.00 a.m. Tokyo-time[11], i.e., just one hour after the opening of the Japanese market. This is consistent with the time indexation of the interventions. Indeed, the exchange rate dated t is observed after all potential interventions dated t–1 and before almost all potential interventions occurring at time *t*.

As suggested by Figure 5, the yen-dollar exchange rate displayed some contrasted dynamics. Basically, over the 1991-2001 period, the evolution of the yen against the dollar can be divided into three distinct phases. Until April 1995, the yen strongly appreciated against the dollar. As pointed out by Mc Kinnon *et al.* (1997) the beginning of this trend may be dated back to August 1971. This evolution tended to dampen political tensions between Japan and the US concerning the important US trade deficit but failed to bring the desired adjustment due to severe recessions in Japan. In 1995 however, with the recognition that the Japanese economy faced important disequilibria, the yen sharply depreciated by almost 50 percents, allowing for some modest recovery of the Japanese business cycle. Since 1999, there has been no clear trend in the level of exchange rate although the volatility remained quite high at a daily frequency.

[11] Source : Bank of International Settlement.

Figure 6 : yen-dollar exchange rate
03/01/1991- 19/10/2001

3.2. The goals of the BoJ and the Fed

During the period under consideration, the Bank of Japan has mainly tried to reduce the yen appreciation in order to boost the Japanese exports and reduce the US trade deficit. However, at the end of the 1995-1998 period in which the yen strongly depreciated, the BoJ intervened in support of the yen. In June 1998, the Fed followed the BoJ by selling 880 millions of USD. As a whole, this suggests that the Japanese monetary authorities reacted to the deviation from some target level. This is consistent with the analysis of Galati and Melick (1999) and Esaka (2000) concluding that the interventions on the yen/dollar rate during the nineties were based on an implicit target level.

While the motivation for Japanese intervention seems quite understandable on economic grounds, the American motivations for acting in coordination with the BoJ are less obvious. In order to investigate this point, let us compare the American interventions on the yen/dollar and euro/dollar rates. [12] The two most recent US interventions are a purchase of yens in 1998 and a sale of euros in

[12] These are the only forex markets on which US monetary authorities do indeed intervene.

2000. In both cases, the intervention was coordinated and the Fed's strategy appeared mainly as a follower's strategy : while sometimes accepting to intervene in concert with other banks, the Fed did not conduct any unilateral intervention.[13]

What happened in Europe in September 2000 ? Because of its fear of inflationist movements, the European Central Bank, decided to support the Euro against the USD. The Fischer's (2000) report mentions the rise in currency market volatility as the main reason for this widely coordinated intervention on the European currency.[14] No clear target value for the Euro/dollar rate is indicated but the report quotes Summers' statement that "a strong dollar is in the national interest of the United States" (p.8).

The Fisher (1998) report commenting on the last US intervention on the yen also includes volatility considerations but the yen weakness appears as the main reason to cooperate with the Japanese monetary authorities in selling dollars and buying yens on June, 17, 1998. However, the commitment of Japanese ministers to restore their banking system seems to have played a crucial role in the negotiation.

Seen from the US viewpoint, the Japanese goal in 1998 and the European goal in 2000 were contradictory : dollar appreciation against the yen and dollar depreciation against the euro. In both cases, the Fed accepted to follow. Why ? We do not believe that a decrease in the volatility was the main goal in the Fed's intervention in 1998. Indeed, the perverse effect of CBI on the forex market volatility is now well-known. The "leaning against the wind" policy has shown its limits in many occasions.

The implicit target zone explanation is another rationale. Galati and Melick (1999) mention that "(...) between Sept. 1993 and April 1996, traders viewed the BoJ as responding mainly to deviations of the exchange rate from what they considered to be some implicit target levels. On the other hand, the Fed was viewed to have mainly intervened when market conditions seemed most conductive to a successful intervention".

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[13] The US Dept of Treasury claimed in September 2000 that the concerted intervention on the Euro was made "at the initiative of the European Central Bank" (see Fisher (2000) p.8).

[14] The participants were the Central Banks from the US, Japan, Canada, UK and, of course, the European Central Bank.

The Fed's intervention could also be part of a wider negotiation with its trading partners. For instance, in the Fisher's (1998) report, the disappointment of the US authorities towards the Japanese expected reciprocal actions is readable in these words : "Following the intervention, the yen initially extended its gain, largely on market expectations of further economic and financial policy developments in the near term. However, in market participants' view, such expectations diminished when (...) no new public commitment from Japanese officials" (p.9). This disappointment is maybe the reason why the Fed did not intervene anymore on the dollar/yen market.

4. The effective signals of CBI : GARCH models

4.1. The model

According to Baillie (2000), "there has been considerable debate on the estimates of the quantitative effects [of CBI] on the level and volatility of exchange rates (...)" (p.226). Based on GARCH/FIGARCH models, the recent literature on this topic has firmly established the existence of destabilizing effects of CBI , i.e., positive effects on the conditional variance. This result is robust since it is found whatever the explanatory variables capturing intervention.

Dominguez (1998) proposes a GARCH(1,1) model of dollar/mark and dollar/yen exchange rates. Her specification includes dummies for the day of the week, holidays, exchange rate policy news (excluding CBI) and a interest rate spread. Intervention are captured through four dummy variables : one for each Central Bank at stake and one for secrecy. She ends up with a nine parameters specification. The estimation is then held over three periods for each currency, which makes six different estimated models. The number of significant parameters at the 95% level varies between 1 and 4. Beine *et al.* (2002) extend this analysis by allowing the dynamics of the conditional variance to follow a fractionally integrated GARCH (FIGARCH) specification. Basically, they confirm the previous results of the literature, emphasizing the important impact of CBI on exchange rate volatility.

Kim *et al.* (2000) include dummies for the sustainability and for the size of interventions. However, their study is about the Australian dollar/US dollar exchange rate on which the Fed does not intervene. Therefore, coordination issues are not tackled.

In these papers, the explanatory variables are the same in both equations (level and volatility). Since our goal is the analysis of the signalling effects of intervention, we will mainly focus on the level equation. In order to gain efficiency in the estimation and avoid as much as possible specification errors, we adopt the following two steps estimation method.

STEP 1 : Given a set of intervention variables, denoted by vector x_t, we estimate the following AR(1)-GARCH(1,1) model :

$$y_t = \mu + \rho \ y_{t-1} + \varepsilon_t + b' \ x_{t-1} \, / \, \varepsilon_t \sim \text{Student}(0, \sigma_t^2) \tag{1}$$

$$\sigma_t^2 = \omega + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2 + \gamma' \left| x_{t-1} \right|, \tag{2}$$

where y_t is the current exchange rate return :

$$y_t = \log \frac{s_t}{s_{t-1}} \quad (s_t = \text{price of 1 USD in JPY at time t}),$$

and x_t denotes the intervention variables whose definition varies across regressions.

STEP 2 : We take out of the specification all non-significant variables at the 95% level, except the x_t variables in the level equation. Thus, while constants and autoregressive terms may disappear from both equations, some x_t variables may disappear from the volatility equation. After this elimination, we re-estimate the resulting parsimonious model. The results from this second step will be reported in the paper, for various choices of the x_t variables.

All models are estimated through maximum likelihood, using Gauss 3.6. The conditions for a positive conditional variance are checked in all cases. Standard diagnostics are investigated but not reported here in order to save place.[15]

[15] All models presented below pass the diagnoses tests for remaining autocorrelation and heteroskedasticity based on the Box-Pierce statistics on residuals and squared residuals computed at the conventional number of lags (20, 50 and 100). Depending on the models, the standardized residuals display some excess of skewness and kurtosis. The complete results are of course available upon request.

4.2. The empirical analysis

The database includes three daily series : dollar/yen exchange rate, Japanese and US interventions on the yen/dollar market during the period ranging from April 1, 1991 to October 20, 2001.

The recent release of these intervention series is important to economists in various respects. On the one hand, the knowledge of the exact amounts of the BoJ past interventions greatly helps in understanding its way of doing. On the other hand, the US monetary authorities (Federal Reserve and Department of the Treasury) do intervene solely on the yen/dollar and the euro/dollar markets. The intervention data, together with the US publicly available quarterly notes, allow to revisit the efficiency issue of forex interventions. The question of the need for coordination between central banks is also a key issue in monetary policy.

We estimate model (1)-(2) with seven different sets of intervention variables. In each case, we make use of the two-step estimation strategy described above. The impact of any CBI is thus captured through one-day lagged US or Japanese intervention variables.

a*) pooled interventions in level*

In order to provide a first look at the CBI effectiveness, we pool together the amounts of the BoJ and Fed interventions in a single explanatory variable:

$\mathrm{CUMINT} =$ amount of the pooled intervention (positive when dollars are bought, negative when dollars are sold).

The second step of our estimation procedure leads to the following results :

$$y_t = \underset{(2.219)}{0.0890}\, \mathrm{CUMINT}_{t-1} + \varepsilon_t \qquad \text{(a.1)}$$

$$\sigma_t^2 = \underset{(2.421)}{0.0064} + \underset{(4.734)}{0.0421}\varepsilon_{t-1}^2 + \underset{(79.070)}{0.9460}\, \sigma_{t-1}^2 \qquad \text{(a.2)}$$

The intervention exhibit a significant impact of about 9% on the exchange rate return but no significant effect on the volatility is captured ($\left|\mathrm{CUMINT}\right|$ has been taken out from the volatility equation according our estimation procedure).

Globally, interventions seem thus useful for influencing the exchange rate in the desired direction. The absence of significant volatility effect is good news. Indeed, these first results do not confirm the existence of destabilizing effects of CBI, although these effects are frequently found in the literature (see, among others, Baillie and Osterberg (1997), Dominguez (1998) and Beine *et al.* (2002)).

b) unilateral versus coordinated interventions

Since coordination is a main issue in the analysis of CBI, we now split the interventions into unilateral ones and coordinated ones. As mentioned before, coordination is here related to simultaneity of operations. Central banks do heavily communicate on their respective interventions and simultaneity in intervention is of course not due to chance. Indeed, simultaneous intervention do always share the same sign. Interestingly, in many occurrences the total amount of both interventions expressed in dollars is a round number, suggesting a concerted choice even regarding the amount involved in some coordinated interventions.[16]

The model includes thus two explanatory variables :

UBOJ = amount of the unilateral intervention of the Bank of Japan (positive when dollars are bought, negative when dollars are sold),

COORD = amount of the coordinated intervention (positive when dollars are bought, negative when dollars are sold)

Since our sample includes only one unilateral US intervention, we consider this single value as a coordinated intervention.

We obtain the following results :

[16] Examples of such coordinated operations are CBI on the 27/05/93 (1.25 billions of dollars), 24/06/94 (2 billions of dollars) or 07/07/95 (1 billion of USD).

$$y_t = \underset{(2.243)}{0.0828}\ UBOJ_{t-1} + \underset{(1.954)}{0.2560}\ COORD_{t-1} + \varepsilon_t \qquad \text{(b.1)}$$

$$\sigma_t^2 = \underset{(2.616)}{0.0069} + \underset{(4.974)}{0.0414}\ \varepsilon_{t-1}^2 + \underset{(80.972)}{0.9430}\ \sigma_{t-1}^2 + \underset{(2.075)}{0.1168}\ \left|COORD_{t-1}\right| \qquad \text{(b.2)}$$

Both types of interventions do significantly influence the exchange rate return in level. The signs of the coefficients are consistent with a basic market argument (selling dollars leads to an appreciation of the dollar). However, coordinated interventions seem much more effective (25.6% to contrast with 8.28%). This confirms the strength of the signalling effect coming from the market's perception of the central banks' coordination.

The variable UBOJ is found insignificant in the volatility equation and has been removed. Coordinated interventions are significant in this equation but the positive sign of the coefficient indicates a destabilizing effect.

During the period under consideration, Japan was probably more concerned than the US about the movements of the dollar/yen rate. Thus, the initiative of a joint intervention could be mainly due to the BoJ. Suppose the following decision scheme is applied : When the BoJ decides to intervene on the forex market, it tries to persuade the Fed to come along. If the Fed accepts, agents observe a bilateral intervention, otherwise they observe a Japanese unilateral intervention. In this framework, a unilateral intervention signals that the Fed has refused to participate. The effect on the exchange rate is thus weak because in this case the Japanese policy is less credible : it is costly and difficult to sustain alone on a long period.

According to this interpretation, a bilateral intervention signals that, for some reason, the US does actively support the Japanese policy. Together the two banks become more credible. This is consistent with the following statement by Sarno and Taylor (2001) : "the coordination of multiple signals is more likely to convince speculators that the signaled policy is credible relative to an individual signal, implying that official intervention coordination may help central banks with relatively low reputation or credibility" (p. 10).

In summary, the results indicate that we are facing an asymmetric situation : a strongly credible US central bank reluctant to intervene and a weaker Japanese central bank more willing but less able to influence the yen/dollar exchange rate.

c*) Japanese versus US interventions in level*

In order to further investigate the relative impacts of the two central banks interventions, we now completely dissociate their interventions. Namely, we define the following explanatory variables :

BOJ = amount of the intervention of the Bank of Japan (positive when dollars are bought, negative when dollars are sold),

FED = amount of the intervention of the Federal Reserve (positive when dollars are bought, negative when dollars are sold),

We obtain the following results :

$$y_t = \underset{(2.218)}{0.0874}\ BOJ_{t-1} + \underset{(0.519)}{0.4519}\ FED_{t-1} + \varepsilon_t \qquad \text{(c.1)}$$

$$\sigma_t^2 = \underset{(2.415)}{0.0065} + \underset{(4.615)}{0.0428}\,\varepsilon_{t-1}^2 + \underset{(76.996)}{0.9452}\,\sigma_{t-1}^2 \qquad \text{(c.2)}$$

As in the first estimation results (see equations (a.1)-(a.2)), interventions have no significant impact on the volatility. In the level equation, the point value of the US intervention coefficient is very high compared to the Japanese one (respectively 45.2% and 8.7%). Unfortunately, this coefficient is not statistically significant. Therefore, we will hereafter favor specifications including unilateral versus coordinated interventions.

d) unilateral versus coordinated interventions: dummies

In order to check whether there is a specific "announcement effect", we estimate a model with dummy variables for the interventions, leaving aside the amounts involved in the financial trades.

The signalling effect of the central banks interventions has been largely documented in the literature. A simple way to evaluate this effect is provided by the use of dummy variables. Let us first separate unilateral and coordinated interventions. The explanatory variables are thus :

$IUBOJ$ = dummy for the unilateral interventions of the Bank of Japan (1 if the BoJ buys dollars and the Fed does not intervene, -1 if the BoJ sells dollars and the Fed does not intervene, 0 otherwise)

$ICOORD$ = dummy for the coordinated interventions (1 if the two banks buy dollars, -1 if they sell dollars, 0 otherwise).

We obtain the following results :

$$y_t = \underset{(-2.400)}{-0.1338}\, IUBOJ_{t-1} + \underset{(0.584)}{0.2059}\, ICOORD_{t-1} + \varepsilon_t \qquad \text{(d.1)}$$

$$\sigma_t^2 = \underset{(2.373)}{0.00600} + \underset{(4.6761)}{0.0393}\, \varepsilon_{t-1}^2 + \underset{(80.479)}{0.9474}\, \sigma_{t-1}^2 + \underset{(2.011)}{0.1395}\, \left|ICOORD_{t-1}\right| \qquad \text{(d.2)}$$

These results look quite surprising. The unilateral interventions of the BoJ show a significant but negative influence on the exchange rate while coordinated interventions seem to have no significant impact. Concerning unilateral Japanese interventions, the negative sign of the estimated coefficient means that the agents do indeed view these unilateral interventions as a signal, but as a bad one. This is totally different from the results obtained with interventions in level, i.e. (b.1)-(b.2). The most striking result is of course this sign change. With interventions expressed in levels, the coefficient is equal to 8% while with dummy variables, it becomes equal to -13.4%. The latter indicates a signalling effect going in the wrong direction while the former supported the effectiveness of Japanese CBI.

We are thus facing a puzzle : we get from the same dataset a perverse signalling effect of Japanese unilateral interventions and a positive impact of the same interventions in level ? We conjecture that this puzzle is due to the BoJ low credibility. The argument goes as follows.

A unilateral Japanese intervention signals an adverse situation for Japan : the yen is far from its targeted value and the Fed does not accept to support the

BoJ in influencing the forex market. This is of course bad news for the Japanese economy. However, on top of the pure market effect, the size of the Japanese intervention indicates the strength with which the BoJ pushes the market in the desired direction. In this view, only large interventions are credible. The next estimation will check the validity of this explanation.

e) large and small Japanese interventions

We start from the assumption that there are two types of Japanese unilateral interventions : small ones and large ones. We will formalize "small" and "large" interventions by means of a threshold value. Following Kim et al. (2000), we take the mean absolute size of unilateral Japanese interventions as the threshold value. The following explanatory variable is added to the two dummies $IUBOJ$ and $ICOORD$:

$SUBOJMO$ = dummy for the unilateral interventions of the Bank of Japan above the mean absolute value.

Two different possibilities were investigated : either the explanatory variables are only $SUBOJMO$ and $ICOORD$, i.e., the dummy for coordinated interventions, or we also include the dummy $IUBOJ$ which stands for the all unilateral Japanese interventions (with the appropriate sign).

In the first case, we obtain positive but insignificant coefficients (at the 10% level) and, therefore, we do not report the results. The second model estimation leads to :

$$y_t = \underset{(2.083)}{0.6353}\, SUBOJMO_{t-1} - \underset{(-3.428)}{0.1980}\, IUBOJ_{t-1} + \underset{(0.501)}{0.2141}\, ICOORD_{t-1} + \varepsilon_t \tag{e.1}$$

$$\sigma_t^2 = \underset{(2.354)}{0.0061} + \underset{(4.528)}{0.0404}\, \varepsilon_{t-1}^2 + \underset{(80.461)}{0.9483}\, \sigma_{t-1}^2. \tag{e.2}$$

This result tends to confirm our previous hypothesis about the importance of the size signal of a central bank perceived as weak by the market. Indeed, the size indicator SUBOJMO does significantly influence the level (but not the volatility) with a quite high estimated coefficient (63.5%). Thus, a large intervention goes far beyond compensating the perverse impact of BoJ low credibility. On the opposite, small unilateral Japanese interventions are highly detrimental for the forex BoJ objectives. Note that the BoJ seems to have become aware of this phenomenon. Indeed, in the most recent episodes, it has clearly chosen massive and timely sustained interventions.

The estimated values of the parameters multiplying ICOORD and IUBOJ in (e.1) remain in the range of the values obtained in (d.1), suggesting that the adjunction of the size effect captures an extra component of the signal involved in CBI. Unfortunately, the coefficient before ICOORD remains not significantly different from zero.

f) successive interventions

Let us now consider the impact of successive versus isolated interventions. Various arguments may be invoked in favor of the efficiency of successive or, alternatively, of isolated CBI. First, by intervening during several days, a bank indicates that it has decided to sustain its intervention policy as long as necessary. On the contrary, one can argue that an intervention is followed by others because it has not fulfilled its initial goal, which is in this case an indication of weakness.

Second, sustained CBI may indicate that the bank is strong enough to do so. On the opposite, if each intervention in this sequence is relatively small, this may indicate that the resources devoted to the defense of the exchange rate are limited.

Lastly, if the amounts involved in CBI do not matter (as advocated by the simplest version of the signalling theory), then only small interventions make sense. Therefore, successive small interventions would be much better than a single large one. If a bank believes that this is indeed the case, it will favor successive small interventions, regardless its ability to sustain interventions. According to this view, the time design of intervention might only reflect the implicit model on which the central bank builds its strategy.

We formalize Japanese unilateral successive interventions by introducing the variable SUCC(n) taking the value of 1, respectively -1, if intervention at time t is positive, respectively negative, (the BoJ buys, respectively sells, USD) and preceded by at least one intervention of any bank in a n-days period. Otherwise, the variable takes a zero value. Thus, zero values correspond either to days for which no intervention is observed, or to days of interventions following a period of n days without any intervention.

No distinction is made between isolated interventions and starting points of clustered interventions. Indeed, at the time the agents observe such an intervention, they do not know whether other interventions will follow or not.

The choice of n is not straightforward. The strictest definition of successive interventions corresponds to n = 1. However, as a matter of facts, episodes of clustered interventions often include short subperiods of no intervention. Therefore, larger values of n might be relevant. According to Fatum (2000), "choosing a period with more than fifteen consecutive days of no intervention seems unappealing, losing the intuition that a particular cluster of days of intervention constitutes a separate event" (p.8).

In the current exercise, we took successively the values of 1, 5 and 10 for n. The empirical results do not support any additional effect associated to a sustained strategy of interventions. According to our two-step parsimonious procedure, SUCC(1) is insignificant in the level equation as well as in the volatility equation. The conclusion is similar for SUCC(5). We report the results for SUCC(10) :

$$y_t = \underset{(1.642)}{0.0212}\ \text{SUCC}(10)_{t-1} - \underset{(-2.557)}{0.1456}\ \text{UIBOJ}_{t-1} + \underset{(0.546)}{0.1913}\ \text{ICOORD}_{t-1} + \varepsilon_t \quad \text{(f.1)}$$

$$\sigma_t^2 = \underset{(2.359)}{0.0060} + \underset{(4.631)}{0.0394}\ \varepsilon_{t-1}^2 + \underset{(80.090)}{0.9475}\ \sigma_{t-1}^2 + \underset{(1.987)}{0.1367}\ \left|\text{ICOORD}_{t-1}\right|. \quad \text{(f.2)}$$

The variable SUCC(10) is significant in equation (f.1), but only at the 10% level. Considering that ten is a relatively large value for n, that the value of the estimated coefficient is quite small (2%) and that the p-value is about 10%, we are not inclined to conclude in favor of the signalling effect of successive interventions.

g) Isolated interventions

In order to test whether isolated or first day unilateral BoJ interventions are more likely to be successful we define the variable ISOBOJ(10) taking the value of 1, respectively -1, if there is a positive, respectively negative, unilateral BoJ intervention at time t which is preceded by no intervention of any bank in a 10-days period. Otherwise, the variable takes a zero value.

We obtain the following results :

$$\begin{aligned} y_t = & \underset{(1.597)}{0.0206}\ \mathrm{ISOBOJ}(10)_{t-1} - \underset{(-2.553)}{0.1453}\ \mathrm{UIBOJ}_{t-1} \\ & + \underset{(0.548)}{0.1920}\ \mathrm{ICOORD}_{t-1} + \varepsilon_t \end{aligned} \qquad \text{(g.1)}$$

$$\sigma_t^2 = \underset{(2.359)}{0.0060} + \underset{(4.633)}{0.0394}\,\varepsilon_{t-1}^2 + \underset{(80.134)}{0.9475}\,\sigma_{t-1}^2 + \underset{(1.987)}{0.1367}\,\left|\mathrm{ICOORD}_{t-1}\right|. \qquad \text{(g.2)}$$

These results are similar to those obtained with the successive intervention dummy variable. Together, the empirical results in (f.1)-(f.2) and (g.1)-(g.2) indicate the timing of the Japanese interventions seems to have no significant impact on the yen/dollar rate.

4.3. Final results

The estimation results concerning the impact of CBI in the level equation are summarized in Table 2. Note that, when the same variable appear in various specifications, the estimated values are remarkably stable. This indirectly confirms the absence of multicollinearity problems.

In the volatility equations, the only explanatory CBI variable that appears to be significant at the 5% level is the one related to coordinated intervention. When this is indeed the case, the estimated coefficient is positive. Therefore, coordinated interventions could well exhibit a destabilizing effect on the exchange rate dynamics. Nevertheless, this result is not very robust.

Table 2 : Summary of the estimation results (level equation)

CBI variables	point estimation	significance (at 5%)
a) cumulated in level	+ 8.9 %	YES
b) unilateral BoJ in level coordinated in level	+ 8.3 % +25.6%	YES YES
c) BoJ in level Fed in level	+ 8.7 % + 45.2 %	YES NO
d) unilateral BoJ : dummy coordinated : dummy	- 13.4 % + 20.6 %	YES NO
e) threshold BoJ : dummy unilateral BoJ : dummy coordinated : dummy	+ 63.6 % - 19.8 % + 21.4 %	YES YES NO
f) successive Boj : dummy unilateral BoJ : dummy coordinated : dummy	+ 2 % - 14.6 % + 19.1 %	NO YES NO
g) isolated Boj : dummy unilateral BoJ : dummy coordinated : dummy	+ 2 % - 14.5 % + 19.2 %	NO YES NO

Globally, the empirical results on the signalling components of the US and Japanese CBI indicate that :
(i) the best way to capture the effect of US interventions in through the coordinated CBI in level ;
(ii) the puzzle about Japanese unilateral interventions (positive effect in level, negative effect for a dummy) is solved by adding a threshold dummy variable ;
(iii) consequently, we retain a specification including two dummies for Japanese unilateral CBI, a global one and a threshold one ;
(iv) the timing of the CBI is not a relevant signal here.

Finally, according to the conclusions drawn from Table 2, we propose the following "final model" :

$$y_t = \underset{(2.0973)}{0.6400}\ SUBOJMO_{t-1} - \underset{(-3.394)}{0.1962}\ IUBOJ_{t-1} + \underset{(3.3052)}{0.2890}\ COORD_{t-1} + \varepsilon_t \tag{h.1}$$

$$\sigma_t^2 = \underset{(2.306)}{0.0063} + \underset{(4.558)}{0.0417}\,\varepsilon_{t-1}^2 + \underset{(75.799)}{0.9466}\,\sigma_{t-1}^2. \tag{h.2}$$

This quite simple specification is sufficient to capture the effects of all effective signals previously detected.

The Fed's interventions appear in the model through coordinated CBI. Since the database does only include a single case of unilateral American intervention, it is impossible to isolate a specific US signal. However, the big difference we observe between the impact of coordinated and Japanese unilateral CBI strongly points towards an interpretation in terms of a US impact.

Concerning Japanese unilateral CBI, the results show a clear duality : small unilateral interventions are counterproductive (perverse effect of about 20 %) while large ones influence the forex market in the desired directions (impact of about 45%).

5.Conclusion

This paper is devoted to the identification of the effective signals of CBI on the forex market. The yen/dollar case is insightful in various respects. First, it is a case where two central banks are active. The most important result on this topic concerns the asymmetry of the impact of the BoJ and the Fed. The Fed is viewed by the market as a strong bank and its interventions always work in the right direction. Actually, due to the lack of unilateral US over our investigated period, we were not able to disentangle the specific US effect from the coordination signal. The recent intervention strategy of the Fed seems to indicate that US interventions mainly occurred in response to Japanese pressures. Therefore, further research could investigate the US motivation to intervene and try to isolate a "pure" Fed effect. The Euro/dollar rate seems to be a good candidate for such an investigation.

Secondly, the BoJ appears as a relatively weak central bank but its behavior on the forex market during the last decade shows that a learning process is at work. Progressively, the BoJ modifies its intervention strategy by using a very effective size signal, i.e., by conducting some massive interventions. The most prominent turning point of this strategy seems to be around the beginning of 1995, but the transition is relatively smooth. This paper has clearly established that this signalling policy is adequate for influencing the yen/dollar exchange rate, but it might reveal very costly. As a matter of facts, our results rehabilitate the effectiveness of central bank intervention in the foreign exchange market.

Traditionally, the objectives considered in the literature on central banks explicit reaction function (see, for instance, Almekinders and Eijffinger (1996)) are the decrease of the volatility, the reversion of an undesirable market trend ("leaning against the wind") and target values. In the yen/dollar case, the BoJ main objective was most probably of the latter kind with a target value around 110-120 yens/dollar. However, further research could endogenise the intervention variables and bring more insights on this important question.

Another interesting output of this research concerns the volatility equation. In the yen/dollar case, we have obtained a rather atypical result : the Japanese unilateral interventions do not increase the exchange rate volatility while coordinated interventions might have a borderline destabilizing effect. The trade-off between effectiveness and destabilization could be further analyzed. We conjecture that the sources of the destabilizing effect of CBI do not coincide with those of that make the signals effective. For instance, the very strong threshold signal is not accompanied by any significant impact on the exchange rate volatility. Thus, one could decompose the CBI into several components and identify more carefully the effectiveness (level equation) and the destabilization (volatility equation) induced by each component. Again, general conclusions on this topic require further investigations.

On the methodological side, this paper contrasts with the existing literature. Indeed, parsimony is not a major concern in most studies on the CBI. Estimated GARCH models include sometimes up to ten explanatory variables in both equations of the model. This inevitably reduces the statistical power of the estimators and makes the interpretation of the results less straightforward.

Our two-steps procedure provides a way to avoid these problems and focuses only on significant variables.

The use of dummy variables for CBI stems from the signalling channel theory. However, this paper has shown that ignoring CBI in levels might lead to incorrect interpretations. It is thus important to consider CBI variables both in levels and as dummies. In the yen/dollar case, it appears that, on the one hand, coordinated interventions are significant in level but not as a dummy. On the other hand, unilateral Japanese interventions are significant in both cases but with coefficients of opposite signs. This puzzling result has been further analyzed and solved thanks to the inclusion of a threshold dummy variable. If the dummy variable specification for CBI were the only one to be considered, one would have concluded that all unilateral Japanese interventions are counterproductive, which is erroneous.

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