Foreign exchange market intervention and expectations: an empirical study of the yen/dollar exchange rate

by Gabriele Galati*[a], William Melick[b] and Marian Micu[a]

[a] Monetary and Economic Department, Bank for International Settlements, CH-4002 Basel, Switzerland

[b] Department of Economics, Kenyon College, 312Ascension Hall, Gambier, Ohio 43022, United States

Abstract

We use official intervention data provided by the Federal Reserve and, recently, the Japanese Ministry of Finance, as well as a new data set based on Reuters news articles on intervention that is perceived by FX traders. We estimate probability density functions (PDFs) from option data to describe market expectations. We find that, between 1993 and 1996, Japanese authorities tended to respond mainly to deviations of the exchange rate from some implicit target levels and to a rise in market uncertainty. Between 1997 and 2000, the Bank of Japan mainly reacted in response to higher uncertainty. On the other hand, the Federal Reserve intervened only in cooperation with the Bank of Japan. We find that intervention had no statistically significant systematic effect on the mean of yen/dollar expectations. Consistently, we detect no evidence that intervention systematically altered market participants' bias between a stronger and a weaker dollar with respect to the forward rate. Contrary to most findings of the literature, we fail to find evidence that intervention was associated on average with higher exchange rate variability. Finally, we find that intervention was not followed by an increase in the tails of the distribution of exchange rate expectations. The consensus view is that sterilized intervention can be effective if it is announced publicly, coordinated across central banks, and most importantly, consistent with underlying fiscal and monetary policies. As we are able to control for public announcement and central bank coordination, our findings suggest that intervention during our sample period was not consistent with underlying fiscal and monetary policy and therefore had little influence on market outcomes and expectations.

JEL Classification: C22 E41 F31

Keywords:

* Corresponding author. Tel.: +41-61-280-8923; fax: +41 61 280-9100.
E-mail address: gabriele.galati@bis.org. (G. Galati)

1. Introduction

This paper presents empirical evidence on the relationship between central bank intervention and market expectations of the daily yen/dollar exchange rate. Over the past years, a number of studies have analysed the effect of intervention on the exchange rate level as well as on the instantaneous and expected volatility of the exchange rate of the yen/dollar, the mark/dollar and other exchange rates. The results are generally mixed and depend on both the sample period being investigated and the intervention strategies being used.

This paper provides further evidence on this issue in four ways. First, it focuses not only on the expected level and variance of the exchange rate, but on the entire distribution of expected exchange rates, which is derived from option prices. The moments of this distribution allow a more complete characterisation of market sentiment. Second, this paper uses two new data sets on intervention episodes. One data set covers actual intervention episodes and was recently provided by the Japanese Ministry of Finance through its website. The other data set contains interventions perceived by market participants and is based on Reuters reports. This data set is more comprehensive than the data sets based on newspaper articles that have been used in the literature. Third, this paper uses a comprehensive data set of "news" about macroeconomic variables that helps to distinguish the effect of intervention from that of the arrival of other relevant information. Finally, the paper also looks at two directions of causality in the relationship between intervention and market expectations. We first examine the reaction function of monetary authorities and estimate how changes in the moments of the expected distribution of future exchange rates affect the likelihood of central bank intervention. We then investigate the effect of intervention on the moments, taking account of the fact that intervention and market expectations are determined simultaneously.

In this paper, the empirical probability density functions (PDFs) of future yen/dollar rates are estimated using risk reversals and at-the-money implied volatilities of one-month OTC options.[1] We use measures of the moments of these distributions – the mean, variance, skewness and kurtosis – and

[1] In this paper, the exchange rate is defined as yen per dollar.

quasi-moments such as interquantile ranges to describe the state of market conditions on a particular day. If we consider the yen/dollar exchange rate, the mean of the PDF is the traders' average expectation of the yen/dollar rate one month ahead, i.e. the one-month forward rate. The second moment of the PDF, the variance of the expected exchange rate, can be used to describe how uncertain market participants are on a specific day about the yen/dollar exchange rate that will prevail over the near future. Skewness can be interpreted as a measure of market participants' balance of risks between a much stronger and a much weaker dollar with respect to the yen around the expected future exchange rate. The fourth moment, kurtosis, measures how "fat" the tails of a PDF are and indicates the market's view of the likelihood of very large exchange rate movements in either direction in the near future. The higher the probability that the market assigns to such an extreme change (in either direction) on a particular day, the higher the kurtosis of the PDF on that day.[2]

Our analysis is conducted over the period from 20 September 1993 to 30 April 2000.[3] For the purpose of this paper, central bank interventions are defined as transactions intended to influence the exchange rate. This definition therefore excludes transactions such as those aimed at altering the currency composition of the central bank's foreign exchange portfolio.

Our results suggest that during the period of dollar weakness between 1993 and 1996, the Bank of Japan seems to have responded to deviations of the spot exchange rate from what traders perceived as implicit target ranges. It also appears to have intervened on average as a response to a rise in market uncertainty, consistent with statements made by central banks in the past that emphasised their attempt to "calm disorderly markets". We found evidence that between 1997 and 2000, the Bank of Japan seems to have intervened mainly following a rise in uncertainty. During the whole sample period, the Federal Reserve intervened always in conjunction with the Bank of Japan.

Consistent with some of the findings in the literature, our regression analysis suggests that, on average, intervention in the yen/dollar market had no statistically significant effect on the mean of the

---

[2] High kurtosis need not come exclusively from "fat tails", since it may also come from having a high proportion of observations close to the mean (a "thick midriff"). Hence, a change in kurtosis may not necessarily imply a change in the tails of the distribution. Equivalently, an increase in the kurtosis of one of the PDFs need not imply a rise in the expected likelihood of major moves.

[3] The start of the sample period is dictated by the availability of option data necessary to estimate the PDFs.

PDF during the period under review. We also find that, between September 1993 and April 2000, central bank intervention directed at the yen/dollar exchange rate was not associated with a significantly higher variance of expected future spot rates. This result indicates that, on average, central bank intervention was not followed by an increase in uncertainty in the market about future exchange rate movements. Consistent with our results for the mean, we find that, on average, intervention did not have a significant effect on the skewness. Hence, following intervention in support of the dollar, market participants did not change the weight that they put on a much stronger rather than a much weaker dollar with respect to the forward rate. Finally, we find that intervention did not influence the kurtosis in a significant way.

In terms of intervention strategies, results for the period 1993 to 1996, when all interventions involved dollar purchases, indicate that at 90% or 95% confidence levels, the impact of coordinated or officially announced interventions was not statistically different from that of unilateral interventions. [4]

Our results can be easily reconciled with the consensus view on the effects of intervention in the foreign exchange market. According to this view (see the literature review in the following section) sterilized intervention can be effective if it is announced publicly, coordinated across central banks, and most importantly, consistent with underlying fiscal and monetary policies. When central banks entered foreign exchange markets in a coordinated, public fashion in the 1980s - particularly around the Plaza or Louvre Agreements - these interventions did succeed in affecting traders' expectations of future exchange rate movements (see Galati and Melick (2002)). For the period under study in this paper, however, all of these conditions were not met; with the result that intervention is found to have little influence on market outcomes and expectations.

The remainder of the paper is organised as follows. Section 2 reviews the main contributions to the literature on the effect of central bank intervention and on central banks' reaction functions. In Section 3, we describe our intervention data and data on macroeconomic news. Section 4 describes the option data and the method that was used to estimate the empirical PDFs. We also discuss the interpretation of PDFs. In Section 5, we first estimate reaction functions for the Federal Reserve and the Bank of

Japan that relate intervention to past market conditions. We then analyse the impact of intervention on market expectations. Section 6 concludes.

2. Review of the literature

The literature on the effect of intervention in foreign exchange markets is extensive. This section reviews some of the main contributions – for comprehensive surveys, refer to Edison (1993), Almekinders (1995), Schwartz (2000) and Sarno and Taylor (2001).[5] In the 1980s and early 1990s, attention focused on the effect of sterilised intervention on the level of the exchange rate and on the channels through which it works. The results on the effectiveness of intervention are mixed and depend on which exchange rate is analysed, what sample period is studied and the intervention strategy that was used. In an influential paper, Dominguez and Frankel (1993a) use daily and weekly official and press report data on intervention directed at the yen/dollar and mark/dollar exchange rates between 1984 and 1990. The authors find that intervention had a significant impact on the exchange rate, especially when it was publicly announced and coordinated.

Later studies have not provided a unanimous confirmation of Dominguez and Frankel's finding that intervention has an impact on exchange rate levels. Using a case study approach for the yen/dollar and mark/dollar exchange rates during the period 1985–91, Catte et al. (1994) confirm that intervention influences exchange rates particularly for coordinated interventions.[6] Fatum (2000) and Fatum and Hutchinson (2002, 2003) argue in favour of an event study approach to examine the effect of intervention on exchange rate changes, as methods relying on time series data do not capture the sporadic occurrence of intervention. Fatum (2000) uses a non-parametric estimation technique to show that during the months following the Plaza agreement, intervention by the Federal Reserve and the Bundesbank was effective, especially when it was coordinated. Using similar techniques, Fatum and Hutchison (2002, 2003) find evidence supporting the effectiveness of intervention in the

---

[4] In this paper we define as coordinated intervention those episodes in which two or more central banks entered the market on the same day.

[5] For a survey of informational aspects of intervention, see Bailie, Humpage and Osterberg (2000).

mark/dollar and yen/dollar markets. Ito (2003) presents evidence based on Japanese Ministry of Finance data that intervention in the yen/dollar market in the second half of the 1990s was effective. Dominguez (2003a) concludes that recent G3 intervention was often successful with regard to both short and longer-term exchange rate movements. However, other papers do not support the conclusion that intervention is effective. Humpage (1988), for example, concludes that intervention was unable to influence the dollar's level. Baillie and Osterberg (1997) find that over the period August 1985 to March 1990, Federal Reserve intervention did not influence the mark/dollar or yen/dollar exchange rates.

In terms of transmission channels, there is now general consensus in the literature that intervention does not affect exchange rates through the portfolio channel, i.e. by changing the relative outstanding supply of domestic and foreign assets and thereby of the expected relative returns on these assets.[7] There is some, but not conclusive, evidence that intervention mainly works through the signalling channel, i.e. by the central bank conveying a signal to market participants about information on future fundamentals.[8] Recent work on the microstructure of foreign exchange markets has highlighted the role of imperfect information as a channel through which intervention might influence exchange rates (Evans and Lyons (2001); D'Souza (2002); Dominguez (2003b)).

Over the past few years, a number of studies have focused on the effects of intervention on exchange rate volatility.[9] Most of these papers have looked at conditional exchange rate volatility, usually estimated with GARCH models. Empirical evidence suggests that central bank intervention tends to increase the conditional exchange rate volatility. Connolly and Taylor (1994), for example, use a GARCH model to describe conditional yen/dollar volatility and use market data on intervention by the Bank of Japan. They present evidence that, between 1977 and 1979, Bank of Japan intervention was

---

6 For a critical view of Catte et al's result, see Truman (1994) and Weber (1994).

7 Rogoff (1984) is among the first to test the importance of the portfolio balance channel. He finds no significant effects of sterilised intervention through this channel. Frankel and Engel (1984), Lewis (1988) and a number of other studies, which are reviewed in detail in Edison (1993), reach a similar conclusion. By contrast, Dominguez and Frankel (1993b) find some supportive evidence for the portfolio channel.

8 An overview of the literature on the signalling channel is provided by Baillie, Humpage and Osterberg (2000). Studies that find a significant effect of intervention through this channel include Dominguez (1990), Klein and Rosengren (1991), Dominguez (1993), Kaminsky and Lewis (1996) and Lewis (1995). On the other hand, evidence provided by Dominguez (1997) suggests that intervention does not serve exclusively as a consistent signal of future monetary policy changes.

9 Dominguez (1998) provides a good overview of this literature.

associated with an increase in conditional yen/dollar volatility. Similarly, Baillie and Humpage (1992) find a positive relationship between Federal Reserve, Bank of Japan and Bundesbank intervention and the conditional volatility of the mark/dollar and yen/dollar exchange rates for the period February 1987 to February 1990. Dominguez (1993), however, argues that the impact on exchange rate volatility depends on how central banks conduct intervention. Looking at daily and weekly data for 1985–91, she finds that intervention that is officially announced reduces volatility while intervention that is not detected by the market increases volatility. Finally, Hung (1997) finds that intervention can affect exchange rate volatility through the noise-trading channel, i.e. by inducing noise traders to react to changing market conditions. A recent paper by Dominguez (2003c) examines the impact of G3 intervention in the Deutsche mark/dollar and yen/dollar markets using intra-daily and daily data. She finds evidence of a significant impact of intervention on exchange rate volatility both at the intraday and the daily frequency, although little lasting effect.

More recently, data on volatility implied by option prices have been used to study the effect of intervention on market participants' assessments of future exchange rate volatility.[10] The advantage of implied volatility over measures of volatility computed from actual exchange rate realisations, for example using GARCH models, is that implied volatility incorporates a market assessment of future volatility that is not directly observable. The idea here is that intervention on a particular day may send a signal to market participants about the future exchange rate policy and hence influence the market's forecasts of future exchange rate volatility.

The evidence on the impact of intervention on implied volatility is mixed. Bonser-Neal and Tanner (1996) are the first to have studied the effect of intervention on implied volatility. They use data on implied volatilities from exchange traded options from 1985 to 1991 together with official data on intervention by the Federal Reserve and the Bundesbank. They also recover data on perceived intervention by the Bank of Japan from newspaper articles. They find that intervention had a different impact on volatility over different time periods. Between February 1987 and December 1989 (the "Louvre period"), intervention actually increased implied volatility, while there is less evidence that

[10] The usefulness of implied volatility from currency options as a forecast of future exchange rate movements has been documented in Figlewski (1997) and Galati and Tsatsaronis (1996).

intervention reduced exchange rate volatility between 1990 and 1991. Over the period 1985 to 1991 as a whole, there is no evidence that central bank intervention reduced exchange rate volatility. Bonser-Neal and Tanner (1996) also examine whether changes in implied volatility Granger cause intervention by the Federal Reserve and find little evidence of Granger causality running from implied volatility to intervention. Murray et al. (1997) investigate the effect of different intervention strategies by the Bank of Canada on implied volatility of the Canadian/US dollar exchange rate. In contrast to Dominguez' (1993) results, they find that intervention that was expected or that was unexpectedly light had no effect on implied volatility, while intervention that was unexpected and heavy significantly reduced implied volatility. Dominguez (1998) looks at the effect of intervention on both GARCH volatility and implied volatility. She finds that the effect depends on both the sample period and the intervention strategy. One of her interesting results is that intervention can lead to an increase in volatility even if market participants do not perceive it. Similarly to Bonser-Neal and Tanner (1996), she also finds that volatility does not Granger-cause intervention.

In summary, there is no unanimity among empirical studies on the size and strength of the effect of intervention on the level and higher moments of exchange rates. Findings vary by time period, data source, and estimation method. In particular, studies that include the Plaza and Louvre time periods are more likely to find that intervention has a significant effect on the mean or the variance of the exchange rate. Those studies that include control for the simultaneous determination of the intervention decision and the exchange rate are less likely to find a significant effect for intervention.

Reviews of all of these studies, and commentaries by policy makers involved in intervention, do suggest a consensus view. As Sarno and Taylor (2001) put it "…official intervention can be effective if the intervention is publicly announced and concerted and provided that it is consistent with the underlying stance of monetary and fiscal policy." Former Federal Reserve and United States Treasury official Truman (2003) argues that "The evidence on the short-run effectiveness of exchange market intervention is sufficient in my view to support the judicious use of intervention by the United States as a supplementary policy instrument as long as it generally is used in a manner consistent with other economic policies, but that same evidence falls substantially short of demonstrating that intervention is a separate policy instrument that can be used to manage exchange rates with any lasting effect."

Edison (1993) and Almekinders (1995) survey empirical work on the determinants of intervention. The approach that is generally followed in the literature consists of specifying and estimating a reaction

function for central banks. The objectives being considered include “leaning against the wind”, minimising deviations of exchange rates from some implicit target levels and reducing uncertainty. Eijffinger and Gruijters (1991) find that, between 1985 and 1987, the Federal Reserve and the Bundesbank intervened mainly to reduce erratic exchange rate movements and “lean against the wind”. Dominguez and Frankel (1993a) find that between September 1985 and December 1990 the Federal Reserve and the Bundesbank mainly intervened when the dollar deviated from its implicit targets. They specify these targets based on Funabashi’s (1988) analysis of central bank intervention and, alternatively, by assuming that the targets equal the exchange rate level implied by purchasing power parity. A similar conclusion is reached by Goodhart and Hesse (1993) based on an analysis of intra-day data between 9 April and 30 June 1989. A recent paper by Frenkel et al (2002) looks at the period 1991–2001 and finds that the Bank of Japan regularly intervened in response to deviations of the yen/dollar rate from a short-term and a long-term target. By contrast, their results suggest that the Federal Reserve intervened only occasionally to accompany the Bank of Japan’s intervention. Almekinders and Eijffinger (1996) present evidence that, from 1987 to 1989, the Federal Reserve intervened with the intention of lowering exchange rate uncertainty. Baillie and Osterberg (1997) find that, between 1985 and 1990, spot exchange rate volatility Granger causes intervention in the yen/dollar market, while the forward premium’s conditional volatility does not. They conclude that intervention is motivated by increases in spot rather than forward market volatility.

3. The data

We study the daily movements of the yen against the dollar between September 1993 and April 2000 (Graph 1). The beginning of the sample is dictated by the availability of options data needed to estimate empirical PDFs. We chose April 2000 as the end of the sample since there was no intervention in the yen/dollar market in the following 12 months. The exchange rate we used is taken at noon in London, quoted in yen per dollar.

3.1 Central bank intervention

In this paper, we use two data sets on intervention in the yen/dollar market. The first set comprises official intervention data that were provided by the Federal Reserve and the Japanese Ministry of

Finance. While the Federal Reserve has made official intervention data available in the past, the Japanese Ministry of Finance started to post official intervention data on its website in July 2001.[11] The second data source for identifying episodes of central bank intervention in the yen/dollar market consists of Reuters press reports.[12] These press reports reveal interventions that are perceived by market participants and hence may overstate or understate actual central bank interventions. For example, Reuters articles may well report cases where market participants thought a central bank was intervening when in fact this was not the case.

With the new data set on official intervention it is now possible to gauge the accuracy of press reports on traders' perceptions of intervention by the Japanese authorities. Previous studies (Dominguez and Frankel (1993a), Bonser-Neal and Tanner (1996), Ramaswamy and Samiei (2000)) have used official data for Federal Reserve interventions and used newspaper articles to build a data set on intervention conducted by the Bank of Japan. A recent paper by Frenkel et al (forthcoming) compares the Ministry of Finance data with reports of interventions in the Financial Times and the Wall Street Journal. They find that between January 1995 and December 1999, press reports are a relatively inaccurate indicator of actual intervention by the Bank of Japan.

In contrast to Frenkel et al's conclusion, Table 1 reveals that Reuters reports quite accurately matched actual intervention in the yen/dollar market. The probability that intervention in the yen/dollar market was reported and perceived by traders given that it actually occurred was 0.77. Likewise, the probability that intervention was actually undertaken given that it was reported in Reuters articles was 0.84. A cross-check with Bonser-Neal and Tanner's (1996) data set for the period from January to July 1991 suggests that the Reuters data set used in this paper contains many more intervention episodes than their data set.[13]

Table 1 also reports information from the two alternative sources on intervention strategies that were followed in the yen/dollar market between 20 September 1993 and April 2000. During this period,

---

[11] www.mof.go.jp/english/e1c021.htm.

[12] Chang and Taylor (1998) have used Reuters' reports to identify the occurrence and timing of intervention in the dollar/yen market during the period 1 October 1992 to 30 September 1993.

[13] Bonser-Neal and Tanner (1996) show that their reporting of intervention episodes is more complete than Dominguez and Frankel's (1993).

almost 90% of all interventions were conducted unilaterally by the Bank of Japan, in a discreet fashion, and on successive days. The Federal Reserve intervened only together with the Bank of Japan. This is in line with the common observation that the U.S. monetary authorities became much less active in foreign exchange markets in the 1990s (see eg Bonser-Neal and Tanner (1996)). About two-thirds of the interventions involved amounts of $1 billion or less. Interestingly, while traders quite accurately perceived the occurrence of central bank intervention in the yen/dollar market, they tended to underestimate the magnitude of interventions.

Between mid-February 1996 and November 1997, no central bank intervention took place in the yen/dollar market. Since November 1997, moreover, the two central banks have tended to enter the yen/dollar market less frequently than in during the period 1993-96. It is therefore useful to split the sample into two sub-periods, September 1993 to February 1996 and November 1997 to April 2000. All econometric tests are carried out separately on these two sub-samples.

3.2 Macroeconomic news

In the empirical analysis of the effect of intervention on exchange rate expectations, we also include a number of variables that capture the effect of news about macroeconomic or policy developments that may arrive on the same day on which intervention is carried out. We measure the unexpected component of macroeconomic news by the difference between official data announcements and the results of opinion surveys conducted during the days preceding the announcements by Money Market Services and Bloomberg. We introduce news variables for both the United States and for Japan. For the United States, we include news about the CPI, the PPI, industrial production, the unemployment rate and the trade balance. For Japan, we include news about Tankan surveys, retail sales and industrial production. In order to capture the effect of news about changes in policy rates, for both the United States and Japan we created a dummy variable that equals one on a day on which the central bank announced that it changed its policy rate and zero otherwise.

4. Estimating and interpreting probability density functions

In recent years, data from foreign exchange option markets have been used to extract information about the entire risk-neutral PDF of the underlying exchange rate (eg BIS (1996 and 1999); Malz

(1996); McCauley and Melick (1996a and 1996b)). The four moments of this distribution – the mean, variance, skewness and kurtosis – can be used to characterise market expectations of future exchange rates.

The mean of a PDF can be interpreted as traders' average expectation of the yen/dollar rate at a future date. For a risk-neutral PDF the mean is equal to the forward rate. We will use this mean in the empirical section but it is important to understand that there is little difference, either in principle or result, between using this measure or the spot exchange rate. Obviously the spot and forward rate are jointly determined and linked via covered interest parity. Given that the correlation between the mean of the PDF (the forward rate) and the spot rate is 0.99 for levels and 0.83 for first differences over the sample period, our results using the mean of the PDF can be understood to apply to the spot exchange rate as well.

The variance of a PDF can be interpreted as providing a measure of how uncertain the market is on a given day about the exchange rate that will prevail over the near future. The third moment of a PDF, skewness, can be interpreted as the weight that market participants put on a much higher and a much lower yen/dollar exchange rate in the near future with respect to the forward rate. We define a PDF to be skewed to the left (or negatively skewed) when, compared with the forward rate, market participants assign more weight to a much weaker dollar rather than to a much stronger dollar against the yen. Similarly, we define a PDF as skewed to the right (or positively skewed) when the market attaches more weight to a much stronger dollar than a much weaker dollar in the near future. Kurtosis, the fourth moment of a PDF, measures how "fat" its tails are, and can be interpreted as indicating how likely market participants think very large exchange rate changes in either direction will be in the near future.

It is important to keep in mind that the interpretation of the estimated risk-neutral PDFs is not as straightforward as might be hoped, given that the PDFs capture market views as to the likelihood of particular exchange rate outcomes as well as market preferences towards risk. Unfortunately, in the absence of strong assumptions, it is impossible to distinguish between the two. A simple example illustrates the problem. Suppose we observe an increase in the price of fire insurance. This increase might reflect the market view that fires are now more likely; hence there is a greater need for insurance. Alternatively, the price increase might reflect a change in market sentiment regarding potential exposures in the event of a fire. The probability of a fire may not have increased; however,

the market view of any loss associated with a fire may have increased. The observation that the price of insurance has increased does not allow us to determine whether fires are more likely, whether exposure is perceived as larger, or some combination of both. In the same way, a change in option prices does not allow us to separate out changes in views on future exchange rates from changes in potential exposures.

Both Jackwerth (2000) and Bliss and Panigirtzoglou (2002), when studying equity markets, decompose the risk-neutral PDF into the product of the subjective or actuarial density function and a risk aversion function. While this approach might in principle be applied to expectations of future exchange rates, we decided not to follow their lead for several reasons. First, we are attempting to answer the question of whether or not central bank intervention has an effect on market participants, and hence we have only a secondary interest in whether the effect is felt with regard to expectations, preferences towards risk or both. Secondly, both studies make strong assumptions with regard to the stationarity of the risk aversion function, assumptions that are not tenable for a study that contemplates changes in expectations and preferences toward risk at a daily horizon. Finally, in the equity market there is a natural measure of wealth to use in recovering preferences towards risk, mainly the value of the equity index itself. However, in the foreign exchange market there is no natural definition of wealth. Therefore, we make use of only the risk-neutral PDFs rather than attempting the further step of decomposing the risk-neutral PDF into its components.

For each day from 20 September 1993 to 30 April 2000, the four moments of the risk-neutral PDF of the yen/dollar exchange rate were estimated using the indicative quotes of a market maker in London on at-the-money implied volatility, the risk reversal and the strangle.[14] The maturity of the options is constant and equal to one month.

The midpoint of the time *t* strangle price can be expressed as

$$STR_t = 0.5\left(\sigma_t^{75\delta} + \sigma_t^{25\delta}\right) - ATM_t \qquad (1)$$

[14] The risk reversal is the price difference between two equally out-of-the money options. It provides a direct measure of the skewness of the probability distribution. A strangle is a financial instrument that consists of a purchase or sale of an out-of-the-money put option and call option on the same underlying instrument, with the same expiration date. A strangle leads to profits if there is a drastic move in the price of the underlying asset.

and the risk reversal price as

$$RR_t = \sigma_t^{25\delta} - \sigma_t^{75\delta}, \tag{2}$$

where STR_t, RR_t and ATM_t denote, respectively, the strangle price, risk reversal price and the at-the-money volatility. $\sigma_t^{25\delta}$ and $\sigma_t^{75\delta}$ represent the implied volatilities of the 25 delta call and 25 delta put.[15] We use the above equations to recover implied volatilities corresponding to the given delta values. Our approach then follows two steps. First, we use standard Garman-Kohlhagen equations to translate the three quotes into six option prices (one put and one call for every strike price) in terms of units of yen per dollar.[16] Second, these option prices are used for the empirical estimation of the PDFs. There are different possible techniques for recovering implied risk neutral density functions from option prices.[17] In our study we use the Hermite polynomial approach, a technique developed by Madan and Milne (1994). We follow this approach since it gives a fairly robust estimation of the PDF moments and has a better convergence performance compared with other techniques.[18] A more detailed description of our empirical methodology is presented in the annex.

Figure 2 shows the times series of estimates of the first two moments of the PDF, the mean and the variance, of the yen/dollar exchange rate. As an alternative measure of the variability of exchange rate expectations, we also computed the difference between the 90% and the 10% quantile of the PDF, which we normalised by the median. Figure 2a shows the time series of this variable. Since the variance of the PDF and the interquantile range comove very closely, in the rest of the paper we report

---

15 The delta of an option is the first derivative of the option price with respect to the underlying asset.

16 See annex or Malz (1996) and McCauley and Melick (1996a) for further details.

17 These techniques can be classified in four broad categories (Bahra (1997), Chang and Melick (1999)): I) techniques that recover the implied density functions by assuming a particular stochastic process for the underlying asset (eg Bates (1991), Malz (1996)); II) a functional form for the PDF is assumed with the parameters for the function estimated by minimizing the difference between actual and predicted option prices (eg Rubinstein (1994), Melick and Thomas (1997), Bahra (1997)); III) the probability density function is implied from some parametric specification of the call pricing function or the implied volatility smile (see eg Shimko (1993), Madan and Milne (1994), Malz (1997)); IV) non-parametric estimation of the density function (see eg Aït-Sahalia and Lo (1998)).

18 Applications of this technique can also be found in Abken, Madan and Ramamurtie (1996), Jondeau and Rockinger (2000), Coutant, Jondeau and Rockinger (2001), and Mc Manus (1999). A potential problem with this technique is that estimated probabilities can be negative (Jondeau and Rockinger (2001)). In our data set, however, this problem turned out not to be relevant. Melick (1999) demonstrates that different techniques for extracting risk-neutral PDFs give very similar results for probabilities between the 10th and 90th quantiles, hence our findings are robust to the technique used to extract the PDF.

only results for the variance of the PDF.[19] Estimates of the skewness are reported in Figure 3 together with estimates of the mean. Figure 4 reports estimates of the fourth moment of the PDF (the kurtosis) over the period September 1993 to November 2000.

To explore the relationship between intervention and exchange rates it is necessary to specify the timing of interventions with respect to the time at which the option data are recorded. Given the difference of nine hours between the Asian time zone and GMT, if the Bank of Japan intervened in Asian markets, the intervention will precede the recording of option prices in London on that day. In this case, the timing of the intervention variables and that of the parameters of the PDFs are set equal in the data set. When intervention occurred on day t in New York, it is introduced at time t+1 in the data set because it will be known in London after the option data are reported. In the few cases in which intervention was carried out in Europe we assume that intervention in European markets always preceded the recording of option prices and therefore use the same timing convention that we use for interventions conducted in Asia.[20]

5. Intervention and market expectations

5.1 Intervention and PDFs

Figure 5 illustrates with an example how risk-neutral PDFs can be used to analyse the effect of foreign exchange intervention. The episode of concerted intervention by Japanese, German and US authorities on 15 August 1995 has been described as "pushing on an open door" (BIS (1996)) given the sharp appreciation of the dollar on 15 and 16 August. Central banks purchased dollars when the US currency was appreciating against the background of heavy Japanese buying of US bonds and option dealers' hedging.

---

[19] The correlation coefficient between the PDF variance and the interquantile range is 0.87. All the econometric results are robust to using the interquantile range instead of the variance.

[20] Robustness checks show that using a different timing assumption for intervention in Europe, according to which intervention carried out in Europe generally followed the recording of option prices, does not alter the empirical results in this paper.

Figure 5 shows that the PDFs around August 1995 exhibited right skewness, indicating that market participants attached a higher probability to a much stronger rather than a much weaker dollar one month ahead with respect to the forward rate.[21] Following central bank intervention, the skewness increased on 16 August, suggesting that the concerted action by central banks increased the market bias towards a much stronger dollar. At the same time, the variance of the PDFs rose on 16 August 1995. It then declined during the following days. This can be interpreted as indicating that intervention was followed by a temporary increase in market uncertainty. Moreover, the kurtosis of the PDFs increased on the day that central banks intervened, suggesting that the concerted effort to boost the already appreciating dollar induced market participants to attach more weight to the possibility of further very large changes of the yen/dollar exchange rate in either direction in the following month.

Figures 6 to 11 provide some information on the average movements of the mean, variance and skewness of the risk-neutral PDFs around intervention episodes over the period from September 1993 to November 2000. For the five days before and five days after intervention, which happens at t = 0, Figure 6 shows the mean of the risk-neutral PDF, ie the forward rate, averaged over all dollar purchases. We report the averages for a horizon of 10 days because most of the empirical literature has suggested that the effect of intervention is short lived. The value of the mean is normalised at zero on the day preceding the intervention, ie at t = -1. The grey area gives an indication of the variability of the changes in the moment of the PDF across all interventions. For each day, it is calculated as the average value of the mean plus/minus one standard deviation, where the standard deviation is computed over all intervention episodes.

Figure 7 shows the same information for dollar sales. The chart looks very similar when we use the spot rate instead of the mean of the PDF. Figures 8 and 11 show averages of the variance, and the kurtosis, respectively for all intervention episodes, while Figures 9 and 10 show the movement of skewness around dollar purchases and sales respectively. Purchases and sales are not separately presented for the variance and kurtosis, since the hypothesis of interest in these cases - whether

[21] The PDFs in Figure 5 are expressed in yen per dollar.

intervention increases uncertainty – is symmetric in both directions. Again, shaded areas indicate standard deviations around the averages of the moments.

Figures 6-8 in particular suggest the possibility that intervention may have had substantial effects on the moments of the expected exchange rate, although the standard deviation shadings encompass zero in all cases. However, one should be careful in using them to draw inferences about the impact of intervention for three reasons. First, the figures do not control for simultaneity. It could be that intervention responds to movements in the moments rather than vice-versa. Second, on the day that central banks intervene, other important macroeconomic or policy news may arrive that could prompt market participants to react. For example, the announcement of an unexpectedly high industrial production figure for Japan could induce traders to revise their expectations of future Japanese interest rates upwards, thereby boosting the yen. Intervention could also be carried out on the same day on which a participating central bank changes its monetary policy rate. The behaviour of the moments would then reflect the effect of both the arrival of macroeconomic or policy news and central bank intervention. The simple averages reported in Figures 6–11 do not account for the influence of these different factors.

The third shortcoming of these graphs is that intervention could be carried out on several successive days. Table 1 shows that this was indeed the case for most of the interventions during our sample period. As a consequence, the average values of the PDF moments on day t reflect not only the effect of intervention that occurred on that day, but also the effect of central bank actions carried out on previous days.

In order to assess the effect of intervention and control for these three issues, we use daily data to estimate regression equations that explain each moment in terms of current and lagged intervention and a set of other explanatory variables. To distinguish the effect of intervention from the effect of news about relevant macroeconomic variables that may arrive on the same day, we include a set of variables that measure the unanticipated component of announcements of major macroeconomic variables. Our set of news variables includes variables for both the United States, as in most previous studies on intervention in the yen/dollar market, and Japan.

In our model of the relationship between intervention and exchange rate expectations, the moments of the PDFs are determined by expectations of exchange rate fundamentals. The expected level of the

exchange rate is determined by, among other things, expected future price levels and future likely monetary policy. The expected volatility of exchange rates is determined by expected future goods price volatility and uncertainty about future monetary and intervention policy and other factors. Similar arguments apply to the skewness and the kurtosis. Hence, the PDF moments change when those expectations change. Intervention is a determinant of these expectations as suggested by the signalling channel.

In formal terms, consider a simple interpretation of the exchange rate s_t as determined by fundamentals $Z_t^1, Z_t^2, Z_t^3, \ldots$.

Assuming linearity and taking expectations, this would imply that the time t expectation of the value of

$$s_t = s(Z_t^1, Z_t^2, Z_t^3, \ldots) \tag{3}$$

the exchange rate at time t+i would be given by:

$$E_t s_{t+i} = \alpha + \beta_1 E_t Z_{t+i}^1 + \beta_2 E_t Z_{t+i}^2 + \beta_3 E_t Z_{t+i}^3 + \ldots \tag{4}$$

Similarly, and assuming for simplicity zero covariances, the variance of the exchange rate would be given by:

$$\text{var}(s_{t+i}) = \beta_1^2 \,\text{var}(Z_{t+i}^1) + \beta_2^2 \,\text{var}(Z_{t+i}^2) + \beta_3^2 \,\text{var}(Z_{t+i}^3) \ldots \tag{5}$$

The expected exchange rates and variances, as well as the expected fundamentals, depend on information available at time *t*, which includes information about intervention at time *t*. As such, if central banks intervene at time *t*, this can potentially lead to a change in the expected moment:

$$E_{t+1} s_{t+i} - E_t s_{t+i} = \beta_1 (E_{t+1} Z_{t+i}^1 - E_t Z_{t+i}^1) + \beta_2 (E_{t+1} Z_{t+i}^2 - E_t Z_{t+i}^2) + \beta_3 (E_{t+1} Z_{t+i}^3 - E_t Z_{t+i}^3) + \ldots \tag{6}$$

The level of intervention directly affects the change in expectations of fundamentals and, thereby, the changes in expectations.

5.2 The simultaneity problem

Regressions that estimate the effect of central bank intervention on market conditions face a potential simultaneity problem. In a regression of the variance of the expected exchange rate on an intervention

dummy, for example, a positive coefficient can mean either that intervention increases expected volatility, or that central banks intervene to smooth rising exchange rate volatility, but are not successful.

A simple example can be used to illustrate this problem. Consider the case where a central bank intervenes to smooth volatility. To simplify the exposition, we ignore here the role of other moments of the PDF. In its simplest form, we can then write the following system of equations:

$$M_t = a_1 + a_2 I_t + a_3 X_t + \varepsilon_t \tag{7}$$

$$I_t = b_1 + b_2 M_t + b_3 Y_t + \eta_t \tag{8}$$

where M_t measures the variance of the PDF, I_t captures intervention, and X_t and Y_t represent other factors that influence volatility and intervention. ε_t and η_t are error terms. Equation (7) is probably of greatest interest, since it describes the effect of intervention on the variance of the exchange rate. Equation (8) is a reaction function that describes how intervention responds to movements in the variance.

Estimating the effect of intervention on the variance implies estimating the coefficient a_2 in Equation (7), while the effect of the variance on intervention is captured by the coefficient b_2 in Equation (8). This would require solving the simultaneous system for M_t and I_t in terms of X_t, Y_t, and ε_t and η_t. If standard OLS procedures are applied to estimate these two equations separately, they will yield biased and inconsistent estimates of a_2 and b_2 because $\text{cov}(I_t, \varepsilon_t) \neq 0$ and $\text{cov}(M_t, \eta_t) \neq 0$.

Ideally then, equations like (7) and (8) would be estimated simultaneously. In practice however, this is not a viable alternative because the results would be very sensitive to specification errors in either of the equations in the system. A method that has been used in the literature to address this simultaneity

problem consists in lagging the intervention variable by one period in equation (7) and then estimating that equation directly with OLS.[22] However, this method will misrepresent the true effect of intervention on market expectations because part of this effect may already be captured in lagged values of the dependent variable (the moment), which are introduced among the explanatory variables.

A better alternative is a limited information estimator such as Instrumental Variables (IV), although even this approach can be problematic. As is well known, and discussed for example in Stock and Yogo (2002) and Stock and Watson (2003), weak instruments can produce biased IV estimators and hypothesis tests with large distortions. An IV estimation of equation (7) requires an instrument for intervention, while an IV estimation of equation (8) requires an instrument for the moment of the exchange rate. Unfortunately, the notorious difficulty in explaining daily exchange rate movements means that it is highly unlikely that a good instrument can be found for the moment of the exchange rate. Fortunately, as shown below, it is possible to obtain a good instrument for intervention. Therefore, a specification like equation (7) can be estimated with IV while a specification like equation (8) probably should not. For equations like (8) the safest approach is to include only lagged values of the exchange rate moments on the right hand side to avoid the simultaneity problem. Humpage (1999) follows a similar approach when estimating reaction functions, including only early morning quotes for the exchange rate on the right hand side.

Although not perfect, this compromise of estimating one equation with IV and the other with only lagged values and OLS is the best strategy. The main question of interest, the effect of intervention on the exchange rate, is answered with the IV estimation, while the OLS estimation of the reaction function will provide a rough description of the behaviour of the central banks. The biggest drawback to this approach is the possibility of omitted variables bias in the OLS estimation of the reaction function, since only lagged values of the exchange rate moments are included and the contemporaneous values of the exchange rate moments via an instrument are omitted. However, this bias is likely to be trivial, since the exchange rate moments show little if any persistence and thus

[22] Studies that followed this method include Dominguez (1993a), Bonser-Neal and Tanner (1996) and Murray et al. (1997). For a critique of this approach to the simultaneity bias, see Humpage (1999).

there is not much correlation between the included lagged moments and the omitted instrument for the contemporaneous moments.

In particular, we estimate the following equations that correspond to the simple system of equations (7) and (8):

$$M_t^j = a + \sum_{i=1}^{5} b_i M_{t-i}^j + \sum_{i=0}^{5} c_i I_{t-i} + \sum_{i=0}^{5} d_i X_i + \varepsilon_t \quad (9)$$

and

$$I_t = a + \sum_{j=1}^{8} \sum_{i=1}^{5} b_i^j \hat{M}_{t-i}^j + \eta_t \quad (10)$$

where M_t^j is the *j*-th moment at time *t*, $\hat{M}_{t-i}^j$ is the target value (explained below) for the jth moment lagged by *i* periods. I_t is the amount of intervention on day *t*, X_t is a vector of macroeconomic variables and ε_t and η_t are error terms. Instead of estimating equation (9) using OLS, we use instrumental variables, essentially replacing intervention with its predicted value from the reaction function. Equation (10), since it only includes lagged moments, can be estimated with OLS.

5.3 Estimating a reaction function for the Federal Reserve and the Bank of Japan

The method we follow to estimate reaction functions (equation (10)) builds on the work of Baillie and Osterberg (1997). In their study of the behaviour of the Federal Reserve and the Bank of Japan, they find that the probability of the two central banks intervening is determined by the deviation of the exchange rate from some "target" nominal exchange rate level and by the volatility of the exchange rate. In the post-Bretton Woods era, the Federal Reserve and the Bank of Japan have never officially announced a target for the yen/dollar exchange rate. However, Funabashi (1988) argues that they adopted some implicit target levels for the nominal exchange rates. This is also consistent with the findings of Ito (2003). Baillie and Osterberg (1997) take the target levels for the nominal exchange rates from Funabashi (1988).

We assume that the Federal Reserve and the Bank of Japan intervened when the spot rate, the variance or the skewness deviated from implicit target ranges. We also assume the likelihood of

intervention depended on the distance from these targets. We choose implicit targets for the spot exchange rate based on press reports, which typically emphasised the role of the spot rate as trigger for central bank intervention (Table 2).[23] Equation (10) is estimated separately for the Bank of Japan and the Federal Reserve. Given that the Federal Reserve were much less active in foreign exchange markets during the sample period and intervened only on days when the Bank of Japan was in the market, we followed Frenkel et al (2002) and included Bank of Japan intervention in the specification for the Federal Reserve's reaction function. We introduced Bank of Japan intervention at time *t* and *t-1*, since central banks almost always intervene in their local markets, a fact noted by Dominguez (2003a,2003c) and confirmed by an examination of the Reuters reports in our dataset. Therefore, U.S. authorities would usually know that the Bank of Japan had intervened, since the Tokyo trading session is well ahead of the U.S. trading session.

As a first approximation, we set the targets for the higher moments equal to their historic average. In other words, we assume that central banks tended to intervene whenever the variance or skewness of market expectations was abnormally high or low with respect to its historical average.[24]

The explanatory variables $\hat{M}^{j}_{t-i}$ include the distance at time *t-i* of the yen/dollar spot rate from the bottom of the target range when the exchange rate is below that limit and a variable for the case in which the exchange rate breaks through the top of the target range. We also include the distance of the variance from its historical average when the dollar is, respectively, appreciating or depreciating. Furthermore, a variable is introduced to measure the distance of skewness from its historical average when the yen is depreciating and the market is skewed towards a much weaker yen. Similarly, we use a measure of the distance from the average of skewness when the yen is strengthening and the market is biased towards a much stronger yen. Finally, we introduced a variable measuring the distance of kurtosis from its historical average when the dollar was, respectively, appreciating and depreciating.

---

[23] An alternative approach used in the literature consists of setting the implicit target equal to the PPP value of the dollar/yen exchange rate, as in Dominguez and Frankel (1993a). Other studies have set the target rate equal to past levels of the exchange rate, thereby assuming that central banks systematically "lean against the wind" (Almekinder and Eijffinger (1991)).

[24] The target bounds are taken here as the historical mean $\pm$ 1.5 standard deviation.

Central banks did not intervene in the yen/dollar market between mid-February 1996 and November 1997. Moreover, they have entered the market less frequently since November 1997 than during the period 1993-96. We therefore estimate equation (10) also for two sub-periods, September 1993 to February 1996 and November 1997 to April 2000.

Tables 3A and 3B report the coefficients, t-statistics and significance levels for the reaction functions. The model seems to capture fairly well the intervention decisions taken by the Bank of Japan during 1993-1996 and 1997-2000, as well as by the Federal Reserve during 1993-1996, as suggested by R^2 values of 0.18, 0.14 and 0.17, respectively. Our results suggest that, between 1993 and 2000, the Bank of Japan (sometimes with the support of the Federal Reserve) tended to intervene mainly when the yen/dollar rate deviated from implicit target ranges. The coefficient on the spot rate in the regression is positive and highly significant. This conclusion is consistent with the study by Gaiotti et al. (1989), who find that, from 1973 to 1987, the Bank of Japan reacted to deviations of the yen/dollar rate from implicit target levels. One explanation of the more pro-active approach followed by the Japanese authorities is that, unlike the US authorities, they were subject to more pressures from the private sector during the period 1993-96 to react to the strength of the yen. Table 3A shows that the likelihood of intervention by Japanese authorities is not influenced by deviations of the yen's value from some implicit target range during the period 1997-2000, suggesting that the incentives for the Japanese authorities to intervene were different in an environment in which the yen was depreciating.

Table 3A also provides some evidence that between 1993 and 1996, and between 1997 and 2000, the Bank of Japan on average also intervened as a response to a rise in market uncertainty, particularly when the dollar is depreciating. This finding is consistent with statements made by central banks in the past that emphasised their attempt to "calm disorderly markets". It confirms Baillie and Osterberg's (1997a) conclusion that, during the period 1985 to 1990, increases in exchange rate volatility tended to prompt the Federal Reserve, the Bank of Japan and the Bundesbank to purchase dollars for yen or mark. It contrasts however with Bonser-Neal and Tanner's (1996) result that between 1985 and 1991, implied volatility does not Granger cause intervention by the Bank of Japan. Finally, we find a positive and highly significant coefficient on Bank of Japan intervention in the reaction function for the Federal Reserve (Table 3B).

5.4 The effect of intervention on market expectations

To investigate the effect of intervention on market expectations, we estimate equation (9) for the mean, the variance, skewness, and kurtosis of the PDFs using daily data from 20 September 1993 to 30 April 2000. We also estimated equation (9) for the two sub-periods, 20 September 1993 to 28 February 1996 and 3 November 1997 to 30 April 2000. Since the literature has emphasised the importance of the simultaneity problem described above, and Hausman tests suggest the problem is relevant when we take equation (9) to the data, we estimated the equation with instrumental variables. The instruments include the sum of the predicted values of intervention by the Federal Reserve and the Bank of Japan taken from the estimated reaction functions (10). Lags of intervention have been used in the literature as an alternative instrument for intervention. However, we opted against this instrument in our case since lagged intervention is less well correlated with actual intervention than is our predicted intervention. Lagged intervention has correlation coefficients of 0.10 for the period 1993-97 and 0.08 for the period 1997-2000, compared to our R^2 values of 0.18 and 0.14 from the estimates of the reaction function.[25]

In light of equation (6), the moments of the PDFs enter on the left hand side of the regression equations as first differences, while intervention enters in levels on the right hand side. Five lags of intervention are added on the right hand side to capture the dynamics of the short-term effect of intervention. We also include lagged values of the moment among the explanatory variables. In addition, we introduced a number of variables that capture the effect of news about macroeconomic or policy developments that may arrive on the same day on which intervention is carried out. The unexpected component of news is measured by the difference between official data announcements and the results of opinion surveys conducted during the days preceding the announcements. As mentioned before, for the United States, we measure the unexpected components of the CPI, the PPI, industrial production, the unemployment rate and the trade balance. For Japan, we measure the unexpected component of the Tankan surveys, retail sales, industrial production, the trade balance

[25] These correlation coefficients suggest that the issue of weak instruments is less relevant for equation (10) than for equation (9).

and the job offers/seekers ratio. We also introduce a dummy variable for each business day to capture day-of-the-week effects, since there is evidence that asset prices follow intra-weekly patterns.[26]

In the regression equations for the variance and the kurtosis, all explanatory variables are expressed in absolute values, as it is assumed that their effect on intervention depends only on their size but not their sign.

The results are summarised in Tables 4-7. For each equation, the coefficient on contemporaneous intervention and the cumulative sum of coefficients on contemporaneous and lagged intervention are reported. Tables 4-7 also show the t-statistics and p-values. The results are reported for the two periods September 1993 to February 1996 and November 1997 to April 2000.

Table 4 shows that in the regression equation for the mean of the PDF, the coefficient on current intervention is not statistically significant. On average during the two sample periods 1993-96 and 1997-2000, intervention in the yen/dollar market had no statistically significant contemporaneous effect on the expected yen/dollar rate. Moreover, the cumulative sums of current and lagged intervention are not statistically significant, indicating no statistically significant dynamic effect of intervention over one week. We also followed the same approach to estimate the impact of intervention on the spot rate. The results (not shown) were very similar to those reported in Table 4 for the regressions for the mean of the PDF, as would be expected given the close correspondence between the mean of the PDF and the spot rate mentioned earlier.

While these findings are consistent with existing literature that also controls for simultaneity and does not include the Plaza and Louvre periods, this dataset can provide a richer description of the effects of intervention by examining the effect of intervention on the variance, skewness and kurtosis of the expected exchange rate. Statistical tests presented in Table 5 also show that, on average during the two periods, intervention did not lead to higher variance of the PDFs. Thus, on average, intervention was not followed by a significant rise in market uncertainty. Our result is in contrast with findings based on both GARCH measures of volatility[27] and implied volatility[28]. Hausman tests indicate that the

---

[26] For reasons of space, we report only the coefficient for the dummy for Mondays.

[27] Connolly and Taylor (1994), Baillie and Humpage (1992).

difference in results can be explained by the method we followed to address the simultaneity issue. Moreover, when the equation is run without the instrumental variables correction, intervention does have a positive and statistically significant effect on the variance of the expected exchange rate.[29] Failure to correct for simultaneity bias leads to the incorrect inference.

Tests of the effect of intervention on the skewness of the PDF are found in Table 6. These results show that on average intervention did not produce a significant change in the trend of the expected future exchange rate since it did not cause a shift in market participants' balance of weights between a stronger and a weaker exchange rate with respect to the forward rate.

Table 7 shows that in the regression equation for the kurtosis, the coefficient on current intervention and the cumulative sum of coefficients on the current and first five lags of intervention are not statistically significant. This can be interpreted as suggesting that during these periods, intervention did not have a statistically significant, systematic impact on the tails of the distribution of expected exchange rates.

We also test whether the average impact of intervention on market expectations depended on the type of strategy that was followed by augmenting our regression equations with either a dummy for coordinated interventions or a dummy for officially announced interventions. The coefficients on both dummies were statistically insignificant.

Finally, similarly to findings by Bonser-Neal and Tanner (1996) and others, in the regressions for the mean and the variance of the PDFs we find some evidence of a significant impact of surprises about macroeconomic news on exchange rate expectations. We also detected some statistically significant weekend effects in the variance equation.

In summary, our empirical analysis highlights several important results. Consistent with the general consensus that exchange rates are difficult to model, we find that changes in exchange rate expectations are not easily explainable by macroeconomic variables or central bank intervention

---

[28] Bonser-Neal and Tanner (1996) for the period 1990–91 and, for the period 1977-94, Dominguez(1998).

[29] We reached the same conclusion when we estimated the variance equation using implied volatility as in Bonser-Neal and Tanner (1996).

activity. We fail to find evidence that over the period 1993 to 2000, intervention on its own had effects that were long lasting and consistent over time. While there is evidence that intervention had some impact, this effect was not statistically significant given the wide dispersion of the responses of exchange rate expectations.

This result contrasts with the findings of Dominguez and Frankel (1993a) and other studies that find that intervention, particularly when coordinated and officially announced, had a statistically significant impact on exchange rates during the 1980s. Our difference with regard to these studies does not appear to be driven by the fact that most interventions during our sample period were carried out in a discreet fashion because in most cases they were perceived by traders. In fact, we do not find evidence of a statistically significant difference between the impact of discreet and officially announced intervention. Our different findings can also not be explained by our use of a richer data set on macroeconomic news variables with respect to previous studies of intervention. Rather, the difference might be explained by the fact in the mid-1980s, monetary authorities made credible statements about undertaking decisive policy action to influence exchange rate, such as those around the Plaza and Louvre agreements. These statements tended to reinforce the effect of intervention. By contrast, monetary authorities refrained from making such statements during the period 1993 to 2000. Unfortunately neither good options data nor official data on intervention by the Japanese authorities are available to apply our methodology to the 1980s. The different sample period may also account for the fact that unlike Dominguez and Frankel (1993a), Catte et al (1994) and others, we fail to find evidence that the effect of interventions on exchange rate expectations was on average stronger when interventions were coordinated. While in the mid-1980s joint interventions were part of a coordination of exchange rate policies among G5 or G7 authorities, in the 1990s interventions were coordinated but exchange rate policies were not.

Our regression results also contrast with Bonser-Neal and Tanner (1996) and other studies that find that intervention tended to increase the variance of exchange rate expectations. Statistical tests indicate that this difference seems to be due to the different methods to control for simultaneity bias. When we estimate the regression for the variance using OLS, we find positive and statistically significant coefficients for intervention. This suggests that accounting for simultaneity is important.

In summary then, our results can be reconciled with the notion that sterilized intervention is only effective when it is announced publicly, coordinated among central banks, and most importantly,

consistent with the stance of fiscal and monetary policy. As we used dummy variables to control for public announcement and coordination between the central banks, the fact that these interventions appear to have had little if any effect would then be explained by inconsistency with underlying fiscal and monetary policies.

It should be stressed that, as shown in section 5.1, depending on circumstances, particular interventions did succeed in affecting traders' expectations of future exchange rate movements in line with policymakers' objectives. Future work on intervention and market expectations derived from option prices might therefore profitably focus on episodes.[30] This is consistent with Fatum and Hutchison's (2002,2003) argument in favour of an event analysis as a fruitful approach to gauging the effectiveness of intervention.

6. Conclusions

This paper presents empirical evidence on the relationship between market expectations of the yen/dollar exchange rate and central bank intervention carried out by Japanese authorities and the Federal Reserve. We examine the period 20 September 1993 to 30 April 1996, during which all central bank intervention in the yen/dollar market was directed at supporting the dollar, and the period November 1997 to April 2000, in which central banks both bought and sold dollars for yen. We use official data on intervention provided by the Federal Reserve and, recently, by the Japanese Ministry of Finance, as well as a new data set on intervention episodes perceived by market participants, which is based on Reuters reports. The paper uses the moments of the expected distribution of future exchange rates, which were estimated from option prices using the Hermite polynomial approach developed by Madan and Milne (1994), as a way to describe market expectations. The four moments of the empirical density functions allow us to give a complete characterisation of market expectations.

The paper quantifies how market expectations affected the likelihood of central bank intervention and the impact of intervention on market expectations. We find that Japanese and US authorities followed

different intervention strategies during the periods 1993-96 and 1997-2000. During the first sample period, Japanese authorities appeared to respond to deviations of the spot yen/dollar rate from some implicit target ranges. We also find evidence that the Bank of Japan intervened to reduce market uncertainty. For the sub-sample 1997-2000, only increases in market uncertainty influenced the likelihood of intervention by the Bank of Japan. Between 1993 and 2000, the Federal Reserve only intervened in support of interventions by the Japanese authorities.

Consistent with the findings of some of the literature, the regression results for the impact of intervention on the moments of the PDF suggest that, on average, intervention in support of the dollar had no statistically significant effect on the mean of expected exchange rates. In particular, we do not find evidence of a contemporaneous impact of intervention on the forward rate, nor any deferred effect. Consistent with the results for the mean of the PDF, we do not find evidence that, on average, intervention influenced the skewness of the PDFs, ie traders' balance between a much stronger and a much weaker dollar around the forward rate.

An important finding is that, between September 1993 and April 1996, and between November 1997 and April 2000, intervention directed at the yen/dollar exchange rate was not associated with a higher variance of expected future spot rates. This suggests that on average central bank intervention did not influence the uncertainty prevailing in the market regarding future movements in the yen/dollar rate.

In summary, the consensus view is that sterilized intervention can be effective if it is announced publicly, coordinated across central banks, and most importantly, consistent with underlying fiscal and monetary policies. As we are able to control for public announcement and central bank coordination, our findings suggest that intervention during our sample period was not consistent with underlying fiscal and monetary policy and therefore did not have a lasting influence on exchange rate moments.

---

[30] We decided not follow this approach in this paper because of the difficulties in controlling for the influence of macro news and other factors during intervention episodes in our sample that sometimes lasted two weeks.

Acknowledgements

We wish to thank Adrian Coghlan for helping to build the data set on intervention from Reuters articles and two anonymous referees, Jan Marc Berk, Robert Bliss, Claudio Borio, Kevin Chang, Kathryn Dominguez, Rasmus Fatum, Owen Humpage, Carol Osler, Frank Smets, and Ted Truman for comments on an earlier version. The views expressed in this paper are those of the authors and not necessarily the views of the BIS.

Appendix: Recovering risk neutral distributions from FX OTC option prices using a Hermite polynomial approximation

The basic framework for the estimation of risk neutral distributions is based on the usual assumption that the exchange rate follows a lognormal diffusion process:

$$dS_t = \mu S_t dt + \sigma S_t dW_t \tag{1}$$

where S_t is the exchange rate (yen/dollar), μ and σ are the mean and the variance of the distribution, W is a Brownian motion and d is a difference operator. Given the spot exchange rate, option prices in yen/dollar recovered from strangle and risk reversals, one-month interest rates and the time to maturity, we can recover the strike price by solving the following equations:

$$C\left(S_t, \tau, K, \sigma, r, r^*\right) = e^{-r^*\tau} S_t \Phi\left(d_1\right) - e^{-r\tau} K \Phi\left(d_2\right) \tag{2}$$

$$P\left(S_t, \tau, K, \sigma, r, r^*\right) = -e^{r^*\tau} S_t \Phi\left(d_1\right) - e^{-r\tau} K \Phi\left(d_1\right) \tag{3}$$

$$d_1 = \frac{\ln\left(S_t / K\right) + \left(r - r^* + \frac{1}{2}\sigma^2\right)\tau}{\sigma\sqrt{\tau}} \tag{4}$$

$$d_2 = \frac{\ln\left(S_t / K\right) + \left(r - r^* - \frac{1}{2}\sigma^2\right)\tau}{\sigma\sqrt{\tau}} \tag{5}$$

where C and P are the prices of call and put options, for an exercise price K and a constant maturity τ equal to 30 days. One-month interest rates for the Japanese yen and US dollar are denoted with r^* and r and Φ is a cumulative normal distribution function.

The basic idea in Madan and Milne (1994) is that the risk neutral density can be obtained through a multiplicative perturbation (λ) to the normal density, such that[31]

$$RND_{HP}(\omega) = \lambda(\omega)\phi(\omega) \tag{6}$$

where $RND_{HP}(\omega)$ is the Hermite polynomial approximation of the risk neutral density, ϕ is a normal distribution and ω is a normalized variable equal to:

$$\omega = \frac{\ln\left(\frac{S_{t+\tau}}{S_t}\right) - \left(\mu - \frac{1}{2}\sigma^2\right)\tau}{\sigma\sqrt{\tau}} \tag{7}$$

As shown in Madan and Milne (1994), a Hermite polynomial expansion around the baseline lognormal solution is analogous to performing a Fourier expansion. Each additional term in the Hermite polynomial expansion is related to higher moments of the distribution. Given the orthogonality property of Hermite polynomials, the price of a call option can be then written as:

$$C = \sum_{k=0}^{\infty} \alpha_k \pi_k \tag{8}$$

with

$$\alpha_k = \frac{1}{k!} \frac{\partial^k \Phi(u, S_t, K, \mu, \sigma, \tau)}{\partial u^k} \bigg| u = 0 \tag{9}$$

where k is the order of the Hermite polynomial approximation and u is a dummy variable in the generating function for Hermite polynomials. In our estimation, we have truncated the sum of Hermite

[31] The approximation is made under the usual assumptions of no-arbitrage opportunities, risk neutrality of agents, the existence of competing and liquid markets, and the price changes of the underlying asset follow a Wiener process (see: Abken, Madan and Ramamurtie (1996)).

polynomials up to the fourth order. In order to estimate the risk neutral density function, we follow Abken, Madan and Ramurite (1996) and impose $\pi_0 = e^{r\tau}$, $\pi_1 = \pi_2 = 0$. With these restrictions, we estimate μ, σ, π_3 and π_4. In this case, the risk neutral density function can be written as:

$$RND_{HP}(\omega) = \phi(\omega)\left[1 + \frac{b_3}{\sqrt{6}}(\omega^3 - 3\omega) + \frac{b_4}{\sqrt{24}}(\omega^4 - 6\omega^2 + 3)\right] \quad (10)$$

where b_i are parameters to be estimated by minimizing the sum of squared deviations of predicted from actual option prices. The first two moments of the implied risk neutral distribution are μ and $\sigma\sqrt{\tau}$. The formulas for the skewness and kurtosis, with this fourth order truncation are given by:

$$Skewness = \sqrt{6}b_3 \quad (11)$$

$$Kurtosis = 3 + \sqrt{24}b_4 \quad (12)$$

We tested the robustness of our estimation by using two additional methods to recover risk neutral densities: the jump diffusion method proposed by Malz (1996) and a semi-parametric method developed by Bliss and Panigirtzoglou (2002). We found that the results were similar across methods in the quantiles of the distributions, an unsurprising result given the findings of Melick (1999).

References

Abken, P.A, Madan, D.B., Ramamurtie, S., 1996. Estimation of risk neutral and statistical densities by hermite polynomial approximation: with an application to eurodollar futures options. Working Paper 96-5, Federal Reserve Bank of Atlanta.

Aït-Sahalia, Y., Lo, A., 1998. Nonparametric estimation of state-price densities implicit in financial asset prices. Journal of Finance, 53(2), April, 499-547.

Almekinders, G.J., 1995. Foreign Exchange Intervention: Theory and Evidence. Edward Elgar.

Almekinders, G.J., Eijffinger, S., 1996. A friction model of daily Bundesbank and Federal Reserve intervention. Journal of Banking and Finance, Vol. 20, 1365-1380.

Bahra, B., 1997. Implied risk-neutral probability density functions from option prices: theory and application. Bank of England Working Paper Series No. 66, July.

Baillie, R., Humpage, O., 1992. Post-Louvre intervention: Did target zones stabilise the dollar?. Federal Reserve Bank of Cleveland Working Paper No. 9203.

Baillie, R., Humpage, O., Osterberg, W.P., 2000: Intervention as information: a survey. Journal of International Financial Markets, Institutions and Money, No. 10.

Baillie, R., Osterberg, W.P., 1997. "Why do central banks intervene?", Journal of International Money and Finance, Vol. 16, No. 6, 909-19.

Bank for International Settlements, 1996. 66th Annual Report.

Bank for International Settlements, 1999. Estimating and Interpreting Probability Density Functions, proceedings of the workshop held at the BIS on 14 June 1999.

Bates, D.S., 1991. The crash of '87: was it expected? the evidence from the options markets. Journal of Finance, Vol. 46, July, 1009-1044.

Bliss, R., Panigirtzoglu N., (2002): Option-implied risk aversion estimates: robustness and patterns. Mimeo, Federal Reserve Bank of Chicago, September.

Board of Governors of the Federal Reserve, 1994. Treasury and Federal Reserve foreign exchange operations, Federal Reserve Bulletin, July.

Board of Governors of the Federal Reserve, 1995a: Treasury and Federal Reserve foreign exchange operations. Federal Reserve Bulletin, June.

Board of Governors of the Federal Reserve, 1995b: Treasury and Federal Reserve foreign exchange operations. Federal Reserve Bulletin, December.

Bonser-Neal, C., Tanner, G., 1996. Central bank intervention and the volatility of foreign exchange rates: evidence from the options market. Journal of International Money and Finance, Vol. 15, No. 6, 853-878

Catte, P., Galli G., Rebecchini, S., 1994. Concerted interventions and the dollar: an analysis of daily data. In: Kenen, Papadia and Saccomanni (Eds.) The International Monetary System, Cambridge University Press, Cambridge.

Chang, P.H.K., Melick, W.R., 1999. Background note. In: Estimating and Interpreting Probability Density Functions. Proceedings of the workshop held at the Bank for International Settlements on 14 June 1999.

Chang, Y., Taylor, S.J., 1998. Intraday effects of foreign exchange intervention by the Bank of Japan. Journal of International Money and Finance, Vol. 17, 191-210.

Connolly, R., Taylor, W., 1994. Volume and intervention effects of yen/$ exchange rate volatility, 1977–1979. In: Advances in Financial Planning and Forecasting, Vol. 5, JAI Press, Greenwich, Connecticut.

Coutant, S., Jondeau, E., Rockinger, M., 2001. Reading PIBOR futures options' smiles: The 1997 snap election. Journal of Banking and Finance, Vol. 25, 1957-1987.

Dominguez, K., 1990. Market responses to coordinated central bank intervention. Carnegie Rochester Conference Series on Public Policy, 32, 121-163.

Dominguez, K., 1993. Does central bank intervention increase the volatility of foreign exchange rates?. NBER Working Paper No. 4532.

Dominguez, K., 1997. The international evidence: an assessment of experience with foreign exchange intervention in the G-3. In: Fenton, P., Murray, J. (Eds.), Exchange Rates and Monetary Policy, proceedings of a conference hosted by the Bank of Canada, Ottawa.

Dominguez, K., 1998. Central bank intervention and exchange rate volatility. Journal of International Money and Finance, Vol. 17, 161-190.

Dominguez, K., 2003a. Foreign exchange market intervention: did it work in the 1990s?. In: Bergsten, C.F., Williamson, J. (Eds.), Dollar Overvaluation and the World Economy, Institute for International Economics, February.

Dominguez, K., 2003b. The market microstructure of central bank intervention. Journal of International Economics, Vol. 59, 25-45.

Dominguez, K., 2003c. When do central bank interventions influence intra-daily and longer-term exchange rate movements. NBER Working Paper No. 9875, July.

Dominguez, K., Frankel, J., 1993a. Does foreign exchange intervention work?. Institute for International Economics, Washington.

Dominguez, K., Frankel, J., 1993b. Does foreign exchange intervention matter? The portfolio effect. American Economic Review, December.

D'Souza, C., 2002. A market microstructure analysis of foreign exchange intervention in Canada. Bank of Canada Working Paper 2002-16, June.

Edison, H., 1993. The effectiveness of central bank intervention: A survey of the literature after 1982. Princeton University Special Papers in International Economics No. 18.

Eijffinger, S., Gruijters, N., 1991. On the short term objectives of daily intervention by the Deutsche Bundesbank and the Federal Reserve System in the US dollar/Deutsche mark exchange market. Kredit und Kapital, 24, March, 50-72.

Evans, M., Lyons, R., 2001. Portfolio balance, price impact, and secret intervention. NBER Working Paper No. 8356, July.

Fatum, R., 2000. On the Effectiveness of Sterilized Foreign Exchange Intervention. European Central Bank Working Paper No. 10.

Fatum, R., Hutchison, M.M., 2002. Is foreign exchange intervention an alternative to monetary policy? Evidence from Japan. Mimeo.

Fatum, R., Hutchison, M.M., 2003. Is sterilized foreign exchange intervention effective after all? An event study approach. Forthcoming in The Economic Journal.

Figlewski, S., 1997. Forecasting volatility. Financial Markets, Institutions & Instruments, 6(1), New York University Salomon Center.

Frankel, J., Engel, C., 1984. Do asset demand functions optimize over the mean and variance of real returns? A six-currency test. Journal of International Economics, 17, 309-23.

Frenkel, M., Pierdzioch, C., Stadtmann, G., 2002. Bank of Japan and Federal Reserve Interventions in the Yen/U.S. Dollar Market: Estimating the Central Banks' Reaction Functions. Mimeo, Kiel Institute of World Economics.

Frenkel, M., Pierdzioch, C., Stadtmann, G, forthcoming. The Accuracy of Press Reports Regarding the Foreign Exchange Interventions of the Bank of Japan. Journal of International Financial Markets, Institutions, and Money.

Funabashi, Y., 1988. Managing the Dollar: From the Plaza to the Louvre, Institute for International Economics, Washington.

Gaiotti, E., Giucca, P., Micossi, S., 1989. Cooperation in managing the dollar (1985–87): Interventions in foreign exchange markets and interest rates. Banca d'Italia, Temi di discussione del servizio studi, No. 119, June.

Galati, G., Melick, W.R., 2002. FX intervention and market expectations", BIS Economic Paper No. 10.

Galati, G., Tsatsaronis, K., 1996. The information content of implied volatility from currency options. In: Financial market volatility: measurement, causes and consequences, Bank for International Settlements, March.

Goodhart, C.A.E., Hesse, T., 1993. Central bank forex intervention assessed in continuous time. Journal of International Money and Finance, Vol. 12, 386-389.

Humpage, O., 1988. Intervention and the dollar's decline. Federal Reserve Bank of Cleveland Economic Review, 2, 2-16.

Humpage, O., 1999. US intervention: assessing the probability of success. Journal of Money, Credit and Banking, Vol. 31, No. 4.

Hung, J.H., 1997. Intervention strategies and exchange rate volatility: A noise trading perspective. Journal of International Money and Finance, Vol. 16, No. 5, 779-793.

Ito, T., 2003. Is foreign exchange intervention effective? The Japanese experiences in the 1990. In: Mizen, P. (Ed.), Monetary History, Exchange Rates and Financial Markets, Essays in Honour of Charles Goodhart , Vol. 2, Edward Elgar Publishers.

Jackwerth, J.C., 2000. Recovering Risk Aversion from Option Prices and Realized Returns. The Review of Financial Studies, 13(2), 433-451.

Jondeau, E., Rockinger, M., 2000. Reading the smile: the message conveyed by methods which infer risk neutral densities. Journal of International Money and Finance, Vol. 19, 885-915.

Jondeau, E., Rockinger, M. 2001. Gram-Charlier densities. Journal of Economic Dynamics and Control, Vol. 25, 1457-1483.

Kaminsky, G., Lewis, K., 1996. Does foreign exchange market intervention signal future monetary policy. Journal of Monetary Economics, 37, April.

Kearns, J., Rigobon, R., 2002. Identifying the efficacy of central bank intervention: the Australian case. NBER Working Paper No. 9062.

Klein, M., Rosengren, R., 1991. Foreign exchange intervention as a signal of monetary policy. Federal Reserve Bank of Boston New England Economic Review, May/June, 39-50.

Lewis, K., 1988. Testing the portfolio balance model: A multi-lateral approach. Journal of International Economics, 24, February, 109-27.

Lewis, K., 1995. Are foreign exchange market intervention and monetary policy related and does it really matter?. Journal of Business, 68, April.

Madan, D.B., Milne, F., 1994. Contingent Claims Valued and Hedged by Pricing and Investing in a Basis. Mathematical Finance, 4, 223-245.

Malz, A., 1996. Using Option Prices to Estimate Ex Ante Realignment Probabilities in the European Monetary System: The Case of Sterling-Mark. Journal of International Money and Finance, 15(5), May, 717-748.

Malz, A., 1997. Estimating the Probability Distribution of the Future Exchange Rate from Option Prices. The Journal of Derivatives, Winter, 20-36.

McCauley, R., Melick, W.R., 1996a. Risk reversal risk. Risk, Vol. 9, No. 11, November.

McCauley, R., Melick, W.R., 1996b. Propensity and Density. Risk, Vol. 9, No. 12, December.

McManus, D., 1999. The Information Content of Interest Rate Futures Options. Working Paper 99-15, Bank of Canada.

Melick, W.R., 1999. Results of the Estimation of Implied PDFs from a Common Dataset. In: Estimating and interpreting probability density functions, proceedings of the workshop held at the Bank for International Settlements on 14 June 1999.

Melick, W.R., Thomas, C.P., 1997. Recovering an Asset's Implied PDF from Option Prices: An Application to Crude Oil During the Gulf Crisis. Journal of Financial and Quantitative Analysis 32(1), March, 91-115.

Murray, J., Zelmer, M., McManus, D., 1997. The effect of intervention on Canadian dollar volatility. In: Fenton, P., Murray, J. (Eds.), Exchange Rates and Monetary Policy, proceedings of a conference hosted by the Bank of Canada, Ottawa, pp. 311-357.

Ramaswamy, R., Samiei, H., 2000. The yen/dollar rate: have interventions mattered?. IMF Working Paper WP/00/95, International Monetary Fund.

Rogoff, K., 1984. On the effects of sterilized intervention: an analysis of weekly data. Journal of Monetary Economics, Vol. 14, September.

Rubinstein, M., 1994. Implied Binomial Trees. Journal of Finance, 49(3), July, 771-818.

Sarno, L., Taylor, M., 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.

Shimko, D., 1993. Bounds of Probability. Risk, Vol. 6 (4), April, 33-37.

Schwartz, A., 2000. The rise and fall of foreign exchange markets intervention. NBER Working Paper No. 7751.

Stock, J., Yogo, M., 2002. Testing for Weak Instruments in Linear IV Regression. NBER Working Paper No. t0284.

Stock, J., Watson, M., 2003. Introduction to Econometrics. Addison Wesley.

Truman, E., 1994. Discussion. In: Kenen, P., Papadia, F., Saccomanni, F. (Eds.), The International Monetary System, Cambridge University Press, pp 248-254.

Truman, E., 2003. The Limits of Exchange Market Intervention. In: Bergsten, F.C., Williamson, J., (Eds.), Dollar Overvaluation and the World Economy, Institute for International Economics, February.

Weber, A., 1994: Foreign exchange intervention and international policy coordination: comparing the G-3 ad EMS experience. In: Canzoneri, M., Ethier, W., Grilli, V. (Eds.), The New Transatlantic Economy, Cambridge University Press, pp 54-113.

Fig. 1. Yen/dollar spot exchange rate, 1993-2000

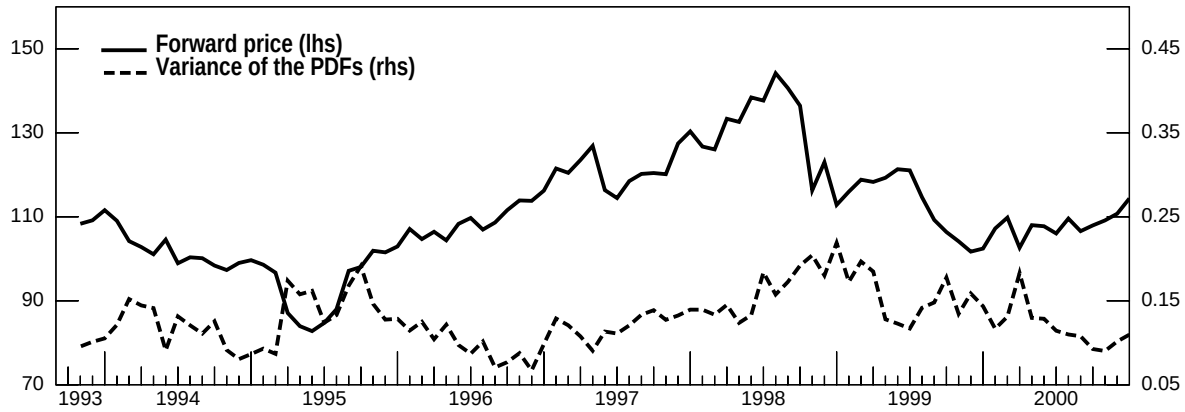

Fig. 2. Mean and variance of risk-neutral probability distributions, yen/dollar, 1993-2000

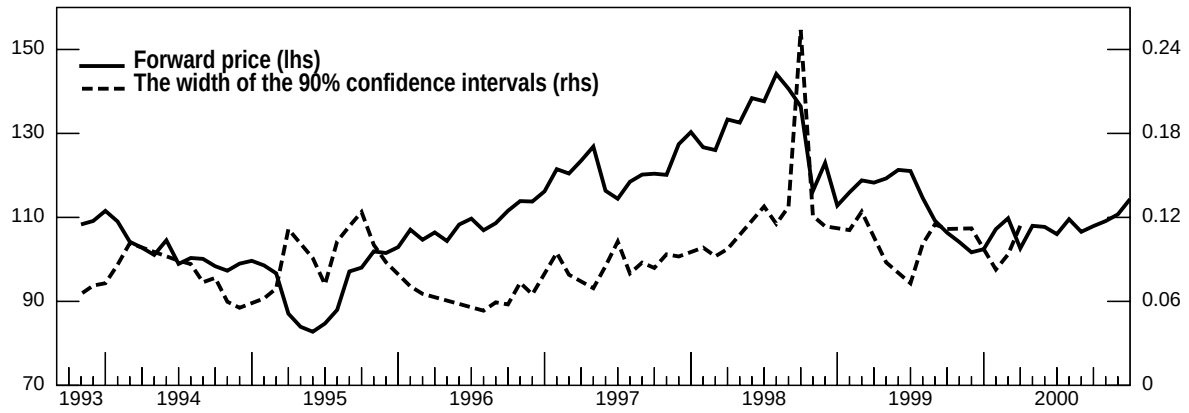

Fig. 2a. Mean and 90-10% quantile of risk-neutral probability functions, yen/dollar, 1993-2000

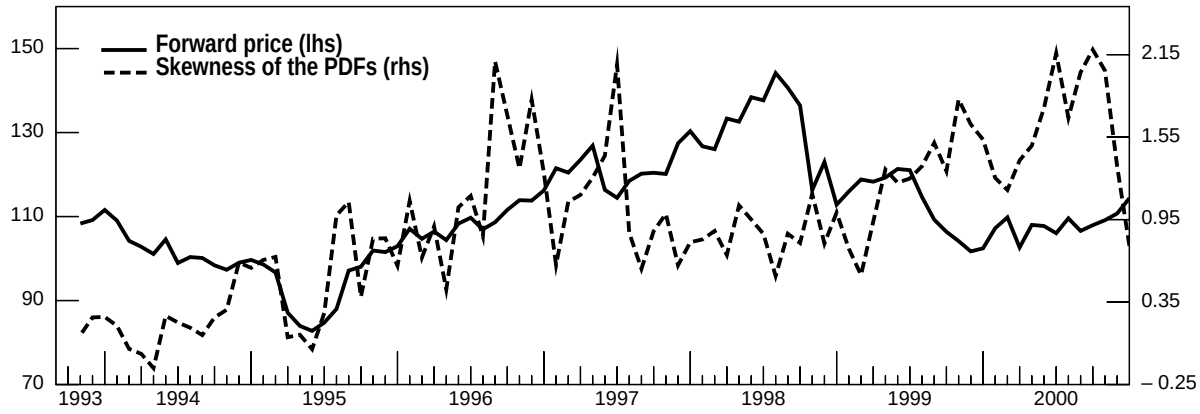

Fig. 3. Mean and skewness of risk-neutral probability distributions, yen/dollar, 1993-2000

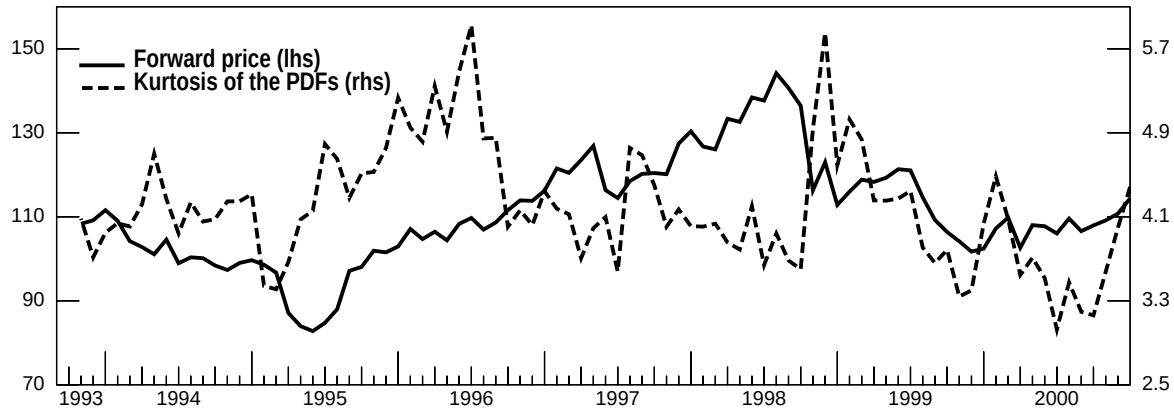

Fig. 4. Mean and the kurtosis of risk-neutral probability functions, yen/dollar, 1993-2000

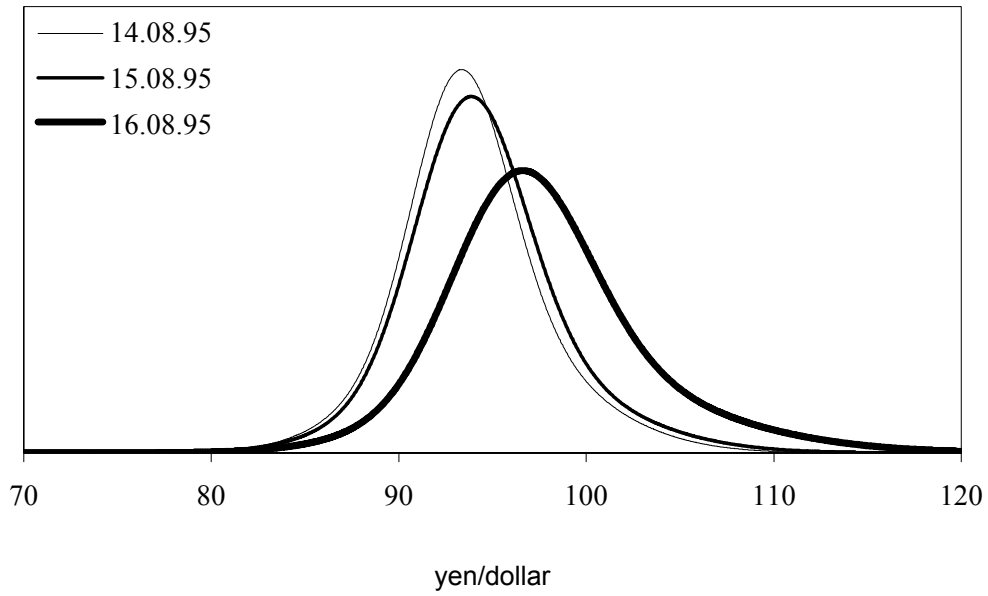

Fig. 5. Risk-neutral probability distributions of the yen against the dollar

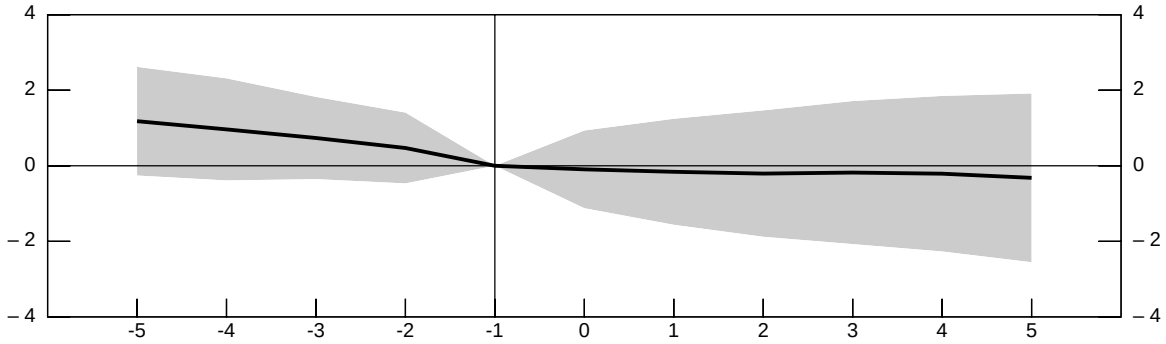

Fig. 6. Mean of the PDFs of the yen against the dollar around all official dollar purchases. Averages over 120 intervention episodes, 1993-2000.

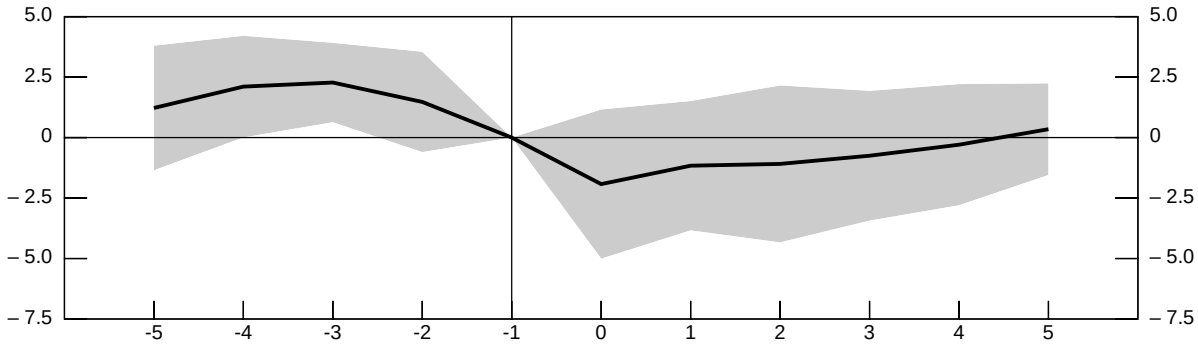

Fig. 7. Mean of the PDFs of the yen against the dollar around all official dollar sales. Averages over 6 intervention episodes, 1993-2000

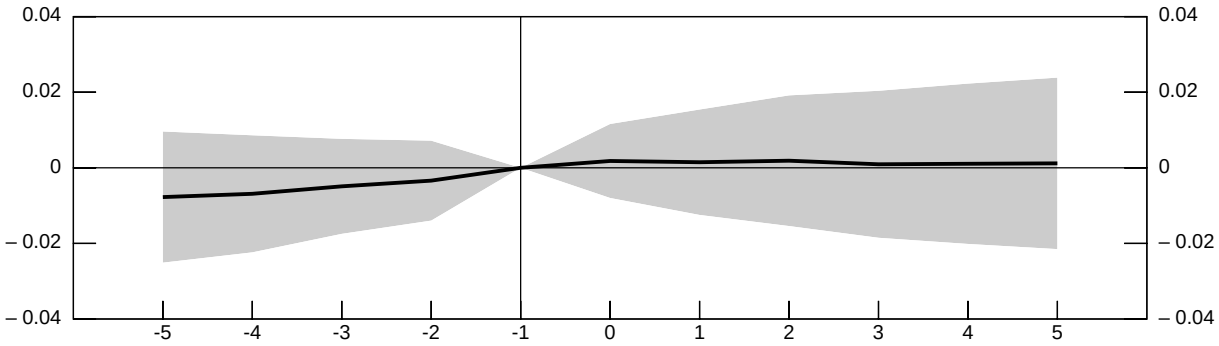

Fig. 8. Variance of the PDFs of the yen against the dollar around all intervention episodes. Averages over 126 episodes, 1993-2000

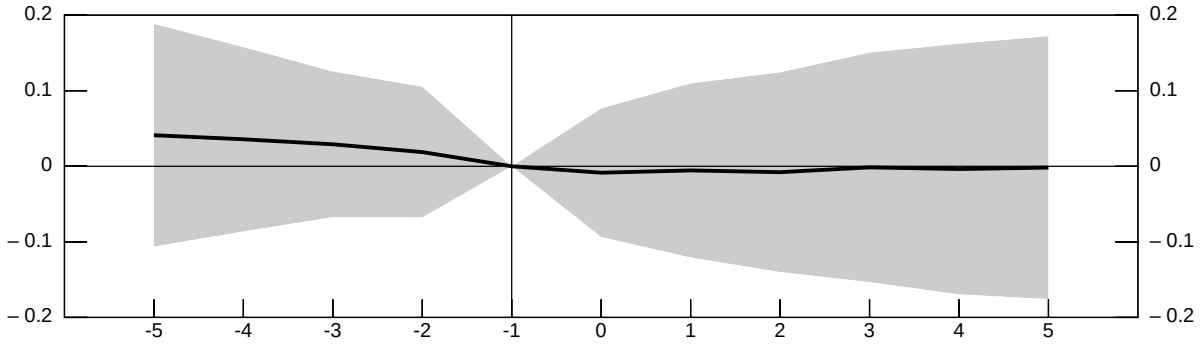

Fig. 9. Skewness of the PDFs of the yen against the dollar around all official dollar purchases. Averages over 120 intervention episodes, 1993-2000.

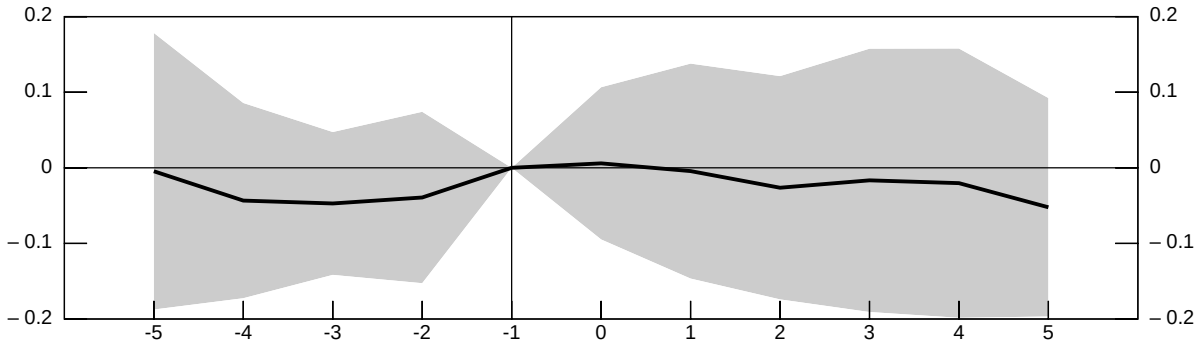

Fig. 10. Skewness of the PDFs of the yen against the dollar around all official dollar sales. Averages over 6 intervention episodes, 1993-2000

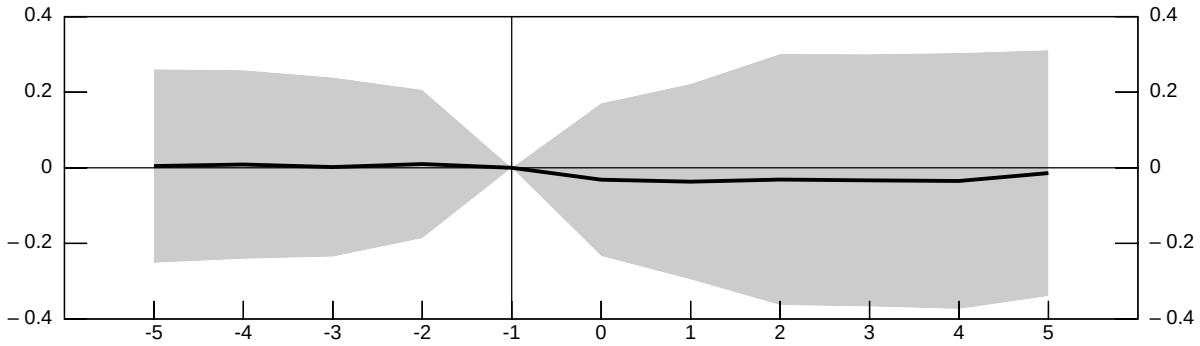

Fig. 11. Kurtosis of the PDFs of the yen against the dollar around all intervention episodes. Averages over 126 intervention episodes, 1993-2000

Table 1

Interventions in the yen/dollar market

	1993-2000		1993-1996		1997-2000	
	Official	**Perceived**	**Official**	**Perceived**	**Official**	**Perceived**
Number of intervention episodes	126	115	103	89	23	26
Unilateral	112	99	90	75	22	23
Coordinated	14	16	13	13	1	3
Bank of Japan	126	115	103	89	23	26
Federal Reserve	14	16	13	13	1	3
Officially announced	20	20	7	7	13	13
Discreet	106	95	95	82	10	13
Light	82	88	81	69	1	19
Heavy	44	27	22	20	22	7
Single-day	13	18	7	11	6	7
Repeated	113	97	96	78	17	19

Notes: Interventions are defined as light if they involved $ 1 billion or less and heavy otherwise. An intervention is classified as single-day if 5 days before or 5 days after no other intervention took place.

Sources: Federal Reserve, Japanese Ministry of Finance; Reuters.

Table 2

Implicit target ranges for the yen/dollar spot rate, 1993-2000

	Upper bound	Lower bound
13 July 1993-17 February 1994	104	125
18 February-4 April 1994	105	125
5 May-1 July 1994	102	125
2 July-17 August 1994	98	125
18 August-25 August	100	125
26 August-6 March 1995	99	125
7 March-3 April 1995	92	125
4 April-10 April 1995	88	125
11 April-27 June 1995	83	125
28 June-1 August 1995	86	125
2 August-5 September 1995	100	125
6-19 September 1995	105	125
20 September 95-19 February 96	100	125
20-29 February 1996	110	125
1 March 1996-10 April 1998	105	125
10 April 1998-9 June 1999	105	150
10-21 June 1999	120	150
11 June 1999-31 April 2000	105	150

Table 3A

Estimates of the reaction function for the Bank of Japan

	1993-2000			1993-1996			1997-2000		
Variable	**coeff.**	**t-stat.**	**Sig. level**	**coeff.**	**t-stat.**	**Sig. level**	**coeff.**	**t-stat.**	**Sig. level**
Constant	-41.76	-0.52	0.60	-15.44	-0.18	0.86	-114.79	-0.46	0.64
Spot $^{(H)}$	20.21	0.62	0.53	0.00	0.00	1.00	91.32	1.63	0.10
Spot $^{(L)}$	151.27	3.87	0.00	164.07	4.46	0.00	248.98	1.49	0.14
Variance $^{(H)}$	2287.09	1.66	0.10	525.97	0.22	0.83	9249.35	2.26	0.02
Variance $^{(L)}$	4698.81	3.24	0.00	4953.54	2.12	0.03	21040.56	4.57	0.00
Skewness $^{(H)}$	-108.20	-1.48	0.14	-153.31	-1.29	0.20	-60.82	-0.30	0.76
Skewness $^{(L)}$	-3.42	-0.04	0.97	2.47	0.02	0.98	-454.00	-1.29	0.20
Kurtosis $^{(H)}$	-66.45	-0.69	0.49	66.11	0.57	0.57	-574.97	-1.66	0.10
Kurtosis $^{(L)}$	-113.16	-1.20	0.23	-123.02	-1.06	0.29	-935.21	-2.87	0.00
R^2	0.10			0.18			0.14		
Number of obs.	1726			638			646		

Note: The table reports coefficients of a model estimated for the Bank of Japan intervention. It is estimated with OLS using daily data over the periods 20 September 1993 to 30 April 2000, 20 September 1993 to 28 February 1996 and 03 November 1997 to 30 April 2000. Explanatory variables are five lags of the distances of the spot rate and PDF moments from their targets when the dollar is appreciating (H) or depreciating (L), as defined in section 5.3. The coefficients on the lags two to five of the distances of the moments from their target values are generally not significant and not reported here for reasons of space.

Table 3B

Estimates of the reaction function for the Federal Reserve

	1993-2000			1993-1996			1997-2000		
Variable	**coeff.**	**t-stat.**	**sig. level**	**coeff.**	**t-stat.**	**sig. level**	**coeff.**	**t-stat.**	**sig. level**
Constant	0.61	0.15	0.88	5.00	0.56	0.58	8.53	1.32	0.19
BoJ interv. (t)	0.01	4.91	0.00	0.03	6.34	0.00	0.00	1.43	0.15
BoJ interv. (t-1)	0.00	0.43	0.67	0.01	1.72	0.09	0.00	0.14	0.89
Spot $^{(H)}$	0.88	0.52	0.60	0.00	0.00	1.00	0.96	0.66	0.51
Spot $^{(L)}$	-2.14	-1.05	0.30	-9.91	-2.58	0.01	0.16	0.04	0.97
Variance $^{(H)}$	21.90	0.31	0.76	29.15	0.12	0.91	11.64	0.11	0.91
Variance $^{(L)}$	-93.10	-1.24	0.22	-488.60	-2.01	0.04	-35.16	-0.29	0.77
Skewness $^{(H)}$	5.90	1.55	0.12	20.17	1.63	0.10	6.28	1.20	0.23
Skewness $^{(L)}$	0.58	0.13	0.90	5.89	0.47	0.64	-5.03	-0.55	0.58
Kurtosis $^{(H)}$	3.00	0.60	0.55	7.38	0.61	0.54	-3.23	-0.36	0.72
Kurtosis $^{(L)}$	8.38	1.72	0.09	26.29	2.18	0.03	4.54	0.54	0.59
R^2	0.09			0.17			0.06		
Number of obs.	1726			638			646		

Note: The table reports coefficients of a model estimated for the Federal Reserve intervention. It is estimated with OLS using daily data over the periods 20 September 1993 to 30 April 2000, 20 September 1993 to 28 February 1996 and 03 November 1997 to 30 April 2000. Explanatory variables are contemporaneous and lagged Bank of Japan intervention, and five lags of the distances of the spot rate and PDF moments from their targets when the dollar is appreciating (H) or depreciating (L), as defined in section 5.3. The coefficients on the lags two to five of the distances of the moments from their target values are generally not significant and not reported here for reasons of space.

Table 4

Estimates of the effect of intervention on the mean of the yen/dollar PDF

	1993-2000			1993-96			1997-2000		
	coeff.	**t-stat.**	**sign. level**	**coeff.**	**t-stat.**	**sign. level**	**coeff.**	**t-stat.**	**sign. level**
Intervention									
Contemp.	0.01	1.11	0.27	0.03	0.64	0.52	0.01	1.28	0.20
Cumulative	0.01	1.55	0.12	0.00	0.19	0.85	0.02	1.51	0.13
Macroeconomic announcements in the United States									
CPI	-11.08	-0.11	0.91	-5.92	-0.04	0.97	-72.47	-0.33	0.74
Ind. prod.	138.23	3.65	0.00	176.66	1.59	0.11	209.32	2.76	0.01
Trade bal.	3.33	0.56	0.57	4.31	0.44	0.66	-3.04	-0.25	0.80
Unemp.	-86.07	-1.32	0.19	-175.93	-1.94	0.05	-169.32	-1.01	0.31
Macroeconomic announcements in Japan									
Ind. prod.	2.58	0.77	0.44	7.39	1.02	0.31	24.67	1.15	0.25
Ret. Sales	-6.10	-0.87	0.39	-12.86	-1.07	0.29	-9.08	-0.73	0.47
Tankan	0.48	0.63	0.53	0.62	0.67	0.50	5.75	0.82	0.41
Announcements of changes in interest rates									
Federal Funds	21.71	0.81	0.42	23.67	0.59	0.56	20.04	0.47	0.64
JP Discount Rate	36.18	0.49	0.62	-18.43	-0.10	0.92	-	-	-
Days of the week effects									
Monday	2.84	0.43	0.67	-1.32	-0.12	0.90	8.90	0.62	0.54
Number of obs.	1720			633			641		

Note: The table reports the estimation results for equation (12). The equation is estimated using daily data. The dependent variable enters the regression equation in log-difference form.

Table 5

Estimates of the effect of intervention on the variance of the yen/dollar PDF

	1993-2000			1993-96			1997-2000		
	coeff.	**t-stat.**	**Sign. Level**	**coeff.**	**t-stat.**	**sign. level**	**coeff.**	**t-stat.**	**sign. level**
Intervention									
Contemp.	0.00	-0.12	0.91	0.02	0.19	0.85	-0.01	-1.56	0.12
Cumulative	-0.01	-0.89	0.37	0.01	0.43	0.67	-0.02	-1.11	0.27
Macroeconomic announcements in the United States									
CPI	-56.81	-0.52	0.60	-99.87	-0.74	0.46	-102.67	-0.35	0.73
Ind. prod.	84.02	1.99	0.05	149.06	0.55	0.58	131.22	1.62	0.11
Trade bal.	-6.86	-1.12	0.26	2.05	0.22	0.83	-24.72	-1.86	0.06
Unemp.	-14.42	-0.21	0.84	9.12	0.08	0.93	-147.18	-0.76	0.45
Macroeconomic announcements in Japan									
Ind. prod.	3.20	0.91	0.37	4.64	0.43	0.66	-2.41	-0.10	0.92
Ret. Sales	-4.52	-0.62	0.53	-9.62	-0.80	0.42	1.04	0.07	0.94
Tankan	0.10	0.12	0.90	0.35	0.39	0.70	-7.11	-0.93	0.35
Announcements of changes in interest rates									
Federal Funds	-12.61	-0.47	0.64	-4.61	-0.12	0.90	-11.45	-0.25	0.80
JP Discount Rate	4.78	0.07	0.95	-103.24	-0.27	0.79	-	-	-
Days of the week effects									
Monday	18.84	2.70	0.01	30.77	2.93	0.00	13.97	0.95	0.34
Number of obs.	1720			633			641		

Note: The table reports the estimation results for equation (12). The equation is estimated using daily data. The dependent variable enters the regression equation in first difference form.

Table 6

Estimates of the effect of intervention on the skewness of the yen/dollar PDF

	1993-2000			1993-96			1997-2000		
	coeff.	**t-stat.**	**sign. level**	**coeff.**	**t-stat.**	**sign. level**	**coeff.**	**t-stat.**	**sign. level**
Intervention									
Contemp.	-0.14	-1.01	0.31	-0.35	-0.59	0.56	-0.04	-0.42	0.68
Cumulative	-0.03	-0.29	0.77	-0.09	-0.48	0.63	-0.04	-0.39	0.69
Macroeconomic announcements in the United States									
CPI	1392.30	1.13	0.26	3302.39	1.80	0.07	646.53	0.32	0.75
Ind. prod.	-545.73	-1.15	0.25	128.60	0.10	0.92	-1162.4	-1.68	0.09
Trade bal.	-12.34	-0.17	0.87	105.15	0.92	0.36	-207.03	-1.88	0.06
Unemp.	-326.46	-0.40	0.69	-61.29	-0.06	0.95	-568.33	-0.37	0.71
Macroeconomic announcements in Japan									
Ind. prod.	-42.92	-1.02	0.31	78.73	0.93	0.35	-58.63	-0.30	0.76
Ret. Sales	-7.07	-0.08	0.94	-106.24	-0.76	0.45	-156.78	-1.38	0.17
Tankan	0.13	0.01	0.99	0.89	0.08	0.93	1.54	0.02	0.98
Announcements of changes in interest rates									
Federal Funds	-157.64	-0.47	0.64	-334.75	-0.73	0.47	-113.77	-0.29	0.77
JP Discount Rate	954.07	1.03	0.31	1980.19	0.87	0.38	-	-	-
Days of the week effects									
Monday	154.09	1.86	0.06	196.17	1.59	0.11	-23.80	-0.18	0.85
Number of obs.	1720			633			641		

Note: The table reports the estimation results for equation (12). The equation is estimated using daily data. The dependent variable enters the regression equation in first difference form.

Table 7

Estimates of the effect of intervention on the kurtosis of the yen/dollar PDF

	1993-2000			1993-96			1997-2000		
	coeff.	**t-stat.**	**Sign. Level**	**coeff.**	**t-stat.**	**sign. level**	**coeff.**	**t-stat.**	**sign. level**
Intervention									
Contemp.	-0.01	-0.05	0.96	0.00	0.00	1.00	-0.05	-0.59	0.55
Cumulative	0.14	0.76	0.44	-0.30	-0.66	0.51	0.08	0.53	0.60
Macroeconomic announcements in the United States									
CPI	-1415.9	-0.64	0.52	-5138.68	-1.18	0.24	-3517.74	-1.15	0.25
Ind. prod.	-169.54	-0.20	0.84	16.78	0.00	1.00	515.05	0.61	0.54
Trade bal.	-120.60	-0.96	0.34	-15.67	-0.05	0.96	159.76	1.16	0.25
Unemp.	-671.33	-0.47	0.64	-1854.75	-0.54	0.59	1080.25	0.54	0.59
Macroeconomic announcements in Japan									
Ind. prod.	-69.82	-0.96	0.34	-1.33	0.00	1.00	121.46	0.49	0.63
Ret. Sales	70.92	0.48	0.63	-113.79	-0.30	0.77	-37.41	-0.26	0.80
Tankan	11.04	0.70	0.48	14.36	0.52	0.60	34.23	0.43	0.67
Announcements of changes in interest rates									
Federal Funds	672.64	1.22	0.22	1909.16	1.58	0.11	165.86	0.35	0.73
JP Discount Rate	433.35	0.29	0.77	924.37	0.08	0.94	-	-	-
Days of the week effects									
Monday	-518.27	-3.63	0.00	-119.91	-0.36	0.72	-574.38	-3.76	0.00
Number of obs.	1720			633			641		

Note: The table reports the estimation results for equation (12). The equation is estimated using daily data. The dependent variable enters the regression equation in first difference form.