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The Effects of Japanese Foreign Exchange Intervention: GARCH Estimation and Change Point Detection*

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Abstract

In this paper we test for the short-term impact of foreign exchange intervention on both the level of the yen/dollar exchange rate and the volatility in the yen/dollar markets. Using newly released data on Japanese foreign exchange intervention, our global GARCH estimation suggests that Japanese foreign exchange interventions between 1991 and 2002 had the intended effect on the same day, but at the cost of higher exchange rate volatility. Testing for the robustness of this finding we show that the results are highly dependent on the time period. From 1991 to 1998 Japan's official currency purchases were unsuccessful and coincided with increased exchange rate volatility. Since 1999 official Japanese currency purchases seem to have had the intended short-term effect while exchange rate volatility is lower. To this end, the paper provides evidence for successful foreign exchange intervention on the same day in Japan's liquidity trap where the borderline between sterilized and unsterilized foreign exchange intervention became blurred.

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1. INTRODUCTION

Japan's persistent post-bubble blues is characterized by a combination of economic stagnation and a strong currency (Schnabl 2001). While real growth of Japanese GDP during the 1990s approached the zero bound, the exchange rate of the Japanese yen has been surprisingly strong. With the Japanese export sector remaining the most reliable pillar of the ailing economy, Japanese monetary authorities[2] have been more and more tempted to sustain output by dollar purchases. Japanese foreign exchange intervention has dwarfed official US official foreign currency transactions, in particular since the early 1990s, both in terms of single intervention events and in terms of cumulated intervention volume (Figure 1 and Figure 2).

[Figure 1 and Figure 2 about here]

With the sustained depression of the Japanese economy—and with fiscal and monetary policy at their limits—many authors have proposed reviving the Japanese economy by even more (un-) sterilized foreign exchange intervention (McCallum, 2000 and Svensson, 2001). To determine the pros and cons of this policy proposition we scrutinize the short-term impact of sterilized foreign exchange intervention on both the level and the volatility of the yen/dollar exchange rate.

In contrast to former studies, which were mostly based on perceived intervention reported by press and wires services, we use newly revealed data on foreign exchange intervention (instead of dummy variables) for our inquiry.[3] Japan provides a particularly interesting case for studying the effects of foreign exchange intervention because now data are available, and intervention volumes are exceptionally high for a freely floating currency.

A GARCH model with interventions as exogenous variables for mean and volatility is fitted to the institutional setting of Japanese foreign exchange intervention. To cope with possible bias caused by parameter changes during the observation period local coefficients for means and volatility are estimated. A change point detector allows the identification of volatility clusters that are matched with intervention periods. The segments computed by the

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[2] 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.

[3] Frenkel, Pierdzioch and Stadtmann (2003) use the newly revealed data to examine the accuracy of former data sets on perceived intervention showing the deviations of the data set by Ramaswamy and Samiei (2000) from the *de facto* data.

change point detector are used to re-estimate our GARCH model based on non-arbitrary segmentation.

2. THEORETICAL AND EMPIRICAL BACKGROUND

The discussion on the effectiveness of foreign exchange intervention has been focused primarily on so-called sterilized intervention, which neutralizes the effects of official currency purchases on the monetary base and thereby the interest rate.[4] Unsterilized intervention, which allows foreign exchange intervention to change the monetary base, is excluded from the discussion because it clearly affects the exchange rate as any other form of monetary policy. Japan's foreign exchange intervention can be assumed to be completely and instantaneously sterilized, as is generally the case for the central banks that issue the major international currencies (Federal Reserve, European Central Bank, Bank of Japan).[5]

Since the so-called Jurgensen report (Jurgensen 1983) there has been a broad discussion as to whether sterilized foreign exchange intervention is capable of successfully targeting a certain level of the exchange rate.[6] The portfolio balance models—based on the assumption that foreign and domestic assets are imperfect substitutes—argued that sterilized intervention can effect the exchange rate by changing the relative supplies and thereby the relative returns of foreign and domestic assets (Rogoff 1984).[7]

An empirical test of the portfolio balance model by Dominguez and Frankel (1993) supported this view for Japanese foreign exchange intervention between 1984 and 1990. More recently Ramaswamy and Samiei (2000) argued 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. Without examining the transmission channel, an extensive study by Ito (2002) concludes that Japanese foreign exchange intervention under "Mr. Yen" Eisuke Sakakibara have produced the intended effects on the yen/dollar rate during the 1990s. Fatum and Hutchison (1999) find evidence for successful sterilized foreign exchange intervention of Japanese monetary authorities based on an event

4 Every buying or selling of foreign exchange by the monetary authorities alters the monetary base. If, for instance, the Japanese central bank buys foreign exchange from financial institutions as an agent of the Ministry of Finance, the official foreign reserves increase. The central bank transfers the value of the foreign currency purchase to the current deposits of the financial institutions at the central bank. Since the current deposits of financial institutions are a part of the monetary base, the monetary base will increase and money market interest rates will fall.

5 Takagi (1991) gives empirical evidence for the pre-1991 period. We will return to this assumption in section 6.

6 Sarno and Taylor (2001) give a comprehensive overview.

7 Further the so-called signalling effect is identified as an effective transmission channel of sterilized foreign exchange intervention. But as successful signalling announces a change in fundamentals (interest rate) it can be regarded as (a first step of) unsterilized intervention.

study approach. Based on a broad variety of GARCH estimations Beine and Szafarz (2003) find Japanese foreign exchange intervention successful—in particular if coordinated with the US.

In contrast, Sarno and Taylor (2001) argue that—at least among the currencies of the major industrial countries where capital markets have become increasingly integrated and the degree of substitutability between financial assets has increased—sterilized intervention does not affect exchange rates through the portfolio channel. According to Dominguez (1998) sterilized foreign exchange intervention is by definition unsuccessful, as 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 has also been discussed. Assuming rational expectations Dominguez (1998) suggests that fully credible and unambiguous sterilized foreign exchange intervention can reduce volatility in efficient foreign exchange markets. Based on a stochastic model with chartists and fundamentalists, De Grauwe and Grimaldi (2003) show 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.

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, with which 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 and Melick (1999) contend for the period from 1993 to 1996 that Japanese foreign exchange intervention has increased foreign exchange traders’ uncertainty regarding future exchange rate movements. Watanabe and Harada (2001) apply a component GARCH model to Japan’s foreign exchange intervention between 1990 to 2000 and find a significant effect on short-term but not on long-term yen/dollar volatility.

All in all, although Sarno and Taylor (2001: 862) argue that the recent literature gives more evidence in favor of effectiveness—the theoretical and empirical evidence for the effects of foreign exchange intervention on the level and volatility of the yen/dollar exchange rate remains mixed. The stylized facts about Japanese foreign exchange intervention give evidence for both sides. The frequent intervention of the Japanese Ministry of Finance in the yen/dollar market might be taken as an indicator of success since repeated failure would discourage intervention. Also recently financial press reports might indicate a growing trust in the success of Japanese interventions. But the persistence of Japanese foreign exchange intervention also indicates that the effect was not lasting.

3. DATA

To test for the short-term impact of foreign exchange intervention on the level and volatility of the yen/dollar exchange rate we use daily data provided by Datastream, the Japanese Ministry of Finance and the Federal Reserve Board. The observation period is from April 1, 1991—when the first data on Japanese foreign exchange intervention became available—up to December 31, 2002. This corresponds to a sample size of 3066 observations.

The data on the yen/dollar exchange rate are daily closing spot prices by Datastream from the European foreign exchange market (5 p.m. Greenwich). We analyse the log returns of the exchange rate series. The statistical properties of the first log differences time series are reported in Table 1 in comparison to the German mark/dollar exchange rate. The respective daily returns and volatilities (defined as squared returns) are plotted in Figure 3.

In Table 1 the negative mean and skewnes represent the prevailing yen appreciation pressure against the dollar. A larger standard deviation than for the mark/dollar rate indicates increased exchange rate volatility (Figure 3). The kurtosis is significantly above 3 representing a leptokurtic distribution of yen/dollar exchange rate returns.[8]

Daily data on Japanese foreign exchange intervention are provided by the Japanese Ministry of Finance starting in April 1, 1991. The amounts are in billion yen subdivided into purchases and sales of dollar, mark (euro) and other (negligible) currencies. Since we focus on the yen/dollar exchange rate, only dollar transactions are included in our sample and the yen amounts are converted into trillion dollars based on daily exchange rates.[9] On 3066 trading days the Ministry of Finance reports 215 dollar intervention days—182 dollars purchases and 33 dollar sales (Table 2).

The US foreign exchange intervention data are provided courtesy of the Federal Reserve Board sub-divided into yen, mark[10] and other currencies purchased and sold. The scale is in million dollars, which is then converted into trillion dollars. For Japan as well, only the

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8 This does not constitute a problem for our GARCH estimation because the specification by Bollerslev (1986) takes a time dependent variance—as a possible reason for leptokurtis—into account.

9 The data transformation into trillions makes the estimated coefficients more readable without changing their levels of significance.

10 No US intervention has taken place since the introduction of the euro.

yen transactions are included into 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, as proposed by Bonser-Neal and Tanner (1996), we use daily notations of Japanese and US stock indices—the Nikkei 300 for Japan and the Dow Jones Industrial Average for the US as provided by Datastream.

The augmented Dickey and Fuller (1979) test as well as the Philips and Perron (1988) test reject the unit root hypothesis for the daily changes of the yen/dollar rate, the Nikkei 300, the DOW Jones Industrial Average as well as for (absolute) intervention data at all common confidence levels.

4. GARCH ESTIMATION

To measure the short-term impact of foreign exchange intervention on both the level and volatility of the yen/dollar rate 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/Bollerslev (1989).

Prior studies have defined volatility in different ways—long-term movements of exchange rate prices as plotted in Figure 4 and percentage exchange rate changes, e.g. absolute or squared returns, as plotted in Figure 5 for daily data. For instance, the Louvre-target zones between dollar, yen and German mark (established in February 1987) were intended to reduce exchange rate volatility in terms of long-term movements of exchange rate prices.[11] This implies that intervention took place when the exchange rate approached a certain exchange rate (price) level.

[Figure 4 and Figure 5 about here]

Similarly, Japanese foreign exchange intervention tried to prevent the yen from falling to above about 150 yen/dollar in 1998, rising above about 105 yen/dollar in 1999/2000, 117 to 120 yen/dollar in 2001, or 115 to 122 yen/dollar in spring 2003.[12] We interpret these attempts to smooth the long-term movements as targeting the exchange rate level. The impact of foreign exchange intervention on the exchange rate level is captured by the mean equation of our GARCH model.

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[11] 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.

[12] These unofficial, perceived exchange rate targets were reported in the financial press.

In contrast, Dominguez (1998) defines volatility as squared returns. There are two possible directions of causality between such short-term exchange rate volatility and foreign exchange intervention. In liberalized foreign exchange markets exchange rate volatility is high because of a large number of private foreign exchange transactions. If—as observed in many countries with hard or soft peg exchange rate arrangements[13]—monetary authorities want to reduce this exchange rate volatility substantially, intervention is conducted on a day-to-day basis. Exchange rate volatility triggers intervention.

In contrast, the central banks of the large industrial countries (Federal Reserve, European Central Bank, Bank of Japan) operate under monetary policy frameworks that target and smooth short-term interest rates. Exchange rates float freely. To sustain the interest rate target, foreign exchange intervention can take place only infrequently and on a discretionary basis.[14] As per definition foreign exchange intervention remains erratic and mainly unexpected, the causation is probable to run from intervention to volatility rather than vice versa.

4.1. Specification

Table 2 summarizes the stylized facts of Japanese and US foreign exchange intervention and 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 97.48% of Japanese foreign exchange intervention is against the US dollar[15], we exclude other yen exchange rates—for instance against the euro (German mark before 1999)—from the investigation.

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 almost tenfold (Japan 215, US 22) and the discrepancy between the transactions volumes is even more pronounced (300.98 billion dollars in Japan and 8.4 billion dollars in the US). We further observe that all 22 US intervention days in the yen/dollar markets coincide with Japanese intervention days,[16] working parallel. This implies that US intervention is triggered by Japanese intervention[17] and we are faced with multicollinearity.

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[13] McKinnon and Schnabl (2003) show that such strategies are observed in many smaller East Asian countries as Hong Kong, Taiwan and Singapore.

[14] As shown in Table 2 even the Bank of Japan—which is regarded as very active in foreign exchange markets— intervened on 222 of 3066 trading days which corresponds to an unconditional probability of intervention of 7.24% (Federal Reserve 1.17%).

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

[16] For the observation period the conditional probability of US intervention on Japanese intervention is 100%.

[17] Ito (2002) and Sakakibara (2000) give anecdotal evidence.

To deal with both the asymmetric scope of intervention and multicollinearity, we add US and Japanese foreign exchange intervention to create one exogenous variable I—which represents Japan's efforts to redirect the yen/dollar rate. This specification is justified by the fact that US intervention is only in support of Japanese intervention and prior tests with solely Japanese intervention as the exogenous variable did not yield significantly different results (as US intervention is negligible). Sarno and Taylor (2002: 846) argue that coordinated sterilized intervention between two or more countries might convince speculators that the signalled policy is more credible as opposed to a single-country intervention. Yet a dummy for coordinated intervention has remained insignificant for the US-Japanese case since 1991.

Third, dollar purchases in Japan clearly dominate intervention activities (Figure 1). Out of 215 intervention days dollars were purchased on 182 intervention days (84.65%), on 33 days (15.34%) dollars were sold. In terms of absolute intervention volumes (in dollars) 263.63 billion dollars were purchased (87.50%) and 37.62 billion dollars were sold (12.50%). 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 (dollar purchases) and negative signs (dollar sales).[18]

[Table 2 about here]

This leads to the following GARCH specification:

$$r_t = b_0 + b_1 I_t + b_2 Nikkei_t + b_3 DOW_t + \varepsilon_t, \tag{1}$$

$$\varepsilon_t |_{\Omega_{t-1}} \sim N(0, h_t), \tag{2}$$

$$h_t = \omega + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i h_{t-j} + \gamma_1 |I_t| + \gamma_2 Nikkei_t^2 + \gamma_3 DOW_t^2 . \tag{3}$$

In equation (1) r_t denotes the logarithmic returns of the yen/dollar spot exchange rate (conditional mean) as plotted in the upper left panel of Figure 3. The exchange rate is assumed to be influenced by official foreign currency transactions I. The deviation of the exchange rate from a certain bliss point increases the probability of foreign intervention as suggested by Figure 4 and shown by Frenkel, Pierdzioch and Stadtmann (2003a).[19] I_t precedes unambiguously the

[18] This assumption will be relaxed below by the estimation of yearly local coefficients.
[19] Ito (2002) specifies this bliss point to 125 yen/dollar during the 1990s.

exchange rate changes measured at 5 p.m. Greenwich time, as Japanese foreign exchange intervention is performed in the Japanese markets and US intervention is negligible.[20]

As proposed by Bonser-Neal and Tanner (1996) we include the daily returns of Japanese and US stock markets—*Nikkei* 300 and *DOW* Jones Industrial—as exogenous variables to control for the impact of disturbances in other asset markets.[21] We do not include any dummies for the announcement of interest rate changes, since prior estimations with dummies did not yield any significant results.[22] In contrast to Dominguez (1998) and Baillie and Osterberg (1997) we do not include dummy variables for the day of the week and holidays for the sake of brevity.

In equation (2) 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 (3) models the volatility of the yen/dollar exchange rate as plotted in the lower left panel of Figure 3. The variance h_t depends on past disturbances ε_{t-i}, the lagged variance h_{t-j}, the absolute official foreign currency intervention $|I_t|$,[23] and the volatility in the Japanese and US share markets defined as the squares of daily returns—$Nikkei_t^2$ and DOW_t^2.

To capture the immediate impact of foreign exchange intervention on exchange rate volatility, the intervention variable $|I_t|$ and the control variables $Nikkei_t^2$ and DOW_t^2 are not lagged in the volatility equation. This specification incorporates the danger of simultaneity bias, as foreign exchange intervention might take place in periods of increased exchange rate volatility (for instance during the 1997 Asian and 1998 Japanese financial crisis). Furthermore, expected foreign exchange intervention could enhance exchange rate volatility prior to intervention.

As volatility tends to persist over longer time periods in clusters lagging the volatility term is not a promising approach to address the simultaneity bias. Although some central bank intervention reaction functions include volatility as exogenous variable (Baillie and Osterberg 1997 or Frenkel, Pierdzioch and Stadtmann 2003b) we assume that volatility is exogenous as explained in section 4.[24]

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[20] Estimations with only Japanese interventions yields by-and-large the same results.

[21] The correlation between the Nikkei and DOW series does not affect our main findings.

[22] As shown by Watanabe (1994), Japanese foreign exchange intervention might signal a change in fundamentals (monetary policy)—at least before 1999 when nominal interest rates reached the zero bound. 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.

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

[24] The Granger tests, not reported here, give evidence for causality from volatility to interventions. Beside the caveat that precedence does not necessarily imply causality (Black 1976) we reject this finding due to the reasons listed above.

The lag-structure of our GARCH model is specified by the Bayes information criterion (BIC) for models of the order $p \in \{1,\ldots,4\}$ and $q \in \{1,\ldots,4\}$. The BIC information criteria adopts the minimum for the global GARCH(1,2) specification.

4.2. Global Results

Table 3 reports the estimates of equations (1) to (3) on daily data between April 1, 1991, and December 31, 2002.[25] The GARCH parameters α_i and β_i are highly significant, indicating a strong explanatory power. The intervention coefficient b_1 is positive and highly significant, providing evidence for successful intervention on the same day.[26] Dollar purchases (yen sales) seem to induce yen depreciation; dollar sales (yen purchases) seem to induce yen appreciation.[27] Further, we observe that movements in the US and Japanese stock markets are strongly related to exchange rate movements on the same day, as portfolios are adjusted across borders.

The coefficient γ_1 estimates the impact of the absolute foreign exchange intervention on the volatility of the yen/dollar exchange rate on the same day. In contrast to Watanabe and Harada (2003) we find clear coincidence between Japanese foreign exchange intervention and yen/dollar volatility at the 1 percent level. This finding is consistent with Figure 5, which plots absolute foreign exchange intervention and yen/dollar exchange rate volatilities defined as 60 days rolling standard deviations. Japan's discretionary foreign exchange intervention seems to increase uncertainty among traders and thereby exchange rate volatility. We also find that the volatility in stock markets is linked to exchange rate volatility since investors adjust their portfolios across borders. This finding supports our attempt to control for volatility in other asset markets.

[Table 3 about here]

To this end the global GARCH estimation yields evidence in favour of—in the short-term—successful foreign exchange intervention as suggested by Ito (2002) and Fatum and Hutchison (2002). The impact of foreign exchange intervention on exchange rate volatility is in line with Schwartz (1996), Bonser-Neal and Tanner (1996) and Galati and Melick (1999).

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[25] The estimations were carried out with EViews.

[26] Lagging the intervention variable by one day yields insignificant coefficients.

[27] Given the positive sign we can exclude the possibility that we measure causality from the exchange rate to intervention (leaning against the wind), as this would require a negative sign (yen appreciation triggers dollar purchases).

4.3. Local Results

Although the GARCH estimation of section 4.1 provides a clear result for the impact of Japanese foreign exchange intervention, it gives only one comprehensive result for the whole observation period. The global estimation might not account for parameter changes that are for instance frequently observed for the volatility of financial time series.

Comparing the sum of autoregressive parameters for the global GARCH estimations with and without exogenous variables provides evidence for parameter changes. The global GARCH(1,1) estimation without exogenous variables yields a λ equal to 0.98 ($\lambda = \sum \alpha_i + \sum \beta_i$) which corresponds to a mean reversion time of about 50 days. The estimated sum of autoregressive parameters being close to unity indicates that parameter changes might not be accounted for (Hillebrand 2003). In contrast, the estimation of the GARCH model with exogenous variables as specified in equations (1) to (3) yields λ equal to 0.92, which in turn corresponds to a mean reversion time of about 12 days when the intervention term is introduced. The reduction of the time of mean reversion (smaller λ) shows that the interventions at least coincided and possibly caused the parameter changes in volatility.

To cope with this problem we re-estimate our GARCH model for sub-periods as proposed by Bonser-Neal and Tanner (1996). In a fist step we subdivide our observation period into calendar years. Although this partition is somewhat arbitrary we get a notion of changing parameters. The results of the local yearly GARCH estimations are reported in Table 4. There seems to be a change in the effects of Japanese foreign exchange intervention starting in 1999. In the period between 1991 and 1998 there is no significant impact from foreign exchange intervention on the mean despite considerable intervention volume and a large number of intervention events. Intervention seems to have increased exchange rate volatility in the years 1993 to 1995.

In the second sub-period starting in 1999 the results undergo a change. In all four years up to 2002 the intervention coefficients b_1 are positive and highly significant. Japanese foreign exchange intervention seems successful during this time period. The impact on exchange rate volatility is less clear-cut. After 1998 negative signs dominate (except for 2001), but are mostly insignificant. Only in the year 2000 foreign exchange interventions seem to have reduced exchange rate volatility significantly at the 10% level. The combination of successful foreign exchange intervention and reduced exchange rate volatility might not be accidental, as successful intervention reduces the scope of appreciation and thus dampens relative exchange rate changes on the respective day.

Understanding that data segmentation considerably affects our estimation results we have pursued an alternative approach. Beine and Szafarz (2003: 6) suggest that Japanese foreign exchange intervention exhibits clear patterns of clusters. Based on Figure 1 we build eight periods of intervention clusters, which are indicated by the numbered bars in the lower part of the Figure. Then we set the boundaries of the segments mid-way between the last and the first day of each intervention period. Although these intervention clusters are again chosen somewhat arbitrarily we obtain additional evidence on the effect of data segmentation.

The main findings as reported in Table 5 widely match the findings of the yearly estimations. Between 1991 and 1998 Japanese foreign exchange intervention seems to have been ineffective and between 1994 and 1996 it seems to have increased exchange rate volatility. Starting from late 1998 there is strong evidence for—in the short-term—effective foreign exchange intervention. In contrast to the yearly estimations, the intervention coefficients in the volatility equation are not only negative but also highly significant. Thus, since 1999 successful Japanese foreign exchange intervention has coincided with reduced exchange rate volatility at highly significant levels.

Based on the findings reported in Table 4 and Table 5 we identify two sub-periods in which Japanese foreign exchange intervention had different impacts on exchange rate returns and exchange rate volatility—1991 to 1998 and 1999 to 2002. To consolidate this result we re-estimated our model as specified in equation (1) to (3) for the two sub-periods. The results are reported in Table 6 and confirm our main conclusion. Up to 1998 Japanese foreign exchange intervention was ineffective, but coincides with increased exchange rate volatility. Since 1999 Japanese foreign exchange intervention had the intended short-term effect with evidence for less exchange rate volatility. Changing the boundary between the two subsamples by one to six months prior to and after January 1, 1999 does change the meaningful results with respect to the mean equation (but less robust with respect to the volatility equation).

5. CHANGE POINT DETECTION

Although the sub-divided GARCH estimations give a more precise view of changing parameter regimes in comparison to the global model, the segmentations might still be criticized as being arbitrary. We use a change point detector for ARCH models as proposed by Kokoszka and Leipus (2000) to identify sub-periods on a more systematic basis. Further, the change point detector provides us with an alternative approach to match increased volatility with intervention periods.

5.1. Specification

The change point detector identifies changes in the data-generating parameters of a time series. Change point detection has a long-standing tradition in the quality control of production processes (Lai 1995) and has also been applied to financial time series (Kokoszka and Leipus 2000). We will base the change point detection on a standard GARCH(1,1) model with constant mean return:

$$r_t = \mu + \varepsilon_t, \tag{7}$$

$$\varepsilon_t \,|_{\Omega_{t-1}} \sim N(0, h_t), \tag{8}$$

$$h_t = \omega + \alpha\varepsilon_{t-1}^2 + \beta\, h_{t-1}. \tag{9}$$

In equation (7), r_t are the daily returns of the yen/dollar exchange rate, μ is the constant mean. The disturbances ε_t are assumed to be normally distributed conditional on the information Ω_{t-1} available at the time t-1 (8). The mean of the disturbances is assumed to be zero and the variance h_t depends on the square of the lagged disturbance of the previous period ε_{t-1} and the variance of the previous period h_{t-1} (9).

Let k* denote a single change point in our time series generated by the GARCH model of equation (7) to (9). At k^* the data generating parameter vector changes from $\theta_1 = (\omega_1, \alpha_1, \beta_1)$ to $\theta_2 = (\omega_2, \alpha_2, \beta_2)$. In other words, the change point detector identifies segments of sufficiently different volatility means.[28] The change point detector is the estimator $\hat{k}$ of k^* defined by

$$\hat{k} = \min\left\{k : |R_k| = \max_{1 \le j \le n} |R_j|\right\} \tag{10}$$

where k and j are indices for time, and the statistic R_k is given by

$$R_k = \frac{k(n-k)}{n^2}\left(\frac{1}{k}\sum_{j=1}^{k} r_j^2 - \frac{1}{n-k}\sum_{j=k+1}^{n} r_j^2\right). \tag{11}$$

[28] In the stationary GARCH(1,1) model, the volatility mean is given by $Eh_t = E\varepsilon_t^2 = \omega/(1-\alpha-\beta)$ (Bollerslev 1986).

Intuitively, the detector measures the distance R_k between the means of the two segments that are induced by the hypothetical change point k. The estimated change point is set where this distance becomes maximal. For the rare case that more than one maximum exists, the first one is chosen. Kokoszka and Leipus (2000) show that this estimator is consistent and converges in probability to the true change point k^* with rate 1/n.

We approach the multi-change point problem of finding a segmentation of the yen/dollar exchange rate series as a sequential single-change point detection problem. The observation period is sub-divided into an increasing number of sub-periods, where the change points mark the boundaries. First, the change point detector is applied to the whole exchange rate series, which yields one change point and two sub-series. The detector then is applied to both sub-series, increasing the number of change points to three and the segments to four and so on.

The starting point of our GARCH estimations performed in section 4 was set by the publication of Japanese foreign exchange intervention data starting from April 1, 1991. To obtain a less arbitrary starting point we extended the observation period to about 20 years starting in October 1983. The change point detection progresses in five steps and thereby theoretically sets 31 change points.[29] We can then choose the change point closest to April 1991 as starting point of the GARCH estimation and re-estimate our model for the new sub-periods.

5.2. Results

Before we report the results, the following caveats must be noted. First, the change point detector as specified by Kokoszka and Leipus (2000) does not allow controlling for disturbances from other asset markets, which might distort the estimation results. Second, a synopsis of foreign exchange intervention periods and the change point estimates cannot be more than a coincidence study. The change point detection does not provide a specific tool to test for the direct correlation or even causality between change points and intervention activity. Third, besides identifying segments of different volatility the change point detector provides a tool for non-arbitrary data segmentation.

Figure 3 shows the results of the change point detection. The upper panel plots the interventions in billion yen. For the period before 1991, we use monthly changes in official

[29] We stop subdividing a segment when its length is either less than 250 points or when a new segment of less than 50 points would be cut off in the next segmentation step. For our sample, this reduces the total number of change points to 17 and the number of segments to 18.

foreign reserves as a proxy for the interventions, because *de facto* data are not available. The lower panels show different numbers of change points at the consecutive steps.[30]

The first change point in early March 1995 corresponds to the period when Japanese (and US) monetary authorities increased their efforts to reverse the record high of the Japanese yen of about 80 yen/dollar. The next change points are set in September 1985—the time of the Plaza Accord—and in September 1999 during the 1999 intervention period. In the third step, additional change points are set in April 1991 one month before the 1991 interventions, and in June 1998 when massive yen purchases tried to prevent the yen falling during the Japanese financial crisis. Additional change points are set in June 2000 after the 2000 intervention cluster and December 2000 shortly before the 2001 intervention period.

[Figure 4 about here]

Increasing the number of segments and change points we observe a concentration of change points in the 1990s, but it gets difficult to associate change points with intervention events. In the year 2002 the change point detector does not associate foreign exchange intervention with increased volatility. Furthermore, testing for the robustness of the change point estimation process we find that the location of change points is sensitive to the length and starting point of the observation period. This indicates the need for further research on this very recent approach to identify volatility clusters.

5.3. Change Point Segmentation and GARCH Estimation

Independent from the starting point, the change point detector is a tool to obtain non-arbitrary segmentation of the volatility series. We can use any of these new segments for local GARCH estimations. We chose the segments provided by the third step for two reasons. First, a change point is set on April 23, 1991 close to the beginning of our Ministry of Finance data sample. Second, at the subsequent steps several segments are too short for reliable GARCH estimation.

The results of the respective local GARCH estimations are reported in Table 6. For the second sub-period from 1999 to 2002 the results are in concordance with the previous local estimations. Foreign exchange intervention is effective and volatility less. For the first sub-period from 1991-1998 the results are mixed. In particular in the first period from April 1991 to February 1995, the b_1 coefficient for the effectiveness of foreign exchange intervention is negative and highly significant. Yen appreciation is associated with dollar purchases provid-

[30] The first step, which sets the first change point on March 1, 1995, is omitted for brevity.

ing evidence for possible endogeneity bias.[31] For the years 1991 up early 1995 foreign exchange intervention seems to have increased exchange rate volatility. After that time and up to mid 1998 the impact seems negative, but at an insignificant level.

6. INTERPRETATION OF FINDINGS

The finding that Japanese foreign exchange intervention has affected the yen/dollar exchange rate so clearly after 1999 is very robust and begs the question as to possible explanations. After 1999 we couldn't observe any fundamental change in the strategy of Japanese foreign exchange intervention with respect to intervention volume, number of events or volume per event (Figure 1 and Table 2). Given the high degree of capital mobility between Japan and the US, the probability for a portfolio balance effect is low. Further, as interest rates declined to zero in early 1999, there is little evidence that foreign exchange intervention announced a fundamental change in interest rate policy. Further, as Japanese foreign exchange intervention after 1999 was purely unilateral, the argument for enhanced effectiveness of co-ordinated intervention does not hold.

Given the caveat that the period since 1999 is too short to conclude that Japan's foreign exchange intervention will be also effective in the future, the following explanations for effective Japanese foreign exchange intervention (after 1999) might apply.

First, there is the portfolio equilibration function of Japanese foreign exchange intervention as outlined by Goyal and McKinnon (2003). Based on a sustained saving surplus, Japan has generated high current account surpluses for more than two decades. The respective net capital exports have produced a huge stock of Japanese net international foreign assets, which constitute an inherent and sustained appreciation pressure on the Japanese currency.

Given Japan's net external foreign asset position, successful foreign exchange intervention can be explained with a simple market clearing condition, assuming that current account (CA), net capital flows (KA) and changes in official foreign reserves (ΔRES) add up to zero:

$$\Delta RES_t + CA_t + KA_t = 0 \qquad (11)$$

Capital flows are assumed exogenous. If Japanese private investors decide to repatriate parts of their foreign assets, they sell US dollar treasuries and convert the earnings into yen (buying yen). The yen comes under appreciation pressure.

[31] Watanabe and Harada (2001) find a similar result that they interpret in the same way.

Two possible adjustment channels then apply. If the government decides to tolerate the appreciation ($\Delta RES_t = 0$), the decline in the net capital exports will be matched by an equal decline in the current account surplus, which is achieved via appreciation. If the government wants to sustain the current account at the present level (CA_t = const.), the changes in net capital inflows have to be matched by a respective change of foreign reserves, which corresponds to foreign exchange intervention. If all additional net capital inflows are absorbed by official currency purchases, the exchange rate and the current account remain constant.[32] The original foreign investment position is restored. Only the structure of Japanese foreign assets has changed. Public foreign assets are substituted by private foreign assets. Foreign exchange intervention is successful.[33]

While the portfolio equilibration approach provides a possible rationale for successful Japanese foreign exchange intervention, it does not explain why the success started in 1999. To this end De Grauwe and Grimaldi (2003) provide an alternative explanation approach. Based on a framework where chartists and fundamentalists interact they argue that sterilized foreign exchange intervention can affect the exchange rate by reducing speculative noise. As exchange rates tend to take systematic deviations from their fundamentals, intervention could be effective by reducing the share of chartists in the market, thereby re-directing the exchange rate towards fundamentals.

De Grauwe and Grimaldi (2003) admit that occasional intervention is unlikely to be effective, as it has very unpredictable effects on the exchange rate. Instead they suggest that successful intervention should be systematic following a clear pattern. Following this line of argument, Japanese foreign exchange intervention could be successful because—as outlined in section 4—Japanese monetary authorities were (are) successful in establishing informal exchange rate targets or target zones which enhance(d) the credibility of intervention.

Very recently, during the first half of the year 2003, Japanese monetary authorities were reported to have stabilized the yen between 115 yen to 122 yen to the dollar. Press reports give evidence that Japanese foreign exchange intervention credibly set (informal) target zones with respect to the exchange rate level and—as a side effect—reduced exchange rate volatility: "*Previous intervention has not been so effective in keeping the rate in such a tight*

32 To this end some observers have argued that the exchange rate of the Japanese yen would be at a level between 87 and 103 yen/dollar without the past foreign exchange intervention.

33 Within this framework money supply can be assumed to be unchanged. When capital flows in, dollars are exchanged against yen and the domestic money supply (M1) declines. When the central bank buys the oversupply of dollars, the money supply M1 is restored, but at the same time the monetary base expands. Finally the expansion of the monetary base is sterilized by the central bank and the holdings of domestic money and foreign reserves remain unchanged.

range. As a result volume has dropped and currency traders have complained about a lack of volatility."[34]

Although this explanation approach seems quite plausible it raises the question as to the impact of systematic (rule-based) foreign exchange intervention on the money supply. De Grauwe and Grimaldi (2003) have not incorporated a money market into their model. We would argue however, that establishing a target zone would require subordinating fundamentals (interest rates and monetary base) to the exchange rate target.

This brings us to Japan's particular monetary framework after 1999. As is generally known, Japanese short-term money market interest rates touched the zero bound in early 1999 which is generally perceived as a "liquidity trap". The Bank of Japan's official commitment to zero interest rates is in line with any growth (but not decline) of the monetary base. Indeed we observe that despite the stagnating economy the monetary base grew rapidly after 1999 reaching yearly growth rates of 20% to 30%. In short, in the liquidity trap, at zero money market interest rates, the money supply is "infinite".

Under these circumstances the borderline between sterilized and unsterilized foreign exchange intervention gets blurred. Disputes between the Bank of Japan and the Ministry of Finance about the pros and cons of sterilization indicate that even in the liquidity trap the sterilization operations of the Bank of Japan have continued (Bank of Japan 2002: 273). But even if the monetary effects of foreign exchange intervention are neutralized, sterilization would be irrelevant if it coincided with a simultaneous increase of the monetary base. In September 2001, the Nikkei Bank of Japan watcher reported that the yen amount released by foreign exchange intervention might not have been absorbed by open market operations in to supply liquidity to the troublesome markets after September 11.[35] This could be hint that sterilization is not pursued completely and automatically as in the United States or the Euro Area.

Thus our estimations might provide evidence that Japanese monetary authorities move slightly towards an exchange rate policy similar to that observed by McKinnon and Schnabl (2003a) for other soft or hard pegs in East Asia, which subordinate interest rate targets to exchange rate targets. At least the official foreign reserves of the "free floater" Japan and the "hard peg" China tend to behave more and more similarly.

All in all, our finding of successful Japanese foreign exchange intervention after 1999 would therefore be in line with the general wisdom on foreign exchange intervention as put forward by Jurgensen (1983) and Dominguez (1998): Foreign exchange intervention can only

[34] Pilling, David: Tokyo spends record amount to weaken yen (Financial Times August 8, 2003).
[35] Nihon keizai shinbun BOJ watcher September 19, 2001 (page 2).

be successful if it remains unsterilized or coincides with respective changes in the money supply—a tentative conclusion which needs further research.

7. CONCLUSION

During the post-bubble economic slump the sustained yen appreciation has triggered increasing foreign exchange intervention. Our global GARCH estimation supports the recent findings by Ito (2002) and Fatum and Hutchison (2002) that Japanese foreign exchange intervention has been successful—at least on the same day. Segmentation approaches that allow for local estimations reveal however, that the success depends on the time period.

Up to 1998 there is no conclusive evidence for effective intervention as argued by Jurgensen (1983) and Dominguez (1998). After 1999 official Japanese foreign currency purchases seem to have reached their targets supporting the arguments of Ito (2002) and Fatum and Hutchison (2002). In Section 6 we have provided two explanations for the changing pattern. The most plausible explanation is that money supply is infinite in the liquidity trap and therefore sterilized intervention corresponds to unsterilized intervention.

We have also examined the impact of Japanese foreign exchange intervention on the volatility in the yen/dollar markets. The results were less conclusive than in our mean equations and the endogeneity problem cannot be solved completely. The global estimation provided evidence that foreign exchange intervention increases exchange rate volatility as suggested by Schwartz (1996), Bonser-Neal and Tanner (1996) and Galati and Melick (1999). For the local estimations the results are less clear-cut. In the period up to 1998 in some years foreign exchange intervention seems to have increased exchange rate volatility. Since 1999 however, we find evidence that interventions may have reduced exchange rate volatility, which can be explained by the success of intervention.

Note that our GARCH estimations only scrutinized the short-term effects of foreign exchange intervention. The long-term perspective is beyond the scope of this paper. Nevertheless recently, McKinnon and Schnabl (2003) have observed reduced month-to-month yen/dollar exchange rate volatility since the year 2002, which might give evidence for successful exchange rate stabilization even in the longer run. This phenomenon is worth further examination.

Finally, the change point detector identified changes in the volatility parameter regime, which could be—to some degree—matched with intervention periods. As the results are sensitive to the choice of the sample period, the application of this very young approach to foreign exchange intervention needs further research.

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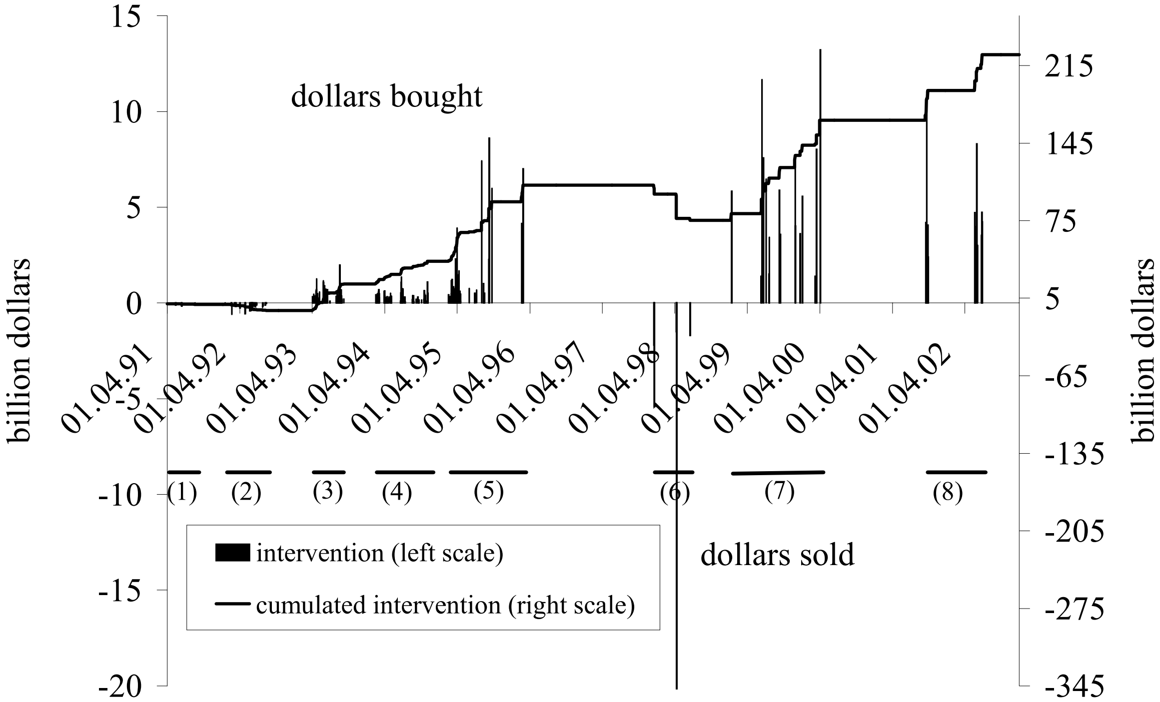
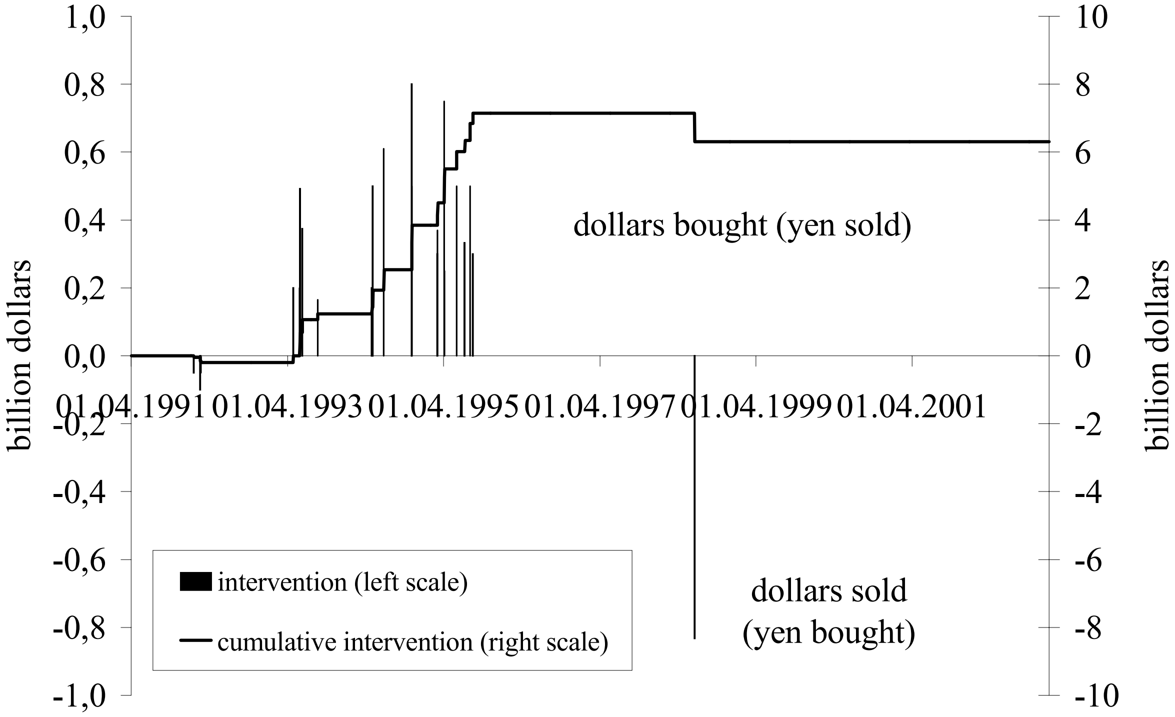
Figure 1: Japan – Absolute and Cumulated Daily Foreign Exchange Intervention



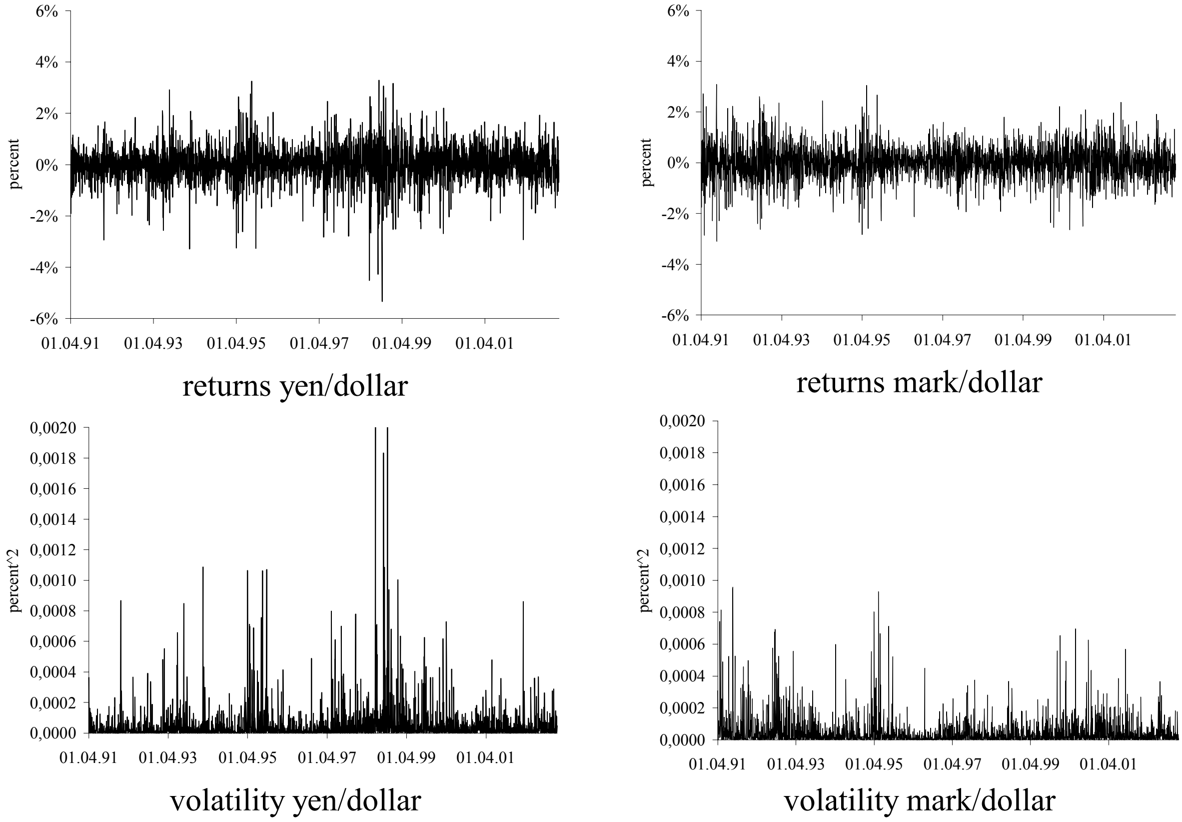
Source: Japanese Ministry of Finance. April 1991 – December 2002. Note different scales for Japan and the US (Figure 2).

Figure 2: US – Absolute and Cumulated Daily Foreign Exchange Intervention



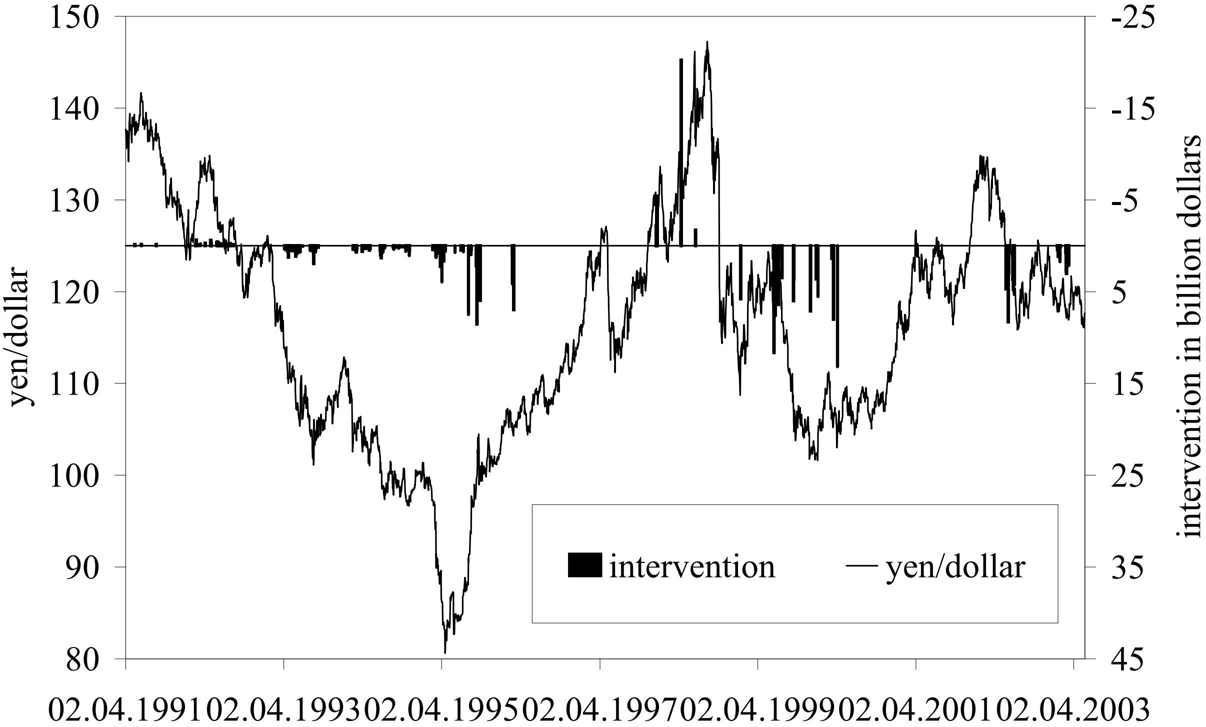
Source: US Federal Reserve Board. Billion Dollars. April 1991 – December 2002. Note different scales for US and Japan (Figure 1).

Figure 3: Daily Yen/Dollar and German Mark/Dollar Exchange Rates (4/1/91 – 12/31/02)



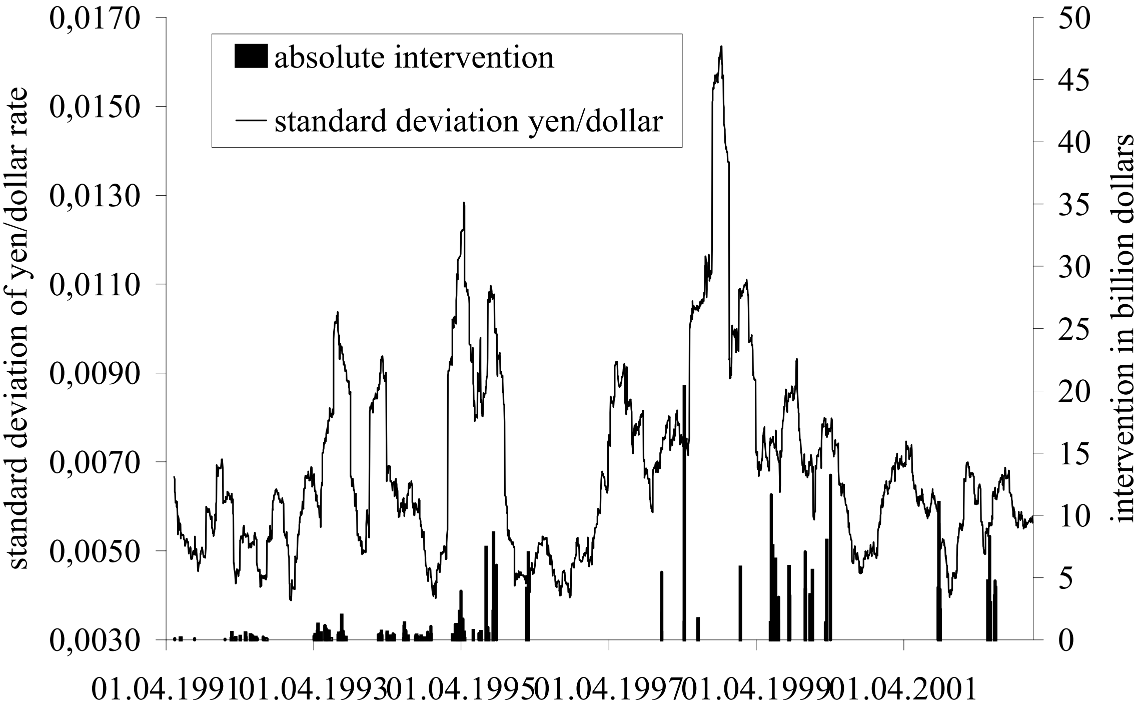
Source: Datastream. Daily volatilities defined as square of daily percentage changes. The DM represents the euro since January 1999.

Figure 4: Foreign Exchange Intervention and Yen/Dollar Exchange Rate



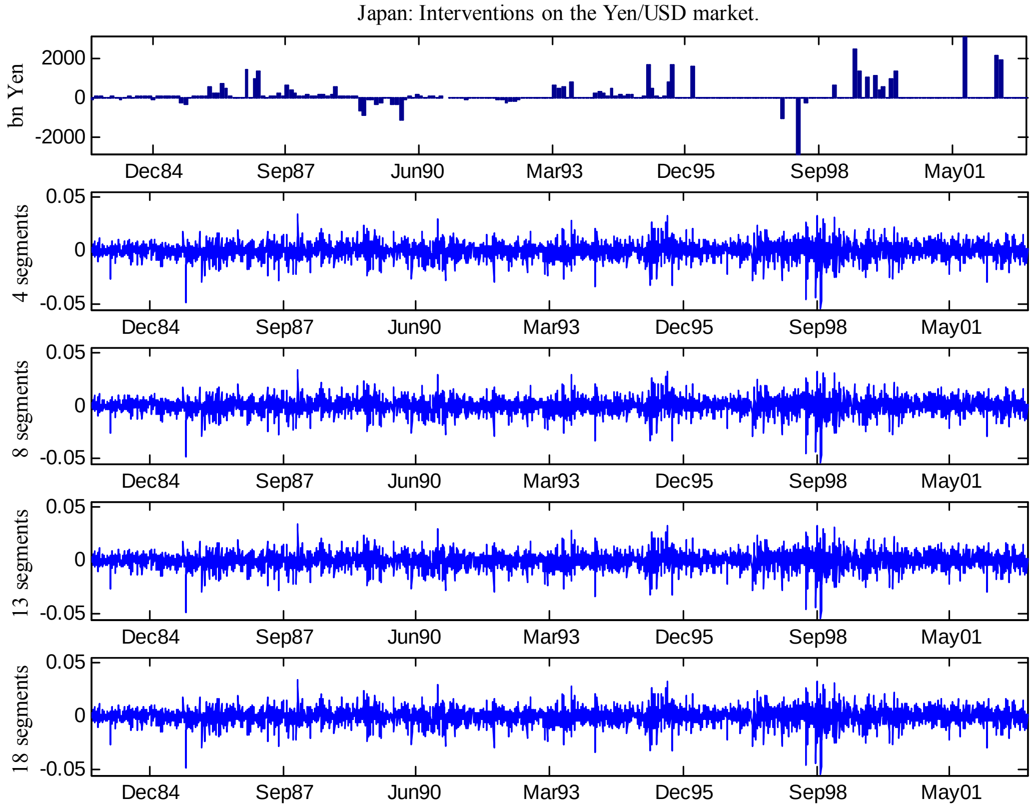
Source: Datastream. Foreign exchange intervention in billion dollars. April 1991 – December 2002.

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



Source: Datastream. Foreign exchange intervention in billion dollars. April 1991 – December 2002. Volatility defined as 60 days rolling standard deviations of the daily percent yen/dollar exchange rate changes around day t.

Figure 6: Foreign Exchange Intervention and Volatility Segmentation (1983–2002)



The first change point that is detected on the entire series is 03-01-1995. In the two resulting sub-series, the change points 09-20-1985 and 09-27-1999 are found (second panel). In the next step (third panel), the segmentation consists of the points 01-Mar-1984, 20-Sep-1985, 23-Apr-1991, 01-Mar-1995, 09-Jun-1998, 27-Sep-1999, 09-Jun-2000. The next step (second panel from below) results in the segmentation 01-Mar-1984, 20-Sep-1985, 05-Jun-1986, 23-Apr-1991, 08-Feb-1993, 01-Mar-1995, 06-Oct-1995, 09-Jun-1998, 20-Oct-1998, 27-Sep-1999, 09-Jun-2000, and 21-Dec-2000. The last step closes with the segmentation 01-Mar-1984, 20-Sep-1985, 05-Jun-1986, 12-May-1989, 23-Apr-1991, 03-Nov-1992, 08-Feb-1993, 21-Sep-1993, 01-Mar-1995, 06-Oct-1995, 02-May-1997, 09-Jun-1998, 20-Oct-1998, 27-Sep-1999, 09-Jun-2000, 21-Dec-2000, 15-Jun-2001.

Table 1: Descriptive Statistics of the Yen/Dollar and Mark/Dollar Exchange Rates

	yen/dollar	**mark/dollar**
number of observations	3066	3066
mean	-0.0057	0.0052
standard deviation	0.7096	0.6587
skewness	-0.6280	-0.0114
kurtosis	7.9681	4.8316
Jarque-Bera	3354.68	428.63

Source: IMF: IFS. The German mark represents the euro starting in 1999.

Table 2: Summary Statistics for Bank of Japan and Federal Reserve Interventions

	Bank of Japan	**Federal Reserve**
total intervention days	215 (222)	22 (36)
total transaction volume (billion dollars)	300.98 (308.77)	8.40 (17.2)
percentage of interventions in the yen/dollar market	97.48%	48.83%
unconditional intervention probability	7.01% (7.24%)	0.71% (1.17%)
number of days with dollar purchases (yen sales)	182 (184)	18 (30)
total amount of dollar purchases (billions)	263.36	7.30
mean absolute value of dollar purchases (billions)	1.30	0.41
number of days with dollar sales (yen purchases)	33 (38)	4 (6)
total amount of dollar sales (billions)	37.62	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 3: Global GARCH (1,2) Estimation for Equation (1) to (3)

	estimate	standard error	z-statistic	probability
b_0	-6.4E-5	1.1E-4	-0.57	0.57
b_1 (I_t)	0.86***	0.30	2.91	0.00
b_2 ($Nikkei_t$)	-0.01	0.01	-1.47	0.14
b_3 (DOW_t)	0.04***	0.01	2.90	0.00
γ_1 ($\|I_t\|$)	4.8E-3**	2.1E-3	2.33	0.02
γ_2 ($Nikkei_t^2$)	3.9E-3*	2.1E-3	1.83	0.07
γ_3 (DOW_t^2)	8.5E-3*	4.4E-3	1.95	0.05
ω	1.8E-6**	7.3E-7	2.42	0.02
α_1	0.07***	0.02	3.64	0.00
β_1	0.39	0.27	1.45	0.15
β_2	0.46*	0.25	1.84	0.07

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 4: Local GARCH Estimation for Equation (1) to (3) – Unlagged Intervention by Year

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
number of events	4	23	49	55	43	5	3	3	12	4	7	7
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
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
GARCH specific.	(1,1)	(1,2)	(4,4)	(1,2)	(2,1)	(1,1)	(1,1)	(1,1)	(1,1)	(2,1)	(1,1)	(1,1)
b_1	-17.51	3.83	-2.54	-0.47	1.20	1.20	1.90	0.29	1.62***	1.17***	0.72**	0.87***
standard error	-19.36	3.43	1.79	1.53	1.05	1.31	3.11	0.26	0.25	0.20	0.37	0.32
z-statistic	-0.90	1.11	-1.41	-0.31	1.15	0.91	0.61	1.11	6.37	5.66	1.94	2.65
probability	0.37	0.26	0.16	0.75	0.25	0.35	0.54	0.26	0.00	0.00	0.05	0.01
γ_1	0.00	0.00	0.02*	0.01***	0.01***	0.02	0.02	-0.00**	-0.00	-0.00*	3.1E-3	-0.00
standard error	0.09	0.01	0.01	0.01	0.00	0.01	0.04	0.01	0.00	0.00	2.5E-2	0.00
z-statistic	0.00	0.17	1.61	2.19	3.31	1.38	0.56	-2.78	-0.40	-1.73	-0.12	-0.90
probability	0.99	0.86	0.10	0.02	0.00	0.16	0.57	0.01	0.68	0.08	0.90	0.36

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) – Unlagged Intervention by Intervention Clusters

intervention period	**05/13/91** **08/19/91**	**01/17/92** **08/11/92**	**04/02/93** **09/07/93**	**02/15/94** **11/03/94**	**02/17/95** **02/27/96**	**11/3/97** **6/17/98**	**01/12/99** **04/03/00**	**09/17/01** **06/28/02**
observation period	**04/01/91** **11/01/91**	**11/04/91** **12/07/92**	**12/08/92** **12/24/93**	**12/27/93** **12/27/94**	**12/28/94** **12/31/96**	**01/01/97** **09/30/98**	**10/01/98** **12/25/00**	**12/26/00** **31/12/02**
number of events	4	23	49	55	48	6	16	14
total volume (bn. $)	-0.50	-5.53	23.88	20.44	69.00	-31.58	90.42	59.26
volume per event	-0.13	-0.24	0.49	0.37	1.44	-5.26	5.65	4.23
GARCH specific.	(1,1)	(1,1)	(2,3)	(1,3)	(1,3)	(2,1)	(1,2)	(1,1)
$\mathbf{b_1}$	-28.01	3.81	-2.68	-1.20	0.14	0.49	1.48***	0.93***
standard error	18.79	4.20	1.79	1.47	0.72	1.25	0.12	0.24
z-statistic	-1.49	0.91	-1.50	-0.81	0.19	0.40	11.93	3.85
probability	0.14	0.36	0.13	0.41	0.85	0.69	0.00	0.00
$\boldsymbol{\gamma_1}$	1E-6	3E-3	0.02	0.01***	0.02***	0.05	-3.7E-3***	-2.3E-3***
standard error	0.08	3.6E-3	0.02	3E-3	0.01	0.05	4.7E-4	7.6E-4
z-statistic	0.00	-1.34	1.13	2.12	2.95	0.92	-7.87	-3.07
probability	1.00	0.18	0.26	0.03	0.00	0.35	0.00	0.00

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: GARCH Estimations for Equation (1) to (3) – 2 Sub-periods

	1991-1998	**1999-2002**
number of events	185	30
total volume (bio. $)	75.7	150.04
volume per event	0.41	5.00
GARCH specific.	(1,4)	(4,3)
b_1	0.24	1.02***
standard error	0.63	0.21
z-statistic	0.37	4.94
probability	0.71	0.00
γ_1	0.03***	-1.0E-3
standard error	8E-3	7.5E-4
z-statistic	3.65	-1.33
probability	0.00	0.18

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: GARCH Estimations of Model (1) to (3) with Unlagged Intervention Variable in the Mean Equation on Segments Identified by the Change Point Detector (10)

	04/23/1991 02/28/1995	**03/01/1995 06/08/1998**	**06/09/1998 09/24/1999**	**09/27/1999 06/08/2000**	**06/09/2000 12/31/2002**
Model order	GARCH(3,1)	GARCH(1,1)	GARCH(1,1)	GARCH(1,1)	GARCH(1,1)
b_1	-3.54***	0.63	1.81***	1.06***	0.91***
std. error	1.20	0.45	0.08	0.24	0.25
Z-statistic	-2.95	1.41	23.05	4.39	3.70
probability	0.00	0.16	0.00	0.00	0.00
γ_1	0.02**	-3.7E-4	-5.1E-3***	-4.2E-3***	-2.1E-3***
std. error	0.01	6.5E-4	6.3E-4	1.0E-3	7.2E-4
Z-statistic	2.38	-0.57	-8.04	-4.06	-2.94
probability	0.02	0.57	0.00	0.00	0.00

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.