EUROPEAN CENTRAL BANK

WORKING PAPER SERIES

NO 650 / JUNE 2006

BCE ECB EZB EKT EKP

A STRUCTURAL BREAK IN THE EFFECTS OF JAPANESE FOREIGN EXCHANGE INTERVENTION ON YEN/DOLLAR EXCHANGE RATE VOLATILITY

by Eric Hillebrand
and Gunther Schnabl

EUROPEAN CENTRAL BANK

WORKING PAPER SERIES

NO 650 / JUNE 2006

A STRUCTURAL BREAK IN THE EFFECTS OF JAPANESE FOREIGN EXCHANGE INTERVENTION ON YEN/DOLLAR EXCHANGE RATE VOLATILITY [1]

by Eric Hillebrand [2]
and Gunther Schnabl [3]

In 2006 all ECB publications will feature a motif taken from the €5 banknote.

1 Comments by Phillip Hartmann, the participants of an internal ECB seminar and an anonymous referee are gratefully acknowledged..
2 Department of Economics, Louisiana State University, Baton Rouge, LA 70803, USA; Tel. +1 225 578 3795, Fax.+1 225 578 3807; e-mail: erhil@lsu.edu
3 Department of Economics and Business Administration, Leipzig University, Marschenerstr. 31, 04109 Leipzig, Germany; Tel. +49 341 97 33560, Fax. +49 341 97 33569; e-mail: schnabl@wifa.uni-leipzig.de

Address
Kaiserstrasse 29
60311 Frankfurt am Main, Germany

Postal address
Postfach 16 03 19
60066 Frankfurt am Main, Germany

Telephone
+49 69 1344 0

Internet
http://www.ecb.int

Fax
+49 69 1344 6000

Telex
411 144 ecb d

ISSN 1561-0810 (print)
ISSN 1725-2806 (online)

CONTENTS

Abstract

While up to the late 1990s Japanese foreign exchange intervention was fully sterilized, Japanese monetary authorities left foreign exchange intervention unsterilized when Japan entered the liquidity trap in 1999. According to previous research on foreign exchange intervention, unsterilized intervention has a higher probability of success than sterilized intervention. Based on a GARCH framework and change point detection, we test for a structural break in the effectiveness of Japanese foreign exchange intervention. We find a changing impact of Japanese foreign exchange intervention on exchange rate volatility at the turn of the millennium when Japanese foreign exchange intervention started to remain unsterilized.

Keywords: *Japan, Foreign Exchange Intervention, Exchange Rate Volatility, GARCH, Change Point Detection, Structural Breaks.*

JEL: E58, F31, F33, G15

Non-technical summary

Since the early 1990s up to March 2004, the scope of Japanese foreign exchange intervention has increased significantly. Japanese foreign exchange intervention has dwarfed US official foreign currency transactions both in terms of intervention events and in terms of cumulative intervention volume.

While an increasing number of papers have tested for the effects of foreign exchange intervention on the yen/dollar exchange rate level and volatility, rather few have scrutinized the possibility of a structural break in the effectiveness. A structural break may be due to the fact that since the turn of the millennium Japanese monetary authorities have left intervention unsterilized to increase the liquidity supply to the sluggish Japanese economy. According to previous studies unsterilized intervention has a much higher probability of success than sterilized intervention.

To test for the effectiveness of Japanese foreign exchange intervention we focus on the relationship between interventions and exchange rate volatility. Intervention is regarded as successful if the volatility of the involved currency pair is reduced significantly. For this purpose we use a GARCH model with interventions as exogenous variables for mean and volatility. The model provides evidence that for the overall sample, intervention increases volatility and therefore seems unsuccessful.

We use several approaches to identify possible parameter changes during the observation period. Segmentation by single years and intervention clusters suggest a structural break around the turn of the millennium. A change-point detector which provides non-arbitrary segments for local GARCH estimations as well as rolling GARCH(1,1) estimations confirm the result.

While the GARCH framework does not allow identifying the reasons for the structural break in the effects of Japanese foreign exchange intervention on exchange rate volatility, the identified structural break coincides with the time when Japan entered the liquidity trap.

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.[2] 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., Castren 2004, Galati, Melick, and Micu (2005), Watanabe and Harada 2006, 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 (i.e. a smaller number of large interventions rather than a large number of small interventions).

In this paper, we focus on the relation between interventions and exchange rate volatility, defining successful intervention as inducing a reduction of 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 most former studies, we use several approaches to identify 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 1997 and decreased volatility after the year 2000. For the period between 1997 and 2000 the evidence is mixed. Although we are not able to directly introduce the degree of sterilization of foreign exchange intervention into our GARCH framework, the negative relationship between Japanese foreign exchange intervention and yen/dollar exchange rate volatility coincides with

---

[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.

the so-called liquidity trap when Japanese foreign exchange intervention could be allowed to affect the monetary base.

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. 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).[3]

An empirical test of the portfolio balance model by Dominguez and Frankel (1993b) supported this view for Japanese foreign exchange intervention between 1984 and 1990. They obtained similar results for US and German interventions (Dominguez and Frankel 1993a). 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. 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 second half of 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. Evans and Lyons (2002) have provided support that secret interventions

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

(common practice of the Japanese monetary authorities) have been effective via the order flow channel.

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 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 line of discussion. 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. Castren (2004) finds a significant impact of interventions in the yen/dollar market on all moments of estimated options-implied risk neutral density functions. Watanabe and Harada (2006) 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 verbal foreign exchange "intervention" can reduce exchange rate volatility while actual interventions raise it.

In summary, although Sarno and Taylor (2001) state that the recent literature gives more evidence in favor of success, the general theoretical and empirical evidence for the effects of foreign exchange intervention on the level and volatility of exchange rates remains mixed. For the case of Japan, however, recently the evidence in favor of intervention that is effectively influencing the exchange rate levels or volatility has become stronger (Ito 2003, Fatum and Hutchison 2003, Castren 2004, Watanabe and Harada 2006).

This might be due to the fact that Japanese foreign exchange intervention seems to have remained effectively unsterilized since 1999. While before 1999, foreign exchange intervention by the Japanese Ministry of Finance was fully and instantaneously sterilized by the Bank of Japan, this "liquidity constraint" was removed afterwards. Under 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 2003). This may have put a constraint on liquidity growth in times of foreign exchange intervention. However, as shown in Figure 1, 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.[4] The upshot is that after 1999 foreign exchange intervention could be used as an instrument to increase money supply and to keep interest rates at the zero level. This would correspond to unsterilized intervention which is likely to increase the probability of success.

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.[5] This corresponds to a sample size of 3542 observations.

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).[6] The daily log returns and squared log returns are plotted in Figure 4.

---

4 There is no evidence that the current balances were adjusted on a daily basis.

5 As of today (January 2006), the Japanese Ministry of Finance has not reported any interventions after October 2004.

6 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.[7] 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 trillion 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 sub-divided into yen, mark[8] and other currencies purchased and sold. The reported scale is in million dollars, we convert it into trillion dollars. As in 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). The last US-Japanese joint intervention was in June 1998.

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

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 to smooth the long-term swings of the exchange rate level. 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.[9] Similarly, financial press reports suggested that during the 1990s and particularly in the new millennium, Japanese monetary authorities tried to prevent the yen from rising above certain levels in order to sustain the competitiveness of the Japanese export industry. [10] As shown in

[7] 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.

[8] The US interventions that have taken place since the introduction of the euro are negligible.

[9] 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.

[10] For instance, Financial Times October 17, 2003, Bloomberg News January 7, 2004, Financial Times January 23, 2004.

Figure 5, Japanese foreign exchange intervention is more intense in periods of appreciation. In some 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.[11]

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, which plots yen/dollar exchange rate volatility (defined as rolling standard deviation) and the absolute volume of Japan's official dollar transactions.

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 is to specify a model for the effect of interventions on volatility, the coefficient of volatility in the reaction function will indicate if we incur simultaneity bias in the GARCH 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—which 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 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.[12]

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,

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

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

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.[13]

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.[14] 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.

Estimations of the reaction function for several sub-periods yield similar results, but are not reported here for brevity. For further analyses of reaction functions of the Japanese authorities, see Dominguez (1998), Frenkel, Pierdzioch and Stadtmann (2004, 2005b), Ito (2003), and Ito and Yabu (2004)[15].

---

13 We use New York closing rates to avoid possible endogeneity bias from interventions that precede exchange rate fixing, as Japanese foreign exchange intervention might be conducted by the Federal Reverve in the New York market on behalf of the Bank of Japan.

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

15 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.

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.[16]

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 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; the probability of Japanese intervention conditional on US intervention is 100%. 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 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. We expect that both results are similar because US intervention is negligible and the last joint intervention took place in 1998.

16 48.7% of US foreign exchange intervention is against the yen during the observation period.

Furthermore, 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.

Third, dollar purchases in Japan clearly dominate intervention activities (Figure 5). Out of 344 intervention days, dollars were purchased on 311 intervention days (90%), on 33 days (10%) 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:

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

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

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

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. 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. We do not include any dummies for the announcement of interest rate changes because they do not yield any significant results.[17] In contrast to Dominguez (1998) and Baillie and 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.

17 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.

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 past disturbances ε_{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 $|Dow_t|$.[18]

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 $p \in \{1,\ldots,7\}$ and $q \in \{1,\ldots,7\}$. 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.[19]

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.[20] Furthermore, 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

18 We assume that dollar sales and dollar purchases affect the volatility in the same way.
19 Kearns and Rigobon (2005) study the impact of interventions on observable returns using a simulated GMM approach.
20 The omitted variable is Japanese intervention which coincides with US intervention and has a much larger scope.

York closing rate only. If the New York 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 seems to increase the volatility of the yen/dollar exchange rate. Yet for some time zones and GARCH specifications, the coefficient is insignificant. The global GARCH estimation yields ambiguous results.

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. We segment the data and estimate the model locally to 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.[21] 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 in line with Galati, Melick and Micu (2005) that Japanese foreign exchange intervention may have 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. While we find reduced vola-

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

tility in 1996, there is a robust relationship between Japanese foreign exchange intervention and lower exchange rate volatility after 1999.

Understanding that data segmentation considerably affects our estimation result, 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 for a change in the relation between intervention and volatility.

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 some evidence in favour 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 subperiods.

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. In contrast to most former studies, we identify a structural break in the effects of Japanese foreign exchange intervention. Unlike Ito (2003), who has identified a structural break in 1995 (when Eisuke Sakikibara changed the intervention strategy) we find a structural break around the turn of the millennium.

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, 2000) to identify non-arbitrary sub-periods. The change-point detector is the estimator $\hat{k}$ of the true change-point k^* defined by

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

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

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

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 $Eh_t(\theta) = E\varepsilon_t^2 = \omega/(1-\alpha-\beta)$, where $\theta = (\omega,\alpha,\beta)$ is the vector of parameters of the conditional variance equation. The change-point detector identifies segments of different volatility means $Eh_t(\theta_1) = \omega_1/(1-\alpha_1-\beta_1)$ and $Eh_t(\theta_2) = \omega_2/(1-\alpha_2-\beta_2)$. 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.

We use these new 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. [22] Alternative segmentation at the turn of the millennium indicates increased volatility (and therefore ineffec-

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

tive intervention) in the 1990s and less volatility (and therefore successful intervention) in the new millennium at highly significant levels.

Together with the results of the estimation of the reaction function in Section 4, we find 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 bias 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.

Figure 7 and 8 show the t-statistics for the rolling GARCH(1,1) γ_1-coefficients. During the first sub-period, it shows a tendency for positive and significant t-values. Japanese foreign exchange intervention seems to increase the volatility of the yen/dollar exchange rate at statistically significant levels. The lines at ± 1.96 represent significance at the 5% level. After a certain transition period, the result is reversed. The γ_1-coefficients now tend to be negative at statistically significant levels. In the new millennium 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 significant downward spike in 1997, a period of indeterminacy between 1997 and 1999, and negative significance after 1999. Increasing the window size (Figure 8) gives a much clearer picture of the downward trend. The levels of significance gradually decline while the coefficient turns negative in the new millennium. Japanese foreign exchange intervention seems to have turned towards reducing volatility.

Putting the results into perspective, a single day can not be identified as the break point. Rather, the change in the coefficient towards significant reduction of volatility that took place between 1997 and 2000 which may coincide with the shift in the liquidity constraint to Japanese foreign exchange intervention in March 1999. In the liquidity trap unsterilized foreign exchange intervention may be more effective than sterilized intervention, because it may enhance the credibility of the Bank of Japan to stimulate the domestic economy. Success would be engineered through the expectations channel (Spiegel 2003). Furthermore the additional money supply may trigger additional capital outflows (carry trade) that contribute to a weaker yen. Figure 9 compares the fluctuations of the euro (German mark) and the yen against the dollar. Before the turn of the millennium, the yen fluctuated more against the dollar than the German mark against the dollar. After that, the level of the Japanese yen was much less volatile than the euro against the dollar. This may be an indication for successful intervention.

Note that our finding is in contrast to Ito (2003), who finds a structural break in 1995 when Japanese monetary authorities changed their intervention strategy from small to large interventions. The possibility that coordinated intervention has increased the success seems unlikely, since the last US-Japanese coordinated intervention took place in June 1998 (one event).

7 CONCLUSION

We studied 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 most of the 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 around the turn of the millenium when Japanese foreign exchange intervention could effectively remain unsterilized.as a result of the liquidity trap.

We segment the data using calendar years, intervention clusters and by using a change-point detector. Furthermore, we estimate rolling GARCH(1,1) coefficients. The results suggest that up to the late 1990s, Japanese foreign exchange intervention correlates with increased volatility of the yen/dollar exchange rate. After 1997 foreign exchange intervention is associated with lower exchange rate volatility, thereby indicating exchange rate stabilization.

In summary, although we can not test systematically for this conjecture, the structural break in the effects of Japanese foreign exchange intervention on exchange rate volatility coincides with 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. We do not find any support for a structural break in 1995 (shift from small intervention to large interventions) and there is no evidence that multilateral intervention may have mattered for this result.

REFERENCES:

Andreou, Elena and Eric Ghysels (2002) "Detecting Multiple Breaks in Financial Market Volatility Dynamics." *Journal of Applied Econometrics* 17, 579-600.

Baillie, Richard and Tim Bollerslev (1989) "The Message in Daily Exchange Rates: A Conditional-Variance Tale," *Journal of Business and Economic Statistics* 7(20), 60-68.

Baillie, Richard and William Osterberg (1997) "Why Do Central Banks Intervene?" *Journal of International Money and Finance* 16 (6), 909-919.

Bollerslev, Tim (1986) "Generalized Autoregressive Conditional Heteroskedasticity," *Journal of Econometrics* 31, 307-327.

Bollerslev, Tim and Jeffrey Wooldridge (1992) "Quasi-Maximum Likelihood Estimation and Inference in Dynamic Models with Time-Varying Covariances," *Econometric Reviews* 11(2), 143-172.

Bonser-Neal, Catherine and Glenn Tanner (1996) "Central Bank Intervention and the Volatility of Foreign Exchange Rates: Evidence from the Options Market," *Journal of International Money and Finance* 15, 853-878.

Castrén, Olli 2004: Do Options implied RND Functions on G3 Currencies Move around the Times of Interventions of the JPY/USD Exchange Rate? *European Central Bank Working Paper* 410.

De Grauwe, Paul and Marianna Grimaldi (2003) "Intervention in the Foreign Exchange Market in Model with Noise Traders," *Mimeo.*

Den Haan, Wouter and Andrew Levin (1997) "A Practitioner's Guide to Robust Covariance Matrix Estimation." In G.S. Maddala and C. Rao (eds.) *Handbook of Statistics, Vol. 15: Robust Inference*. Amsterdam: North-Holland, 299-342.

Dickey, David and Wayne Fuller (1979) "Distribution of Estimators for Autoregressive Time Series with a Unit Root," *Journal of the American Statistical Association* 74, 427-431.

Dominguez, Kathryn (1998) "Central Bank Intervention and Exchange Rate Volatility," *Journal of International Money and Finance* 17, 161-190.

Dominguez, Kathryn and Jeffrey Frankel (1993a) "Does Foreign Exchange Intervention Matter? The Portfolio Effect," *American Economic Review* 83(5), 1356-1369.

Dominguez, Kathryn and Jeffrey Frankel (1993b) "Does Foreign Exchange Intervention Work?" Institute for International Economics, Washington DC.

Doornik, Jurgen and Marius Ooms (2003) "Multimodality in the GARCH Regression Model," Nuffield Economics Working Paper 2003-W20.

Engle, Robert (1982) "Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation," *Econometrica* 50 (4), 987-1007.

Evans, Martin and Richard Lyons (2002) "Time Varying Liquidity in Foreign Exchange," *Journal of Monetary Economics* 49(5), 1025-1051.

Fatum, Rasmus and Michael Hutchison (2003) "Is Sterilized Foreign Exchange Intervention Successful after All? An Event Study Approach." *Economic Journal* 113, 390-411.

Frenkel, Michael, Christian Pierdzioch, and Georg Stadtmann (2004) "On the Determinants of "Small" and "Large" Foreign Exchange Market Interventions: The Case of the Japanese Interventions in the 1990s," *Review of Financial Economics*, 13, 231-243.

Frenkel, Michael, Christian Pierdzioch, and Georg Stadtmann (2005a) "The Effects of Japanese Foreign Exchange Market Interventions on the Yen/U.S. Dollar Exchange Rate Volatility," *International Review of Economics and Finance*, 14, 27-39.

Frenkel, Michael, Christian Pierdzioch, and Georg Stadtmann (2005b) "Japanese and U.S. Interventions in the Yen/U.S. Dollar Market: Estimating the Monetary Authorities' Reaction Functions," *Quarterly Review of Economics and Finance*, 45(4-5), 680-698.

Fratzscher, Marcel (2005) "On the Long-Term Effectiveness of Exchange Rate Communication and Interventions," forthcoming in *Journal of International Money and Finance*.

Funabashi, Yoichi (1988) *Managing the Dollar: From Plaza to Louvre*. Washington, DC: Institute for International Economics.

Galati, Gabriele, William Melick, and Marian Micu (2005) "Foreign Exchange Market Intervention and Expectations: An Empirical Study of the Yen/Dollar Exchange Rate," *Journal of International Money and Finance*, 24, 982-1011.

Hillebrand, Eric (2005) "Neglecting Parameter Changes in GARCH Models," *Journal of Econometrics* 129, 121-138.

Ito, Takatoshi (2003) "Is Foreign Exchange Intervention Effective? The Japanese Experience in the 1990s." In Paul Mizen (ed.) *Monetary History, Exchange Rates and Financial Markets. Essays in Honour of Charles Goodhart*, Vol. 2, pp. 126-153.

Ito, Takatoshi and Michael Melvin (1999) "Japan's Big Bang and the Transformation of Financial Markets," NBER Working Paper 7247.

Ito, Takatoshi and Tomoyoshi Yabu, (2004) "What Promotes Japan to Intervene in the Forex Market? A New Approach to a Reaction Function," NBER Working Paper 10456.

Jeanne, Olivier and Andrew Rose (2002) "Noise Trading and Exchange Rate Regimes," *Quarterly Journal of Economics* 117(2), 537-569.

Jurgensen, Phillipe (1983) Report of the Working Group on Exchange Market Intervention. U.S. Treasury, Washington, D.C.

Kearns, Jonathan and Roberto Rigobon (2005) "Identifying the Efficacy of Central Bank Interventions: Evidence from Australia and Japan," *Journal of International Economics* 66(1), 31-48.

Kokoszka, Piotr and Remigijus Leipus (1999) "Testing for Parameter Changes in ARCH Models," *Lithuanian Mathematical Journal* 39(2), 182-195.

Kokoszka, Piotr and Remigijus Leipus (2000) “Changepoint Estimation in ARCH Models," *Bernoulli* 6, 513--539.

McKinnon, Ronald and Gunther Schnabl (2004) "The East Asian Dollar Standard, Fear of Floating and Original Sin," *Review of Development Economics* 8(3), 331-360.

Neely, Christopher (2005) "An Analysis of Recent Studies of the Effect of Foreign Exchange Intervention," *Federal Reserve Bank of St. Louis Review* 87(6), 685-717.

Phillips, Peter and Pierre Perron (1988) "Testing for a Unit Root in Time Series Regression," *Biometrika* 75, 335-346.

Ramaswamy, Ramana and Hossein Samiei (2000) "The Yen-Dollar Rate. Have Interventions Mattered?" IMF Working Paper WP/00/95.

Rogoff, Kenneth (1984) "On the Effects of Sterilized Intervention: An Analysis of Weekly Data," *Journal of Monetary Economics* 14, 133-150.

Sakakibara, Eisuke (2000) "nihon to sekai ga furueta hi" [The Day when Japan and the World Trembled], Tokyo Chuokoron-Shinsha.

Sarno, Lucio and Mark Taylor (2001) "Official Intervention in the Foreign Exchange Market: Is it Effective and, if so, How Does it Work?" *Journal of Economic Literature* 39, 839-868.

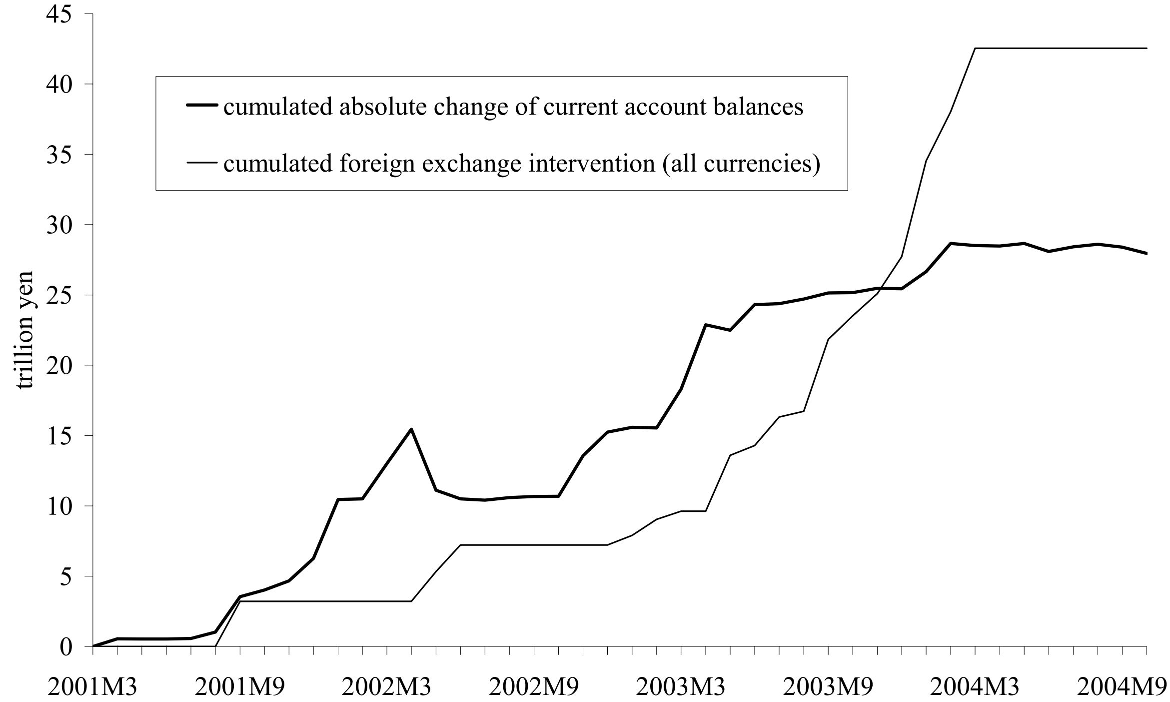
Schwartz, Anna (1996) "U.S. Foreign Exchange Intervention since 1962," *Scottish Journal of Political Economy* 43(4), 379-397.

Spiegel, Mark (2003) "Japanese Foreign Exchange Intervention" FRBSF Economic Letter 2003-36, December 12, 2003.

Watanabe, Toshiaki and Kimie Harada (2006) "Effects of the Bank of Japan's Intervention on Yen/Dollar Exchange Rate Volatility," *Journal of Japanese and International Economies 20, 99-111*.

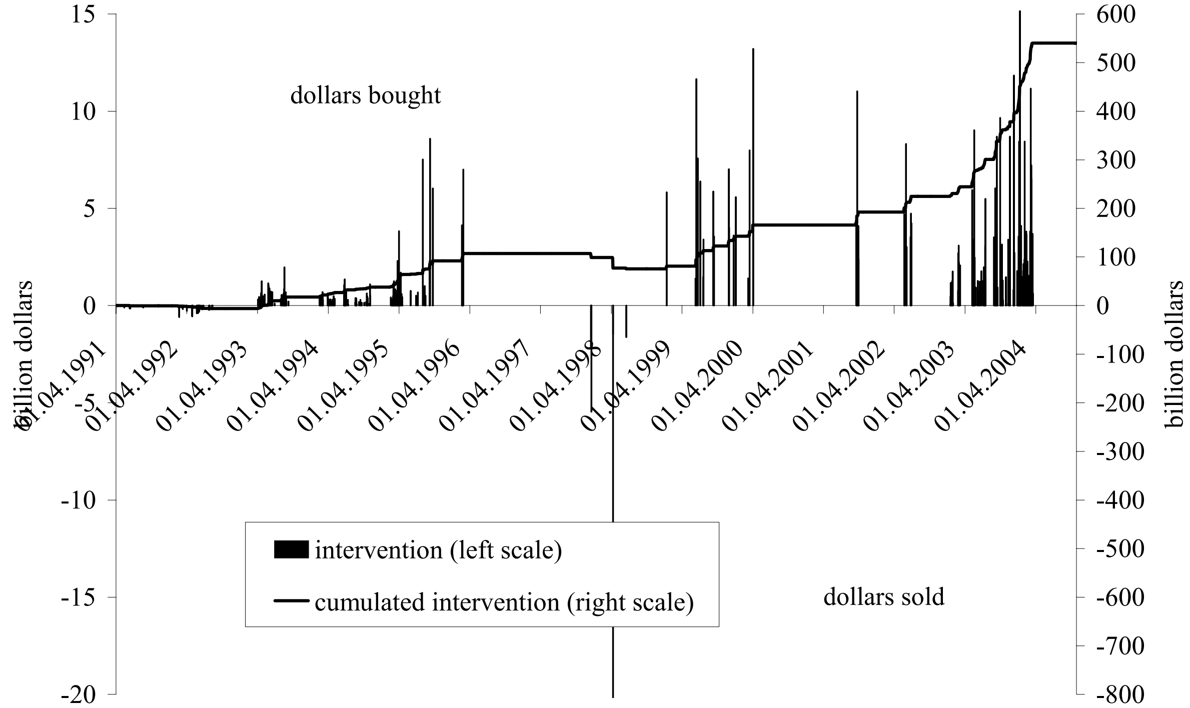
Watanabe, Toshiaki (1994) "The Signalling Effect of Foreign Exchange Intervention: the Case of Japan." In Reuven Glick and Micheal Hutchison (eds.) *Exchange Rate Policy and Interdependence: Perspectives from the Pacific Basin*. Cambridge, 258-286.

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



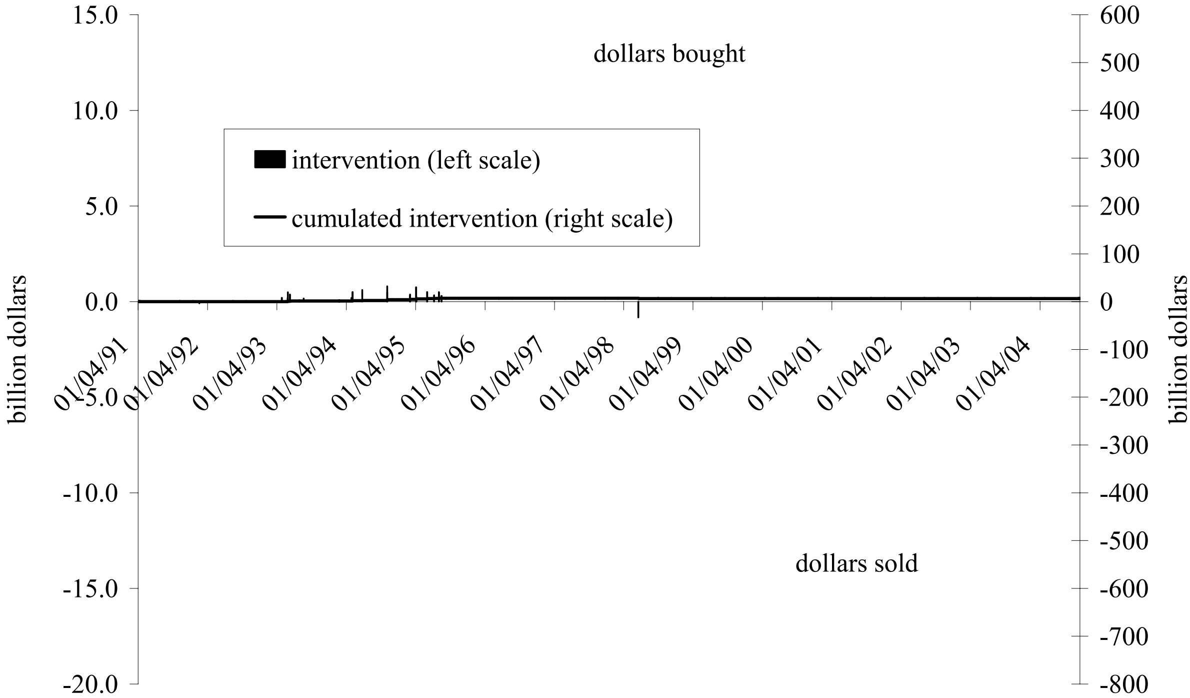
Source: Bank of Japan.

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



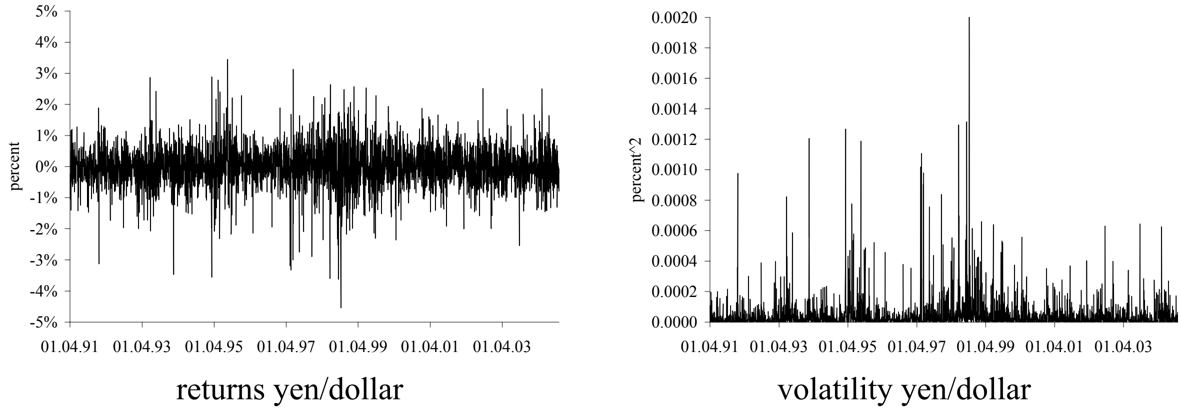
Source: Japan: Ministry of Finance. April 1991 – October 2004. Note same scale for Japan and the US (Figure 2).

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



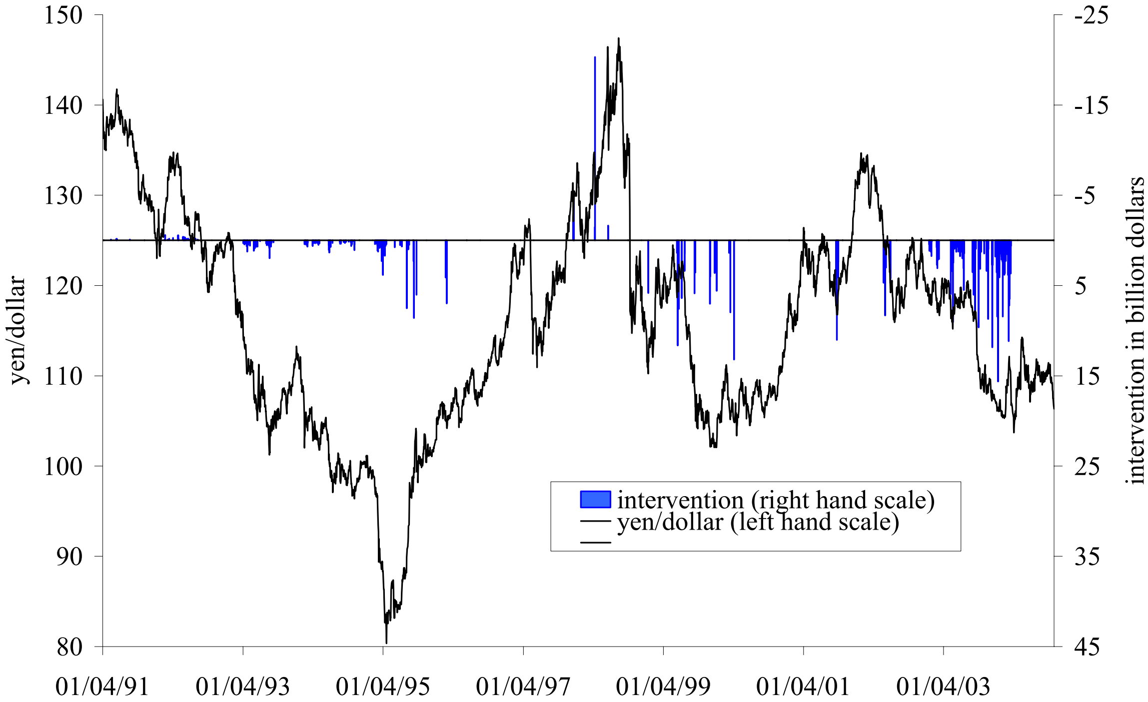
Source: US Federal Reserve Board. Billion Dollars. April 1991 – October 2004. Note same scale for US and Japan (Figure 1).

Figure 4: Daily Yen/Dollar Exchange Rates



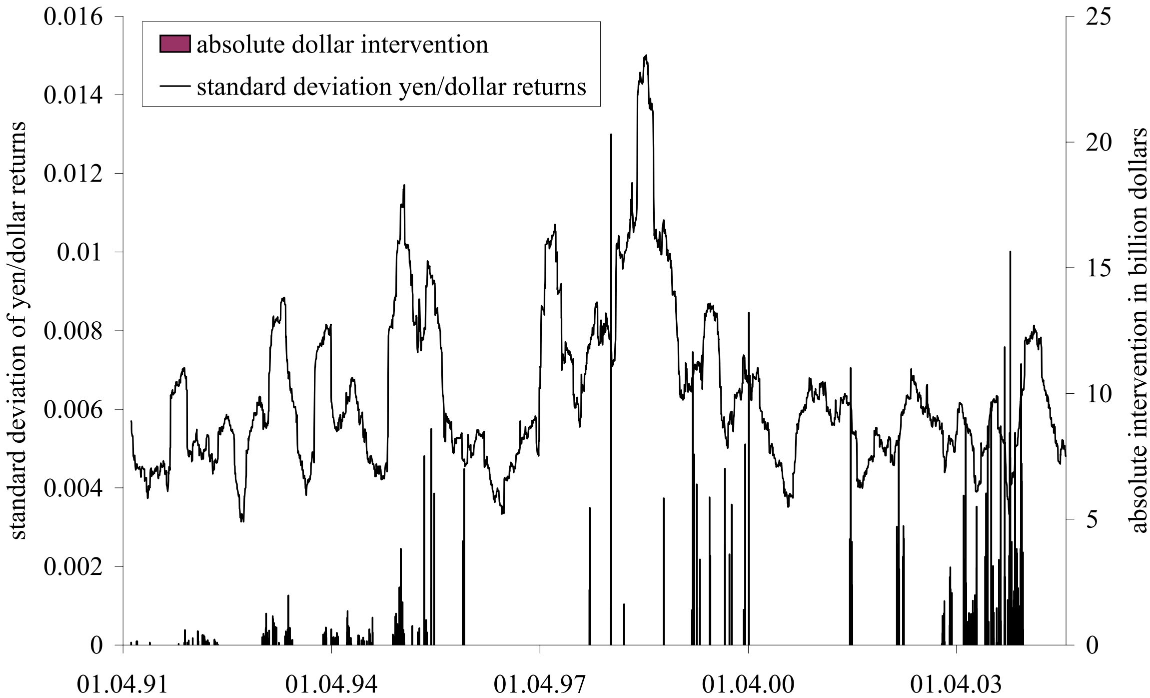
Source: Bloomberg. April 1991 – October 2004. Tokyo closing rate.

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



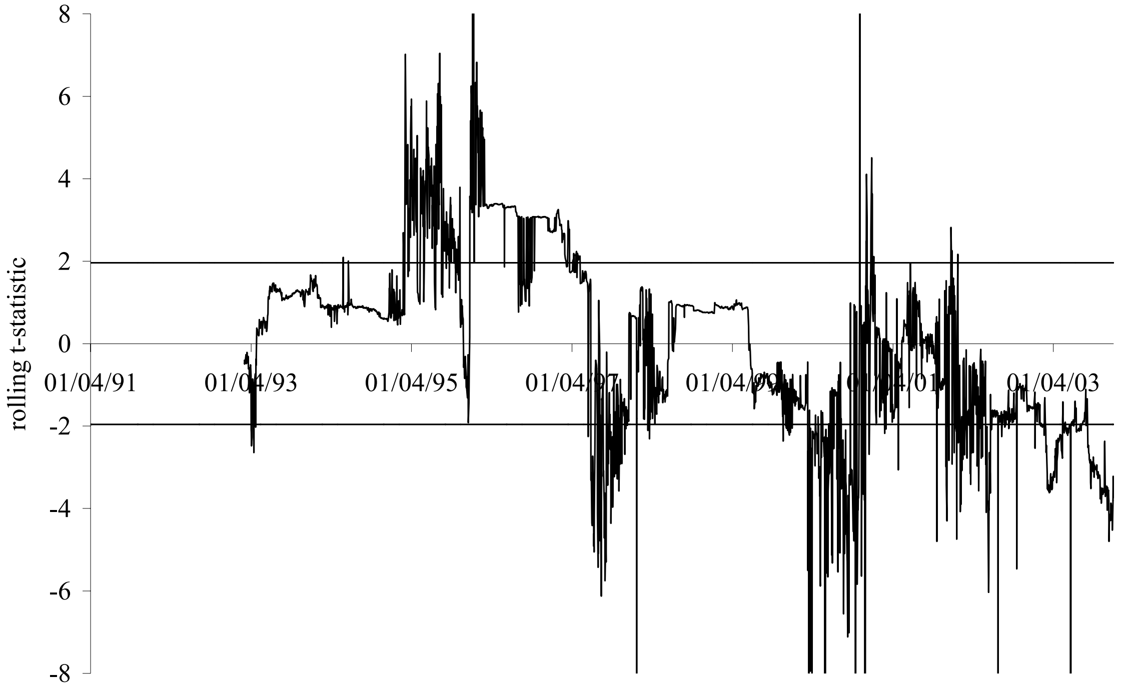
Source: Bloomberg, Japan: Ministry of Finance. Foreign exchange intervention in billion dollars. April 1991 – October 2004.

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



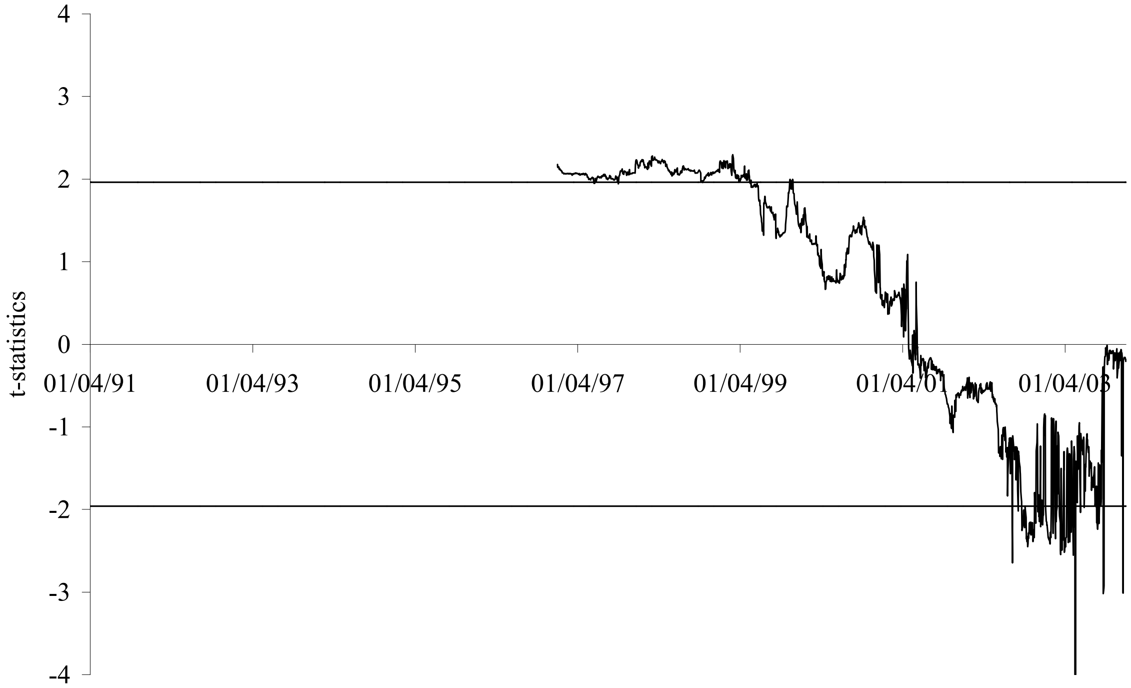
Source: Bloomberg. Foreign exchange intervention in billion dollars. April 1991 – October 2004. Volatility defined as 60 days rolling standard deviations of the daily percent yen/dollar exchange rate changes around day t.

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



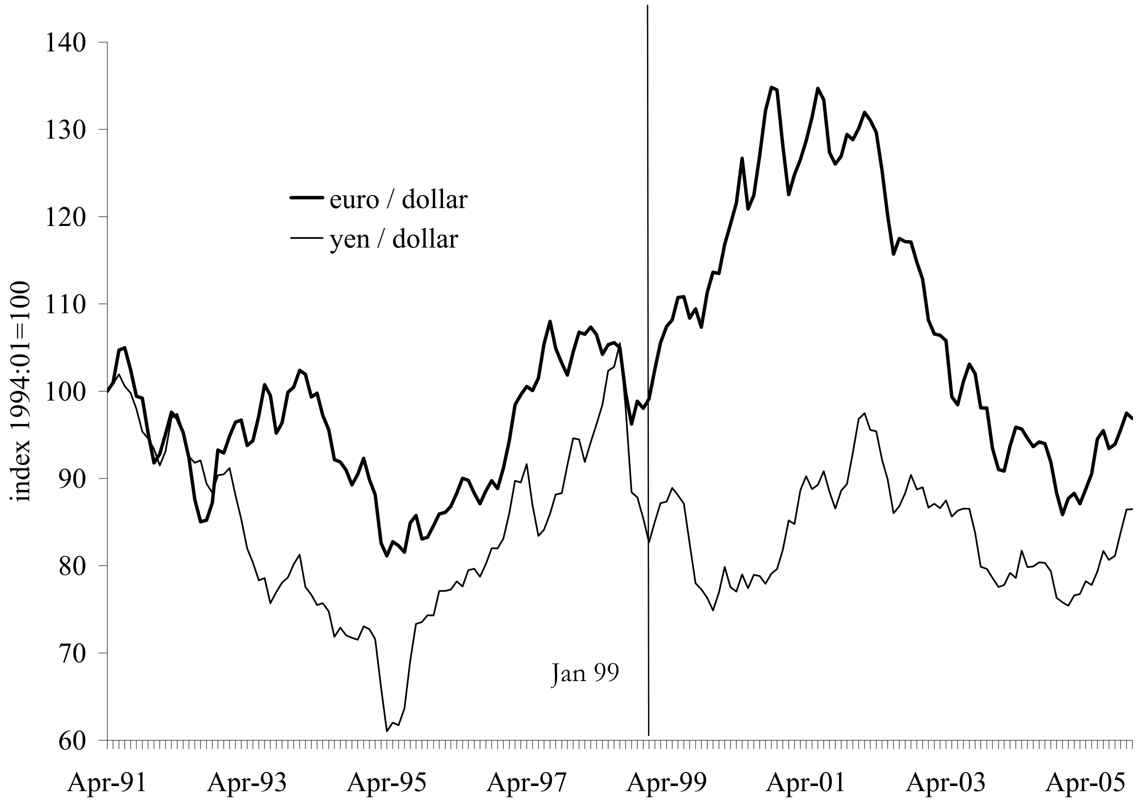
Source: Bloomberg (New York Closing Rates). March 1993 – December 2004.

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



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

Figure 9: Euro/Dollar and Yen/Dollar Exchange Rate Movements



Source: IMF.

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 $(\bar{e} - e_{t-21})$	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)
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)
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)
b_0	-0.0001	-2.8e-5	-0.0002
	(0.0001)	(2.6e-4)	(0.0002)
b_1	0.2602	1.3539***	0.3864***
	(0.7347)	(0.2001)	(0.0396)
b_2	0.0741***	0.0349	0.0399***
	(0.0163)	(0.0275)	(0.0147)
b_3	-0.0083	-0.0749***	-0.0349**
	(0.0149)	(0.0180)	(0.0140)
ω	3.1e-6***	1.1e-5***	5.1e-6***
	(3.8e-7)	(1.9e-7)	(3.6e-7)
α_1	0.0842***	0.0936***	0.0313
	(0.0274)	(0.0153)	(0.0198)
α_2		0.0504***	
		(0.0115)	
β_1	-0.1029***	-0.4580***	0.7518***
	(0.0313)	(0.0073)	(0.0484)
β_2	0.0758**	0.2439***	
	(0.0384)	(0.0103)	
β_3	-0.1486***	0.8898***	
	(0.0371)	(0.0079)	
β_4	0.3007***		
	(0.0474)		
β_5	0.5564***		
	(0.0516)		
γ_1	**0.0396*** **	**-0.0024*** **	**-0.0009** **
	(0.0067)	**(0.0006)**	**(0.0004)**
γ_2	2.6e-5	0.0005***	9.7e-5
	(0.0002)	(0.0001)	(0.0001)
γ_3	0.0005***	-0.0002**	0.0002
	(0.0002)	(8.6e-5)	(0.0001)
GARCH (1,1)			
γ_1	0.0089**	-0.002*	
	(0.0041)	(0.001)	

New York Closing Rates.

Table 8: Local GARCH Estimation for Equation (1) to (3) – Two sub-segments before and after Jan 1, 2000.

intervention period	**04/02/1991 12/31/1999**	**01/03/2000 10/27/2004**
GARCH specific. (BIC)	(1,5)	(5,5)
b_0	-0.0001	-0.0002
	(0.0001)	(0.0001)
b_1	1.0883**	0.3623***
	(0.4271)	(0.0994)
b_2	0.0888***	0.0433***
	(0.0191)	(0.0129)
b_3	-0.0373***	-0.0395***
	(0.0124)	(0.0124)
ω	-1.7e-6	7.3e-6***
	(1.5e-6)	(3e-7)
α_1	0.1021***	0.0625***
	(0.0312)	(0.0185)
α_2		0.0529**
		(0.0216)
α_3		0.0531***
		(0.0202)
α_4		0.0183
		(0.0176)
α_5		-0.0272*
		(0.0161)
β_1	0.1117	-0.4529***
	(0.0871)	(0.0552)
β_2	-0.1163**	-0.6196***
	(0.0522)	(0.0360)
β_3	0.1188*	0.3918***
	(0.0690)	(0.0526)
β_4	0.1448*	0.3827***
	(0.0799)	(0.0375)
β_5	0.4782***	0.8632***
	(0.0836)	(0.0405)
γ_1	**0.0210*** **	**-0.0008** **
	(0.0058)	**(0.0003)**
γ_2	0.0010***	7.7e-5
	(0.0002)	(0.0003)
γ_3	0.0003*	0.0002**
	(0.0002)	(7.6e-5)
GARCH (1,1)		
γ_1	0.0054**	-0.0010***
	(0.0024)	(0.0003)

New York Closing Rates.

European Central Bank Working Paper Series

For a complete list of Working Papers published by the ECB, please visit the ECB's website (http://www.ecb.int)

594 "The euro's trade effects" by R. Baldwin, comments by J. A. Frankel and J. Melitz, March 2006

595 "Trends and cycles in the euro area: how much heterogeneity and should we worry about it?" by D. Giannone and L. Reichlin, comments by B. E. Sørensen and M. McCarthy, March 2006.

596 "The effects of EMU on structural reforms in labour and product markets" by R. Duval and J. Elmeskov, comments by S. Nickell and J. F. Jimeno, March 2006.

597 "Price setting and inflation persistence: did EMU matter?" by I. Angeloni, L. Aucremanne, M. Ciccarelli, comments by W. T. Dickens and T. Yates, March 2006.

598 "The impact of the euro on financial markets" by L. Cappiello, P. Hördahl, A. Kadareja and S. Manganelli, comments by X. Vives and B. Gerard, March 2006.

599 "What effects is EMU having on the euro area and its Member Countries? An overview" by F. P. Mongelli and J. L. Vega, March 2006.

600 "A speed limit monetary policy rule for the euro area" by L. Stracca, April 2006.

601 "Excess burden and the cost of inefficiency in public services provision" by A. Afonso and V. Gaspar, April 2006.

602 "Job flow dynamics and firing restrictions: evidence from Europe" by J. Messina and G. Vallanti, April 2006.

603 "Estimating multi-country VAR models" by F. Canova and M. Ciccarelli, April 2006.

604 "A dynamic model of settlement" by T. Koeppl, C. Monnet and T. Temzelides, April 2006.

605 "(Un)Predictability and macroeconomic stability" by A. D'Agostino, D. Giannone and P. Surico, April 2006.

606 "Measuring the importance of the uniform nonsynchronization hypothesis" by D. A. Dias, C. Robalo Marques and J. M. C. Santos Silva, April 2006.

607 "Price setting behaviour in the Netherlands: results of a survey" by M. Hoeberichts and A. Stokman, April 2006.

608 "How does information affect the comovement between interest rates and exchange rates?" by M. Sánchez, April 2006.

609 "The elusive welfare economics of price stability as a monetary policy objective: why New Keynesian central bankers should validate core inflation" by W. H. Buiter, April 2006.

610 "Real-time model uncertainty in the United States: the Fed from 1996-2003" by R. J. Tetlow and B. Ironside, April 2006.

611 "Monetary policy, determinacy, and learnability in the open economy" by J. Bullard and E. Schaling, April 2006.

612 “Optimal fiscal and monetary policy in a medium-scale macroeconomic model” by S. Schmitt-Grohé and M. Uribe, April 2006.

613 “Welfare-based monetary policy rules in an estimated DSGE model of the US economy” by M. Juillard, P. Karam, D. Laxton and P. Pesenti, April 2006.

614 “Expenditure switching vs. real exchange rate stabilization: competing objectives for exchange rate policy” by M. B. Devereux and C. Engel, April 2006.

615 “Quantitative goals for monetary policy” by A. Fatás, I. Mihov and A. K. Rose, April 2006.

616 “Global financial transmission of monetary policy shocks” by M. Ehrmann and M. Fratzscher, April 2006.

617 “New survey evidence on the pricing behaviour of Luxembourg firms” by P. Lünnemann and T. Y. Mathä, May 2006.

618 “The patterns and determinants of price setting in the Belgian industry” by D. Cornille and M. Dossche, May 2006.

619 “Cyclical inflation divergence and different labor market institutions in the EMU” by A. Campolmi and E. Faia, May 2006.

620 “Does fiscal policy matter for the trade account? A panel cointegration study” by K. Funke and C. Nickel, May 2006.

621 “Assessing predetermined expectations in the standard sticky-price model: a Bayesian approach” by P. Welz, May 2006.

622 “Short-term forecasts of euro area real GDP growth: an assessment of real-time performance based on vintage data” by M. Diron, May 2006.

623 “Human capital, the structure of production, and growth” by A. Ciccone and E. Papaioannou, May 2006.

624 “Foreign reserves management subject to a policy objective” by J. Coche, M. Koivu, K. Nyholm and V. Poikonen, May 2006.

625 “Sectoral explanations of employment in Europe: the role of services” by A. D’Agostino, R. Serafini and M. Ward-Warmedinger, May 2006.

626 “Financial integration, international portfolio choice and the European Monetary Union” by R. A. De Santis and B. Gérard, May 2006.

627 “Euro area banking sector integration: using hierarchical cluster analysis techniques” by C. Kok Sørensen, J. M. Puigvert Gutiérrez, May 2006.

628 “Long-run money demand in the new EU Member States with exchange rate effects” by C. Dreger, H.-E. Reimers and B. Roffia, May 2006.

629 “A market microstructure analysis of foreign exchange intervention” by P. Vitale, May 2006.

630 “Implications of monetary union for catching-up member states” by M. Sánchez, May 2006.

631 “Which news moves the euro area bond market?” by M. Andersson, L. J. Hansen and S. Sebestyén, May 2006.

632 “Does information help recovering structural shocks from past observations?” by D. Giannone and L. Reichlin, May 2006.

633 “Nowcasting GDP and inflation: the real-time informational content of macroeconomic data releases” by D. Giannone, L. Reichlin and D. H. Small, May 2006.

634 “Expenditure reform in industrialised countries: a case study approach” by S. Hauptmeier, M. Heipertz and L. Schuknecht, May 2006.

635 “Identifying the role of labor markets for monetary policy in an estimated DSGE model” by K. Christoffel, K. Kuester and T. Linzert, June 2006.

636 “Exchange rate stabilization in developed and underdeveloped capital markets” by V. Chmelarova and G. Schnabl, June 2006.

637 “Transparency, expectations, and forecasts” by A. Bauer, R. Eisenbeis, D. Waggoner and T. Zha, June 2006.

638 “Detecting and predicting forecast breakdowns” by R. Giacomini and B. Rossi, June 2006.

639 “Optimal monetary policy with uncertainty about financial frictions” by R. Moessner, June 2006.

640 “Employment stickiness in small manufacturing firms” by P. Vermeulen, June 2006.

641 “A factor risk model with reference returns for the US dollar and Japanese yen bond markets” by C. Bernadell, J. Coche and K. Nyholm, June 2006.

642 “Financing constraints and firms’ cash policy in the euro area” by R. Pál and A. Ferrando, June 2006.

643 “Inflation forecast-based-rules and indeterminacy: a puzzle and a resolution” by P. Levine, P. McAdam and J. Pearlman, June 2006.

644 “Adaptive learning, persistence, and optimal monetary policy” by V. Gaspar, F. Smets and D. Vestin, June 2006.

645 “Are internet prices sticky?” by P. Lünnemann and L. Wintr, June 2006.

646 “The Dutch block of the ESCB multi-country model” by E. Angelini, F. Boissay and M. Ciccarelli, June 2006.

647 “The economic effects of exogenous fiscal shocks in Spain: a SVAR approach” by F. de Castro Fernández and P. Hernández de Cos, June 2006.

648 “Firm-specific production factors in a DSGE model with Taylor price setting” by G. de Walque, F. Smets and R. Wouters, June 2006.

649 “Monetary and fiscal policy interactions in a New Keynesian model with capital accumulation and non-Ricardian consumers” by C. Leith and L. von Thadden, June 2006.

650 “A structural break in the effects of Japanese foreign exchange intervention on yen/dollar exchange rate volatility” by E. Hillebrand and G. Schnabl, June 2006.

ISSN 1561081-0