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DO OPTIONS-IMPLIED RND FUNCTIONS ON G3 CURRENCIES MOVE AROUND THE TIMES OF INTERVENTIONS ON THE JPY/USD EXCHANGE RATE?

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In 2004 all publications will carry a motif taken from the €100 banknote.

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Abstract

This paper focuses on changes in the currency options market's assessment of likely future exchange rate developments around the times of official interventions in the JPY/USD exchange rate. We estimate the options-implied risk-neutral density functions (RNDs) using daily OTC quotes for options prices with fixed moneyness that avoids the biases that typically characterise the exchange traded price quotes. We find that the episodes of interventions on the JPY/USD exchange rate coincide with systematic changes in all moments of the estimated RNDs on the JPY/USD currency pair, and in several of the moments of the estimated RNDs on the JPY/EUR and USD/EUR currency pairs. In particular, the operations where Japanese yen is sold coincide with a movement in the mean of the RND towards a weaker yen both against the US dollar and the euro, as well as with an increase in implied standard deviations. Prior to the interventions, the RNDs tend to move into opposite direction suggesting, on the average, increasingly unfavourable market conditions and leaning-against-the wind by the Japanese authorities.

Keywords: Foreign exchange market intervention, option-implied distributions, GARCH estimation

JEL-classification: E58, F31, F33.

Non-technical summary

Foreign exchange interventions are a tool that monetary authorities have available to address imperfections in the foreign exchange markets. However, despite the rather widespread use of FX interventions in certain economic areas, there is ample controversy about how, if at all, such market operations actually work in generating changes in exchange rates. Not surprisingly, therefore, previous work in the field, starting from the seminal Juergensen (1983) report, has failed to find conclusive evidence that interventions would in a systematic manner affect the daily spot exchange rate returns.

Earlier studies on FX interventions frequently suffered from data problems that originate from the tendency by policymakers not to disclose the timing and amounts of the FX operations. Over the past years, however, increased transparency regarding FX intervention activity has stimulated plenty of new research. In particular, the decision by the Japanese Ministry of Finance (MoF) to publish the daily statistics on the FX interventions that the Bank of Japan has carried out as an agent to the MoF provides an important source of information. Using the MoF data, Ito (2002) found that since the early 1990s the Japanese authorities have made large profits by buying US dollar low and selling it high in the open market operations. Moreover, Ito argues that over the daily horizon the interventions were capable of moving the JPY/USD spot exchange rate in the second half of the 1990s.

In this study, instead of analysing the daily changes in the spot exchange rate, we investigate the changes in the currency options market's assessment of future exchange rate developments around the times of official interventions. There are several reasons why focusing on the conditions on the options markets rather than changes in spot exchange rates is a more compelling approach. First, since FX interventions are often aimed at reducing future FX volatility over some time horizon ahead, it is natural to analyse how the market's assessment of likely future developments move around the time of the market operations. Second, by using data on the currency options prices that is inherently forward-looking we can extract information about the market's views regarding near-time exchange rate developments that covers all moments of the distribution. Third, since changes in the higher moments of the distribution are known to be more persistent than changes in levels, we can also study whether the options market's movements around the time of interventions last over the daily horizon. Finally, since most central banks today pursue a monetary policy strategy that takes a forward-looking perspective, analysing the changes in perceived future FX market conditions could be more relevant also from the monetary policy perspective.

Concentrating on the interventions by the Bank of Japan and the US Federal Reserve on the JPY/US dollar exchange rate, we assess how the options market's move around the time of interventions on the JPY/US dollar exchange rate. However, we also analyse the movements in prices of options on the JPY/EUR and US dollar/EUR exchange rates. In particular, we want to study whether the assessment on likely future movements on the JPY/EUR and US dollar/EUR exchange rates changes systematically around the episodes of interventions on the JPY/US dollar currency pair, in line with the triangular arbitrage condition. If the various moments of the RNDs on the JPY/US dollar rate move at the times of interventions on the JPY/US dollar rate, then the changed assessment regarding likely future movements in that currency pair should be reflected in the dynamics of the RNDs on the two cross-currency pairs as well. Finally, in addition to contemporaneous movements, we also look at both leading and lagging (persistent) effects to analyse whether the options implied distributions moved before and/or after the date of interventions.

Our main findings can be summarised as follows. The interventions on the JPY/US dollar exchange rate are preceded by clear and systematic changes in the options market's assessment on that currency pair, as reflected in the moments of the implied RNDs. In particular, the market has tended to price in a stronger (weaker) yen prior to yen-selling (purchasing) operations by the BoJ, suggesting that the market conditions could have become increasingly unfavourable prior to the interventions. Consequently, we find some evidence that the BoJ could be leaning-against-the-wind not only regarding the spot exchange rate as has been suggested by earlier studies, but regarding the market conditions more generally. Yen-selling interventions against the US dollar coincided with a movement in the mean of the RND on both JPY/USD and JPY/EUR exchange rates towards a weaker yen and an increase in the implied standard deviations. In contrast, we did not find evidence of the yen-selling operations coinciding with movements in the mean of the RND on the US dollar/EUR currency pair. The contemporaneous movements tend in many occasions to revert in the following day, suggesting that interventions have no systematic persistent impact on options implied moments. Finally, including as control variables the surprise components of the US macroeconomic data releases and the US and the euro area monetary policy decisions unearthed several systematic and persistent relationships with the implied RNDs.

1. Introduction

Foreign exchange interventions are a tool that monetary authorities have available to address imperfections in the foreign exchange markets. However, despite the rather widespread use of FX interventions in certain economic areas, there is ample controversy about how, if at all, such market operations actually work in generating changes in exchange rates. Not surprisingly, therefore, previous work in the field, starting from the seminal Juergensen (1983) report, has failed to find conclusive evidence that interventions would in a systematic manner affect the daily spot exchange rate returns.

Earlier studies on FX interventions frequently suffered from data problems that originate from the tendency by policymakers not to disclose the timing and amounts of the FX operations. Over the past years, however, increased transparency regarding FX intervention activity has stimulated plenty of new research. In particular, the decision by the Japanese Ministry of Finance (MoF) to publish the daily statistics on the FX interventions that the Bank of Japan has carried out as an agent to the MoF provides an important source of information. Using the MoF data, Ito (2002) found that since the early 1990s the Japanese authorities have made large profits by buying US dollar low and selling it high in the open market operations. Moreover, Ito argues that over the daily horizon the interventions were capable of moving the JPY/USD spot exchange rate in the second half of the 1990s.

The analysis of FX interventions is complicated by the fact that interventions are often conducted with differing objectives in mind. By intervening in the spot FX market, the policymaker may want to attempt to turn the ongoing trend of the exchange rate (leaning-against-the-wind), to enforce the ongoing trend (leaning-in-the-wind), or to try to reduce volatility in the FX market over some future time horizon. Interventions can also be of many different types. The policymaker may want to announce his presence in the market or to carry out the operation in secret. Interventions can be unilateral or multilateral; in the latter case they usually involve the monetary authority of the other economic area of the particular currency pair. Interventions can also differ in size, and their impact on the money market can be sterilized or not. In all these cases, the benchmark to measure the impact of the intervention on the spot exchange rate could be somewhat different, thus complicating the empirical assessment using data that comprises of intervention volumes only.

In this study, instead of analysing the daily changes in the spot exchange rate, we investigate the changes in the currency options market's assessment of future exchange rate developments around the times of official interventions. There are several reasons why focusing on the conditions on the options markets rather than changes in spot exchange rates is a more compelling approach. First, since FX interventions are often aimed at reducing future FX volatility over some time horizon ahead, it is natural to analyse how the market's assessment of likely future developments move around the time of the market operations. Second, by using data on the currency options prices that is inherently forward-looking we can extract information about the market's views regarding near-time exchange rate developments that covers all moments of the distribution. Third, since changes in the higher moments of the distribution are known to be more persistent than changes in levels, we can also study whether the options market's movements around the time of interventions last over the daily horizon. Finally, since most central banks today pursue a monetary policy strategy that takes a forward-looking perspective, analysing the changes in perceived future FX market conditions could be more relevant also from the monetary policy perspective.

Previous work analysing the interactions between FX interventions and movements in the currency options markets has typically focused on volatility implied by currency options prices. Bonser-Neal and Tanner (1996), Murray et al. (1997) and Dominguez (1998) all find evidence that interventions tend to be followed by increased implied volatility. Over the past decade, there has been a growing literature in deriving and exploiting measures of the entire distribution of risks around forward prices on various asset classes. Soderlind (2000), Bhar and Chiarella (2000), Mandler (2003) and Vahamaa (2004) all find that the risk-neutral density (RND) functions estimated from options prices on exchange rates, bonds and money market instruments tend to move around important events such as monetary policy changes. To our knowledge, however, the only work that combines the RND approach with analysis of FX interventions is Galati and Melick (2002). Using data on interventions on the JPY/US dollar and DEM/US dollar exchange rates, as well as data on currency options prices obtained from the Chicago Mercantile Exchange, they conclude that the impact of interventions varies considerably across episodes. In particular, while some individual interventions may have succeeded in affecting traders' assessment about future exchange rate movements, no statistically significant, systematic impact of interventions on the moments of the RNDs could be detected.

In this paper, we combine elements from the work by Galati and Melick (2002) and Ito (2002) and extend the analysis in several important dimensions. Concentrating on the interventions by the Bank of Japan and the US Federal Reserve on the JPY/US dollar exchange rate, we assess how the options market's move around the time of interventions on the JPY/US dollar exchange rate. However, we also analyse the movements in prices of options on the JPY/EUR and US dollar/EUR exchange rates. In particular, we want to study whether the assessment on likely future movements on the JPY/EUR and US dollar/EUR exchange rates changes systematically around the episodes of interventions on the JPY/US dollar currency pair, in line with the triangular arbitrage condition. If the various moments of the RNDs on the JPY/US dollar rate move at the times of interventions on the JPY/US dollar rate, then the changed assessment regarding likely future movements in that currency pair should be reflected in the dynamics of the RNDs on the two cross-currency pairs as well. Finally, in addition to contemporaneous movements, we also look at both leading and lagging (persistent) effects to analyse whether the options implied distributions moved before and/or after the date of interventions.

The data on the foreign exchange market operations that we use in our empirical investigation originates from the Japanese Ministry of Finance and the Federal Reserve Bank of New York, like in Ito (2002). The options data we use to calculate the risk-neutral density functions (RNDs) is over-the-counter (OTC) data from a large international bank. This consitutes the third major departure from the work by Galati and Melick (2002) who use exchange-traded options. Our choice is motivated by recent research suggesting that due to different quotation practices, the use of market traded options is complicated relative to OTC options for fixed-horizon forecasting purposes such as the density function estimation. In this sense, OTC data has been found to be of superior quality for volatility and density forecasting. In our estimations we also include as control variables real-time data on monetary policy and macroeconomic data releases. In this way the "news", or surprise component, measured by the difference between the expected and actual readings of a data release, can be appropriately accounted for. Information on expected data movements, that is captured by various polls and specific instruments such as interest rates futures, has become increasingly relevant amid the markets' tendency to price in future data releases before the figures are actually released.

Our main findings can be summarised as follows. The interventions on the JPY/US dollar exchange rate are preceded by clear and systematic changes in the options market's assessment on that currency pair, as reflected in the moments of the implied RNDs. In particular, the market has tended to price in a stronger (weaker) yen prior to yen-selling (purchasing) operations by the BoJ, suggesting that the market conditions could have become increasingly unfavourable prior to the interventions. Consequently, we find some evidence that the BoJ could be leaning-against-the-wind not only regarding the spot exchange rate as has been suggested by earlier studies, but regarding the market conditions more generally. Yen-selling interventions against the US dollar coincided with a movement in the mean of the RND on both JPY/USD and JPY/EUR exchange rates towards a weaker yen and an increase in the implied standard deviations. In contrast, we did not find evidence of the yen-selling operations coinciding with movements in the mean of the RND on the US dollar/EUR currency pair. The contemporaneous movements tend in many occasions to revert in the following day, suggesting that interventions have no systematic persistent impact on options implied moments. Finally, including as control variables the surprise components of the US macroeconomic data releases and the US and the euro area monetary policy decisions unearthed several systematic and persistent relationships with the implied RNDs.

The rest of this paper is structured as follows. Section 2 includes some stylised facts on FX interventions and discusses the data. Section 3 shows the results from estimated risk neutral density functions and verifies the accuracy of these estimations. The results from the assessment of movements of the various moments of the RNDs on the three exchange rates considered are reported in section 4, starting with graphical analysis and moving then to econometric estimation. Finally, using binary regression techniques we estimate whether the changes in the moments of the RNDs can explain the interventions carried out by the BoJ 1992-2003. Section 5 concludes.

2. Stylised facts and the options data

2.1. Institutional factors behind interventions and previous studies

Since the beginning of the era of floating exchange rates in the early 1970s, the exchange rates of the major currencies have principally been determined by the market forces. However, occasionally monetary authorities have attempted influence the supply and demand conditions in the FX market and manage the relative value of their currencies by resorting to foreign exchange market interventions. Almekinders (1995) suggests that the needs to intervene in the market are diverse and may vary over different time horizons. In the short term, as part of the commitment to promote exchange rate stability in the context of the IMF Article I as amended effective November 1, 1992, all central banks share the common objective of countering disorderly market conditions.[3] The medium-term objectives could relate to smoothing large or erratic fluctuations that exceed a certain size over a certain time horizon, or buying time for the monetary authorities to re-assess their policies. The long-term

[3] In the Juergensen (1983) report, "disorderly market conditions" are indicated by a substantial widening of the bid-ask spreads, large intra-day exchange rate movements, "thin" or highly uncertain trading, de-stabilising impacts of essentially non-economic shocks and self-sustaining exchange rate movements which may gain momentum of their own.

objectives of interventions vary from resisting exchange rate movements that are perceived unjustified given the underlying fundamental determinants of exchange rates, to attempts to provide some leeway for domestic monetary policy against the impact of imported shocks to price stability or price competitiveness. Finally, by using sterilised interventions in the FX markets the monetary authority may attempt to replenish depleted foreign currency reserves without generating downward pressure on the domestic currency.

Against this institutional background, the bulk of the academic work on foreign exchange market interventions in major currencies has tended to focus on the question of "effectiveness" of the FX market operations against the background of some pre-specified objective that the monetary authorities are assumed to be pursuing. In this context, it has been common to classify interventions according to what the perceived aim of the particular operation might have been, and whether the subsequent development of the spot exchange rate corresponds to those particular "goals." The operations have commonly been judged as "leaning-against-the-wind" if they involved purchasing of a currency that was under a depreciating trend. In contrast, the interventions are titled as "leaning-in-the-wind" if the operations involved selling the depreciating currency. The "effectiveness" or "success" of the intervention has then typically been assessed against whether the spot exchange rate did, at least in the short run, either change the direction or accelerate its past trend. Needless to say, generalising such assessments has typically attracted a great deal of controversy, not least due to the vast daily trading volumes in the FX market relative to the intervention trades and the random walk nature of the daily spot exchange rate changes.

Traditionally, three distinct channels of transmission for FX interventions have been considered in the literature. The *monetary channel* suggests that by not sterilising the money market effects of its foreign currency operations the central bank aims at using the FX interventions to bring about a change in the domestic monetary policy stance. In practice, the monetary channel tends to be identified by the notion of whether or not interventions are accompanied by an explicit change in the domestic interest rates. The *portfolio channel* of interventions makes a difference between sterilised and unsterlised operations in so far as domestic and foreign assets are considered imperfect substitutes. In particular, monetary authorities may induce the investors to demand a higher expected return on the asset whose outstanding stock has increased, thereby leading to a change in exchange rates even when the domestic money market effects are sterilised. Finally, the proponents of the *signalling channel* of the interventions argue that even with no notable impact on the relative prices of domestic and foreign assets in the market, intervention can be effective in providing information about the monetary authority's view regarding the prevailing exchange rate trends. The seminal work by Dominguez and Frenkel (1993 a, b) and the subsequent literature including Lewis (1995), Kaminsky and Lewis (1996) and Bonser-Neal, Roley and Sellon (1998) provides evidence of effectiveness of the portfolio and signalling channels. However, as suggested by Sarno and Taylor (2001), over the years a consensus has emerged that for developed markets the portfolio channel may have became less relevant, given that the average size of the interventions has fallen increasingly short of the overall daily turnover in the FX market. On the other hand, the signalling channel continues to be subject to active research with recent efforts to quantify the impacts of oral statements by policymakers that do not necessarily involve any market transactions at all (see Fratzscher, 2004).

Over the past decade, the general increase of interest in research in volatility and expected future exchange rate movements has contributed to a large number of studies on the interaction between interventions and volatility. In particular, it has been argued that in many cases the objective of the interventions has been to reduce volatility, rather than to attempt to turn the trend. In that context, Bonser-Neal and Tanner (1996), Murray et al. (1997) and Dominguez (1998) resorted to implied volatility extracted from currency options prices to obtain information about the options market's assessment of the future exchange rate volatility. The general empirical consensus (see also Beine, Benassy-Quere and Lecourt, 2002) seems, however, to support the observation that interventions in most cases increase rather than decrease market volatility in the short run. This finding, together with the observation that despite the perceived merits of the signalling channel FX interventions have often been conducted in secret, has provided support to the exchange rate *order flow* as yet another channel for FX intervention (see Lyons, 2001, and Evans and Lyons, 2002). According to that view, the monetary authority could in fact achieve a higher success rate by "hiding" its operations in the FX market rather than exploiting the signalling channel. This is because central banks are known gradually over time to reverse the intervention trades in order to balance their accounts. Under rational expectations an expected future reversal would then induce no price reaction in the market. In contrast, the arrival of a large, but unidentified trade in the FX market creates perceptions of private information that induces the traders to jump the bandwagon and bid up the exchange rate. Along this line of reasoning, an intervention would generally be followed by increased volatility in the exchange rate.

Reflecting these considerations, Galati and Melick (2002) argue that foreign exchange interventions could more recently have been aimed at the current and future variability of the exchange rate. In particular, the general awareness of the limited ability to influence the levels of the spot exchange rates by means of interventions, as well as the increased need among central banks to guide market sentiment in the context of forward-looking monetary policy strategies, could support such a view. However, despite some evidence based on case studies, Galati and Melick find no systematic, statistically significant impact of interventions on options market's assessment of future FX movements as measured by the moments of the implied distributions. This result is somewhat in contrast with Bhar and Chiarella (2000), Mandler (2003) and Vahamaa (2004) who look at changes in RNDs on money market instruments and bond yields around the times of monetary policy decisions and find systematic changes in distributions around the times of interest rate changes.

2.2. The data

Until recently, a frequent problem in measuring the impact of foreign exchange interventions has been the lack of reliable and generally accessible data on daily central bank operations. The tendency towards increased transparency among the major central banks throughout the last decade has provided a significant improvement in this respect.

The FX intervention data used in our empirical investigation originates from two different sources. The data on Japanese interventions was downloaded from the website of the Japanese Ministry of Finance that provides data on daily operations form 1991 onwards. The data on US Federal Reserve interventions was obtained from the Federal Reserve Bank of New York Quarterly Foreign Exchange Reports. Regarding the data on currency options prices we use over-the-counter (OTC) data from Citigroup that is quoted at noon London time. As control variables, we include data on news on unanticipated changes in the the US and euro area monetary policy as calculated using figures from the Reuters' polls taken prior to the relevant central bank meetings. In addition, we consider news on macroeconomic data releases covering the GDP, unemployment rate and business sentiment in the US. The source of the latter data is MMS International.[4]

Given the focus of our investigation, the choice of the options data warrants some discussion. Traditionally, the bulk of trading in options is on OTC basis and not at a centralised futures/options exchanges. Christensen, Hansen and Prabhala (2001) and Christoffersen and Mazzotta (2004) argue that in terms of forecasting properties, OTC options data tends to be of superior quality relative to exchange traded options. This is because OTC prices are quoted

[4] Previous studies on the impact of macroeconomic news on financial market variables has found that US data releases tend to dominate the financial market reactions also outside the US (see for example Ehrmann and Fratzscher, 2004). The survey data for US data releases is also more readily available for the sample period covered in this study.

daily with fixed “moneyness“ (the distance between the forward rate and the option’s strike price) in contrast with market-traded options, which have fixed strike prices and thus time-varying moneyness as the forward exchange rate changes. This time-varying moneyness complicates the use of market-traded options for estimating risk-neutral density functions in that the effective support of the distribution is changing over time. Moreover, the trading volume in OTC options is often much larger than in the corresponding market traded contracts. The underlying liquidity on OTC quotes is therefore deeper, which makes the OTC quotes a more reliable source for information extraction. The fact that the currency options market is heavily concentrated on a few global players does that the liquidity problems can be reduced further if data from these institutions is available. Citigroup, that is the source of the data used in this study, has a significant market share both in options on major exchange rates as well as on the emerging currencies.

The options data used in this study consist of 1-month implied volatility, 1-month risk reversals and 1-month strangles. Implied volatility is the market’s forecast for future exchange rate volatility that can be extracted from options prices as will be described in more detail below. Risk reversals and strangles in turn are standardised options contracts consisting of combinations of different types of options. Risk reversal is an options strategy where an investor simultaneously purchases an out-of-the-money call option and sells an out-of-the-money put option on a given currency. A positive price of a risk reversal means that the call option is valued higher than the put option by the market as a whole, thereby implying that the implied distribution has positive skewness. A strangle is a strategy of consisting of a simultaneous purchase of an out-of-the-money put and an out-of-the-money call option on the underlying exchange rate, in anticipation of a large movement in the exchange rate in any one direction.

3. Estimated implied risk neutral density functions

3.1. Methodology

There are several ways of deriving information about future changes in asset prices. For example, bonds and futures can be used to extract point estimates for the expected future values of interest rates, exchange rates, inflation rates and commodity prices. However, the most accurate view of the market’s assessment of the likely future developments in market conditions is provided by options prices that implicitly capture the entire distribution around point estimates, such as forward exchange rates. A straightforward use of option prices is the calculation of implied volatility that measures the degree of uncertainty that the market attaches to the future return on an asset. Implied volatility can be backed out from observed options prices by inverting the Black and Scholes options pricing formula where the only unobserved variable is the market's view on future volatility. With a range of strike prices (agreed future payoff prices on the options), the entire Black and Scholes volatility smile function can be derived that plots the levels of implied volatility for any given strike price. Form the volatility smile it is, in turn, possible to estimate the probability density function for future prices of the underlying asset.

An important characteristic of the analyses based on the Black and Scholes approach is that the resulting probability densities represent the risk neutral distribution, *i.e.* they abstract from possible risk premium considerations. Therefore, the risk-neutral density approach does not allow for distinguishing the expectation component from the role played by changes in the investors' attitude towards risk. Despite the rather widely used quotation of "expectations" in the RND literature (see *e.g.* Soderlind, 2000, Bhar and Chiarella, 2002, Galati and Melick, 2002, and Vahamaa, 2004), strictly speaking the RND approach does not measure the impact on expectations but on market conditions more generally. Hordahl and Vestin (2003) derive methods to incorporate risk in the markets' probability distribution function and find that the role of the time-varying risk premium is potentially important in driving a wedge between the true density and the risk-neutral densities. However, the estimation of the risk premia using their methodology presupposes a specification of a dynamic model for the forward exchange rate, which is beyond the scope of this exercise.

The literature has suggested several approaches to estimate the risk-neutral volatility smile and the risk-neutral density function. Methods based on stochastic processes make an assumption on the model driving the underlying asset price to derive the necessary parameters for estimation. For instance, Hordahl (1999) applied the Longstaff-Schwartz model to Swedish interest rates. Another approach introduced by Rubinstein (1994) uses non-parametric Bayesian techniques to construct a binomial tree for the value of the underlying asset. The approximating function approach applies different functions that are minimised to find the necessary parameter values. Among these studies, the most common technique is to exploit the assumption that financial time series are lognormally distributed and estimate the density function as a weighted average of two fitted lognormal density functions (see Melick and Thomas, 1997, Bahra, 1997, and Bliss and Panigirtzoglou, 2004 for reviews of the method). This method requires data for minimum five different strike prices that can be used to fit the volatility smile in the strike price-volatility space. As an alternative to the two-lognormal method Madan and Milne (1994) use Hermite polynomials. Finally, the implied volatility smile smoothing approach developed by Malz (1997) does not assume that the underlying price process is lognormal but uses lower-order polynimial functional forms to fit the implied volatility smile. Since it can be applied using three data points only, the Malz method is particularly suitable for currency options where specific standardised options contracts are available. Campa, Chang and Reider (1997) performed an analytical comparison of different implied RND estimation methods and did not find conclusive evidence of large differences across the results. On the other hand, Bliss and Panigirtzoglou (2000) focused on the two-lognormal and Malz methods to evaluate the reliability of the respective estimated implied RNDs and their associated summary statistics. Their results provide strong evidence of superior stability of estimates obtained using the Malz method.

In what follows, we estimate the RNDs using the Malz method. The technique builds on a result by Breeden and Litzenberger (1978) where the implicit distribution function (denoted below with *g*) that is contained within option prices can be recovered by calculating the second partial derivative of the Black and Scholes call option price function *c* with respect to the strike price *K:*

$$\frac{\partial^2 c}{\partial K^2} = e^{-r\tau} g(S_T) \tag{1}$$

In (1), r and τ are the risk-free interest rate and the maturity of the option, respectively. In theory, this result requires a continuum of option prices with differing strike prices which is not available for the researcher. Therefore, interpolations and extrapolations have to be used as an approximation. Specifically, the Malz technique interpolates across implied volatilities using the Black & Scholes delta that measures the rate of change of the option price with respect to the underlying exchange rate. The delta has to pass through the points on the volatility smile given by the observed quotes:

$$\Sigma(\delta) = atm - 2rr(\delta - 0.5) + 16str(\delta - 0.5)^2 \ . \tag{2}$$

In (2), $\Sigma(\delta)$ denotes the interpolated volatility smile, *atm* denotes the "at-the-money implied volatility", *i.e.* implied volatility of an option whose strike price equals the forward exchange rate, *rr* denotes risk reversal and *str* is the acronym for strangles. Since the option's delta is a function of the strike price and volatility, we can express volatility as $\sigma = \Sigma\left[\delta(\sigma, K)\right]$. Solving this equation gives the volatility as a function of the strike price. Since the Black &

Scholes formula provides the option prices with respect to the strike price and volatility (which is now also a function of the strike price), the option price only depends on the strike price. This result enables us to compute the second derivative of the call option price function as in (1).

3.2. Results from estimated RNDs

The results here are reported by first plotting the RNDs, estimated using the Malz method, for various currencies for selected dates. While such results are very useful in terms of illustrativeness, we also want to know how relevant the obtained results are. We therefore test the estimated RNDs to evaluate their accuracy, particularly regarding the behaviour of the tails of the distribution.

3.2.1. Estimated RNDs around selected intervention episodes: a case study approach

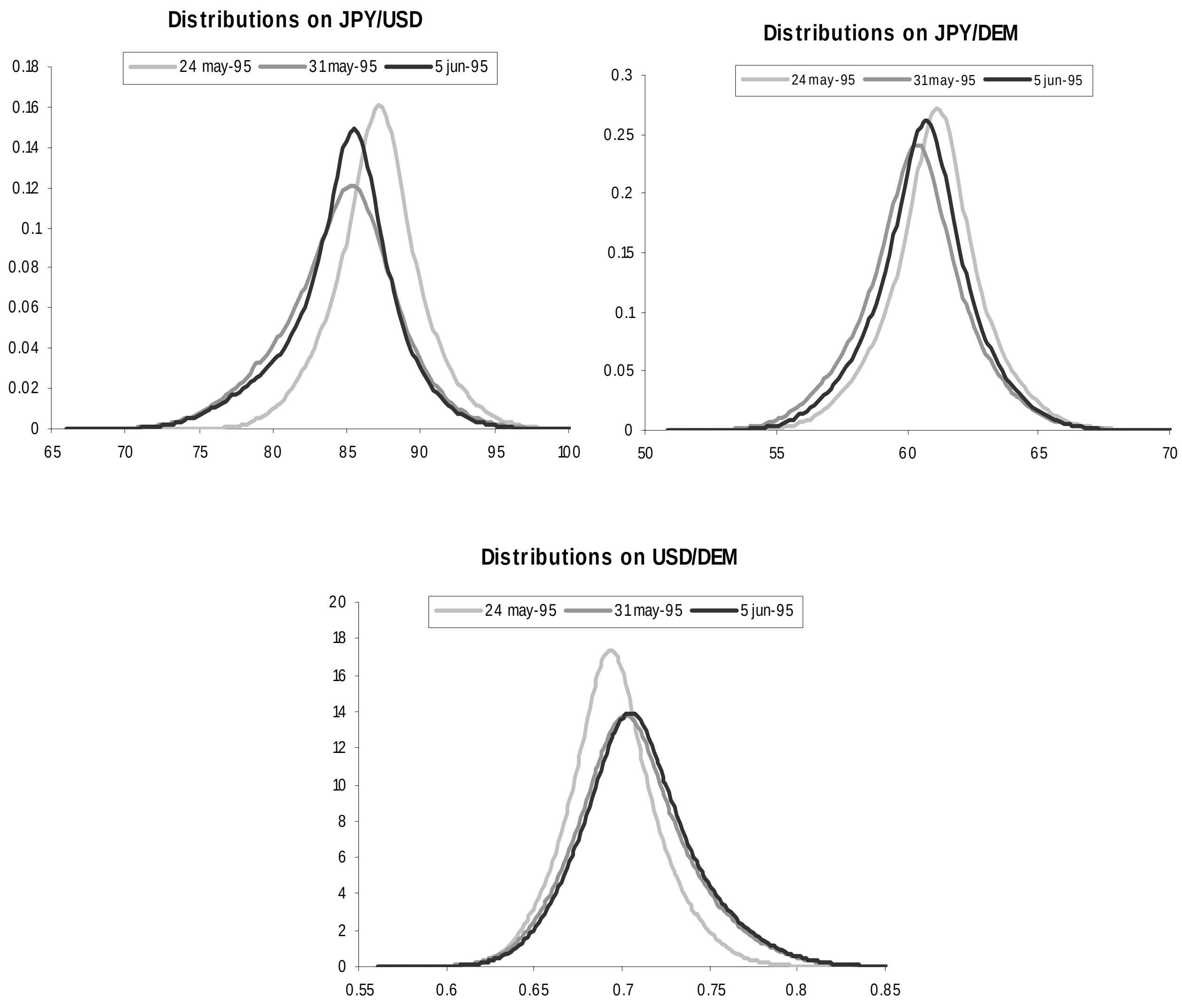
As an example of the changes to the expectations that have taken place around the time of interventions on the JPY/US dollar exchange rate, Chart 1 illustrates the entire RND functions for the JPY/US dollar, JPY/DEM and US dollar/DEM exchange rates a few days before and after a joint JPY selling (US dollar purchasing) operation by the BoJ and the Fed on 31 May 1995. It can be seen that the shapes of the distributions changed considerably within this time interval, both regarding the width and the symmetry of the functions.[5]

Days before the interventions the RNDs on the JPY/US dollar currency pair were almost symmetric showing no particular uncertainty as measured by large standard deviation, or expectations on directional moves as measured by skewness (asymmetry). However, in the run-up to the intervention day the forward exchange rate moved towards a stronger expected yen (leftwards). Moreover, the RND became characterised by high standard deviation and sharp skewness to the left (towards further expected yen appreciation). A few days after the yen-selling/US dollar-purchasing interventions the RND had moved back to the right (towards a weaker yen) and the skewness was clearly reduced. Over the same time period, prior to the intervention, the RND on the JPY/DEM exchange rate also moved to the left (towards a stronger expected yen), with increasing standard deviation. Days after the yen-

[5] The horizontal axes of the RND functions illustrate the 1-month forward exchange rate. Movements to the right in the bilateral JPY forward rates illustrate weaker expected yen, while a similar movement in the case of the US dollar/DEM forward rate shows a weaker expected US dollar.

selling operation the RND had moved to price in a stronger D-mark against the Japanese currency. Regarding the RND on the US dollar/DEM rate, prior to the US dollar purchasing intervention it moved towards a weaker expected US dollar (rightwards) with heightened standard deviation and skewness to the right. Days after the operation, however, the US dollar depreciated slightly further against the euro.[6]

Chart 1: Interventions on JPY/USD: May 1995



[6] The graphical examination of the RNDs can be extended to the density bands that illustrate the evolution of the percentiles of the distribution around the 1-month forward rate over time (typically the 10th, 30th, 50th, 70th and 90th percentiles are included). When carrying out this exercise we found that the bands remain rather stable around the 1-month forward exchange rate throughout the sample period. This would suggest that extreme changes in the probability distributions are rather rare events in the currency options market, at least for the major exchange rates.

Appendix 1 reports the statistics of the Christoffersen-Mazzotta test procedure that was applied to verify the accuracy of the estimated RNDs. Overall, the tests suggest that while the fit of the estimated density functions is generally good within the 70th percentiles of the distribution, the tails are not always well specified. This result could partially reflect the fact that in many cases there is insufficient number of very small and very large observations in the sample, and that the Malz method may lack power at the far ends of the distribution tails. Christoffersen and Mazzotta (2004) conduct a more thorough evaluation of the options-based indicators for the major currency pairs using data from 1992-2003 and find that the risk neutral density forecasts are generally reliable when the extreme percentiles are excluded from the assessment.

3.2.2. The estimated moments

Movements in the entire distribution functions provide interesting snapshots to changes in exchange rate expectations. However, to gauge information about any systematic impacts on the expectations it is more useful to resort to changes in the implied moments: the mean, standard deviation, skewness and kurtosis. By focusing on the moments we can also analyse whether the movements in various cross-currency pairs are correlated with each other, as could be expected on the basis of the triangular arbitrage condition. Appendix 2 shows graphical plots of the various moments for all currency pairs covered in this study.

The mean of the RND is the one-month forward exchange rate. Since the forward rate is constructed by augmenting the spot exchange rate by the interest rate differential, it provides a measure of expected exchange rate movement that is consistent with the uncovered interest rate parity (UIP) condition. Table 1 illustrates the correlation among implied moments across currency pairs. The forward exchange rates (means) are not particularly strongly correlated, perhaps apart from the two bilateral euro exchange rates where a positive correlation coefficient of 0.67 is obtained.

Implied standard deviation of the RNDs provides a measure of the overall uncertainty prevailing at the market regarding the movements in the exchange rate over the lifetime of the underlying options. Two RNDs with the same mean and equally symmetric shape but differing standard deviations would indicate that the market regards the outlook more uncertain in the case where higher standard deviation is encountered. The implied standard deviations between the JPY/US dollar and the JPY/EUR RNDs are quite highly correlated (with coefficient value of 0.81), suggesting that uncertainty tends to spill over from one JPY bilateral exchange rate to another.

Table 1: Correlations across implied moments

		USD/JPY	JPY/EUR	USD/EUR
Means	USD/JPY	1		
	JPY/EUR	0.353825	1	
	USD/EUR	-0.457671	0.663631	1
Stdev	USD/JPY	1		
	JPY/EUR	0.809257	1	
	USD/EUR	0.01432	0.338184	1
Skew	USD/JPY	1		
	JPY/EUR	0.283854	1	
	USD/EUR	-0.280659	0.247977	1
Kurt	USD/JPY	1		
	JPY/EUR	0.616523	1	
	USD/EUR	0.436421	0.423594	1

Implied skewness, being a measure of asymmetry of the estimated RNDs, provides information on the direction of expectations regarding future exchange rate movements. In particular, large changes in implied skewness could indicate that the market's assessment on the probability of future appreciation or depreciation of a particular currency has changed, based on some fundamental or non-fundamental news. The series for implied skewness derived from the RNDs on the JPY exchange rates fluctuate around zero most of the sample period, while the implied skewness on the US dollar/EUR RNDs is positive on average. This would suggest that over time, the options markets tends to have assigned a slightly higher probability on the future euro appreciation rather than depreciation vis-à-vis the US dollar. Table 1 suggests no correlation among skewness across the currency pairs involved in our study.

Finally, implied kurtosis provides a measure of the market's expectations of extreme events, by measuring the length of the tails of the RND function. The series on all currency pairs show moderate excess implied kurtosis, meaning that the implied RNDs are leptokurtotic and demonstrate long tails. In this respect, there seems to be no marked difference between the

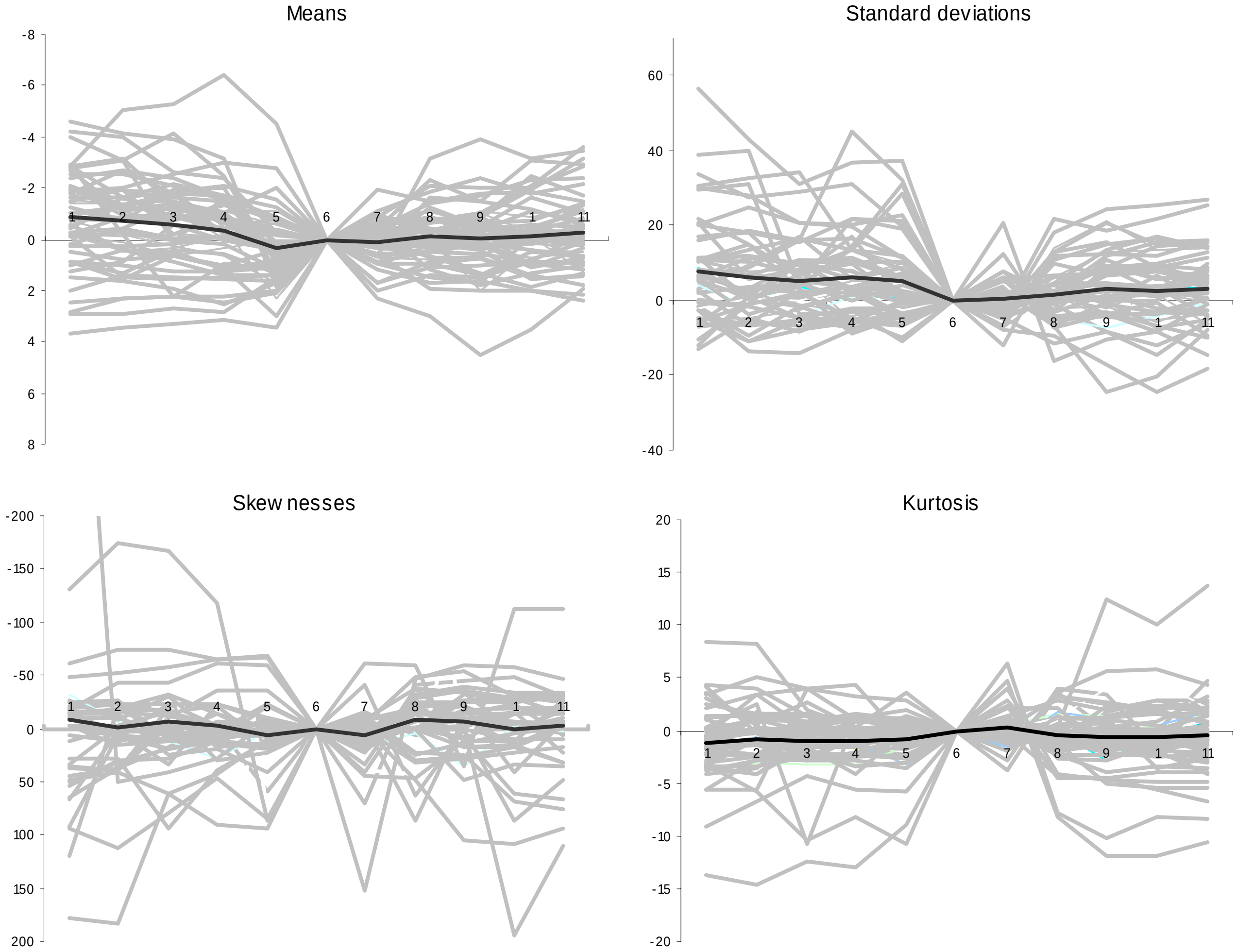
JPY exchange rates and the US dollar/EUR currency pair. Furthermore, there are no signs of particularly high correlation on implied kurtosis across the exchange rates.[7]

4. Interventions on the JPY/US dollar currency pair and movements in RNDs on G3 exchange rates

In this section we introduce the intervention data and combine that with the data on the implied moments of the RNDs. The particular questions we want to ask are: have the Japanese and the US interventions coincided with movements in the RNDs and their moments on the G3 exchange rates? Have the movements in RNDs around the time of interventions turned persistent, and has the options market moved prior to the interventions? Before proceeding to the empirical investigation, we first graphically illustrate how the individual moments of the RNDs on the JPY/USD currency pair change around intervention episodes. Chart 2 plots the percentage changes in the implied moments 1, 2, 3, 4 and 5 days prior to and after the operations (day 6 denotes the day of intervention). In an average episode, the mean and the implied skewness of the RND moved towards a stronger expected yen a day before a yen-selling intervention. After the operations, the average movements were rather small. However, the movements in the moments differed quite markedly between the episodes.

[7] However, as stressed by Bliss and Panigirtzoglou (2000), estimates of kurtosis are not always reliable when they are obtained using a limited number of options contracts and should therefore be interpreted with caution. This would most likely apply to our results as well, as suggested by the results from the Christoffersen-Mazotta tests reported above.

Chart 2. Changes in moments of the RNDs on JPY/USD around interventions



4.1. The estimated model

The empirical models assessing the impact of official interventions on exchange rates have traditionally focused on the monetary channel (in the case of unsterilised interventions) or portfolio channel (in the case of sterilised interventions). Along these lines, temporary disequilibria in money and bond markets that are caused by the changed relative supply and demand of domestic and foreign assets induce exchange rate adjustments so as to restore the equilibrium conditions. As an illustration, let S_i denote the spot exchange rate on currency pair i, with a higher S_i illustrating appreciation of the home currency against the foreign currency. In a simplified form, the exchange rate can be assumed to be determined by the domestic and foreign money supplies (M and M^*, respectively) and the relative supply of domestic and foreign bonds (B and B^*, respectively), with asterisks denoting foreign variables:

$$S_i = f\,[M(-), M^*(+), B(-), B^*(+)] \qquad (3)$$

An unsterilised intervention where domestic currency is sold against a foreign currency amounts to an increase in the domestic money supply relative to foreign money supply. On the other hand, a sterilisation of an intervention where domestic currency is sold against the foreign currency would leave domestic money supply unchanged while increasing the supply of domestic bonds relative to foreign bonds. In either case, in the process of portfolio re-balancing private investors dispose of some of their holdings of domestic money or bonds while increasing their holdings of foreign assets. This process generates a rise of domestic interest rates, a fall in foreign interest rates, and a depreciation of the domestic currency vis-à-vis the foreign currency until the equilibrium is restored.[8]

How is intervention transmitted to the moments of RND? To see this, recall first that the mean of the RND (the 1-month forward exchange rate) is defined as $R_{t,T} = S_t\, e^{(r-r^*)\tau}$, the price on period t of a claim deliverable on period T, where r and r^* are the domestic and foreign risk-free interest rates, respectively, and $\tau = T-t$ is set at 1 month. The higher moments are then defined as $\mu_t^n = \int_0^\infty (K - R_{t,T})^\tau g(K)dK$, with g denoting the implied distribution and K the strike price of the option. Thus, we can define implied standard deviation (the second moment) as $\hat{\sigma}_t \equiv \sqrt{\frac{\mu_t^{(2)}}{\tau}}$, implied skewness (the third moment) as $\hat{\zeta}_t \equiv \frac{\mu_t^{(3)}}{(\mu_t^{(2)})^{\frac{3}{2}}}$, and implied kurtosis (the fourth moment) as $\hat{\kappa}_t \equiv \frac{\mu_t^{(4)}}{(\mu_t^{(2)})^2} - 3$. Via the definition of $R_{t,T}$ all moments are affected by an intervention that aims at moving the daily exchange rate S_t.

To analyse how interventions in one currency pair might affect the cross rates associated with that currency pair, recall first that the proportional future change (return) of exchange rate i is given by $r_i = \ln\left(\frac{S_{i,t+1}}{S_{i,t}}\right)$. In the context of the G3 currencies the yen, the euro and the US dollar, let S_1 now denote the US dollar/euro exchange rate, S_2 the JPY/EUR exchange rate and

[8] Alternatively, it could be assumed that the FX intervention is transmitted to the spot exchange rate S_i via the information aggregation process as described in Lyons (2001) and Evans and Lyons (2002).

S_3 the JPY/US dollar exchange rate. From the definition of the cross rates, it follows that the per-period proportional future change in the JPY/US dollar exchange rate can be expressed as $r_3 = \ln\left(\frac{S_{1,t+1}/S_{2,t+1}}{S_{1,t}/S_{2,t}}\right)$. Rearranging this relationship yields the triangular arbitrage condition for exchange rate returns:

$$r_3 = r_1 - r_2 \,. \tag{4}$$

According to the triangular parity condition, a change in the return on exchange rate 3 would be instantaneously matched by a change in the two cross rates. In particular, increased supply of domestic money/bonds should lead to a depreciation of the domestic exchange rate against all foreign currencies, whilst the decreased relative supply of money/bonds of one foreign country should contribute to an appreciation of that country's currency against all other currencies. For example, an intervention where Japanese yen is sold against the US dollar should lead to an instantaneous depreciation of the yen against the euro and an appreciation of the US dollar relative to the euro to restore the equilibrium. In other words, the two bilateral euro exchange rates should diverge as a result of the operation on the JPY/US dollar exchange rate. Due to the mechanistic link between the spot and the forward rates, the portfolio effects and the triangular arbitrage condition can be extended to cover also forward exchange rates to allow for an analysis of changes in the higher moments of the RNDs of the cross rates around the times of official interventions.

To test econometrically how the individual moments on the RNDs on the various currency pairs move around times of interventions, we write down an equation where changes in implied moments are regressed by the variables capturing interventions by the Bank of Japan and the US Federal Reserve as well as a set of control variables.

$$\Delta\mu_t^{n,s} = \alpha^s + \beta_1^{BoJ} INT_{t+j}^{BoJ} + \beta_2^{BoJ} INT_{t+j}^{BoJ1} + \beta_3^{Fed} INT_{t+j}^{Fed} + \sum_{i=1}^{m} \beta_i Z_{i,t+j}$$

$$n=1, 2, 3, 4; \;\; j=0, 1, -1 \tag{5}$$

In (5), $\Delta\mu^{n,s}$ denotes the change in the n^{th} moment implied by the RND on the exchange rate s. Variables INT^{BoJ} and INT^{BoJ1} denote the interventions by the Bank of Japan, the latter capturing the first of the series of interventions (that is, all interventions that are not preceded by another operation less than five days earlier), measured in trillions of yen. The variable INT^{FED} captures the operations carried out by the Federal Reserve, measured in millions of

US dollars. In the case where j equals zero, contemporaneous movements of the moments at the time of an intervention are considered. When j equals 1, the leading effect is captured while j= -1 measures the lagged (persistent) movement of a given moment following an intervention. The set of control variables Z_i includes the news impact of monetary policy decisions in the US and in the euro area, and the news impact of two US macro variables, the advance GDP estimate and the unemployment rate. The motivation for using the news component rather than the actual data release is twofold. From the economic point of view, there is widespread evidence that the financial markets tend to price in data changes according to surveys and polls conducted prior to the release of the data. From the econometric point of view, the failure to account for the difference between actual data and the news component creates an endogeneity problem as identified by Rigobon and Sack (2003). Against this background, and following Kuttner (2001), Rigobon and Sack (2003) and Ehrmann and Fratzscher (2004), we define the news component $N_{k,t}$ of data release k as the difference between the actual data release $A_{k,t}$ and the markets prior expectation $B_{k,t}$, scaled by the sample standard deviation Ω of each data release:

$$N_{k,t} = \frac{A_{k,t} - B_{k,t}}{\Omega_k}$$

Using daily frequency for the analysis of the various time series shows that most of the moment series exhibit serial correlation, non-normality, skewness systematically different from zero, and excess kurtosis. A way to account for these characteristics of the data, that are rather typical for financial time series, is to apply the exponential GARCH technique first developed by Nelson (1991). Using this specification also means that we do not need to impose any non-negativity constraints on the coefficients of the conditional second moments. Using E-GARCH (1,1), we specify the conditional variance equation as follows:

$$\begin{aligned} \log(\vartheta_t^{2,s}) &= \omega^s + \gamma^s \log(\vartheta_{t-1}^{2,s}) + \chi^s \left(\frac{\varepsilon_{t-1}^s}{\vartheta_{t-1}^s} - \sqrt{2/\pi} \right) + \phi^s \frac{\varepsilon_{t-1}^s}{\vartheta_{t-1}^s} \\ &+ \tau_1^{BoJ,s} \left| INT_t^{BoJ} \right| + \tau_2^{BoJ1,s} \left| INT_t^{BoJ1} \right| + \tau_3^{Fed,s} \left| INT_t^{Fed} \right| + \sum_{i=1}^{m} \tau_i^s \left| Z_{i,t} \right| \end{aligned} \qquad (7)$$

In (7), the conditional variance on exchange rate s, $v_t^{2,s}$, is determined by past variance $v_{t-1}^{2,s}$, past innovations ε_{t-1}, the absolute values of the intervention variables, as well as the control variables. The actual estimation uses the familiar maximum likelihood estimator of the following form:

$$L(\theta) = -\frac{N}{2}\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{N}(\ln|H_t| + \varepsilon_t' H_t^{-1}\varepsilon_t)$$

Here H denotes the time-varying conditional variance-covariance matrix and N is the number of observations. Before proceeding to he estimation results, we need to discuss the issue of timing that is relevant for empirical studies on FX interventions where several central banks operate in different time zones.

4.1.1. Timing issues

A careful specification of timing is important in assessing the daily impact of market interventions on exchange rates, due to the different time zones the different central banks operate in. While central banks, in principle, can use each other as agents in the market so as to intervene in any trading hours they might want, in the absence of detailed data on the intra-day timing of the interventions we make the assumption that central banks only intervene in local trading hours. This assumption is supported by the simple fact that the bulk of the counterparties for the central bank operations tend to be domestic financial institutions, or domestic affiliates of foreign financial institutions. Of course, the largest counterparties often have offices located in all major financial centres that could allow a central bank to use these facilities for the operations outside the domestic trading hours. Nevertheless, we abstract here from such possibilities.

In principle, a way to minimise the problems arising from the timing issues would be to take the options price quote at the time when the last relevant marketplace (*i.e.*, New York) closes (see Galati and Melick, 2002, who use Chicago closing quotes for options prices and Ito, 2002, who uses the New York closing quotes for the spot JPY/USD exchange rate). However, our options prices are quoted at noon, London time (GMT), which makes the timing issue more complicated. In particular, at noon GMT the Tokyo market has already closed while the New York market has not yet opened. Our solution is to make the convention that a Japanese intervention at any given day has a contemporaneous impact on the options price quote of the same calendar day, while the interventions by the Fed are said to have a contemporaneous impact on the options price quote of the *following* calendar day. In other words, the timing of the intervention variables and that of the moments of the RNDs are set equal in the data set when the intervention took place during Japanese trading hours. When intervention occurred on day *t* in New York it is introduced at date *t+1* in the data set. Consequently, a change in a given day's options price quote reflects a lagging (persistent) impact if it follows a Japanese intervention that was carried out in the *previous* calendar day, or a Fed operation that was carried out *two calendar days ago.* Finally, a change in a given day's options price quote illustrate a leading impact if it precedes a Japanese operation to be carried out in the *following calendar day* or a Fed operation executed *in the same calendar day.* The control variables, being all recorded after noon, London time, are introduced in the same manner as the Fed interventions.

In our sample period 2 April 1992 - 31 December 2003 all Fed interventions are conducted as joint operations with the BoJ within the same calendar day. Therefore, our timing specification implies that in the absence of any other news hitting the options market an options price quote that captures the leading impact of a Fed intervention coincides with the options price quote that measures the contemporaneous impact of a BoJ operation. In other words, the information the options market has available at noon GMT when it forms its expectations about the Fed behaviour already incorporates the observed action by the BoJ. Similarly, a price quote that captures the contemporaneous impact of a Fed operation coincides with the price quote that incorporates the persistent impact of a BoJ operation.[9]

Finally, as often happens in financial market analysis, the issue of simultaneity between the interventions data and the estimated implied moments may arise. Previous literature has paid varying degrees of attention to this issue. On one hand, Galati and Melick (2002), who use the Chicago closing quotes for options prices and introduce all explanatory variables in contemporaneous terms, resort to instrument variables to address the emerging simultaneity bias. On the other hand, Mandler (2003) and Vahamaa (2004) who studied the movements in the RNDs on the euro area money and bond markets around the times of ECB monetary policy decisions do not explicitly account for this potential problem. Regarding our present study, in statistical terms the timing convention that owes to the options price quotation at noon, London time has a favourable implication. The fact that the various intervention operations and data releases are clearly measured at different points in time, and that the Fed

[9] Since in the full sample period the Fed interventions were always carried out as joint operations with the BoJ, it could be somewhat difficult to precisely distinguish between the impacts of the two central banks' operations. Moreover, because the yen operations are measured in yen and the Fed operations in US dollars, the coefficient estimates are not fully comparable. In the post-1999 sample, no Fed operations were included.

operations and the control variables are introduced with a lag in our estimations, should effectively mitigate the effects of the simultaneity bias in the estimations.[10]

4.2. The impact of intervention on the expectations on JPY/US dollar exchange rate

In what follows, we run our estimations using two sample periods, the full sample from 2 April 1992 to 31 December 2003, and a subsample running from the launch of the euro on 4 January 1999 to 31 December 2003. This split into two samples has some implications regarding the control variables, since the latter subperiod incorporates no interventions by the Fed on the JPY/USD exchange rate. Moreover, complete monetary policy expectations (polls) data was available only for the latter subperiod. In the estimations using the full sample period, we include a dummy variable that takes the value of 0 prior to 21 June 1995 and 1 thereafter. The latter period reflects the perceived change in the BoJ intervention tactics that was associated with the appointment by Eisuke Sakakibara as a Director General responsible for exchange rate issues at the MoF. The beginning of the Sakakibara ("Mr. Yen") era was generally seen as a move from small and frequent interventions to large but less frequent operations (see Ito, 2002, for a detailed account). The dummy variable received a significant coefficient in all regressions where the mean of the RND was used as the dependent variable, suggesting that there indeed seems to be a structural break in the relationship.

Before reporting the results from the regressions of the implied moments of the JPY/US dollar exchange rate on the interventions data, some general observations are warranted. Compared with the work by Galati and Melick (2002), our results are clearly improved, suggesting that the OTC data we use indeed seems to be of "better" quality relative to the exchange traded quotes used by them, at least in the sample period applied by us. We suspect that the so-called telescoping-bias arising from the rolling-maturity structure of the exchange traded options (see Christensen, Hansen and Prabhala, 2001) could be part of the reason. Furthermore, the fact that OTC options are quoted daily with fixed moneyness, as opposed to the fixed strike price in exchange traded options, ensures that the options used for the density forecasting that forms the base for our moments series are exactly at-the-money each day. Finally, the large volume of transactions in OTC currency options compared with exchange traded options may offer an additional explanation. Overall, in our data, interventions have

[10] However, the timing conventions cannot fully exclude the presence of a bias in the estimated coefficients and therefore these should be interpreted with caution. This is of course the case regarding the estimates of the leading and the lagging coefficients as well.

statistically significant impacts on all moments, and in some cases the impacts are either anticipated or persistent over a 2-day horizon.

The movements of the various moments of the RNDs on the JPY/US dollar options around the times of interventions are reported in Appendix 3 as follows. The relevant tables include the coefficient estimates and standard errors for the intervention and control variables, both from the conditional mean and the conditional variance equations. The first table considers the immediate effect, while the second and the third tables illustrate the lagged (persistent) and leading effects, respectively. Statistical significance is always measured at 5% level.

4.2.1. Means of the RND

Regarding the equations where the means of the RNDs are regressed on the intervention variables, in the contemporaneous equations all intervention variables received the correct (negative) sign. This indicates that sales of the yen tend to coincide with a move in the mean of the RND towards a weaker Japanese currency against the US dollar, and vice versa. The coefficients on the Fed interventions are, however, not statistically significant on the 5% level. The coefficients are also rather small – suggesting that the impact of an intervention of 1 trillion yen by the BoJ tends to move the mean by no more than 0.5%. These figures are low compared to those reported by Ito (2002) who used OLS techniques and found that a BoJ intervention by 1 trillion JPY would move the *spot* exchange rate by almost 1%, while Fed intervention by 1 billion US dollars would move the spot rate by 5%. Furthermore, our E-GARCH regressions suggest that BoJ interventions coincide with a significant contemporaneous increase in the conditional variance of the mean.

Regarding the persistent impact of the interventions, in the full sample the mean of the RND tends to re-bound the day after the first of the series of BoJ interventions, by 0.2% for any 1 trillion yen that was spent in the preceding operation. Moreover, while there is no statistically significant contemporaneous link between the Fed purchases of the yen and the movements in the mean, the mean nevertheless moves one day after the Fed purchases. In the latter sample period, conditional volatility of the mean has continued to increase the day after BoJ operations.

Turning to the leading effects, all BoJ interventions were generally preceded by a large and statistically significant movements in the mean towards a stronger (weaker) yen prior to yen-selling (purchasing) intervention by the BoJ (by around 0.3% for any 1 trillion JPY spent in the subsequent operation). This suggests that the BoJ operations could, on average, be seen as conducted leaning-against-the wind. The contrary is true for the Fed interventions as the mean moved, on average, by 1.8% towards a weaker (stronger) yen for any 1 billion US dollar spent in the subsequent yen-selling operation the following day. This result can be explained with the timing choice we have employed in our analysis. Since the Fed operations in all occasions were concerted interventions with the BoJ, the Fed always entered the market when the BoJ had already concluded its operation. Recall that a movement in an options price quote on day *t* that measures the anticipatory impact of a forthcoming Fed intervention already incorporates the contemporaneous impact of the BoJ operation. Since the BoJ's yen-selling operations were above shown to be associated with a statistically significant contemporaneous move in mean towards yen depreciation, it is not surprising that the yen-selling operations by the Fed, that take place after the options price quote which includes the impact of the BoJ operation has been released, were conducted leaning-in-the-wind. Finally, in the post-1999 sample period the BoJ operations were anticipated by increased conditional variance of the mean.

Regarding the control variables, macroeconomic news conveying information about higher-than-expected US unemployment rate was associated with a depreciation of the mean of the US currency against the yen that persisted over the following trading day. Positive surprises on the US GDP coincided with an appreciation of the US dollar (although the coefficients were not significant at 5% level).

4.2.2. Implied standard deviations

When assessing the systematic movements in implied standard deviation and kurtosis around the time of interventions, we use absolute values of the intervention series. The reason is that since implied standard deviation and kurtosis could, in theory, either increase or decrease independent on whether the intervention involves buying or selling a currency, the signs of the coefficients would be inconsistent if the simple amounts of interventions were used as explanatory variables (see Galati and Melick, 2002, for further discussion).

The first BoJ intervention is associated with a significant contemporaneous increase in implied standard deviation, suggesting that interventions might rise the uncertainty as perceived by the options market regarding future exchange rate movements. In other words, over the daily horizon, interventions would not seem to be able to improve the market's view regarding future volatility. Conditional volatility of the implied standard deviation also goes up following the operations by the BoJ (the first intervention). Interestingly, the increase in implied standard deviations seems to have been partially reversed the following day (the coefficints are significant at 5% level). In the case of the conditional variability of implied standard deviation the re-bound is almost complete the day after BoJ interventions. Moreover, the interventions by the BoJ have been preceded by systematic and significant increase in conditional volatility of implied standard deviation, as the measure increased the day before the first of the series of BoJ interventions. The Fed operations had no systematic impact whatsoever on the implied standard deviation. Implied standard deviation declined the day after data surprises on US unemployment but increased after surprises in the GDP figures, suggesting that the latter news could have a more lasting impact on the options market uncertainty.

4.2.3. Implied skewness

In the whole sample, sales of the yen in the Fed operations seem to have coincided with a strong contemporaneous movement in implied skewness towards a weaker yen, as a sale of yen worth of 1 billion US dollars was, on average, associated with a more than 0.4 percentage points movement in skewness. Therefore, the yen sales by the Fed tend to have pushed the market's assessment towards a weaker expected yen. Moreover, the first of the BoJ interventions and the Fed interventions are associated with a significant contemporaneous decline in the conditional variance of implied skewness.

The leading effects show that the symmetry of the RND tends to move in the opposite direction prior to BoJ operations, *i.e.*, yen-selling interventions are preceded by increasing perceptions of near-term JPY strength. In the post-euro sample, higher than expected US unemployment figures were associated with a statistically significant movement in the skewness of the RND towards a weaker US dollar. The conditional variability of implied skewness increases prior to the interventions by the BoJ, suggesting that the operations tend to be preceded by increasing nervousness in the options market.

4.2.4. Implied kurtosis

In the regressions with implied kurtosis, absolute values were again used for intervention variables for the same reason as in the case of implied standard deviation. The first BoJ intervention and the Fed operations coincided with an immediate fall in implied kurtosis. Therefore, while the overall uncertainty as measured by increased implied standard deviation tends to increase, the probability of large exchange rate movements tends to decline immediately after the operation. However, the decline in implied kurtosis re-bounds a day later. The conditional variability of implied kurtosis shows more mixed patterns, with the first BoJ operation preceded and followed by increased variability and the regular BoJ operations preceded and followed by decreased variability in kurtosis. Kurtosis significantly increases the day prior to US GDP surprises and decreases the day after (the latter happens also in the case of unemployment surprises).

In sum, some rather interesting patterns emerge from our results. The interventions by the Bank of Japan are preceded by clear and systematic changes in expectations as reflected in all moments implied by the currency options prices. In particular, the day before the operations the mean and the implied skewness of the RNDs moved to a direction opposite than indicted by the subsequent intervention. At the same time, variability in the implied standard deviation of the RNDs increased. This suggests two things. First, the market sentiment might have tended to move in an increasingly "unfavourable" direction prior to the operations. Second, the increased standard deviation could also indicate that the market could have become increasingly capable of anticipating interventions when their probability has increased, most likely due to intensified oral communication by the policymakers prior to the interventions. In most cases, the interventions were associated with either a change in the direction of the mean and skewness of the RND or a reduction in implied standard deviation and kurtosis, although in many cases these movements were reversed the following day. Another interesting result is that since the Fed interventions – that were always joint operations with the BoJ – tend to be conducted during the New York trading hours after the BoJ interventions in the Tokyo hours, the movement in the mean of the RND was in many cases already ongoing when the Fed entered the market. Nevertheless, the subsequent operations by the Fed tended to reinforce the movement after the initial BoJ intervention, as suggested by the estimated daily contemporaneous movements in the mean and implied skewness. Finally, options implied moments on the JPY/USD exchange rate also seem to react to the unanticipated components of US macro data releases, with surprises in the US unemployment rate associated with persistent movements in the means of the RNDs.

4.3. "Spill-over effects" of intervention: interventions and the movements in the RNDs on the USD/EUR and JPY/EUR exchange rates

We now turn to analyse what is the impact, if any, of the interventions on the JPY/US dollar exchange rate on the RNDs on the two cross rates of the named currency pair. In this way, the question we ask is: Do the interventions have any “spill-over effects” in terms of future risks to exchange rates other than those directly affected by the market operations?

The detailed results are illustrated in Appendix 4-5. Looking at the contemporaneous equations for the mean of the RNDs on the JPY/EUR rate, all coefficients suggest that yen-selling interventions against the US dollar conducted by the BoJ are associated with a movement towards a weaker yen also against the euro. The coefficients of the BoJ operations are all significant at 5% level and suggest that a 1 trillion yen purchase coincides with an appreciation of the mean by 0.2-0.5% on the average (the first operation has a higher impact). The persistent movements are not significant on 5% level. However, the leading effects of the first BoJ and the Fed operations are significant and again suggest leaning-against-the-wind behaviour by the BoJ and the leaning-in-the-wind behaviour by the Fed. In other words, the mean of the RND on the JPY/EUR currency pair moves towards a weaker yen before the BoJ’s yen-purchasing operations and towards a stronger yen before the Fed purchases. The operations are not associated with any contemporaneous, persistent or anticipated impacts on the conditional variance of the mean.

Regarding the higher moments, those coefficient estimates that are also statistically significant suggest that implied standard deviation on the JPY/EUR rate tends to increase immediately after the interventions but is often reversed the day after. Implied standard deviation increased in anticipation of the BoJ interventions in the post-euro sample, while it also tends to increase prior to US macro news surprises. Finally, in the post-euro sample surprise Fed interest rate hikes were associated with an increase in skewness towards a weaker JPY.

How do the interventions on the JPY/US dollar rate affect expectations on the US dollar/EUR currency pair? The BoJ’s yen-selling (USD-purchasing) operations coincided with a contemporaneous appreciation of the US dollar against the euro (though the coefficient is not statistically significant). However, post-1999, the BoJ yen-sales (US dollar purchases) were anticipated by a movement in the mean of the RNDs towards a weaker US dollar vis-à-vis the euro, suggesting that prior to the BoJ’s yen-selling (US dollar purchasing) operations the market tends to be characterised by a general weakness of the US currency.

Interestingly, in the post-euro sample US monetary policy surprises coincide with strong and statistically significant movements in the RNDs on the USD/EUR exchange rate. Surprise Fed interest rate hikes are associated with movements in the mean of the RNDs towards a stronger US dollar, with the effects persisting over the following trading day. The market thus seems to have interpreted higher than anticipated interest rates as positive news for the currency, in line with the interest rate parity and arbitrage conditions. A day after the policy hike skewness also moved in favour of a stronger US dollar. Finally, prior to surprise policy hikes (cuts) by the Fed and the ECB, there has been a movement towards an appreciation (depreciation) of the domestic currency of the central bank in question. This suggests that while the size of the interest rate hike may have been larger than anticipated, the direction of the change in the monetary policy stance has nevertheless been correctly priced in by the options market in line with successful prior communication by the policymakers.

4.4. Do changes in expectations predict the decisions to intervene?

As a final point, we briefly invert the logic applied in the investigation so far and ask whether the changes in exchange rate expectations might have had a systematic effect in the decisions to intervene. In this context we only look at the interventions carried out by the Bank of Japan, owing to the nature of the Fed interventions that always were joint operations carried out in collaboration with the BoJ. Ito (2002) carries out a similar exercise using the changes in the spot JPY/US dollar exchange rate over different horizons, and its deviation from the long run average level, as explanatory variables in a linear regression model. His results suggest that the BoJ has generally been leaning against the wind, the interventions being more frequent when the rate of change of the spot exchange rate has been high or when the deviation from the long run average has been more pronounced. Furthermore, the BoJ was found to be more concerned about short-term changes and about the deviation from the long-run equilibrium level after 1995 when Mr Sakakibara became in charge of the policy.

We model the decision to intervene as nonlinear binary (logit) regression. The dependent variable is defined as a 0-1 variable where the variable receives the value 1 when the BoJ intervenes and 0 otherwise. Yen-purchasing and yen-selling operations are considered in separate regressions. The explanatory variables are the one-period lagged changes in implied moments of the JPY/US dollar RNDs, as well as the lagged deviation of the spot exchange rate from the "long-run average" level JPY 125 per US dollar.[11] In the binary logit framework, a significant positive coefficient estimate would indicate that a movement in the level relative to the long-run average or a change in the implied moments increased the probability of intervention taking place one day later.

The results are reported in Appendix 6. They show that in both sample periods, the BoJ yen purchasing interventions were systematically preceded by large deviations from the long-run average level towards a weaker yen. Similarly, the BoJ operations where yen was sold against the US dollar were preceded by large deviations from the long-term average towards the stronger yen. In addition, the BoJ's yen-selling operations were systematically preceded by increased implied standard deviation. Two alternative explanations can be provided to this tendency. First, the BoJ may have reacted to increasingly deteriorating market conditions as measure by increased standard deviation. Second, the options market could have been increasingly capable of anticipating interventions when their probability has grown, possibly due to improved communication by policymakers. In the estimations where yen-selling operations enter the left-hand side, the mean and implied skewness received the correct (negative) coefficient signs in all regressions, suggesting that yen-selling interventions were conducted in an environment characterised by a strengthening yen. However, these coefficients are not statistically significant.

All in all, apart from implied standard deviation, it cannot be concluded that short-term changes in the implied moments of the estimated RNDs would have had any systematic explanatory power in prediciting interventions by the BoJ. The main determinant remains the level of the spot exchange rate relative to its long-term average. Looking at longer horizons, however, could reveal that trends in the higher moments have a bearing on the decisions to buy or sell currency in the FX market.

5. Conclusion

This paper focused on the movements in options prices on G3 currencies around the times of official interventions on the JPY/US dollar exchange rate. Using a new data set based on daily OTC options quotes we first estimated the risk-neutral density functions (RNDs) to measure the perceived risks of near-term exchange rate movements and studied the changes in the individual moments of the RNDs before and after the market operations. We found evidence that implied moments move systematically around the times of the operations. In particular, the mean and the implied skewness of the RNDs on the JPY/US dollar exchange rate tend to move towards a stronger (weaker) expected yen prior to operations where yen is sold (bought) by the Bank of Japan. This suggests that the market conditions might have become

[11] This level reflects the level above which there were no yen-selling interventions and below which there were no yen-purchasing interventions in our data sample. See Ito (2002) for more details.

increasingly unfavourable prior to the operations. On the other hand, the mean and the implied skewness were found to move towards a weaker (stronger) expected yen prior to operations where yen is sold (bought) by the Fed. This outcome in turn most obviously reflects the timing convention applied in our investigation, whereby the daily options prices are quoted in London at the time when the Tokyo market has already closed but the New York market has not yet opened. Given that all Fed interventions were joint operations with the BoJ, the anticipatory movements in the options prices prior to the Fed operations already incorporate the information about the BoJ operation that were shown to coincide with significant movements in the exchange rate towards the "desired" direction. Implied standard deviation often increased prior to and immediately after the interventions. The prior increase in standard deviation could reflect, in addition to worsening market conditions, also increased ability of the options market to anticipate interventions when their probability increased, possibly due to intensified communication by policymakers. In many cases, however, the movements did not persist over the following trading day. The interventions on the JPY/USD rate coincided with systematic movements in several of the moments of RNDs on the JPY/EUR and USD/EUR currency pairs, reflecting potential spill-over effects across the options markets.

Our results are encouraging and provide new insight in several respects. First, the OTC data on currency options prices seems to be more responsive to news in form of exchange rate interventions than data on exchange traded options. This finding could reflect the problems related to the way the exchange-traded options are quoted, in that it imposes distortions to the time series of moments that are derived from the distribution functions. Second, the findings that moments of the RNDs on the cross-exchange rates also move around the time of interventions in a given currency pair lend support to the argument that the options markets for the bilateral exchange rates are rather closely integrated. Third, the data on macroeconomic and monetary policy news surprises that was included as control variables indicates that the various moments of the implied RNDs often strongly and persistently react to unanticipated data releases and policy changes. In particular, it turned out that the RNDs on the JPY/USD and JPY/EUR exchange rates seem to be relatively more sensitive to macroeconomic surprises whereas the RNDs on the USD/EUR currency pair more often move with news on monetary policy events.

References

Almekinders, G. (1995): Foreign Exchange Intervention: Theory and Evidence. Vermont, U.S., Edgar Elgar Publishing.

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

Beine, M., A. Benassy-Quere and C. Lecourt (2002): Central bank intervention and foreign exchange rate: new evidence from FIGARCH estimations, *Journal of International Money and Finance*, 21.

Bhar, R. and C. Chiarella (2000): Expectations of monetary policy in Australia implied by the probability distribution of interest rate derivatives, *European Journal of Finance*, 6

Bliss, R. and N. Panigirtzoglou (2000): Testing the stability of implied probability density functions, *Bank of England Discussion Paper*

Bliss, R. and N. Panigirtzoglou (2004): Option-implied risk aversion estimates, *Journal of Finance,* forthcoming

Bonser-Neal, C. V. Roley and G. Sellon (1998): Monetary policy actions, intervention, and exchange rates: a reexamination of empirical relationships using Federal Funds Target Rate data, *Journal of Business*, 71.

Bonser-Neal, C. and N. Tanner (1996): Central bank intervention and the volatility of foreign exchange rates: evidence from the options market. *Journal of International Money and Finance* 15:6

Bontemps, C. and N. Meddahi (2001): Testing normality: A GMM approach, *Mimeo*, Department of Economics, University of Montreal

Breeden, D. and R. Litzenberger (1978): Prices of state-contingent claims implicit in option prices, *Journal of Business*, Vol. 51

Butler, C. and N. Cooper (1997): Implied exchange rate correlations and market perceptions of European Monetary Union, *Bank of England Quarterly Bulletin*, November 1997

Campa, Chang and Reider (1997): Implied exchange rate distributions: evidence from the OTC option markets, *NBER Working Paper*, No 6179

Castrén, O. (2004): Do financial market variables show (symmetric) leading and lagging indicator properties relative to exchange rate returns? *European Central Bank Working Paper* No 297.

Castrén and Cappiello (2003): Estimating and forecasting correlations among major euro exchange rates, *Mimeo*, European Central Bank

Christensen, B., C. Hansen and N. Prabhala (2001): The telescoping overlap problem in options data, *Mimeo*, Aarhus University.

Christoffersen and Mazzotta (2004): The informational content of over-the-counter currency options, *Mimeo*, McGill University and European Central Bank

Dominguez, K. and J. Frankel (1993a): Does foreign exchange intervention work? Washington D.C.: *Institute for International Economics*

Dominguez, K. and J. Frankel (1993b): Does foreign exchange intervention matter? The portfolio effect, *American Economic Review* 83

Dominguez, K. (1998): Central bank intervention and exchange rate volatility, *Journal of International Money and Finance*, Vol. 17.

Ehrmann, M. and M. Fratzscher (2004): Exchange rates and fundamentals: new evidence from real-time data, *ECB Working Paper* No 365

Evans, M. and R. Lyons (2002): Order flow and exchange rate dynamics, *Journal of Political Economy*

Fratzscher, M (2004): Communication and exchange rate policy: are oral interventions effective? *Mimeo*, European Central Bank.

Galati, G. and W. Melick (2002): FX interventions and market expectations, *BIS Economic Paper* No. 10

Hordahl, P. (1999): Estimating the implied distribution of the future short-term interest rate using the Longstaff-Schwartz model", *ECB Working Paper* No xxx

Hordahl, P. and D. Vestin (2003): Interpreting implied risk-neutral densities: the role of risk premia, *ECB Working Paper* No 274

Ito, T. (2002): Is foreign exchange intervention effective? The Japanese experience in the 1990s. *NBER Working Paper* No. 8914

Juergensen, Ph. (ed.) (1983): *Report of the working group on exchange rate market intervention*, Paris.

Kaminsky, G. and K. Lewis (1996): Does foreign exchange intervention signal future monetary policy? *Journal of Monetary Economics*, Vol 37.

Kuttner, K. (2001): "Monetary Policy Surprises and Interest Rates: Evidence from the Fed Funds Futures Market", *Journal of Monetary Economics*, 47

Lewis, K. (1995): Are foreign exchange intervention and monetary policy related and does it really matter? *Journal of Business*, Vol. 68.

Lyons, R. (2001): The Microstructure approach to exchange rates, Cambridge: *The MIT Press*

Lyons, R. and M. Moore (2004): An information approach to international currencies, *Mimeo*, UC Berkeley

Madan, D. and F. Milne (1994): Contingent claims valued and hedged by pricing and investing in a basis, *Mathematical Finance*, Vol. 4

Malz, A. (1997): Estimating the probability distribution of future exchange rates from option prices, *Journal of Derivatives*

Mandler, M. (2003): Comparing risk-neutral probability functions implied by options prices: market uncertainty and ECB council meetings. Unpublished working paper.

Melick, W. and C. Thomas (1997): Recovering an asset's implied PDF from options prices: an application to crude oil during the Gulf crisis, *Journal of Finance and Quantitative Analysis*, Vol. 32.

Murray, J. M. Zelmer and D. McManus (1997): The effect of intervention on Canadian dollar volatility. In: P. Fenton and J. Murray (eds.): *Exchange rates and monetary policy*, Bank of Canada, Ottawa.

Nelson, D. (1991): Conditional heteroscedasticity in asset returns: a new approach. *Econometrica* 59

Rigobon, R. and B. Sack (2003): "Measuring the Response of Monetary Policy to the Stock Market", *Quarterly Journal of Economics* 118

Rubinstein, M. (1994): Implied binomial trees, *Journal of Finance*, Vol .49

Sarno, L. and M. Taylor (2001): Official intervention in the foreign exchange market: Is it effective, and if so, how does it work? *Journal of Economic Literature* 39

Sodelind, P. (2000): Market expectations in the UK before and after the ERM crisis. *Economica* 67

Vahamaa, S. (2004): Option-implied asymmetries in bond market expectations around monetary policy actions of the ECB", *ECB Working Paper Series* No 315

Appendix 1: Tests of the accuracy of the density forecasts

In verifying the accuracy of the estimated RNDs we follow Christoffersen and Mazzotta (2004) who develop a series of statistical tests for this purpose. To start with, let $F_{t,h}(S)$ and $f_{t,h}(S)$ denote the cumulative and probability density function forecasts made on day *t* for the FX spot rate *S* on day *t+h*. We can then define the so-called probability transform variable as

$$U_{t,h} \equiv \int_{-\infty}^{S_{t+h}} f_{t,h}(u)du \equiv F_{t,h}(S_{t+h}), \qquad \text{(A.1)}$$

which will take on values in the interval [0,1]. If the density forecast is correctly calibrated then we should not be able to predict the value of the probability transform variable $U_{t,h}$ using information available at time *t*. Moreover, if the density forecast is a good forecast of the true probability distribution then the estimated probability will be uniformly distributed on the [0,1] interval. We can now use the standard normal inverse cumulative density function to transform the uniform probability transform to a normal transform variable:

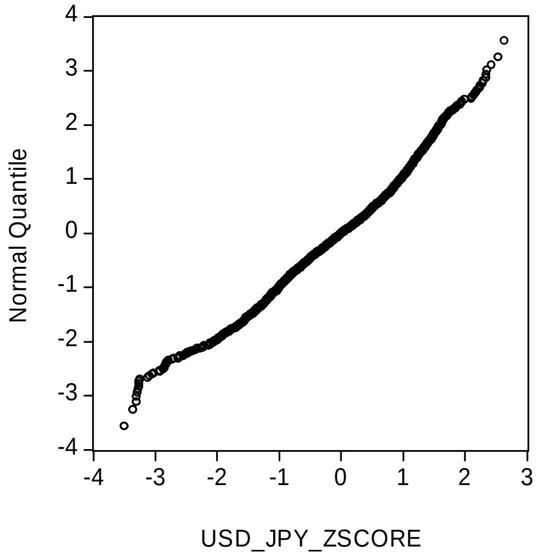
$$Z_{t,h} = \Phi^{-1}(U_{t,h}) = \Phi^{-1}(F_{t,h}(S_{t+h})) \qquad \text{(A.2)}$$

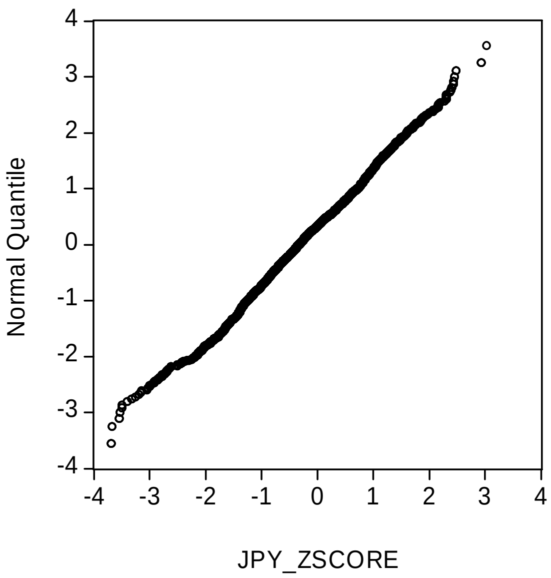
If the implied density forecast is to be useful for forecasting the physical density, it must be the case that the distribution of $U_{t,h}$ is uniformly distributed and independent of any additional variables observed at time *t*. Consequently, the normal transform variable must be normally distributed and also independent of all variables observed at time *t*.

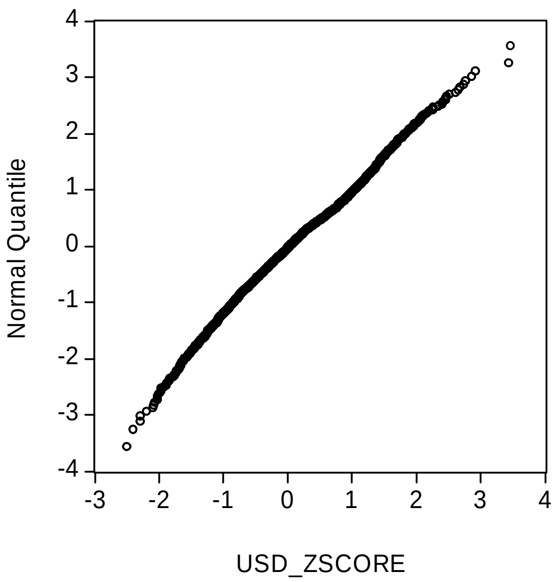
We want to focus attention on the performance of the density forecasts in the tails of the distribution. To this end, we report QQ-plots of the normal transform variables $Z_{t,h}$ in Chart A.1. The QQ-plots display the empirical quantile of the normal transform variable against the theoretical quantile from the normal distribution. If the distribution of the normal transform is truly normal then the QQ-plot should lie close to the 45-degree line. Chart A.1 shows that the left tail fits poorly in the case of the US dollar/EUR, and that the right tail is fit poorly in the case of the JPY/USD rate. Moreover, in the latter case the right tail of the distribution appears to bee too thick. All in all, the evaluation suggests that the information implied in options prices is useful for density forecasting as long as the interest concentrates on the intervals with coverage in the 10-70% range of the implied distribution.

Chart A1: QQ plots for distribution functions

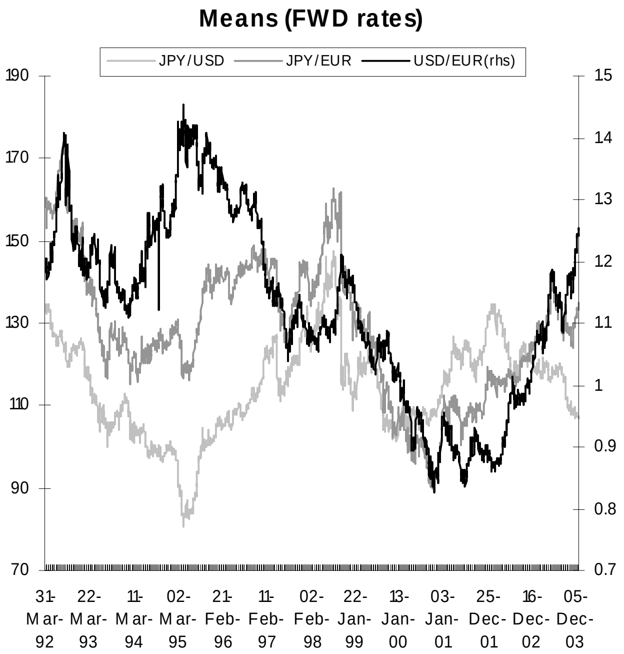
Deviations from the 45-degree line illustrate measurement errors

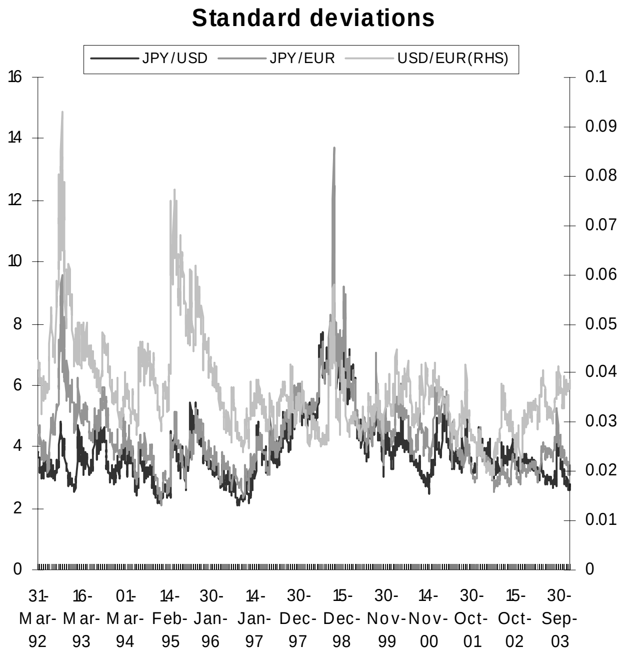


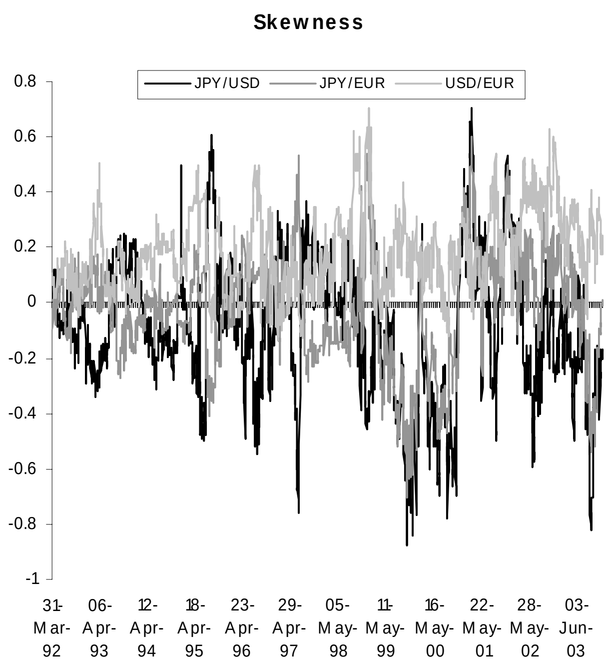


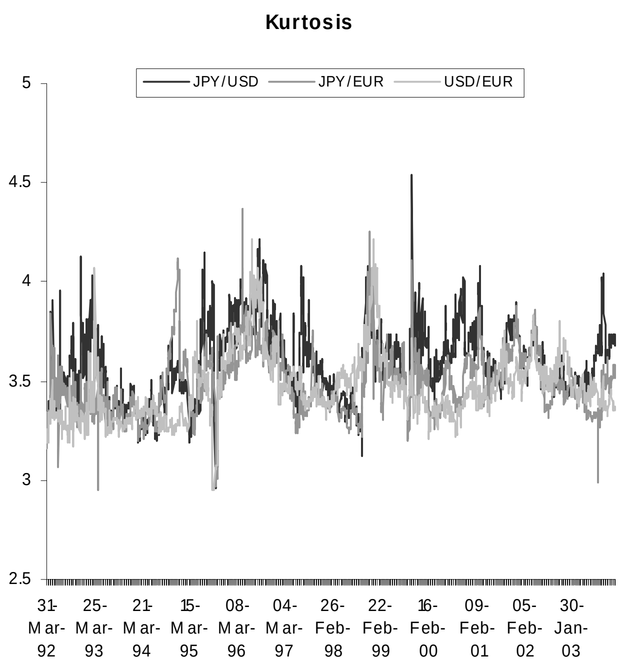


Appendix 2: Plots of the moments of the implied RNDs









Appendix 3: Estimations results on US dollar/JPY

Table A.3.1: The impact of interventions on the mean of the RND

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00199*	0.00415	-0.00011	0.00020
BOJ 1	-0.00535*	0.00111	0.000429	0.00399
FED	-0.00094	0.00106	0.00047	0.0079
USUE	-0.004*	0.001	-0.626	0.737
USGDP	0.0006	0.0006	-0.120	0.320
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00174*	0.001526	0.00023*	0.00011
BOJ 1	-0.00343*	0.000402	0.00045	0.00029
FEDF	0.0017	0.0059	-0.205	1.704
ECB	0.0008	0.0025	1.45*	0.48
USUE	-0.00017	0.0032	0.009	0.686
USGDP	0.0013	0.0015	0.250	0.343

Table A.3.2: The impact of interventions on the mean of the RND: persistent effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000461	0.000735	-0.00027	0.00039
BOJ 1	0.00218*	0.000104	-0.000143	0.00496
FED	-0.00245*	0.00200	-0.00202	0.000736
USUE	-0.0025	0.0017	0.279	0.751
USGDP	-0.00028	0.00069	0.728	0.577
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00513	0.00075	0.00025*	0.00015
BOJ 1	0.00208*	0.00105	-0.0005	0.0028
FEDF	0.0010	0.0059	0.488	1.224
ECB	-0.0008	0.0002	0.366	0.689
USUE	-0.008	0.003	0.515	0.777
USGDP	-0.0009	0.001	0.115	0.327

Table A.3.3: The impact of interventions on the mean of the RND: anticipated effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.0037*	0.000442	-0.00027	0.000307
BOJ 1	0.00210*	0.000881	-0.000567	0.000414
FED	-0.0176*	0.00323	-0.00376	0.000848
USUE	-0.001	0.001	1.879*	0.941
USGDP	0.0003	0.001	-0.429	0.617
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.00102	0.000834	0.00014	0.00097
BOJ 1	0.00573*	0.00125	-0.00076*	0.00023
FEDF	0.0053	0.0075	0.9698	1.31
ECB	-0.00035	0.0044	0.314	0.659
USUE	-0.0056	0.0036	0.313	0.729
USGDP	0.0013	0.0017	0.241	0.297

Table A.3.4: The impact of interventions on the implied standard deviation

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.0034	0.00379	-0.000056	0.00014
BOJ 1	0.0491*	0.00942	0.0014*	0.00032
FED	0.0185	0.0159	0.00065	0.000337
USUE	0.0017	0.0124	3.136*	0.251
USGDP	0.0004	0.005	-0.528*	0.249
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.00405	0.00594	0.0001	0.000135
BOJ 1	0.0372*	0.0111	0.0011*	0.00027
FEDF	-0.030	0.062	-0.0202	1.474
ECB	-0.023	0.016	0.043	0.551
USUE	0.007	0.027	2.896*	0.495
USGDP	-0.008	0.008	0.030	0.314

Table A.3.5: The impact of interventions on the implied standard deviation: persistent effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00916*	0.00223	-0.015*	0.0083
BOJ 1	-0.0018*	0.00572	-0.170*	0.0023
FED	0.00038	0.00148	0.00696	0.0027
USUE	-0.026*	0.0131	1.111*	0.249
USGDP	0.008*	0.003	-0.501*	0.224
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.0173*	0.00440	-0.000142	0.000135
BOJ 1	-0.963	0.00709	0.000174	0.00029
FEDF	0.0052	0.038	1.633	1.49
ECB	0.018	0.017	0.168	0.578
USUE	-0.053*	0.027	2.987*	0.508
USGDP	0.018	0.005	-0.113	0.356

Table A.3.6: The impact of interventions on the implied standard deviation: anticipated effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.0025	0.0037	0.0000201	0.00024
BOJ 1	0.0124	0.00158	0.00127	0.00027
FED	0.0220	0.0125	0.00069*	0.00025
USUE	-0.004	0.017	2.052*	0.301
USGDP	-0.004	0.004	-0.936*	3.82
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.0069	0.00622	0.00019	0.00016
BOJ 1	0.0136	0.00201	0.0012*	0.00029
FEDF	-0.0368	0.052	0.049	1.440
ECB	-0.022	0.033	-0.42	0.544
USUE	-0.0044	0.023	2.044*	0.499
USGDP	-0.0044	0.007	-0.304	0.334

Table A.3.7: The impact of interventions on the implied skewness

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000986	0.0158	0.00012	0.00012
BOJ 1	-0.0245	0.0209	-0.0012*	0.00044
FED	-0.0545*	0.0125	0.00037*	0.000170
USUE	-0.055	0.038	0.430	0.650
USGDP	0.011	0.024	0.380	0.328
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.00189	0.0106	-0.00022*	0.00007
BOJ 1	-0.0695*	0.0183	0.00083*	0.00019
FEDF	0.009	0.011	1.650	1.310
ECB	0.002	0.003	0.073	0.425
USUE	-0.008	0.004	0.148	0.612
USGDP	0.001	0.001	-0.277	0.246

Table A.3.8: The impact of interventions on the implied skewness: persistent effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000430	0.0155	0.000012	0.00024
BOJ 1	0.0368	0.0201	0.000077	0.00040
FED	-0.0885	0.0184	-0.000181	0.000419
USUE	0.0152	0.032	-0.817	0.723
USGDP	0.030	0.024	0.512	0.499
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00308*	0.00633	-0.00485	0.00876
BOJ 1	0.0476*	0.0127	0.0039*	0.00020
FEDF	0.004	0.011	1.048	1.223
ECB	-0.001	0.006	-0.258	0.441
USUE	-0.002	0.004	-0.119	0.572
USGDP	-0.003*	0.002	-0.460	0.285

Table A.3.9: The impact of interventions on the implied skewness: anticipated effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.0324*	0.0115	0.00018*	0.00027
BOJ 1	-0.00414	0.0250	-0.00095	0.00050
FED	0.00229	0.0225	-0.00098	0.00058
USUE	-0.024	0.045	-1.906	1.032
USGDP	0.025	0.027	0.396	0.715
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.231*	0.0922	-0.0002	0.00112
BOJ 1	-0.0504	0.0349	0.00083	0.00021
FEDF	-0.012*	0.006	1.522	1.343
ECB	-0.013*	0.003	0.263	0.470
USUE	0.004	0.005	-0.140	0.492
USGDP	0.002	0.002	-0.408	0.251

Table A.3.10: The impact of interventions on the implied kurtosis

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.000162	0.00105	-0.00032*	0.000062
BOJ 1	-0.00799*	0.00214	0.0010*	0.00019
FED	-0.00833*	0.00177	-0.000232	0.00016
USUE	-0.006*	0.003	1.574*	0.219
USGDP	-0.0008	0.001	-0.869*	0.120
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000189	0.000106	-0.00021*	0.00007
BOJ 1	-0.00695*	0.00183	0.0008*	0.0002
FED	0.0024	0.0034	1.050	1.3095
ECB	0.002	0.003	0.073	0.425
USUE	-0.008	0.0044	0.148	0.612
USGDP	0.0012	0.0012	-0.277	0.246

Table A.3.11: The impact of interventions on the implied kurtosis: persistent effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.00189*	0.000498	-0.00015*	0.00066
BOJ 1	0.00622*	0.00138	0.00025	0.00022
FED	-0.000106	0.00254	-0.000447*	0.00019
USUE	-0.001	0.0034	1.196	0.199
USGDP	-0.0029	0.0011	-0.825	0.149
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.00398*	0.000633	-0.000048	0.0000876
BOJ 1	0.00476*	0.00127	0.00039*	0.00020
FEDF	0.0040	0.0115	1.0448	1.2223
ECB	-0.001	0.0056	-0.258	0.441
USUE	-0.0018	0.0039	-0.119	0.572
USGDP	-0.0033	0.0016	-0.460	0.286

Table A.3.12: The impact of interventions on the implied kurtosis: anticipated effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000812*	0.000398	-0.00029*	0.000061
BOJ 1	-0.0038*	0.00324	0.0010*	0.00016
FED	-0.00209	0.00323	0.00017	0.000143
USUE	0.0057	0.0048	1.679*	0.199
USGDP	0.0026	0.0012	-0.981*	0.116
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.00231*	0.00092	-0.00015	0.00012
BOJ 1	-0.00504	0.0035	0.00083*	0.00021
FEDF	-0.012*	0.0059	1.522	1.343
ECB	-0.013*	0.003	0.263	0.469
USUE	0.0043	0.0054	-0.140	0.492
USGDP	0.0021	0.0017	-0.408	0.251

Appendix 4: Estimation results on JPY/EUR

Table A.4.1: The impact of interventions on the mean of the RND

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00204*	0.000692	0.000068	0.000170
BOJ 1	-0.00456*	0.00154	0.000181	0.000370
FED	-0.00141	0.00158	-0.000427	0.000387
USUE	-0.000292	0.001504	-0.323	0.923
USGDP	0.00067	0.0008	-0.123	0.069
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00220*	0.000727	0.0000614	0.000211
BOJ 1	-0.0049*	0.000149	-0.0000487	0.000587
FEDF	0.00123	0.00124	-0.000792	0.00119
ECB	-0.00057	0.0037	0.034	0.198
USUE	-0.00049	0.0025	0.678	0.359
USGDP	0.0012	0.0010	-0.565*	0.113

Table A.4.2: The impact of interventions on the mean of the RND: persistent effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.00050	0.000601	0.0000592	0.00011
BOJ 1	-0.000236	0.000991	0.0000592	0.000111
FED	0.000412	0.00202	-0.000356	0.000342
USUE	-0.0022	0.002	1.087	0.754
USGDP	-0.0015*	0.00087	0.247	0.229
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000332	0.000619	0.0000607	0.0000942
BOJ 1	0.000024	0.00141	0.000220	0.000216
FEDF	0.000041	0.00316	-0.000725	0.000494
ECB	-0.00041	0.00254	-0.093	0.217
USUE	-0.007*	0.003	0.878*	0.372
USGDP	-0.0014	0.0013	-0.604*	0.104

Table A.4.3: The impact of interventions on the mean of the RND: anticipated effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000511	0.000687	0.0000695	0.000146
BOJ 1	0.00398*	0.00168	-0.000474	0.000307
FED	-0.00745*	0.00381	-0.00029	0.000544
USUE	0.00056	0.0018	1.022	0.712
USGDP	-0.0011	0.00076	0.114	0.202
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000148	0.000723	0.0000973	0.000123
BOJ 1	0.00392*	0.00167	-0.000383	0.000268
FEDF	-0.0177*	0.00197	-0.00170	0.000495
ECB	0.0023	0.0023	0.0051	0.1855
USUE	0.00122	0.002	0.538	0.357
USGDP	-0.0019	0.0013	-0.603	0.101

Table A.4.4: The impact of interventions on the implied standard deviation

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.00483*	0.00349	-0.0000444	0.00018
BOJ 1	0.0286*	0.00788	0.00095*	0.00044
FED	0.0148	0.0103	0.00121	0.00086
USUE	-0.016	0.013	2.101	1.205
USGDP	-0.002	0.004	-0.289	0.455
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.00381	0.00328	-0.0559	0.00018
BOJ 1	0.0285*	0.00780	0.0010*	0.00042
FEDF	0.0640*	0.0288	0.0009	0.00065
ECB	-0.028	0.016	0.149	0.863
USUE	-0.019	0.015	0.774	1.364
USGDP	-0.0019	0.0057	0.189	0.557

Table A.4.5: The impact of interventions on the implied standard deviation: persistent effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00262	0.00331	-0.000077	0.00020
BOJ 1	-0.00572	0.00752	0.00012	0.00043
FED	-0.0215	0.0154	0.00091	0.00096
USUE	-0.020	0.009	0.089	0.933
USGDP	0.004	0.005	-0.145	0.461
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00255	0.00331	-0.0684	0.00019
BOJ 1	-0.00545	0.00748	0.00016	0.00040
FEDF	-0.0363*	0.0135	-0.00032	0.00092
ECB	0.015	0.014	-0.409	0.934
USUE	-0.0198	0.015	0.511	1.421
USGDP	0.0078	0.007	0.0499	0.515

Table A.4.6: The impact of interventions on the implied standard deviation: anticipated effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.000059	0.00215	-0.00026	0.00017
BOJ 1	0.0113*	0.00605	0.00131	0.00037
FED	0.0149	0.0129	0.00146*	0.00076
USUE	-0.024	0.010	0.833	1.072
USGDP	-0.008	0.003	-1.101*	0.405
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00029	0.00216	-0.00052	0.00017
BOJ 1	0.0113*	0.00593	0.0012*	0.00035
FEDF	0.0962*	0.0393	0.00273*	0.00078
ECB	-0.002	0.011	0.092	0.906
USUE	-0.009	0.013	0.625	1.292
USGDP	-0.007	0.004	-0.285	0.564

Table A.4.7: The impact of interventions on the implied skewness

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00532	0.00735	0.000328	0.000210
BOJ 1	0.0436	0.0357	-0.001648*	0.000510
FED	0.0832	0.0819	0.000812	0.00222
USUE	0.009	0.023	0.322	0.812
USGDP	0.009	0.015	0.771	0.473
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00532	0.00735	0.000328	0.000210
BOJ 1	0.0436	0.0357	-0.00165*	0.000510
FEDF	0.0832	0.0819	0.000812	0.00222
ECB	-0.040	0.039	-0.657	0.399
USUE	-0.038	0.028	0.378	0.421
USGDP	-0.024	0.021	0.039	0.183

Table A.4.8: The impact of interventions on the implied skewness: persistent effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.0121	0.00812	0.000256	0.000228
BOJ 1	0.0191	0.0222	-0.000643	0.000467
FED	-0.00974	0.00991	0.000872	0.000843
USUE	-0.017	0.017	-1.036	0.757
USGDP	0.009	0.011	0.092	0.301
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.0117	0.00788	0.000239	0.0002
BOJ 1	0.0180	0.0224	-0.00066	0.000432
FEDF	-0.0466	0.0461	0.000852	0.00183
ECB	-0.059	0.030	-0.517	0.351
USUE	0.019	0.038	0.209	0.409
USGDP	0.041	0.025	-0.056	0.167

Table A.4.9: The impact of interventions on the implied skewness: anticipated effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00386	0.00599	0.000409	0.000221
BOJ 1	-0.0352	0.0189	-0.00186*	0.000501
FED	0.00711	0.00979	0.000994	0.00077
USUE	-0.024	0.021	0.732	0.719
USGDP	-0.014	0.012	0.902	0.475
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00334	0.00597	0.000341	0.000188
BOJ 1	-0.0178	0.0173	-0.001576*	0.000479
FEDF	0.0651	0.0578	0.000231	0.02104
ECB	-0.0399	0.039	-0.657	0.399
USUE	-0.038	0.028	0.378	0.421
USGDP	-0.024	0.021	0.039	0.182

Table A.4.10: The impact of interventions on the implied kurtosis

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.000121	0.000463	-0.00039	0.00034
BOJ 1	-0.00304	0.00224	0.000617	0.00078
FED	-0.000254	0.00148	-0.00045	0.00062
USUE	-0.002	0.003	-2.285	1.751
USGDP	0.0018	0.002	-1.101	0.590
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.000435	0.00056	-0.00075*	0.00038
BOJ 1	-0.00250	0.00250	0.0012	0.0008
FEDF	-0.00127	0.00206	-0.00115	0.0011
ECB	0.00015	0.0042	-1.269	1.498
USUE	-0.0056	0.0035	-1.695	2.971
USGDP	0.0023	0.0019	-0.084	0.562

Table A.4.11: The impact of interventions on the implied kurtosis: persistent effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.00084	0.000774	-0.00033	0.00033
BOJ 1	0.00386*	0.00198	0.000021	0.00076
FED	0.00275	0.00154	-0.00048	0.00065
USUE	0.003	0.003	-1.909	1.704
USGDP	-0.0018	0.0018	-0.857	0.632
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.00105	0.000821	-0.00068	0.00035
BOJ 1	0.00341	0.00201	0.00042	0.00078
FEDF	0.00283	0.00269	-0.00092	0.0012
ECB	0.00015	0.0042	-1.269	1.498
USUE	-0.0057	0.0035	-1.695	2.971
USGDP	0.002	0.0019	-0.084	0.561

Table A.4.12: The impact of interventions on the implied kurtosis: anticipated effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.00019	0.00055	-0.00043	0.00037
BOJ 1	-0.00474*	0.00152	0.00053	0.00074
FED	0.000436	0.00106	-0.00057	0.00057
USUE	0.0053*	0.0026	-1.694	2.023
USGDP	0.0038*	0.0018	-1.489*	0.529
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000491	0.000669	-0.0008	0.00037
BOJ 1	-0.00560*	0.00181	0.0011	0.00066
FEDF	-0.000187	0.00179	-0.00165	0.00098
ECB	-0.0019	0.004	-0.759	1.462
USUE	0.004	0.003	-3.536	2.955
USGDP	0.0033*	0.0015	-0.525	0.704

Appendix 5: Estimation results on US dollar/EUR

Table A.5.1: The impact of interventions on the mean of the RND

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000181	0.00165	0.0186	0.0654
BOJ 1	0.000724	0.00292	-0.0932	0.000148
FED	-0.00597	0.00334	-0.0726	0.000451
USUE	-0.002	0.003	0.827	0.443
USGDP	-0.001	0.001	-0.241	0.209
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000156	0.000228	-0.00092*	0.000217
BOJ 1	0.00156	0.00304	-0.000250	0.000422
FEDF	-0.00657*	0.00131	-0.00122	0.000828
ECB	-0.001	0.004	-2.405*	0.712
USUE	0.003	0.004	0.144	0.979
USGDP	-0.002	0.002	-0.824*	0.414

Table A.5.2: The impact of interventions on the mean of the RND: persistent effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.0000139	0.000802	0.000021	0.0000692
BOJ 1	-0.00362	0.00206	-0.0000638	0.000168
FED	-0.000317	0.00414	-0.0366	0.000503
USUE	0.002	0.004	0.732*	0.306
USGDP	-0.001	0.002	-0.189	0.190
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000190	0.00104	0.00034	0.000276
BOJ 1	-0.00383	0.00235	-0.0006	0.00075
FEDF	0.00434*	0.000318	-0.00345	0.000835
ECB	0.003	0.004	0.205	0.846
USUE	0.001	0.007	0.435	1.685
USGDP	-0.001	0.002	0.499	0.405

Table A.5.3: The impact of interventions on the mean of the RND: anticipated effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00223*	0.00112	-0.00140	0.0628
BOJ 1	-0.00279	0.00234	-0.000104	0.00017
FED	0.00974	0.00571	0.0589	0.000514
USUE	0.013*	0.003	0.915	0.490
USGDP	-0.005*	0.002	-0.267	0.218
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00221*	0.000654	-0.00046*	0.000189
BOJ 1	-0.00344	0.00253	-0.000195	0.000534
FEDF	0.0103*	0.000461	-0.00397*	0.00190
ECB	0.005*	0.002	1.991*	0.923
USUE	0.008	0.004	2.797*	0.829
USGDP	-0.007*	0.003	-0.474	0.352

Table A.5.4: The impact of interventions on the implied standard deviation

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000323*	0.000273	-0.00018	0.000145
BOJ 1	0.00135*	0.000674	0.00061*	0.00031
FED	0.00250*	0.00123	0.00038	0.00045
USUE	-0.001	0.001	0.004	0.913
USGDP	0.0003	0.0003	-0.689*	0.311
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000301	0.000278	-0.000173	0.00016
BOJ 1	0.00138*	0.000666	0.00084*	0.00035
FEDF	0.00132	0.00178	0.00067	0.00078
ECB	-0.002	0.001	0.031	0.558
USUE	0.001	0.001	-1.011	0.946
USGDP	0.001	0.001	-0.245	0.342

Table A.5.5: The impact of interventions on the implied standard deviation: persistent effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.000234	0.000204	-0.000212	0.00016
BOJ 1	0.000204	0.000428	0.00037	0.00035
FED	0.00130	0.00133	0.000121	0.00039
USUE	-0.001	0.001	-0.227	0.992
USGDP	-0.0001	0.0002	-0.860*	0.309
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.000235	0.000190	-0.000212	0.000179
BOJ 1	0.000492	0.000520	0.00059	0.00039
FEDF	-0.000216*	0.000472	0.00022	0.00062
ECB	0.001	0.001	0.296	0.515
USUE	-0.001	0.001	-1.204	0.991
USGDP	0.0000	0.0003	-0.442	0.375

Table A.5.6: The impact of interventions on the implied standard deviation: anticipated effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000020	0.000258	-0.000221	0.00014
BOJ 1	0.00105	0.000637	0.00093*	0.00035
FED	0.000429	0.00106	0.00028	0.00043
USUE	-0.0004	0.0006	-0.159	0.930
USGDP	-0.001	0.0002	-0.963*	0.291
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.0000315	0.000269	-0.000244	0.00016
BOJ 1	0.00117	0.00674	0.00125*	0.0004
FEDF	-0.000620	0.00098	0.00032	0.00079
ECB	-0.0004	0.001	0.059	0.532
USUE	-0.0003	0.001	-1.329	0.968
USGDP	-0.001	0.0003	-0.583	0.361

Table A.5.7: The impact of interventions on the implied skewness

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00424	0.0107	-0.0175	0.0733
BOJ 1	-0.0297	0.0228	0.000133	0.000220
FED	0.0466	0.0335	0.000248	0.000353
USUE	0.057	0.032	0.406	2.094
USGDP	-0.056*	0.016	-0.154	0.308
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00152	0.00440	-0.000549	0.00027
BOJ 1	-0.0393*	0.0193	-0.000370	0.000471
FEDF	0.282*	0.0029	-0.00261*	0.0009
ECB	-0.026	0.019	1.065	0.788
USUE	0.045	0.040	1.100	1.819
USGDP	-0.022	0.017	0.072	0.439

Table A.5.8: The impact of interventions on the implied skewness: persistent effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.0126	0.00837	-0.0254	0.0677
BOJ 1	-0.0103	0.0185	0.000209	0.000245
FED	0.0234	0.0174	0.000263	0.000341
USUE	-0.012	0.018	-4.712	2.482
USGDP	0.010	0.010	-0.910	0.480
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.0176	0.0103	0.000140	0.000313
BOJ 1	-0.0194	0.0197	-0.000142	0.00104
FEDF	-0.0249	0.00979	0.00496*	0.00094
ECB	0.047	0.040	-0.943	0.871
USUE	0.0001	0.038	-1.247	1.348
USGDP	0.011	0.014	-0.378	0.472

Table A.5.9: The impact of interventions on the implied skewness: anticipated effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00293	0.0064	0.0778	0.000135
BOJ 1	-0.00946	0.0280	-0.000695	0.000423
FED	-0.00698	0.0116	0.000718	0.00062
USUE	0.010	0.015	4.447*	2.282
USGDP	0.011	0.015	1.228*	0.625
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.00185	0.00585	-0.0000325	0.000150
BOJ 1	-0.00547	0.0252	-0.00058	0.00041
FEDF	-0.0525*	0.0380	0.00061	0.00176
ECB	0.008	0.033	-0.747	0.805
USUE	-0.025	0.044	-1.365	1.299
USGDP	-0.035	0.024	0.369	0.594

Table A.5.10: The impact of interventions on the implied kurtosis

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	0.000481	0.00466	-0.00026*	0.000116
BOJ 1	0.00537	0.0192	0.00134*	0.000521
FED	-0.000648	0.0194	0.0011*	0.00039
USUE	0.016	0.018	-0.556	0.638
USGDP	-0.022	0.009	-1.045*	0.383
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00447	0.00946	0.000373	0.00047
BOJ 1	0.00854	0.0161	-0.000097	0.0097
FEDF	-0.0570	0.0687	0.00154	0.00092
ECB	0.016	0.016	-0.895	0.799
USUE	0.026	0.035	-0.088	1.409
USGDP	-0.016	0.011	-0.409	0.508

Table A.5.11: The impact of interventions on the implied kurtosis: persistent effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.0113*	0.00571	-0.00028*	0.00015
BOJ 1	0.0143	0.0210	0.00013	0.00076
FED	-0.0106	0.0167	0.00076	0.00058
USUE	0.005	0.015	-0.983	0.736
USGDP	0.004	0.006	-0.939*	0.402
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.0118*	0.00547	-0.00038	0.000297
BOJ 1	0.0183*	0.00926	0.000130	0.00062
FEDF	0.0353*	0.00869	-0.00048*	0.000481
ECB	-0.031	0.018	-0.829	0.901
USUE	-0.015	0.027	-1.042	1.544
USGDP	0.003	0.008	-0.419	0.528

Table A.5.12: The impact of interventions on the implied kurtosis: anticipated effect

	Conditional mean equation		Conditional variance equation	
Full sample	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00500	0.00557	-0.00024*	0.00013
BOJ 1	-0.00849	0.0133	0.00127*	0.00057
FED	-0.0152	0.0119	0.00093*	0.00048
USUE	0.036	0.031	-0.203	0.725
USGDP	0.008	0.008	-0.963*	0.381
Post-1999	*Coefficient*	*Standard error*	*Coefficient*	*Standard error*
BOJ	-0.00523	0.00678	0.0002	0.00041
BOJ 1	0.000692	0.0122	0.00044	0.00076
FEDF	-0.0138	0.0168	-0.00129	0.00099
ECB	-0.017	0.012	-1.183	0.642
USUE	0.011	0.020	-0.394	1.223
USGDP	0.008	0.009	-0.361	0.453

Appendix 6: Logit estimations of interventions

Dependent variable: 1 when Japanese intervention on JPY/USD exchange rate, 0 otherwise

Independent variables from RNDs on JPY/USD, deviation from equilibrium measured by distance of sport rate from JPY 125

	Dependent variable	
	BOJ	BOJ1
	Full sample	
Dev. From equilibrium (-1)	-15.76* (1.39)	-12.58* (2.82)
Mean of RND (-1)	-1.73 (2.05)	-2.34 (2.76)
Stdev of RND (-1)	6.57* (2.96)	9.30* (4.54)
Skewness of RND(-1)	-1.87 (1.06)	-3.67 (2.01)
Kurtosis of RND(-1)	-8.24 (8.75)	-2.49 (1.69)
	Sample from June 1995	
Dev. From equilibrium (-1)	-9.33* (2.26)	-5.02* (0.302)
Mean of RND (-1)	-1.11 (2.51)	-1.96 (3.10)
Stdev of RND (-1)	5.39 (4.29)	13.40* (6.43)
Skewness of RND(-1)	-2.23 (1.36)	-4.01 (2.28)
Kurtosis of RND(-1)	-6.18 (12.38)	-21.21 (18.57)

** Denotes statistical significance at 5% level.*

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