A Structural Break in the Effects of Japanese Foreign Exchange Intervention on Yen/Dollar Exchange Rate Volatility

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Abstract

We study the impact of Japanese foreign exchange intervention on the volatility of the yen/dollar exchange rate since the early 1990s in a GARCH framework with interventions as exogenous variables. Using daily intervention data provided by the Japanese Ministry of Finance, we show that the effect of interventions varies over time. From 1991 up to the late 1990s, Japanese foreign exchange intervention is associated with an increase in volatility of the yen/dollar exchange rate. After the year 2000, Japanese foreign exchange intervention correlates with reductions in exchange rate volatility.

Keywords: *Exchange Rate Volatility, Foreign Exchange Intervention, GARCH, Change Points, Japan*

JEL: C22, E58, F31, F33, G15, C32

1 INTRODUCTION

Since the early 1990s up to March 2004, the scope of Japanese foreign exchange intervention has increased significantly. With the export sector remaining the most reliable pillar of economic growth, Japanese monetary authorities have been tempted to sustain output by dollar purchases.[1] Japanese foreign exchange intervention has dwarfed US official foreign currency transactions since the early 1990s both in terms of intervention events and in terms of cumulative intervention volume.

Recent research on Japanese foreign exchange intervention has tested for the effects on the exchange rate level (e.g., Ito 2003, Kearns and Rigobon 2005) or the exchange rate volatility (e.g., Watanabe and Harada 2005, Frenkel, Pierdzioch, and Stadtmann 2005a). While most studies assume that the impact of interventions on the exchange rate is constant over time, Ito (2003) identifies a structural break in the effects of Japanese foreign exchange intervention around 1995, which he attributes to a different intervention pattern introduced by “Mr. Yen”, Eisuke Sakakibara.

In this paper, we focus on the relation between interventions and exchange rate volatility. In this context, a successful intervention reduces the volatility of the involved currency. We use a GARCH model with interventions as exogenous variables for mean and volatility of the yen/dollar exchange rate. In contrast to former studies, we allow for possible parameter changes during the observation period. A change-point detector provides non-arbitrary segments for local GARCH estimation. Segmentations by intervention periods, calendar years and rolling GARCH(1,1) estimations provide additional evidence.

We find that Japanese foreign exchange intervention increased volatility before the turn of the millennium and decreased volatility afterwards. A possible reason for this change besides different intervention patterns may be the sterilization of intervention, which became ineffective after 1999 when Japan entered the so-called liquidity trap.

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1 According to the Foreign Exchange and Foreign Trade Law (article 7, paragraph 3), the Ministry of Finance is in charge of Japanese foreign exchange intervention. The central bank acts solely as an agent (Article 36 and article 40; paragraph 2, Bank of Japan Law) and buys or sells foreign currency on the government’s account.

2 THEORETICAL AND EMPIRICAL EVIDENCE

Given the large scope of Japanese foreign exchange intervention, an extensive discussion on the effects of Japanese foreign exchange intervention has evolved. The theoretical research has focused primarily on so-called sterilized intervention, which neutralizes the effects of official currency purchases on the monetary base by offsetting domestic open market operations and thereby leaves the interest rate unchanged. Up to the late 1990s, Japan's foreign exchange intervention was completely and instantaneously sterilized, as is generally the case for the major central banks (Federal Reserve, European Central Bank, Bank of Japan). In practice, the Japanese Ministry of Finance raised the amount of yen that was required to buy dollars by issuing financing bills thereby ensuring "automatic" sterilization.

After the so-called Jurgensen report (Jurgensen 1983) there has been a broad discussion whether sterilized foreign exchange intervention is capable of successfully targeting a certain exchange rate level or volatility. Sarno and Taylor (2001) and Neely (2005) give comprehensive overviews. Based on the assumption that foreign and domestic assets are imperfect substitutes, the portfolio balance models argue that sterilized intervention can affect the level of the exchange rate by changing the relative supplies and thereby the relative returns of foreign and domestic assets (Rogoff 1984).[2]

An empirical test of the portfolio balance model by Dominguez and Frankel (1993b) supports this view for Japanese foreign exchange intervention between 1984 and 1990. They obtain similar results for US and German interventions (Dominguez and Frankel 1993a). More recently, Ramaswamy and Samiei (2000) argue that Japanese foreign exchange interventions in the yen/dollar market during the 1990s have been "at least partially effective" and that even sterilized interventions have mattered in the yen/dollar market. An extensive study by Ito (2003) concludes that Japanese foreign exchange interventions under Eisuke Sakakibara have (for the most part) produced the intended effects on the yen/dollar rate during the 1990s. Fatum and Hutchison (2003) find evidence for successful sterilized foreign exchange intervention for US and German intervention based on an event study approach. Scalia (2004) tests for the effectiveness of sterilized foreign exchange intervention based on a microstructure framework of Evans and Lyons (2002) and finds interventions to be effective.

[2] The so-called signalling effect is also identified as an effective transmission channel of sterilized foreign exchange intervention. Because successful signalling announces a change in fundamentals (interest rates) it can be regarded as (a first step of) unsterilized intervention.

In contrast, Sarno and Taylor (2001) argue that sterilized intervention does not affect exchange rate levels through the portfolio channel, at least not among the currencies of the major industrial countries. In these countries, capital markets have become increasingly integrated and the degree of substitutability between financial assets has increased. According to Dominguez (1998), sterilized foreign exchange intervention can by definition not influence the exchange rate since it leaves the domestic money supply unchanged. If the official foreign currency transactions do not affect domestic interest rates, and thus do not trigger adjustments in the international investment portfolios, the intervention volumes are too small in relation to the huge international foreign exchange markets to have a sustained effect.

The impact of foreign exchange intervention on volatility in foreign exchange markets is the second main area of study. Assuming rational expectations, Dominguez (1998) suggests that fully credible and unambiguous sterilized foreign exchange intervention can reduce volatility in efficient foreign exchange markets. De Grauwe and Grimaldi (2003) show in a stochastic model with chartists and fundamentalists that systematic sterilized intervention can be effective by reducing noise generated by chartist forecast rules. Jeanne and Rose (2002) assume endogenous noise trading and argue that it is possible to reduce exchange rate volatility without sacrificing monetary autonomy. Watanabe and Harada (2005) apply a component GARCH model to Japan's foreign exchange intervention between 1990 to 2000 and find a significant effect on lower short-term but not on long-term yen/dollar volatility.

In contrast, Schwartz (1996) contends that foreign exchange intervention is an "exercise in futility" which is likely to increase uncertainty and volatility. Bonser-Neal and Tanner (1996) support Schwartz's analysis using implied volatilities of currency option prices. They find that Japanese foreign exchange intervention increased the volatility in the yen/dollar foreign exchange markets during the period from 1987 to 1991. Galati, Melick, and Micu (2005) contend that for the period from 1993 to 1996, Japanese foreign exchange intervention has increased foreign exchange traders' uncertainty regarding future exchange rate movements. Finally, Fratzscher (2005) argues that announcements as a form of foreign exchange "intervention" can reduce exchange rate volatility while actual interventions raise it.

The general theoretical and empirical evidence for the effects of foreign exchange intervention on the level and volatility of exchange rates remains mixed. In the case of Japan, there seems to be a recent trend in favor of successful intervention in terms of influence on exchange rate levels (Sarno and Taylo 2001, Ito 2003, Fatum and Hutchison 2003, Kearns and Rigobon 2005). This might be due to the fact that Japanese foreign exchange intervention seems to have remained effectively unsterilized since 1999. Under almost zero interest rates, which were reached during 1999, the monetary base could grow at any desired level without interfering with the zero-interest rate target of monetary policy. Since March 2001, the Bank of Japan shifted the operating target for money market operations from the uncollateralized overnight call rate to the outstanding balance of current accounts (Spiegel 2001). This may have put a constraint on liquidity growth in times of foreign exchange intervention. As is shown in Figure 1, however, the ceiling of the Bank of Japan current accounts has grown steadily on a monthly basis together with the cumulated foreign exchange intervention volume until early 2004.[3] This facilitated monetary growth as a result of Japanese foreign exchange intervention.

[Figure 1 about here]

In this study, we concentrate on the relation of interventions and exchange rate volatility. We find that for volatility, there is indeed a change in the effects towards success of interventions that occurred at the turn of the century.

3 DATA

We use daily data provided by Bloomberg, Datastream, the Japanese Ministry of Finance, and the Federal Reserve Board (Figure 2 and Figure 3). The observation period is from April 1, 1991—when the first data on Japanese foreign exchange intervention became available—up to October 2004.[4] This corresponds to a sample size of 3542 observations.

[Figures 2 and 3 about here]

The data on the yen/dollar exchange rate are spot prices by Bloomberg from three time zones: Tokyo closing rates (5 p.m.), London 5 p.m. (corresponding to Tokyo 2 a.m. on the next day and New York noon on the same day) and New York closing rates (Tokyo 7 a.m. the next day, London 10 p.m. the same day).[5] The daily log returns and squared log returns are plotted in Figure 4.

[Figure 4 about here]

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[3] There is no evidence that the current balances were adjusted on a daily basis.
[4] As of today (June 2006), the Japanese Ministry of Finance has not reported any interventions after October 2004.
[5] Bloomberg series JPY CMPT, JPY CMPL, and JPY CMPN.

Daily data on Japanese foreign exchange intervention are provided by the Japanese Ministry of Finance starting in April 1, 1991.[6] The amounts are in billion yen subdivided into purchases and sales of dollar, mark (euro) and other currencies, for which the intervention volumes are negligible. Since we focus on the yen/dollar exchange rate, only dollar transactions are included in our sample. The yen amounts are converted into billion dollars based on daily exchange rates. Out of 3542 trading days, the Ministry of Finance reports 344 dollar intervention days—311 dollars purchases and 33 dollar sales (Table 1).

The US foreign exchange intervention data are provided by the Federal Reserve Board and are subdivided into yen, mark[7] and other currencies purchased and sold. The reported scale is in million dollars, we convert to billion dollars. As for the case of Japan, only the yen transactions are included in the sample. The Federal Reserve Board reports 22 intervention days in the yen/dollar market for the observation period —18 days with dollar purchases (yen sales) and 4 days with dollar sales (yen purchases).

To control for disturbances in other asset markets, we follow Bonser-Neal and Tanner (1996) and include daily returns of Japanese and US stock indices, the Nikkei 300 for Japan and the Dow Jones Industrial Average for the US, both provided by Datastream.

[Table 1 about here]

4 REACTION FUNCTION

Foreign exchange intervention may target the level or the volatility of the exchange rate or both. If the exchange rate appreciates (depreciates) above (below) a certain level, the monetary authorities might intervene. For instance, the Louvre-target zones (established in February 1987) intended to prevent the exchange rate from surpassing certain levels between dollar, yen and German mark.[8] Similarly, financial press reports suggested that during the 1990s and particularly after 2000, Japanese monetary authorities tried to prevent the yen from rising above certain levels in order to sustain the competitiveness of the Japanese export industry.[9] As is shown in Figure 5, Japanese foreign exchange intervention seems to be more intense in periods of appreciation. In some

[6] The exact intervention time, the number of interventions within a day, the intervention market (Tokyo, London, New York), and the exchange rate at the time of intervention remain undisclosed.
[7] The US interventions that have taken place since the introduction of the euro are negligible.
[8] The communiqué stated that current exchange rates were "*broadly consistent with underlying fundamentals*" (Funabashi 1988) which implied target zones around the (by that time) present levels.
[9] For instance, Financial Times October 17, 2003, Bloomberg News January 7, 2004, Financial Times January 23, 2004.

cases, the financial press even believed to have identified informal target zones—for instance between 115 and 122 yen per dollar in the first seven months of 2003.[10]

[Figure 5 about here]

Further, foreign exchange intervention may intend to reduce exchange rate volatility. In countries with free trade and capital flows (such as Japan and the US), exchange rate volatility is high and pervasive. If monetary authorities want to reduce exchange rate volatility, volatility triggers intervention. McKinnon and Schnabl (2004) show that many smaller East Asian countries such as Taiwan, Korea, or Singapore reduce exchange rate volatility on a daily basis. If intervention is less regular, it may occur in periods of turbulent foreign exchange markets. For the case of Japan, such an influence of exchange rate volatility on intervention is not obvious in Figure 6 that plots yen/dollar exchange rate volatility and the absolute volume of Japan's official dollar transactions.

[Figure 6 about here]

To test for the impact of both the exchange rate level and exchange rate volatility on Japanese foreign exchange rate intervention, we estimate a reaction function. Since our main interest in this study is to specify a GARCH-model for the effect of interventions on volatility (in the following section), the coefficient of volatility in the reaction function will indicate if we incur simultaneity bias in the GARCH conditional volatility equation.

We use the following specification: First, the Japanese monetary authorities might decide to buy or sell dollars based on the exchange rate movements of the previous day, mostly to prevent the yen from appreciating. To capture this "leaning against the wind", we introduce the yen/dollar returns of the previous day (r_{t-1}) as explanatory variable. Second, the decision to intervene in foreign exchange markets might be based on medium-term factors. The more the exchange rate level departs from a certain level that is regarded as an adequate exchange rate level by the monetary authorities, the higher is the probability of intervention. Ito (2003) specifies the level that Japanese monetary authorities regard as appropriate during the 1990s to 125 yen per dollar. We use the mean of the yen/dollar level over the observation period and a one month lag of the exchange rate e_t for the

[10] As reported by Deutsche Bank Global Investment Committee (June 16, 2003) and Financial Times (August 7, 2003).

calculation of the medium-term deviation $(\bar{e} - e_{t-21})$ of the yen/dollar exchange rate. Here, $\bar{e} = \sum e_t / T$ is the global sample average and e_{t-21} the one-month lagged exchange rate.[11]

Since the monetary authorities might attempt to reduce exchange rate volatility, we introduce the squared returns of the previous day $(r_{t-1})^2$ as explanatory variable. Furthermore, following Ito (2003) and Frenkel, Pierdzioch, and Stadtmann (2005b), we introduce the foreign exchange intervention dummy of the previous period (I_{t-1}^D) as explanatory variable, since interventions usually have first order autocorrelations. This leads to the following specification:

$$I_t^D = \alpha_0 + \alpha_1 r_{t-1} + \alpha_2 (\bar{e} - e_{t-21}) + \alpha_3 (r_{t-1})^2 + \alpha_4 I_{t-1}^D + \varepsilon_t \qquad (1)$$

In equation (1), I_t^D denotes the dummy for foreign exchange intervention of the same day. A binary probit model is estimated for (a) purely Japanese intervention and (b) pooled Japanese and US intervention, using New York closing rates.[12]

The estimation results are reported in Table 2. They give very clear evidence that Japanese foreign exchange intervention targets the exchange rate level. Both variables capturing the short-term (r_{t-1}) and medium term changes $(\bar{e} - e_{t-21})$ in the exchange rate level have the expected negative sign and are significant at the 1%-level. If the dollar depreciates, the Japanese authorities are likely to intervene; if the dollar appreciates, they are unlikely to intervene, reflecting the sustained upward pressure of the yen. In contrast, there is no evidence that the volatility of the yen/dollar exchange rate $(r_{t-1})^2$ had any impact on the intervention of Japanese monetary authorities during the observation period. As expected, the lagged intervention dummy (I_{t-1}^D) is positive and significant at the 1%-level.[13] We can therefore conclude that for our data set, we will not encounter simultaneity bias in a model that relates exchange rate volatility to interventions.

[Table 2 about here]

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11 Alternative benchmarks such as Ito's (2003) 125 yen/dollar bliss point, moving averages or the consumer price based purchasing power parity all lead to similar results.

12 Since New York closing corresponds to 7 a.m. Tokyo time the next day, the returns at time *t-1* are stamped Tokyo 7 a.m. the next day (*t*) and clearly precede any interventions stamped *t* that will occur on that day. If the intervention stamped *t-1* included interventions of the Federal Reserve on behalf of the Japanese authorities in the New York market, these interventions will be reflected in the returns stamped *t-1*.

13 The result is not sensitive to using a logit instead of a probit model.

For further analyses of reaction functions of the Japanese authorities, we refer to Dominguez (1998), Frenkel, Pierdzioch and Stadtmann (2004, 2005b), Ito (2003), and Ito and Yabu (2004)[14].

5 GARCH ESTIMATION

To measure the effects of foreign exchange intervention on the yen/dollar exchange rate volatility we use a GARCH model with exogenous intervention data in both the conditional mean and variance equations as proposed by Engle (1982), Bollerslev (1986), and Baillie and Bollerslev (1989). We draw on the result in Section 3 that volatility does not determine intervention and interpret the conditional variance equation only. We do include the interventions into the mean equation to avoid omitted variable bias but do not interpret the estimated coefficients, which probably suffer from simultaneous equation bias. This procedure follows Dominguez (1998).

5.1 Specification

Table 1 gives the necessary information for the GARCH model specification. First, we observe that in contrast to the US, Japanese foreign exchange intervention is highly focused on the yen/dollar market. Since 98.41% of Japanese foreign exchange intervention is against the US dollar, we exclude other yen exchange rates—for instance against the euro (German mark before 1999)—from the investigation. [15]

Second, Japan has a much higher propensity to intervene in foreign exchange markets than the US, both in terms of intervention days and absolute intervention volume. The number of intervention days in the yen/dollar market is more than 15 times higher (Japan 344, US 22) and the discrepancy between the transactions volumes is even more pronounced (615.49 billion dollars by Japan and 8.4 billion dollars by the US). We further observe that all 22 US intervention days in the yen/dollar markets coincide with Japanese intervention days. This indicates that US intervention is coordinated with Japanese intervention. Ito (2003) and Sakakibara (2000) provide anecdotal evidence for this.

To deal with both the asymmetric scope of intervention and multicollinearity between US and Japanese intervention, we use two approaches. First, we estimate the impact of Japanese intervention alone. Second, we pool US and Japanese foreign exchange intervention to create one exogenous variable I_t which represents Ja-

[14] Ito (2003) uses a GMM estimation with full intervention volumes which yields similar results. An alternative approach to reaction functions is provided by Ito and Yabu (2004). We estimated the Ito and Yabu (2004) ordered probit specification and obtained the qualitatively same result that the squared returns have no significance in the reaction function. The estimated limit points for pooled interventions were $\mu_1 = -0.49^{***}$ and $\mu_2 = 4.06^{***}$, respectively. For the Japanese interventions only, the numbers were very similar.

[15] 48.7% of US foreign exchange intervention is against the yen during the observation period.

pan's efforts to redirect the yen/dollar rate. I_t contains the volume and sign of the transactions; it is not a dummy variable. We expect that the results for both Japanese and pooled Japanese-US interventions are similar because US intervention is negligible and the last joint intervention took place in 1998.

Sarno and Taylor (2001) argue that coordinated sterilized intervention between two or more countries might convince speculators that the signalled policy is more credible than a single-country intervention. However, a dummy for coordinated intervention remains insignificant for the US-Japanese case since 1991; therefore, it is not included in the specification.

Dollar purchases in Japan clearly dominate intervention activities (Figure 5). Out of 344 intervention days, dollars were purchased on 311 intervention days (98%), on 33 days (2%) dollars were sold. In terms of absolute intervention volumes, 577.79 billion dollars were purchased (93.87%) and 37.70 billion dollars were sold (6.13%). Due to the comparatively small amount of Japanese dollar sales, we do not estimate the effects of dollar purchases and dollar sales separately, but treat intervention as one time series with positive sign for dollar purchases and negative sign for dollar sales.

This leads to the following GARCH specification:

$$r_t = b_0 + b_1 I_t + b_2 Nikkei_t + b_3 DOW_t + \varepsilon_t , \tag{2}$$

$$\varepsilon_t \,|_{\Omega_{t-1}} \sim N(0, h_t) , \tag{3}$$

$$h_t = \omega + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-1}^2 + \sum_{i=1}^{p} \beta_i h_{t-i} + \gamma_1 \,|\, I_t \,| + \gamma_2 \,|\, Nikkei_t \,| + \gamma_3 \,|\, Dow_t \,|, \quad t = \max\{p, q\}, \ldots, T . \tag{4}$$

In Equation (2), r_t denotes the logarithmic returns of the yen/dollar spot exchange rate, plotted in the left panel of Figure 4 for the Tokyo closing rate. Following Bonser-Neal and Tanner (1996), we include the daily returns of Japanese and US stock markets, *Nikkei* 300 and *Dow* Jones Industrial Average, as exogenous variables to control for the impact of disturbances in other asset markets. While the coefficients are estimated significantly, the correlation between the Nikkei and Dow series does not affect our main findings: excluding one or the other variable does not change the results qualitatively. We do not include any dummies for the announcement of interest rate changes because they do not yield any significant results.[16] In contrast to Dominguez (1998) and Baillie and

[16] As shown by Watanabe (1994), Japanese foreign exchange intervention might signal a change in fundamentals (monetary policy). The failure to trace the impact of the announced interest rate changes on the exchange rate might be due to the fact that markets gradually anticipate interest rate changes.

Osterberg (1997), we also do not include dummy variables for the day of the week and holidays in the variance equation. Doornik and Ooms (2003) show that this procedure may lead to degenerated likelihood surfaces.

In Equation (3), the disturbances ε_t are modelled as normally distributed conditional on the information set Ω_{t-1} available at time $t-1$, with zero mean and variance h_t. Equation (4) models the volatility of the yen/dollar exchange rate, plotted in the lower left panel of Figure 4. The variance h_t depends on squared past disturbances ε^2_{t-i}, the lagged conditional variance h_{t-i}, the absolute official foreign currency intervention $|I_t|$, and the volatility in the Japanese and US share markets defined as the modulus of daily returns, $|Nikkei_t|$ and $|Dow_t|$.[17]

To capture the immediate impact of foreign exchange intervention on exchange rate volatility, the intervention variable $|I_t|$ and the control variables $|Nikkei_t|$ and $|Dow_t|$ are not lagged in the volatility equation. The lag-structure of our GARCH model is specified in two ways. First, we specify the number of lags by the Bayes information criterion (BIC) for models of the order $p \in \{1,...,7\}$ and $q \in \{1,...,7\}$. As a benchmark, we also estimate the GARCH(1, 1) specification, which is usually sufficient to eliminate ARCH-effects from the residuals.

Since both causality directions—interventions trigger changes in returns or changes in returns trigger interventions—are plausible, any single equation econometric model relating returns and interventions could suffer from possible simultaneous equation bias. We follow Dominguez (1998) and understand interventions to be successful if they reduce volatility defined as squared returns. Since we show in the reaction function estimation in Section 4 that changes in volatility do not trigger interventions, we can reasonably rule out that simultaneity bias influences our results in Equation (4).

5.2 Global Results

Table 3 reports the estimates of equations (2) to (4) on daily data between April 1, 1991, and October 27, 2004. The results are reported for the yen/dollar exchange rate in different markets and thereby time zones, i.e. Tokyo 5 p.m. (closing rates), London 5 p.m. (equivalent to New York noon) and New York 5 p.m. (closing rates). The results are reported for Japanese intervention only and for pooled Japanese and US intervention. US interventions alone are not reported because they would be subject to omitted-variable bias.[18] We report the lag order specification favored by a search for the lowest BIC as well as a GARCH(1,1) specification.

If Japanese intervention takes place during the Tokyo market opening hours, it precedes the time stamps of all three exchange rate series. Pooled intervention precedes the New York closing rate only. If the New York

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[17] We assume that dollar sales and dollar purchases affect the volatility in the same way.

[18] The omitted variable is Japanese intervention, which coincides with US intervention and has a much larger scope.

Fed intervenes on behalf of the Japanese monetary authorities in the US markets, intervention precedes New York closing rates only.

In Equation (4), the coefficient γ_1 estimates the impact of the absolute foreign exchange intervention on the volatility of the yen/dollar exchange rate. Table 3 shows that all γ_1 coefficients are positive and some are significant at the common levels. Foreign exchange intervention is associated with an increase in the volatility of the yen/dollar exchange rate. However, for some time zones and GARCH specifications, the coefficient is insignificant. The global GARCH estimation yields ambiguous results.

[Table 3 about here]

Hillebrand (2005) shows that neglecting parameter changes in GARCH models leads to an estimated sum of autoregressive parameters close to one. If we estimate a simple GARCH(1,1) model on the yen/dollar exchange rate without explanatory variables in the conditional variance equation, the sum of the estimated autoregressive parameters is close to one. If the intervention series is introduced as explanatory variable, this sum is reduced substantially to the order of 0.90 approximately. This may indicate that the intervention series captures changing volatility regimes. Segmenting the data and estimating the model locally will shed more light on this issue.

5.3 Local Results

The global estimation might not account for parameter changes that are frequently observed for the volatility of financial time series (for example, Andreou and Ghysels 2002). To cope with this problem, we re-estimate our GARCH model for sub-periods.[19] As a first step, we subdivide our observation period into calendar years. Although this partition is arbitrary from a statistical perspective and might yield too short observation periods, we get a first notion of changing parameters. We use New York closing rates for this estimation to ensure that intervention clearly precedes the exchange rate fixing.

The results of the local yearly GARCH estimations are reported in Table 4. The γ_1 coefficient is positive and significant at the common levels in the years 1993, 1995, and 1997, suggesting that Japanese foreign exchange intervention increased the volatility of the yen/dollar exchange rate. In the year 1996 and from 1999 up to 2004, the γ_1 coefficient is negative and significant at the common levels, possibly providing evidence of reduced exchange rate volatility.

[19] The estimations of the reaction function as specified in equation (1) for the respective sub-periods lead to similar results as the global reaction function.

[Table 4 about here]

Understanding that data segmentation considerably affects our estimation results, we test for the robustness of our results to different observation periods. Japanese foreign exchange intervention exhibits clear patterns of clusters. Based on Figure 1, we build ten periods of intervention clusters, which are indicated in the first line of Table 5. Then we set the boundaries of the segments mid-way between the intervention clusters. Although these intervention clusters are again statistically arbitrary, we obtain additional evidence on the effect of data segmentation on our estimation results.

[Table 5 about here]

The main findings are reported in Table 5 and largely match the findings of the yearly estimations. In the first cluster (1991), the γ_1 coefficient is insignificant at the common levels. In the second cluster (1992), there is evidence in favor of reduced volatility as the γ_1 coefficient is negative and highly significant. Between 1993 and 1998 (clusters 3 to 5), Japanese foreign exchange intervention seems to have increased exchange rate volatility (positive and highly significant γ_1 coefficients). In the sixth cluster (1997/98), the γ_1 coefficient is positive but insignificant. For the period from 1999 up to 2004 (clusters 7 to 10), there is evidence of reduced exchange rate volatility. The γ_1 coefficients are highly significant for all four sub-periods.

Based on the findings reported in Table 4 and Table 5, we can roughly divide the data into two regimes: From 1991 up to the late 1990s, Japanese foreign exchange intervention seems to have increased exchange rate volatility. Starting from the late 1990s, it seems to have reduced volatility.

6 CHANGE POINT DETECTION AND ROLLING GARCH(1,1) COEFFICIENTS

Although the sub-divided GARCH estimations give a more precise view of changing parameter regimes in comparison to the global model, a non-arbitrary segmentation is desirable. We use the change-point detector for ARCH models proposed by Kokoszka and Leipus (1999) to identify non-arbitrary sub-periods. The change-point detector is the estimator $\hat{k}$ of the true change-point k^* defined by

$$\hat{k} = \min\left\{k : \left|R_k\right| = \max_{1 \le t \le T}\left|R_t\right|\right\}, \tag{5}$$

where k and t are indices for time, and the statistic R_t is given by

$$R_t = \frac{t\left(T-t\right)}{T^2}\left(\frac{1}{t}\sum_{\tau=1}^{t} r_\tau^2 - \frac{1}{T-t}\sum_{\tau=t+1}^{T} r_\tau^2\right), \quad t = 1,\ldots,T. \tag{6}$$

Intuitively, the detector measures the distance R_t between the means of the two segments that are induced by the hypothetical change point t. The estimated change-point $\hat{k}$ is set where this distance becomes maximal. For the rare case that more than one maximum exists, the first one is chosen.

In the stationary GARCH(1,1) model, the volatility mean is given by $Eh_t(\theta) = E\varepsilon_t^2 = \omega/\left(1-\alpha-\beta\right)$, where $\theta = \left(\omega, \alpha, \beta\right)$ is the vector of parameters of the conditional variance equation. The change-point detector identifies segments of different volatility means $Eh_t\left(\theta_1\right) = \omega_1/\left(1-\alpha_1-\beta_1\right)$ and $Eh_t\left(\theta_2\right) = \omega_2/\left(1-\alpha_2-\beta_2\right)$. Kokoszka and Leipus (1999) show that this estimator is consistent, converges in probability to the true change point k^* with rate $1/T$, and that the asymptotic distribution is given by

$$\sqrt{T}R_t \sim \sigma W_t^0, \tag{7}$$

where W_t^0 is a Brownian Bridge and σ^2 is the variance of R_t. We follow Andreou and Ghysels (2002) and use the VARHAC estimator of Den Haan and Levin (1997) for σ. Applying the detector to the New York closing rate, we identify two change-points that are significant at the 5% level. These are 05/07/1997 and 04/03/2000 as indicated in Table 6.

[Table 6 about here]

We use the implied segments for local GARCH estimations. The results reported in Table 7 show a clear trend over time: While interventions correlate positively and significantly with volatility in the first segment from 1991 through 1997, in the second and third segments the correlation between volatility and intervention is significantly negative. [20]

[Table 7 about here]

Together with the results of the estimation of the reaction function in Section 4, which we also estimated with qualitatively similar results on the sub-segments considered here, we find evidence that between 1991 and 1997, interventions of the Japanese authorities in the yen/dollar market increased the volatility of the exchange rate. After 1997 there is evidence that intervention has reduced exchange rate volatility.

Where is the exact turning point in the effect of foreign exchange interventions on volatility? The yearly estimations reported in Table 4 would suggest reductions in volatility starting in January 1999. The estimation based on intervention clusters reported in Table 5 suggests lower volatility starting from December 1999. The estimation based on change point detection suggests lower volatility starting in May 1997.

To get a clearer picture of the evolution of the effects of Japanese foreign exchange intervention, we compute a rolling GARCH estimation for the volatility coefficient γ_1. For this purpose, we have to make two restrictive assumptions. First, for simplicity we have to restrict the estimation to the GARCH(1,1) model at the risk of misspecification. Second, we have to select a window size. To minimize possible distortion caused by the window size, rolling GARCH coefficients are computed for the windows of 500, 750, 1000, 1250 and 1500 trading days. For the sake of brevity we report the results for 500 and 1500 trading days. The other window sizes do not add much to what can be seen from these two.

[Figures 7 and 8 about here]

Figures 7 and 8 show the t-statistics for the rolling GARCH(1,1) γ_1-coefficients. During the first subperiod, it shows a tendency for positive t-values that would be significant in single estimations.[21] Japanese foreign exchange intervention seems to increase the volatility of the yen/dollar exchange. The lines at ±1.96 represent significance at the 5% level in single estimations. After a certain transition period, the result is reversed. The

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[20] Ito and Melvin (1999) find a significant reduction in volatility around the deregulation in early 1998. A dummy in the spirit of their analysis for the important deregulation date April 1, 1998, does not change the findings in the segment between 05/07/1997 and 04/03/2000.

[21] The rolling window scheme does not allow for a statistically rigorous interpretation of the time series of t-statistics.

γ_1-coefficients now tend to be negative. After 1999 at the latest, Japanese foreign exchange intervention seems to reduce the volatility of the yen/dollar exchange rate.

Small window sizes (Figure 7) reveal a pattern of positive coefficients before 1997, a pronounced downward spike in 1997, a period of indeterminacy between 1997 and 1999, and negative coefficients after 2000. Increasing the window size (Figure 8) gives a much clearer picture of the downward trend. The coefficients gradually decline and turn negative after 2000. Japanese foreign exchange intervention seems to have turned towards reducing volatility.

Putting these results into perspective, it is not reasonable to emphasize a specific single day as the break point. This is a common phenomenon in the application of change-point detectors. Rather, the gradual change in the coefficient towards significant reduction of volatility that took place between 1997 and 2000 is the main result.

7 CONCLUSION

We study the effects of Japanese foreign exchange interventions on the volatility of the yen/dollar exchange rate between April 1991 and October 2004 using daily intervention data released by the Japanese Ministry of Finance. In contrast to earlier studies, we allow for changes in this relation over time. While global GARCH estimations of the effect of Japanese foreign exchange intervention on the volatility of the yen/dollar exchange rate are inconclusive, local estimations provide evidence in favor of a structural break occurring between 1997 and 2000.

We segment the data using calendar years, intervention clusters and by applying a change-point detector. Further, we estimate rolling GARCH(1,1) coefficients. The combined results suggest that up to the late 1990s, Japanese foreign exchange intervention correlates with increased volatility of the yen/dollar exchange rate. After 1999, foreign exchange intervention is associated with lower exchange rate volatility, thereby indicating exchange rate stabilization. The structural break in the effects of Japanese foreign exchange intervention on exchange rate volatility may be explained by the liquidity trap of the Japanese economy, in which foreign exchange intervention can be understood as being left unsterilized because of the nearly infinite money supply and the adjustment of the ceiling of the Bank of Japan's current account.

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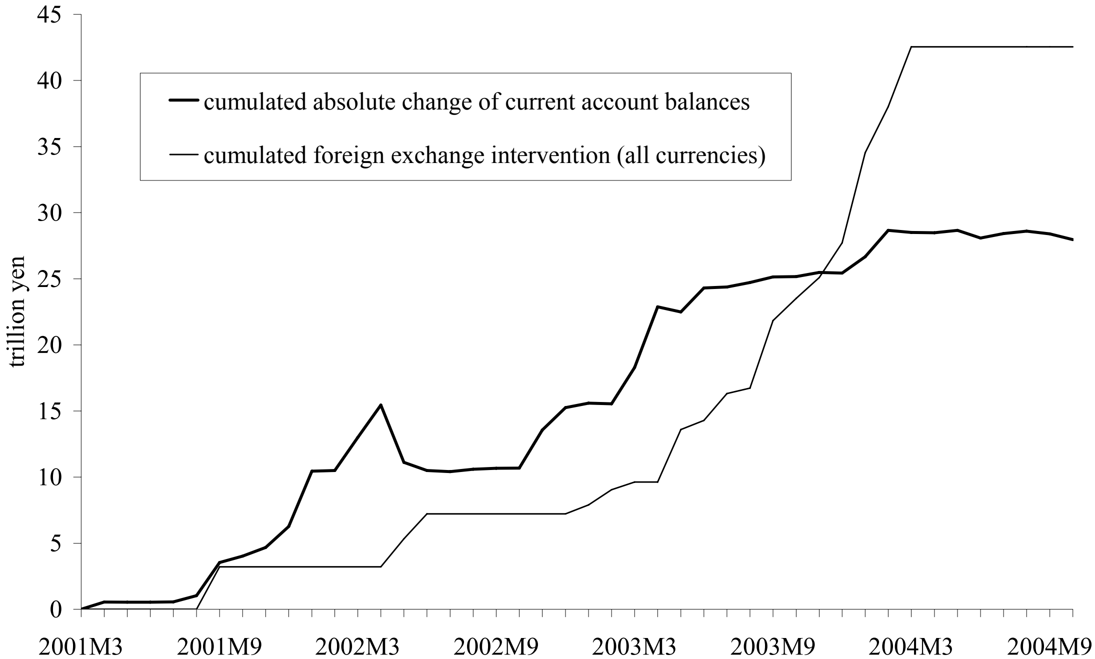
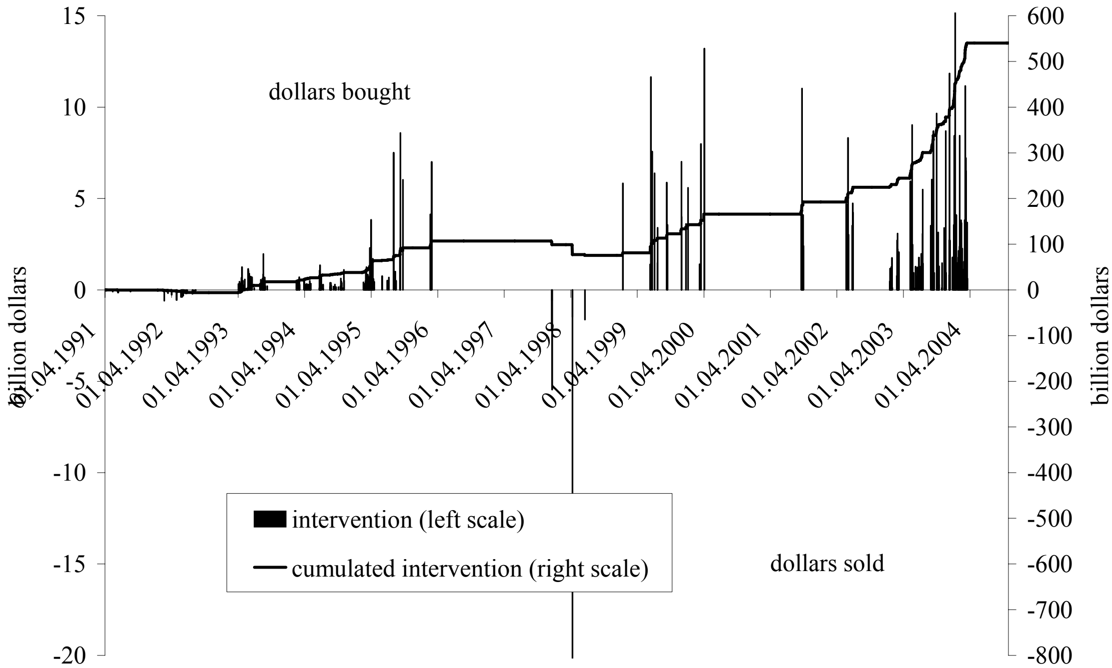
Figure 1: Cumulated Absolute Bank of Japan Current Account Balances and Cumulated Foreign Exchange Intervention



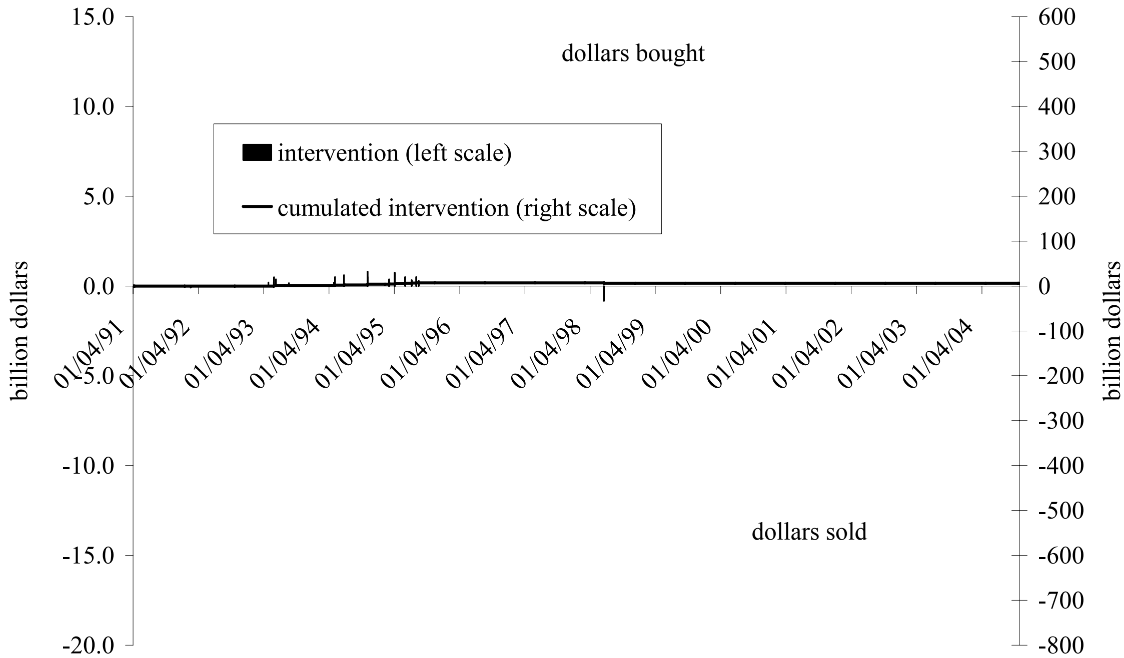
Source: Bank of Japan.

Figure 2: Japan – Absolute and Cumulated Daily Dollar Foreign Exchange Intervention



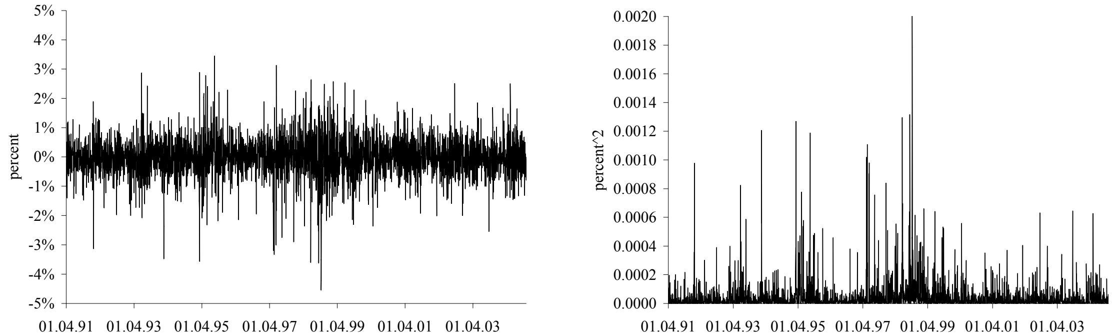
Source: Japan: Ministry of Finance. April 1991 – October 2004. Note same scale for Japan and the US (Figure 2).

Figure 3: US – Absolute and Cumulated Daily Yen Foreign Exchange Intervention



Source: US Federal Reserve Board. Billion Dollars. April 1991 – October 2004. Note same scale for US and Japan (Figure 1).

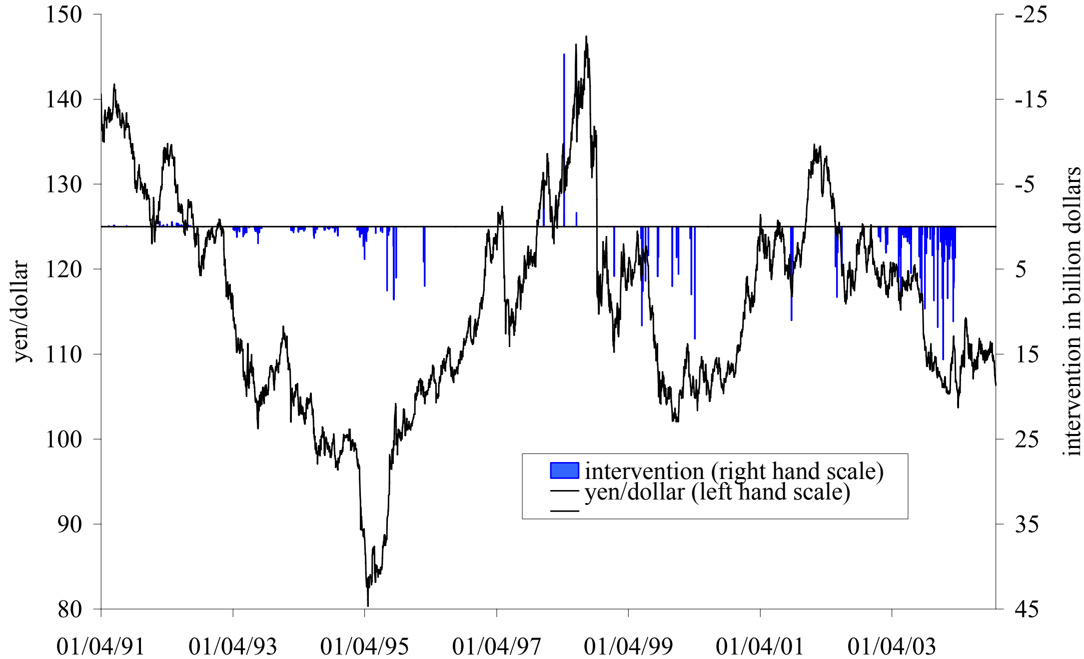
Figure 4: Daily Yen/Dollar Exchange Rates



returns yen/dollar | volatility yen/dollar

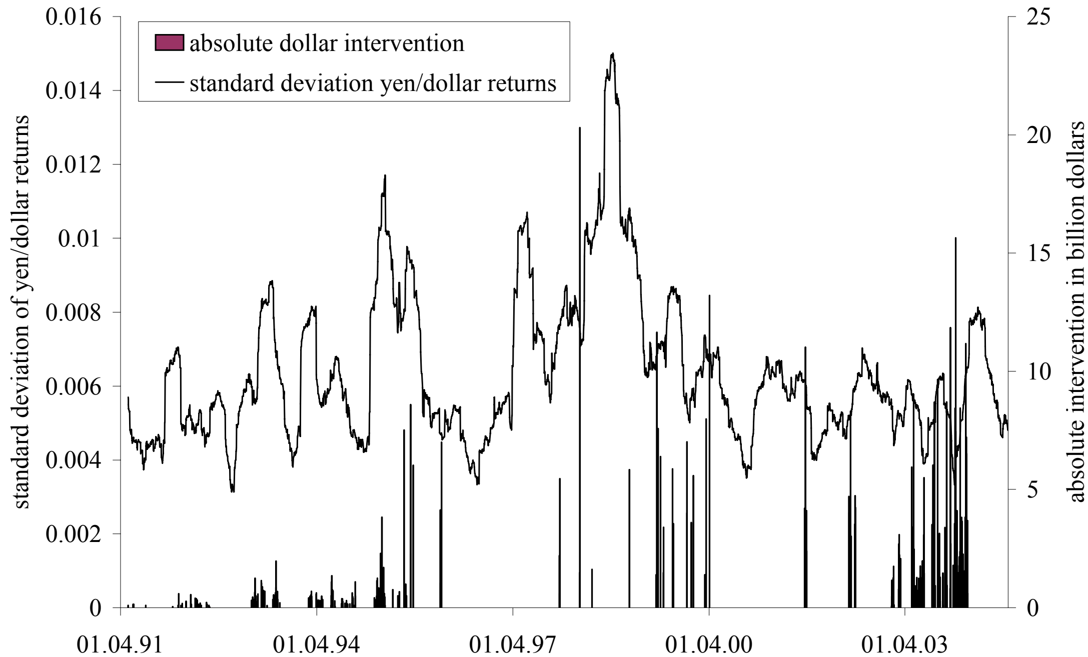
Source: Bloomberg. April 1991 – October 2004. Tokyo closing rate.

Figure 5: Foreign Exchange Intervention and Yen/Dollar Exchange Rate



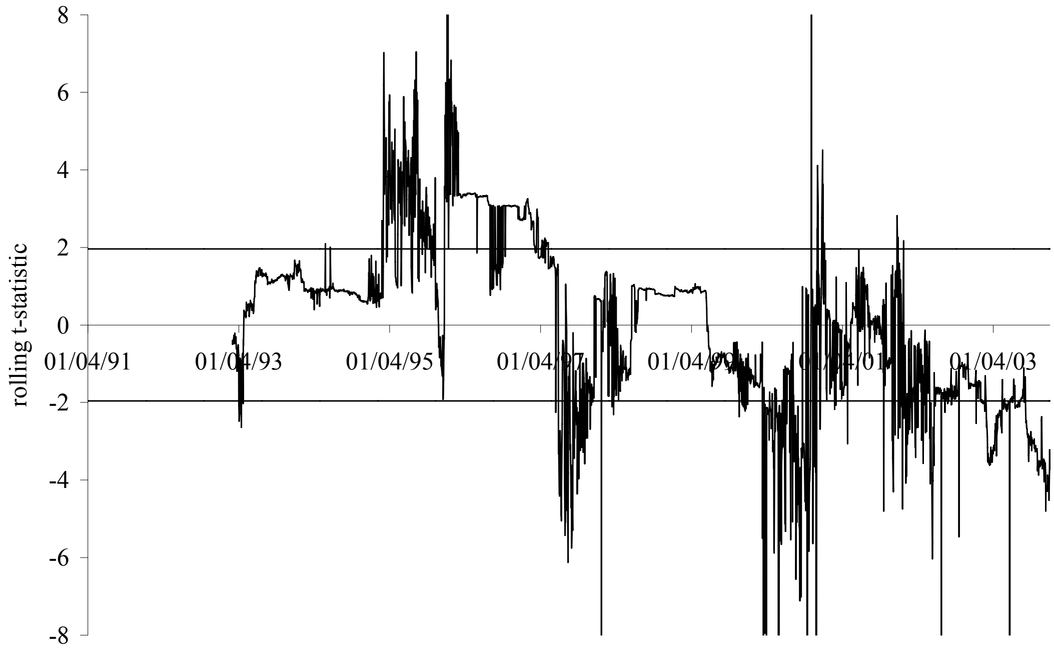
Source: Bloomberg, Japan: Ministry of Finance. Foreign exchange intervention in billion dollars. April 1991 – October 2004.

Figure 6: Foreign Exchange Intervention and Yen/Dollar Exchange Rate Volatility



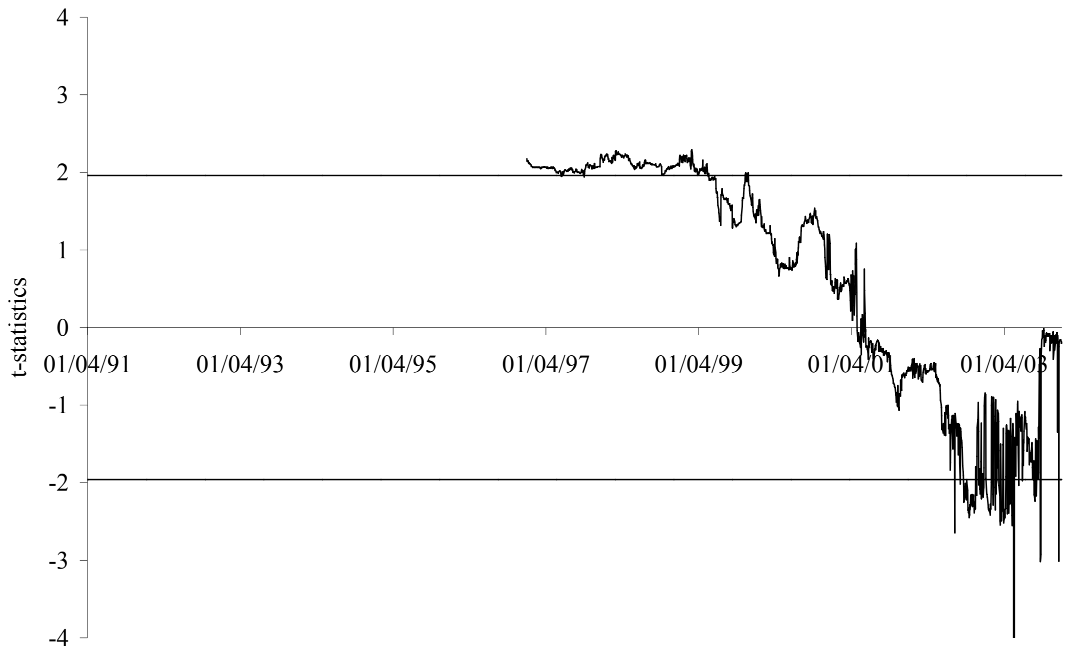
Source: Bloomberg. Foreign exchange intervention in billion dollars. April 1991 – October 2004. Volatility defined as 60 days rolling standard deviations of the daily percent yen/dollar exchange rate changes around day t.

Figure 7: Rolling GARCH(1,1) t-Statistics for γ_1 (Window = 500 Observations)



Source: Bloomberg (New York Closing Rates). March 1993 – December 2004.

Figure 8: Rolling GARCH(1,1) t-Statistics for γ_1 (Window = 1500 Observations)



Source: Bloomberg (New York Closing Rates). January 1997 – December 2004.

Table 1: Summary Statistics for Bank of Japan and Federal Reserve Interventions, 1991:04-2004:10

	Bank of Japan	Federal Reserve
Total intervention days	344 (351)	22 (36)
Total transaction volume (billion dollars)	615.49 (625.41)	8.40 (17.2)
Percentage of interventions in the yen/dollar market (volume)	98.41%	48.83%
Unconditional intervention probability	9.71% (9.99%)	0.62% (1.01%)
Number of days with dollar purchases (yen sales)	311 (313)	18 (30)
Total amount of dollar purchases (billions)	577.79	7.30
Mean absolute value of dollar purchases (billions)	1.86	0.41
Number of days with dollar sales (yen purchases)	33 (38)	4 (6)
Total amount of dollar sales (billions)	37.70	1.00
Mean absolute value of dollar sales (billions)	1.14	0.25

Source: Japan: Ministry of Finance and Federal Reserve Board. Yen/dollar interventions (interventions against all currencies in brackets).

Table 2: Binary Probit Reaction Function for Japanese Foreign Exchange Intervention, 1991-2004

	Japan	**Pooled Intervention**
Constant	-1.917***	-1.925***
	(0.049)	(0.049)
Yen/dollar returns r_{t-1}	-40.83***	-41.67***
	(5.45)	(5.478)
Medium-term deviation $(\overline{e} - e_{t-21})$	2.229***	2.197***
	(0.373)	(0.375)
Yen/dollar volatility $(r_{t-1})^2$	-159.44	-174.47
	(198.79)	(199.30)
Intervention Dummy (t-1) I_{t-1}^{D}	2.178***	2.231***
	(0.090)	(0.090)

Table 3: Global GARCH Estimation for Equation (1) to (3)

	[New York 3am (t)] **Tokyo 5pm (t)**		**New York Noon (t)** [Tokyo 2am (t+1)]		**New York 5pm (t)** [Tokyo 7am (t+1)]	
	GARCH	**Coefficient**	**GARCH**	**Coefficient**	**GARCH**	**Coefficient**
Japan	(4,5)	γ_1=.0024(.0011)**	(2,3)	γ_1=.0006(.0007)	(2,4)	γ_1=.0015(.0008)*
Japan	(1,1)	γ_1=.0005(.0004)	(1,1)	γ_1=1e-5(.0002)	(1,1)	γ_1=5e-5(.0002)
Pooled†	(4,4)	γ_1=.0035(.0013)***	(2,3)	γ_1=.0007(.0007)	(2,4)	γ_1=.0016(.0008)**
Pooled†	(1,1)	γ_1=.0005(.0004)	(1,1)	γ_1=4e-5(.0002)	(1,1)	γ_1=6e-5(.0002)

Heteroskedasticity consistent standard errors according to Bollerslev and Wooldridge (1992). * denotes significance at the 10 percent level. ** denotes significance at the 5 percent level. *** denotes significance at the 1 percent level.
† For the Tokyo exchange rate, the Federal Reserve interventions of day t-1 are considered.

Table 4: Local GARCH Estimation for Equation (1) to (3) – Effect of Pooled Intervention on Yen/Dollar New York Closing Rate by Calendar Years

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Number of events	4	23	49	55	43	5	3	3	12	4	7	7	78	47
Total volume (bn. $)	-0.50	-5.53	23.88	20.44	53.68	15.32	-8.17	-23.42	62.62	28.16	26.72	32.54	177.4	137.77
Volume per event	-0.13	-0.24	0.49	0.37	1.25	3.06	-2.72	-7.81	5.22	7.04	3.82	4.65	2.27	2.93
GARCH specific. (BIC)	(1,1)	(1,3)	(1,1)	(2,2)	(4,3)	(1,1)	(1,1)	(2,1)	(2,2)	(2,5)	(3,1)	(1,1)	(1,1)	(1,2)
γ_1	-0.059	-0.0007	0.0061***	0.0104	0.0325***	-0.0018**	0.0156***	-0.0020	-0.0017***	-0.0018**	-0.0019**	-0.0020*	-0.0019***	-0.0010***
	(0.049)	(0.0031)	(0.0007)	(0.0071)	(0.0060)	(0.0007)	(0.0055)	(0.0017)	(0.0006)	(0.0009)	(0.0009)	(0.0012)	(0.00004)	(0.0002)
$\mathbf{b_1}$	-32.34**	4.91	-2.95	-.0868	1.86***	0.3602	2.65***	1.16	1.68***	1.05***	0.72***	0.91**	0.79***	0.17
	(14.62)	(3.22)	(2.79)	(1.6661)	(0.69)	(0.2992)	(0.95)	(1.70)	(0.16)	(0.29)	(0.2734)	(0.3615)	(0.1629)	(0.11)
GARCH(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)
γ_1		-0.0044		0.00003	0.0758**			0.0155	-0.0041**	-0.0013	0.0015			-0.0017
		(0.0138)		(0.003)	(0.0320)			(0.0149)	(0.0017)	(0.0022)	(0.0092)			(0.0016)
$\mathbf{b_1}$		5.12		0.9567	1.87			1.79	2.16***	1.43***	0.6309			-0.007
		(3.74)		(0.9679)	(1.30)			(3.81)	(0.32)	(0.43)	(0.9515			(0.11)

Heteroskedasticity consistent standard errors according to Bollerslev and Wooldridge (1992). * denotes significance at the 10 percent level. ** denotes significance at the 5 percent level. *** denotes significance at the 1 percent level.

Table 5: Local GARCH Estimation for Equation (1) to (3) – Effect of Pooled Intervention on Yen/Dollar New York Closing Rate by Intervention Clusters

Intervention cluster	**05/13/91**	**01/17/92**	**04/02/93**	**02/15/94**	**02/17/95**	**11/3/97**	**01/12/99**	**09/17/01**	**01/15/03**	**02/01/04**
	08/19/91	**08/11/92**	**09/07/93**	**11/03/94**	**02/27/96**	**6/17/98**	**04/03/00**	**06/28/02**	**12/31/03**	**16/03/04**
Observation period	**04/01/91**	**11/04/91**	**12/08/92**	**12/27/93**	**12/28/94**	**01/01/97**	**10/01/98**	**12/26/00**	**01/01/03**	**01/01/04**
	11/01/91	**12/07/92**	**12/24/93**	**12/27/94**	**12/31/96**	**09/30/98**	**12/25/00**	**31/12/02**	**31/12/03**	**27/10/04**
Period number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Number of events	4	23	49	55	48	6	16	14	78	47
Total volume (bn. $)	-0.50	-5.53	23.88	20.44	69.00	-31.58	90.42	59.26	177.4	137.77
Volume per event	-0.13	-0.24	0.49	0.37	1.44	-5.26	5.65	4.23	2.27	2.93
GARCH specific. (BIC)	(1,1)	(1,1)	(1,2)	(3,2)	(2,5)	(1,1)	(1,3)	(1,1)	(1,1)	(1,2)
γ_1	-0.0128	-0.0076***	0.0177***	0.0124***	0.0409***	0.0141	-0.0022***	-0.0031***	-0.0019***	-0.0010***
	(0.0461)	(0.0019)	(0.0054)	(0.0027)	(0.0061)	(0.0138)	(0.0006)	(0.0012)	(0.00004)	(0.0002)
b_1	-34.66**	4.67*	-3.48	-0.5971	0.5911	1.59	1.63***	0.7992***	0.7850***	0.17
	(16.66)	(2.84)	(3.35)	(1.49)	(0.81)	(1.66)	(0.18)	(0.2587)	(0.1629)	(0.11)
GARCH(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)
γ_1			0.0056***	0.0005	0.0111***		-.0017*			-0.0017
			(0.0011)	(0.0029)	(0.0022)		(0.0009)			(0.0016)
b_1			-3.15	0.9243	1.69***		1.79***			-0.007
			(2.71)	(1.07)	(0.50)		(0.22)			(0.11)

Heteroskedasticity consistent standard errors according to Bollerslev and Wooldridge (1992). * denotes significance at the 10 percent level. ** denotes significance at the 5 percent level. *** denotes significance at the 1 percent level.

Table 6: Change-Points According to the Kokoszka and Leipus (1999) Detector

Date	Observation Number	Statistic $\sqrt{n}R_k / \hat{\sigma}_{VARHAC}$	Probability
07-May-1997	1592	2.2466	0.000
03-Apr-2000	2350	1.5932	0.013

New York closing rate. Change points with confidence level 0.95 or higher.

Table 7: Local GARCH Estimation for Equation (1) to (3) – Pooled Intervention for Change-Points as Indicated in Table 6

intervention period	**04/02/1991 05/07/1997**	**05/08/1997 04/03/2000**	**04/04/2000 10/27/2004**
GARCH specific. (BIC)	(1,5)	(2,3)	(1,1)
γ_1	0.0396*** (0.0067)	-0.0024*** (0.0006)	-0.0009** (0.0004)
GARCH (1,1)			
γ_1	0.0089** (0.0041)	-0.002* (0.001)	

New York Closing Rates.