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ESTIMATING AND ANALYSING CURRENCY OPTIONS IMPLIED RISK-NEUTRAL DENSITY FUNCTIONS FOR THE LARGEST NEW EU MEMBER STATES

by Olli Castrén

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In 2005 all ECB publications will feature a motif taken from the €50 banknote.

1 The views expressed in this paper are those of the author only and they do not represent the views of the European Central Bank or the European System of Central Banks. Useful comments by Peter Christoffersen, Stelios Makrydakis and participants in internal ECB seminars are gratefully acknowledged.

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CONTENTS

Abstract 4

Non-technical summary 5

1. Introduction 6

2. Stylised facts and the options data 7

   2.1. Data issues 8

   2.2. Related research 9

3. Estimated implied risk neutral density functions 10

   3.1. Methodology 10

   3.2. Results 12

      3.2.1. Estimated RNDs for selected dates 12

      3.2.2. Estimated moments 13

4. Changes in implied moments around times of monetary policy decisions 18

   4.1. The estimated model 19

   4.2. Results from the econometric analysis 22

      4.2.1 The dummy variable specification 22

      4.2.2 The news impact variable specification 25

   4.3. Do movements in implied moments predict interest rate changes? 26

5. Robustness check: findings for the USD/EUR currency pair 28

Conclusion 30

References 32

Appendices 35

Charts 38

European Central Bank working paper series 48

Abstract

This paper uses data on currency options prices for the exchange rates of the three largest new EU member states Poland, Czech Republic and Hungary vis-à-vis the euro and the US dollar to estimate the risk-neutral density (RND) functions and the density interval bands. Analysing the RNDs, we find that only some of the implied moments on the Polish zloty exchange rate systematically move around policy events, while the implied moments on the RNDs on the Czech koruna and Hungarian forint show more systematic changes. Regarding the HUF/EUR currency pair, monetary policy news have a significant impact on all moments, while changes in implied standard deviation signal a higher probability of interest rate changes by the Hungarian central bank. The more marked results for HUF/EUR exchange rate could reflect the fixed exchange rate regime prevailing throughout the sample period.

Keywords: Foreign exchange rate market sentiment, monetary policy news, currency options data

JEL classification: E52, F31, G15

Non-technical summary

In May 2004 ten new countries joined the European Union. After the enlargement, the euro faces 13 intra-EU bilateral exchange rates. This paper focuses on the currencies of three largest new EU member states (NMS) Poland, the Czech Republic and Hungary. Using data on currency options prices on the exchange rates of these countries' currencies against the euro and the US dollar we estimate the implied risk-neutral density (RND) functions that, under certain caveats, allow for analysis of changes in the options market's assessment regarding future currency movements.

Currency options data has proven very useful in analysing the changes in sentiment and uncertainty in foreign exchange markets. Because options markets are inherently forward looking, prices of options with different maturities provide information on the market's views regarding the future movements in exchange rates, as well as the market's perception of risk. Moreover, currency options provide a unique piece of information as they cover all moments of the distribution. Analysis of individual moments of the RNDs can shed light on, for example, whether the currency options market's sentiment changes prior to policy movements, or how the assessment adjusts after such movements have taken place.

It turns out that for the currencies covered in our analysis, many of which tend to be more volatile than the currencies of major economic areas, the methods used to extract information from options prices are particularly illustrative. The estimated density functions are rather accurate apart from the extreme tail percentiles. Moreover, apart from the Polish zloty, the moments of the distributions often move around times of monetary policy announcements, suggesting that the options market could have anticipated impending policy changes. We find little evidence that the movements of the distributions would be correlated across currencies. We conclude that monitoring currency options markets is useful to gauge information about sentiment in the largest new EU states' exchange rates.

1. Introduction

In May 2004 ten new countries joined the European Union. After the enlargement, the euro faces 13 intra-EU bilateral exchange rates. This paper focuses on the currencies of three largest new EU member states (NMS) Poland, the Czech Republic and Hungary. Using data on currency options prices on the exchange rates of these countries' currencies against the euro and the US dollar we estimate the implied risk-neutral density (RND) functions that, under certain caveats, allow for analysis of changes in the options market's assessment regarding future currency movements.

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The rest of this paper is structured as follows. Section 2 includes stylised facts about the past developments in the exchange rates covered in this study and introduces the currency options data. Section 3 shows the results from estimated risk neutral density functions and the estimated density percentile bands. Section 4 reports the results from the assessment of movements in implied moments around the times of monetary policy announcements. In section 5, we conduct a robustness check by applying similar data on USD/EUR currency options. Section 6 concludes.

2. Stylised facts and the options data

During the period of their gradual return to convertibility throughout the 1990s, the three largest new EU member states' currencies (the Polish zloty, the Czech koruna and the Hungarian forint) have gone through several regime shifts. In Poland, the authorities devised a crawling peg regime for the zloty in October 1991 with initially a narrow fluctuation band. By the time of the launch of the euro in January 1999 the fluctuation band had been gradually widened, and in April 2000 Poland switched to a floating exchange rate regime with no formal restrictions for currency movements. Since 1999, Poland has pursued a direct inflation targeting approach and the authorities have generally refrained from exchange rate intervention. In the Czech Republic, the initial exchange rate peg was abandoned in favour of an inflation targeting regime with a floating exchange rate in January 1998 after an exchange rate crisis in May 1997. Over the years, the Czech authorities have occasionally intervened in the market to smooth out excessive fluctuations. Since mid-1990s, the Hungarian forint followed a crawling peg regime initially in a narrow band. In May 2001, the width of the band was first extended to +/- 15%. In June 2001, all controls on capital account transactions were lifted and in October 2001 a new exchange rate corridor was established. Soon thereafter Hungary also adopted an inflation target. The forint's fluctuation band was adjusted in the context of a devaluation of the central rate in June 2003.

Chart 1 illustrates the developments in the three currencies vis-à-vis the euro from the launch of the single currency in January 1999. It can be seen that the Polish zloty and the Czech koruna both initially appreciated against the euro. Since mid-2001, the appreciation trend of the zloty reversed, while the koruna continued to appreciate until late 2002 whereafter it has modestly depreciated. After the widening of the fluctuation band in 2001, the Hungarian forint initially appreciated before reverting that trend in 2003. Chart 2 shows the developments against the US dollar, illustrating that all three new EU member currencies broadly depreciated against the US currency between early 1999 and late 2000. Since then, there has been a broad-based appreciation against the US dollar that has been most pronounced in the case of the Czech koruna.

2.1. Data issues

Options contracts on the Polish zloty, the Czech koruna and the Hungarian forint have been gradually introduced as the exchange rates have become increasingly convertible, the restrictions on the foreign exchange transactions have been lifted and the currencies have been allowed to fluctuate freely or within wider bands. Like in the case of currency options more generally, options in these currencies are usually traded on the over-the-counter (OTC) basis and not in centralised futures/options exchanges. The OTC trading structure, mainly operated through the largest international banks, obviously creates some limitations to the liquidity of the market. However, the fact that the currency options market is heavily concentrated on a few global players suggests that the liquidity problems can be minimised if data from these institutions is available.[1]

The options data used in this study consist of 1-month implied volatilities, 1-month risk reversals and 1-month strangles for all three currencies, both against the euro and vis-à-vis the US dollar. 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. A 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 a skewness towards an expected appreciation of the base currency. A strangle is a strategy 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. All the data is extracted from European options, i.e. options that cannot be exercised prior to the date of maturity (as opposed to American options). Appendix 1 includes the descriptive statistics of the options data. For the estimation of the RNDs, data on 1-month forward exchange rates and 1-month interest rates is also required. The source of this data is BIS. Prior to estimation, all data was filtered and carefully checked for errors and omitted observations.

[1] Citigroup, the source of the data used in this study, has a large market share in options on major exchange rates as well as on the emerging market currencies. Options on all the exchange rates covered by this study are available on daily basis from September 2002. Throughout our sample period – that stretches to January 2004 – only the HUF/EUR exchange rate was subject to a formal exchange rate regime in the context of its +/- 15% fluctuation band around the central parity.

2.2. Related research

The analysis in this paper builds upon two main branches of research. The first branch analyses options implied distributions building on the seminal Black and Scholes options pricing model. The work has been extensively surveyed by Bahra (1997), Jackwerth (1999), Jondeau and Rockinger (2000), and Bliss and Panigirtzoglou (2000, 2004). Christoffersen and Mazzotta (2004) analyse the properties of the RNDs for all major currencies and find that the distributions provide generally good estimates of the true density functions. The movements in the estimated RNDs around times of macroeconomic data releases have been studied by Melick and Thomas (1997) and Soderlind (2000), who focus on episodes of financial crises. Using exchange-traded options data, Galati and Melick (2002) analysed the movements of the implied moments of the estimated RNDs around times of official interventions on the JPY/US dollar exchange rate.

The second branch of relevant literature covers the reactions of asset prices on monetary policy news. Among the more well-known studies, Neumann and Wiedmann (1998), Perez-Quiros and Timmermann (2000), Lee (2002), Bomfim (2003) and Gasbarro and Monroe (2004) find systematic evidence of movements in money market interest rates, bond yields and stock prices around times of changes in monetary policy stance. Changes in options implied probability distributions around times of monetary policy decisions have been studied by Bhar and Chiarella (2001) and Mandler (2000) for money market rates and by Vahamaa (2004) for bond yields. Both find systematic evidence of movements in expectations before and after interest rate announcements. In this field of research, a prominent problem has been the identification of monetary policy shocks that arises from the fact that central banks might react to developments in financial markets and exchange rates. Rigobon and Sack (2003) show that causality between interest rates and asset prices runs in both directions, and not accounting for this endogeneity could impose a bias in the estimation. In this respect, Kuttner (2001), Bernanke and Kuttner (2003) and Ehrmann and Fratzscher (2003) derive monetary policy shocks through measures of market expectations. Their results show that on the days of policy announcements, financial markets do not react on the announcement *per se* but to the unexpected component that is not yet priced into the market.

In this study we analyse the impact of monetary policy decisions on exchange rate implied distributions rather than money market or bond distributions. We include variables capturing monetary policy news impact to avoid such identification problems. Another novelty is that we use data on currencies of rather small and open economies that may respond in a different way to monetary policy news than the currencies of major economic areas. This is because for small open economies, the exchange rate channel typically plays a more important role in the monetary transmission mechanism, and the exchange rate is thus often included among the prominent indicator variables for monetary policy. Moreover, the degree of development of capital markets and the scale of international capital movements are more limited in smaller economies, also affecting the links between exchange rates and monetary policy.

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 prices can be used to extract point estimates for the expected future values of interest rates, exchange rates, inflation rates or commodity prices. However, the most comprehensive view of market sentiment is provided by options prices that contain information on the entire distribution around the point estimates. A straightforward use of option prices is the calculation of *implied volatility* via the classic Black and Scholes model. In that context, implied volatility measures the degree of uncertainty that the market attaches to the future return on an asset, and it can be backed out from observed options prices by inverting the Black and Scholes formula where the only unobserved variable is the market's view on future volatility.

The literature has suggested several approaches to estimate the risk-neutral volatility smile and the risk-neutral density function. First, 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. Second approach, introduced by Rubinstein (1994) uses non-parametric Bayesian techniques to construct a binomial tree for the value of the underlying asset. Third, 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). The 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. 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.

As our focus is on currency options, we apply here the Malz method. The technique builds on a result obtained by Breeden and Litzenberger (1978), whereby 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 call 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 strikes which is not available to the researcher. Therefore, interpolations and extrapolations have to be used. To represent the exercise prices, the Malz technique interpolates across implied volatilities using the Black and 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 the 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 and 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 price following (1).

Over the past few years, methodological research has contributed to a re-interpretation of the RND concept. The RNDs are now seen as incorporating two distinct components, the traders' perception of asset price movements, and the traders' degree of risk aversion. Ait-Sahalia et al (2001), Beber and Brandt (2003) and Bliss and Panigirtzoglou (2004) have demonstrated the importance of distinguishing the two RND components. Scheicher (2003) and Tarashev (2003) discuss the ways to extract the risk aversion component from options prices by comparing options-based and GARCH-estimated RNDs. 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 is beyond the scope of this exercise.

3.2. Results

The results here are reported by first plotting the RNDs estimated using the Malz method for various currencies at selected dates. We then plot the density bands that illustrate the time series of the distribution quantiles around the forward rate. While such results are very useful for illustrative purposes, we also want to know how relevant these findings are. We therefore subject the estimated RNDs to a number of tests to evaluate their accuracy, particularly regarding the behaviour of the tails of the distribution.

3.2.1. Estimated RNDs for selected dates

Charts 3-8 illustrate the entire RND functions for the various currency pairs. It can be seen that the shapes of the distributions vary considerably over time, both regarding the width and the symmetry of the functions. A graphical examination of the RNDs thus already provides interesting information about changes in financial markets' perception of future exchange rate movements, the traders' risk preferences, or both. Looking at the density bands that illustrate the percentiles of the distribution around the 1-month forward rate (the 10^{th}, 30^{th}, 50^{th}, 70^{th} and 90^{th} percentiles are included, see Charts 9-14), apart from the Hungarian forint the width of the bands remains rather stable around the 1-month forward exchange rate. This would suggest that extreme changes in the probability distributions are rather rare events in the currency options market.

An interesting case study is the episode of interest rate cut by the Hungarian central bank on 15 January 2003 that took place amid heightened exchange rate volatility. Chart 5 shows that the policy move was associated with a movement of the HUF/EUR 1-month forward exchange rate towards a weaker forint (a movement to the right of the mean of the distribution). At the same time, the increase in the standard deviation of the RND indicates that there was either an increase in the market's uncertainty regarding future movements, or an increase in risk aversion. While the distribution soon after the rate cut remained skewed to the left (towards future forint appreciation), over the following days the mass of the distribution moved to the right suggesting that the majority of the market participants came to consider future depreciation more likely than appreciation. Finally, the tails of the distribution lengthened considerably after the policy move, illustrating increased kurtosis. Chart 11 shows that from November 2002 through early January 2003 the lower 90^{th} percentile band was outside the lower boundary of the HUF/EUR fluctuation band (the dark dotted line in the Chart). This suggests that the prior to the interest rate cut, the market assigned a non-negligible probability to the event that the exchange rate were to appreciate outside the band in the near future. After the interest rate cut the left tail of the distribution gradually moved inside the interval. The overall width of the distribution also declined quite markedly over the following months, before it widened again after the devaluation of the parity in June 2003. Throughout the same time interval, the skewness of the distribution changed from left to right, suggesting that the market had came to assign a relatively higher probability of future HUF weakness.

Finally, we can compare the above developments in the changes of the distributions on the HUF/USD currency pair over the same episode (see Chart 8). While the Hungarian rate cut on 15 January 2003 was associated with a depreciation of the forint also against the US currency, moving the mean of the distribution to the right, the implied higher moments changed by much less. This asymmetry in reactions suggests that the HUF/EUR options market could be more responsive to news than the HUF/USD market. This is perhaps not so surprising given that throughout the sample period the Hungarian exchange rate regime was characterised by a fixed peg to the euro, albeit with a wide fluctuation band.

3.2.2. Estimated moments

While the movements in the entire distribution function provide interesting snapshots to daily changes in exchange rate expectations, to gauge any information about systematic impacts on the expectations it is more useful to resort to changes in the individual moments: standard deviation, skewness and kurtosis. By focusing on the moments we can also analyse whether the movements in various currency pairs are correlated with each other, which could suggest co-movement or contagion across markets.

Standard deviation

The standard deviations of the estimated RNDs show significant differences across currencies (see Charts 15-16). The standard deviation of the RNDs on the PLZ/EUR, PLZ/USD, CZK/EUR and CZK/USD currency pairs is, on average, lower than the standard deviation on the HUF exchange rates. Again, this overall uncertainty, or higher risk aversion, associated with the Hungarian currency could be related to the fixed exchange rate regime that does not allow for as substantial adjustment to potential shocks as is the case with the other two NMS currencies.

The standard deviations of the RNDs are not systematically correlated, although there are signs that the standard deviation of the RNDs on the PLZ/EUR currency pair tends to be positively correlated with the standard deviation of the RNDs on the PLZ/USD currency pair (see Table 1.a). Likewise, the standard deviation of the RNDs on the HUF/EUR and HUF/USD currency pairs are positively correlated. There are no signs of correlation between currency pairs where the base currency is not the same.

Table 1.a: Correlations across implied standard deviations

		STDEV				
	PLZEUR	CZKEUR	HUFEUR	PLZUSD	CZKUSD	HUFUSD
PLZEUR	1					
CZKEUR	-0.2986	1				
HUFEUR	0.561555	-0.24227	1			
PLZUSD	**0.81212**	-0.364026	**0.672701**	1		
CZKUSD	0.175291	0.195738	-0.086681	0.199026	1	
HUFUSD	0.452396	-0.153829	**0.845978**	0.615857	0.187222	1

Figures printed in bold refer to significant estimates at 5% level

Skewness

Implied skewness, being a measure of asymmetry of the estimated RNDs, provides useful information in so far that it is a measure of the direction of the market's view 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 reasons.

The series for implied skewness for the RNDs on various currency pairs are plotted in Charts 17-18. The RNDs derived from the data on all three currencies show positive skewness almost throughout the sample period, suggesting that the market's positioning was, on average, biased towards a higher probability of future appreciation of the euro. The picture is somewhat different when turning to the data on the bilateral US dollar rates, however. The PLZ/USD and HUF/USD rates show rather consistent positive skewness (suggesting a bias towards future USD strength), while the skewness of the RND on the CZK/USD currency pair is more mean-zero reverting, becoming more consistently positive only around mid-2002. The fact that there were consistent expectations among market participants of future PLZ and HUF weakness is in conflict with the actual developments throughout the sample period whereby the zloty and the forint in fact *appreciated* against the US currency.

The series of skewness are positively correlated between the PLZ/EUR and PLZ/USD currency pairs and between the HUF/EUR and CZK/USD currency pairs (see Table 1.b).

Table 1.b: Correlations across implied skewnesses

		SKEW				
	PLZEUR	CZKEUR	HUFEUR	PLZUSD	CZKUSD	HUFUSD
PLZEUR	1					
CZKEUR	-0.120168	1				
HUFEUR	0.468962	0.312983	1			
PLZUSD	**0.736756**	0.104085	0.369627	1		
CZKUSD	0.252691	0.51252	**0.726244**	0.324595	1	
HUFUSD	0.349773	0.362628	0.501553	0.199818	0.359839	1

Figures printed in bold refer to significant estimates at 5% level

Kurtosis

Implied kurtosis provides a measure of the market's assessment of the likelihood of extreme events, by measuring the length of the tails of the RND function. As demonstrated in Charts 19-20, the series on all currency pairs show excess kurtosis. Again, the phenomenon is more distinctive in the case of the HUF/EUR currency pair, possibly reflecting the features of the fixed currency regime.

The kurtosis series for RNDs on PLZ/EUR and PLZ/USD on one hand and HUF/EUR and HUF/USD currency pairs on the other hand show moderate positive correlation as reported in

Table 1.c. Therefore, the probability of large PLZ and HUF movement tends to increase or decrease simultaneously both vis-à-vis the euro and the US dollar.[2]

Table 1.c: Correlations across implied kurtosis

KURT	PLZEUR	CZKEUR	HUFEUR	PLZUSD	CZKUSD	HUFUSD
PLZEUR	1					
CZKEUR	-0.265616	1				
HUFEUR	0.230705	0.355281	1			
PLZUSD	**0.582747**	-0.542542	-0.209782	1		
CZKUSD	0.179696	0.074854	-0.173552	0.349965	1	
HUFUSD	0.222079	0.46677	**0.621826**	-0.244658	-0.039678	1

Figures printed in bold refer to significant estimates at 5% level

Finally, to take a closer look at the potential measurement problems associated with RNDs estimated using the Malz method, and to verify the accuracy of the estimated RNDs and the implied moments, we follow Christoffersen and Mazzotta (2004) who report results from several statistical tests. To this end, 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

$$U_{t,h} \equiv \int_{-\infty}^{S_{t+h}} f_{t,h}(u)du \equiv F_{t,h}(S_{t+h}), \tag{3}$$

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 then use the standard normal inverse cumulative density function to transform the uniform probability transform to a normal transform variable:

$$Z_{t,h} = \Phi^{-1}(U_{t,h}) = \Phi^{-1}(F_{t,h}(S_{t+h})) \tag{4}$$

[2] The results on the higher moments (skewness and kurtosis) need generally to be qualified by the fact that the estimation methodology uses only three observations in the cross-section. Against this background, Bliss and Panigirtzoglou (2000) argue that no far-reaching implications should be drawn from the movements in the highest moments.

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 variables X_t observed at time t. Consequently, the normal transform variable must be normally distributed and also independent of all variables observed at time t.

To focus attention on the performance of the density forecasts in the tails of the distribution, we report QQ-plots of the normal transform variables in Chart A.2 in Appendix 2. 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 be close to the 45-degree line. The Chart shows that the left tail fits somewhat poorly in the case of the PLZ/EUR and the CZK/EUR currency pairs, and that the right tail fits somewhat poorly in the case of the CZK/EUR and the PLZ/USD rates. The main reason is that there are too few small observations in the data, and this problem is particularly obvious in the case of the euro exchange rates. This suggests that in general, the tails of the probability transform variables are too thick which is confirmed by the test statistics reported in Tables A.2.1 and A.2.2. In the case of the US dollar rates there are generally more small observations in the data, while the right tails tend to be too thick. This is particularly the case for the PLZ/USD rate.

Finally, consider a generic random variable x with observations x_t, $t = 1, 2,\ldots,T$. We can define the empirical cumulative distribution function as

$$F_T(x) = \frac{1}{T}\sum_{t=1}^{T} I(x_t \leq x) \qquad (5)$$

We apply three Kolmogorov tests (denoted by $D+$, $D-$ and D), and the Kuiper test (denoted by V), to compare the empirical distribution, $F_T(x)$, with the hypothesized cumulative distribution function $F(x)$ as follows

$$\begin{aligned} D_+ &= \sup_x \{F_T(x) - F(x)\} \\ D_- &= \sup_x \{F(x) - F_T(x)\} \\ D &= \sup_x \{|F_T(x) - F(x)|\} \\ V &= D_+ + D_- \end{aligned} \qquad (6)$$

In (6), sup refers to the supremum over *x*. The other three tests, Cramer-von-Mieses (C-M), Watson (W), and Anderson-Darling (A-D), rely on integrated deviations rather than the supremum of the deviations. As can be expected, no single test has superior power against all alternatives.

Table A.2.1 shows the results of the unconditional normal tests. Notice that the P-values are virtually zero in most cases implying a rejection of the option implied densities (apart from the HUF/EUR rate). In the other cases the P-value is sometimes very different from zero but the P-value is then zero in the complementary test (*D*+); thus the large P-value can be attributed to a lower power of this particular test for this particular exchange rate. In Table A.2.2 we report the first four moments of the normal transform variable along with *t*-statistics from the test that they equal the first four moments in the normal distribution (that is 0, 1, 0 and 3 respectively). Notice that the rejections vary across exchange rates. The zero mean hypothesis is rejected for the CZK/EUR and HUF/USD rates. The variance is rejected for the PLZ/EUR and the CZK/EUR rates. In both cases the variances are too small. Zero skewness is not rejected for any currency while kurtosis of three is rejected for the PLZ/USD rate.

All in all, the tests above tend to suggest that – possibly due to insufficient data coverage regarding the small and the large values of the exchange rate – the tails of the distributions are not always well specified. This result partially reflects the short sample period but it could also be that the Malz method lacks power at the far ends of the distribution tails. Christoffersen and Mazzotta (2004) report similar, although slightly less severe, findings for the major currency pairs using data from 1992-2003. Overall, however, we can conclude that the density functions provide rather reliable forecasts of future realised density in so far as the attention focuses on the area between the 20th and 70th percentiles.

4. Changes in implied moments around times of monetary policy decisions

We now turn to analyse the movements of the individual moments of the distribution (standard deviation, skewness and kurtosis) around the dates of monetary policy events. In so doing we try to gauge information on whether a) the FX options markets moved in anticipation of the policy moves, b) whether the market reacts to the “surprise” components of the policy announcement, and c) whether the change in monetary policy stance was followed by a change in the market's assessment regarding future exchange rate movements and/or the market's perception of risk.

Before proceeding to the econometric analysis, it is important to discuss how monetary policy shocks are likely to be transmitted to exchange rates. Based on interest rate parity and arbitrage conditions, an unanticipated monetary loosening should induce a depreciation of the domestic currency. Also, more accommodative domestic monetary policy (lower short-term interest rates) would shift the expected fundamentals towards higher demand, higher trade deficit and increased capital outflows. Via the expected simultaneous deterioration of the trade and the capital accounts, the domestic currency would depreciate relative to the foreign currency. Since the markets are forward looking, such expected future movements would be anticipated (discounted to period *t*). However, the reaction of exchange rates also depends on the market's interpretation of the underlying reasons behind the monetary policy decision and the expected effect on the economy. For instance, an unanticipated loosening of monetary policy stance may signal to market participants that the real economy and other asset prices, such as equities, will receive a boost and thus be positively affected. In such circumstances, easier monetary policy stance may even contribute to an appreciation of the domestic currency.[3]

4.1. The estimated model

To analyse empirically how monetary policy news might affect exchange rates we model the exchange rate in the standard asset-pricing framework. In that context, the exchange rate S_t reflects the discounted value of private agent's expectations about future economic fundamentals, x_{t+i}:

$$S_t = (1-\delta)\sum_{i=0}^{\infty}\delta^i E_t(x_{t+i}|\Omega_t) \qquad (i=0,1,2,\ldots\infty) \qquad (7)$$

In (7), δ denotes the discount factor, E the expectations operator and Ω_t the private agents' information set available at time *t*. A change in monetary policy stance can then be modelled as a change in the information set available for the private sector that is engineered by the central bank by adjusting domestic short-term interest rates.

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[3] For further discussion on the links between exchange rates and monetary policy decisions in the European context, see Gaspar, Perez-Quiros and Sicilia (2001), Perez-Quiros and Sicilia (2002), and Ross (2002).

How is the change in the exchange rate, caused by the adjustment in the monetary policy stance, transmitted to the moments of the 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 τ=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 as $\hat{\sigma}_t \equiv \sqrt{\frac{\mu_t^{(2)}}{\tau}}$, implied skewness as $\hat{\zeta}_t \equiv \frac{\mu_t^{(3)}}{(\mu_t^{(2)})^{\frac{3}{2}}}$ and implied kurtosis as $\hat{\kappa}_t \equiv \frac{\mu_t^{(4)}}{(\mu_t^{(2)})^2} - 3$. Via the definition of $R_{t,T}$, all moments are thus affected by a change in monetary policy stance that has an impact on the daily exchange rate S_t.

To analyse empirically whether the moments of the estimated RNDs moved around times of changes in monetary policy stance, we first run regressions of the various moments on a set of dummy variables that capture the days around the monetary policy changes in the relevant economic areas.[4] More specifically, we apply two sets of dummy variables that are defined as follows:

$$D^- = \begin{cases} 1 & 3\, days\ prior\ to\ a\ policy\ move \\ 0 & otherwise \end{cases} \quad ; \; D^+ = \begin{cases} 1 & 3\, days\ after\ a\ policy\ move \\ 0 & otherwise \end{cases}$$

The dummy variables capture movements in the various moments that reflect anticipation of policy changes on one hand and movements that reflect changes in the market's assessment following policy changes on the other hand. Among policy changes we list cuts and hikes of policy interest rates, as well as adjustments of the central parity in a fixed exchange rate mechanism (in the case of Hungary). While the sample period is rather short (2 September 2002 - 12 May 2004), it nevertheless incorporates for Poland 8 interest rate cuts, for Czech Republic 3 rate cuts and 1 rate hike, and for Hungary 7 rate cuts, 3 rate hikes and 1 parity adjustment (devaluation). For the euro area the sample incorporates two rate cuts and for the United States one rate cut. The estimated equations amount to the following:

$$\Delta\mu^{i}_{PL} = \alpha + \beta_1 D^{-}_{PL,CUT} + \beta_2 D^{+}_{PL,CUT} + \beta_3 D^{-}_{Foreign,CUT} + \beta_4 D^{+}_{Foreign,CUT}$$

$$\Delta\mu^{i}_{CZ} = \alpha + \beta_1 D^{-}_{CZ,CUT} + \beta_2 D^{+}_{CZ,CUT} + \beta_3 D^{-}_{Foreign,CUT} + \beta_4 D^{+}_{Foreign,CUT} + \beta_5 D^{-}_{CZ,HIKE} + \beta_6 D^{+}_{CZ,HIKE} \quad (8)$$

$$\Delta\mu^{i}_{H} = \alpha + \beta_1 D^{-}_{H,CUT} + \beta_2 D^{+}_{H,CUT} + \beta_3 D^{-}_{Foreign,CUT} + \beta_4 D^{+}_{Foreign,CUT} + \beta_5 D^{-}_{H,HIKE} + \beta_6 D^{-}_{H,HIKE} + \beta_7 D^{-}_{H,DEV} + \beta_8 D^{+}_{H,DEV}$$

In equation 8, μ^i denotes the i^{th} moment of the distribution *(i=2,3,4)* and $D_{Foreign,CUT}$ denotes the interest rate reduction by the monetary authority in the other country of the currency pair (the ECB in the case of the EUR currency pairs and the Fed in the case of the US dollar currency pairs).

The above specification does not, however, distinguish between the expected and unexpected components of the monetary policy decisions. Therefore, by construction, the estimates may be more prone to the endogeneity problems as identified by Rigobon and Sack (2003). To address this issue, we also look at an alternative specification where the news components of the monetary policy decisions are explicitly identified. 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:

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

The data on expectations on NMS, Fed and ECB monetary policy originates from Reuter's polls. The observations capture the median of a survey of interest rate expectations between 20-30 market participants on a week prior to the policy announcement. In the case of the central parity devaluation in Hungary in June 2003, we define the anticipation simply as the old parity and the announcement as the new parity rate. The estimated equations, that focus on the contemporaneous changes in the various moments only, are now specified as follows.

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[4] By adopting the dummy variable approach we follow Vahamaa (2004) who uses similar approach to study the changes in skewness implied by RNDs on bond yields around the times of ECB monetary policy decisions.

$$\Delta\mu^{i}_{PL} = \alpha + \beta_1 N_{PL} + \beta_2 N_{Foreign}$$

$$\Delta\mu^{i}_{CZ} = \alpha + \beta_1 N_{CZ} + \beta_3 N_{Foreign} \quad (9)$$

$$\Delta\mu^{i}_{H} = \alpha + \beta_1 N_{H} + \beta_2 N_{Foreign} + \beta_3 N_{H,DEV}$$

The series for the individual implied moments are characterised by serial correlation and heteroscedasticity that is not unusual for financial time series. Under such circumstances, a GARCH specification would be an obvious choice for estimation technique, but due to the relatively short sample period we decided to opt for OLS where the serial correlation is accounted for by specifying an AR error structure when appropriate. It turned out that in such cases an AR(1) specification was sufficient.

4.2. Results from the econometric analysis

4.2.1 The dummy variable specification

The results from the estimations are summarised in Tables 2 a-c, starting from the Polish zloty and proceeding then to the Czech and Hungarian currencies. In the tables the first three rows incorporate the results on bilateral rates vis-à-vis the euro while the bottom three rows capture the results on the US dollar exchange rates.

Table 2.a. Regression coefficients for Poland (standard errors in parenthesis)

	$D^{-}_{PL,\,CUT}$	$D^{+}_{PL,\,CUT}$	$D^{-}_{ECB,\,CUT}$	$D^{+}_{ECB,\,CUT}$	$D^{-}_{FED,\,CUT}$	$D^{+}_{FED,\,CUT}$
PLZ/EUR STDEV	0.002 (0.008)	-0.004 (0.008)	0.022 (0.013)	0.020 (0.012)	*N/A*	*N/A*
PLZ/EUR SKEW	-0.021 (0.012)	0.009 (0.010)	0.017 (0.019)	0.021 (0.017)	*N/A*	*N/A*
PLZ/EUR KURT	-0.003 (0.002)	0.002 (0.002)	-0.004 (0.004)	-0.0004 (0.003)	*N/A*	*N/A*
PLZ/USD STDEV	0.002 (0.008)	-0.008 (0.007)	*N/A*	*N/A*	-0.012 (0.021)	0.010 (0.019)
PLZ/USD SKEW	**-0.039*** **(0.021)**	0.004 (0.020)	*N/A*	*N/A*	0.040 (0.057)	0.019 (0.050)
PLZ/USD KURT	**-0.009*** **(0.003)**	-0.0002 (0.003)	*N/A*	*N/A*	0.010 (0.008)	0.005 (0.007)

A star (*) denotes statistical significance at 5% level.

The signs of the coefficients suggest that standard deviation of the RNDs tends to increase before and decrease after the interest rate cuts in Poland. Moreover, interest rate cuts in Poland are preceded by reduced skewness, that is, reduced perception of near-term zloty depreciation, and lower kurtosis. However, only the estimated coefficients for skewness and kurtosis on the PLZ/USD RNDs are statistically significant. The observed reduction in skewness prior to interest rate cuts could indicate that during the sample period, lower interest rates were perceived by the markets as providing a positive impetus for the economy, thus contributing to a more positive assessment of near-term exchange rate prospects.

The results for the Czech koruna suggest that like in the case of Poland, prior to monetary policy easing (strengthening) in Czech Republic the options implied skewness on the RND on CZK/EUR currency pair declined (increased), suggesting that expectations for koruna depreciation (appreciation) were reduced. Again, this result suggests that during our sample period, lower interest rates could have been perceived as positive news for the NMS currencies. In the case of the ECB interest rate cuts, in contrast, the market has priced in a weaker euro prior to the moves which is in line with the interest arte parity/arbitrage condition. Kurtosis of the distribution increased prior to and after Czech rate cuts, indicating higher near-term risk of large exchange rate movements or, alternatively, increased risk aversion around times of policy changes. In contrast, kurtosis decreased prior to ECB policy moves. Finally, in the case of the RNDs on the CZK/USD rate, the coefficients are broadly of similar sign, but only the increased standard deviation prior to Czech rate cuts is statistically significant.

Table 2.b. Regression coefficients for Czech Republic (standard errors in parenthesis)

	$D^{-}_{CZ,\,CUT}$	$D^{+}_{CZ,\,CUT}$	$D^{-}_{ECB,\,CUT}$	$D^{+}_{ECB,CUT}$	$D^{-}_{FED,\,CUT}$	$D^{+}_{FED,CUT}$	$D^{-}_{CZ,\,HIKE}$	$D^{+}_{CZ,HIKE}$
CZK/EUR STDEV	0.014 (0.016)	0.000 (0.001)	0.000 (0.001)	-0.000 (0.001)	*N/A*	*N/A*	0.001 (0.001)	0.001 (0.002)
CZK/EUR SKEW	**-1.841* (0.107)**	0.003 (0.008)	**-0.015* (0.007)**	-0.003 (0.008)	*N/A*	*N/A*	**0.0211* (0.007)**	0.0018 (0.014)
CZK/EUR KURT	**7.642* (2.230)**	**0.3233* (0.172)**	**-0.4978* (0.149)**	-0.008 (0.1717)	*N/A*	*N/A*	0.0892 (0.1496)	-0.015 (0.295)
CZK/USD STDEV	**0.0144* (0.008)**	0.004 (0.008)	*N/A*	*N/A*	-0.010 (0.014)	0.0055 (0.013)	0.032 (0.041)	0.019 (0.029)
CZK/USD SKEW	-0.225 (0.484)	0.140 (0.440)	*N/A*	*N/A*	0.193 (0.831)	0.157 (0.721)	0.048 (0.075)	-0.009 (0.040)
CZK/USD KURT	0.000 (0.000)	-0.001 (0.002)	*N/A*	*N/A*	0.002 (0.004)	0.000 (0.003)	0.015 (0.018)	0.007 (0.006)

A star (*) denotes statistical significance at 5% level.

Regarding Hungary, standard deviation of the RND on the HUF/EUR currency pair tends to increase after both interest rate hikes and cuts by the Hungarian central bank. This could indicate that the markets have become increasingly risk-averse after policy changes, possibly reflecting uncertainty regarding the future course of the exchange rate. Skewness increased after Hungarian rate cuts, indicating that the market priced in a higher probability of near-term HUF weakness after interest rates had been lowered. Regarding the US dollar data, Fed rate cuts have been followed by reduced standard deviation of the RND on HUF/USD. In contrast, Hungarian rate hikes have been anticipated and followed by higher standard deviation, again suggesting increased risk aversion among investors around times of policy movements. Interestingly, while there seemed to be no significant movements in the moments of the HUF/EUR RNDs around the time of the HUF devaluation against the euro, the standard deviation of the RND on the HUF/USD declined and the kurtosis increased during the days prior to the parity adjustment. It is not immediately obvious why this might have been the case.

Table 2.c. Regression coefficients for Hungary (standard errors in parenthesis)

	$D^-_{H,CUT}$	$D^+_{H,CUT}$	$D^-_{ECB,CUT}$	D^+_{ECBCUT}	$D^-_{FED\ CUT}$	D^+_{FEDCUT}	$D^-_{H,HIKE}$	$D^+_{H,HIKE}$	$D^-_{H,DEV}$	$D^+_{H,DEV}$
HUF/EUR STDEV	0.023 (0.025)	**0.079* (0.023)**	-0.041 (0.035)	0.021 (0.031)	*N/A*	*N/A*	0.018 (0.032)	**0.115* (0.031)**	-0.059 (0.067)	0.064 (1.222)
HUF/EUR SKEW	0.019 (0.090)	**-0.543* (0.079)**	0.010 (0.128)	-0.020 (0.116)	*N/A*	*N/A*	0.018 (0.118)	-0.042 (0.118)	0.002 (0.247)	0.039 (0.194)
HUF/EUR KURT	0.008 (0.009)	-0.010 (0.008)	0.006 (0.013)	-0.012 (0.012)	*N/A*	*N/A*	0.017 (0.012)	**-0.028* (0.012)**	0.011 (0.024)	0.013 (0.682)
HUF/USD STDEV	0.010 (0.011)	0.019 (0.01)	*N/A*	*N/A*	0.011 (0.025)	**-0.093* (0.025)**	**0.030* (0.0167)**	**0.060* (0.014)**	**-0.052* (0.029)**	0.025 (0.021)
HUF/USD SKEW	**0.935* (0.256)**	-0.322 (0.231)	*N/A*	*N/A*	-0.015 (0.579)	0.025 (0.576)	0.018 (0.388)	0.009 (0.338)	0.113 (0.665)	**1.656* (0.502)**
HUF/USD KURT	0.004 (0.004)	0.003 (0.004)	*N/A*	*N/A*	0.0002 (0.010)	**0.021* (0.010)**	0.006 (0.007)	-0.005 (0.006)	**0.026* (0.012)**	**0.024* (0.009)**

A star (*) denotes statistical significance at 5% level.

All in all, it seems that changes in monetary policy stance had generally a more profound impact on the CZK and HUF exchange rates than on the PLZ exchange rates. Moreover, interest rate moves and parity adjustments seem to have been reflected by anticipatory movements in the moments of the HUF/USD distributions, while the HUF/EUR distributions were less affected.

4.2.2 The news impact variable specification

The results from the regressions where the news impact variables are used as right-hand side variables are listed in Table 3 a-c. It turns out that the effects are not very remarkable. In the cases of Poland and the Czech Republic, the coefficients are small and tend to suggest that implied standard deviations increase around the times of domestic monetary surprises and decrease around the times of foreign surprises. None of the estimated coefficients are significant at the 5% level, however. Again, the results are more encouraging for Hungary. Implied standard deviation on both HUF/EUR and HUF/USD currency pairs increases systematically around the time of Hungarian monetary surprises, while implied skewness and kurtosis on the HUF/EUR rate decrease around the time of the surprises. The decline in implied skewness suggests that positive Hungarian monetary policy news (smaller than expected rate cut or larger than expected rate hike) tend to be associated with an increase in the relative likelihood assigned by the options market on near-term HUF appreciation.

Table 3.a. Regression coefficients for Poland (standard errors in parenthesis)

	PLZ/EUR STDEV	*PLZ/EUR SKEW*	*PLZ/EUR KURT*	*PLZ/USD STDEV*	*PLZ/USD SKEW*	*PLZ/USD KURT*
Polish news	0.02 (0.06)	-0.06 (0.10)	-0.01 (0.02)	0.002 (0.052)	0.003 (0.15)	-0.000 (0.02)
ECB news	-0.05 (0.03)	-0.02 (0.05)	0.003 (0.01)	-	-	-
FED news	-	-	-	-0.006 (0.01)	0.002 (0.019)	0.001 (0.003)

Table 3.b. Regression coefficients for Czech Republic (standard errors in parenthesis)

	CZK/EUR STDEV	*CZK/EUR SKEW*	*CZK/EUR KURT*	*CZK/USD STDEV*	*CZK/USD SKEW*	*CZK/USD KURT*
Czech news	0.01 (0.02)	0.01 (0.29)	-0.001 (0.007)	-0.01 (0.02)	-0.183 (0.91)	0.000 (0.004)
ECB news	-0.05 (0.03)	-0.03 (0.40)	0.01 (0.01)	-	-	-
FED news	-	-	-	-0.003 (0.005)	-0.004 (0.304)	0.000 (0.001)

Table 3.c. Regression coefficients for Hungary (standard errors in parenthesis)

	HUF/EUR STDEV	*HUF/EUR SKEW*	*HUF/EUR KURT*	*HUF/USD STDEV*	*HUF/USD SKEW*	*HUF/USD KURT*
Hungarian news	**0.131*** **(0.01)**	**-0.57*** **(0.04)**	**-0.03*** **(0.005)**	**0.02*** **(0.006)**	-0.01 (0.15)	0.002 (0.003)
Hungarian devaluation	0.002 (0.002)	-0.000 (0.01)	0.000 (0.001)	0.000 (0.000)	0.002 (0.02)	0.000 (0.000)
ECB news	-0.01 (0.07)	0.01 (0.25)	0.006 (0.03)	-	-	-
FED news	-	-	-	-0.000 (0.01)	-0.011 (0.19)	-0.000 (0.003)

A star (*) denotes statistical significance at 5% level.

4.3 Do movements in implied moments predict interest rate changes?

We now turn our focus around and ask whether changes in implied moments of the RNDs actually increased the probability of impending monetary policy decisions. In that way, large movements in exchange rates, or in uncertainty related to future movements in exchange rates, could work as an explanatory factor for policy moves. It is not implausible to think that this could be the case in small open economies where the exchange rate plays an important role as an inflation indicator, or is the de facto target variable for monetary policy. To analyse the likely effect of changes in RNDs on the probability of monetary policy changes we resort to binary logit analysis. In that context, we first have to define a left-hand side variable that captures the central bank's decision; we state that the left-hand side variable receives the value of 1 at the dates of monetary policy changes, and 0 otherwise. Since our data set covers a period where a large majority of the policy decisions for Poland, the Czech Republic and Hungary have been interest rate cuts, we exclude the episodes of interest rate hikes from the analysis. In that case, we choose

$$Y_t = \begin{cases} 1 & \textit{in dates of a policy rate cut} \\ 0 & \textit{in all other dates} \end{cases}.$$

Under this specification of Y_t, the logit technique specifies the probability of Y_t occurring given an information set. Since the probability must lie between 0 and 1, a transformation function must be used that maps from the real values to the 0-1 interval. For the logit model, the transformation function takes the form of the logistic function

$$\Phi(x) \equiv (1+e^{-x})^{-1} = \frac{e^x}{1+e^x}.$$

The estimation itself is run by means of maximum likelihood, and the estimated equation for country *j's* currency now takes the following form.

$$Y_t^j = \alpha + \beta_1 \Delta r_{t-1}^j + \Delta\beta_i \mu_{i,t-1}^j + \varepsilon_t \text{ , } i = 2,3,4. \quad (10)$$

According to (10), the probability of change in monetary policy stance is modelled as a function of the previous-period change in the short-term domestic money market interest rate (our control variable) and the previous-period change in the implied moments (separate regression is run for each moment).

Table 4a: Logit estimation of determinants of interest rate cuts: euro exchange rates

	Explanatory variable			
	Δr_{t-1}	$\Delta Stdev_{t-1}$	$\Delta Skew_{t-1}$	$\Delta Kurt_{t-1}$
Rate cut Poland	3.31 (5.55)	4.31 (4.83)		
	3.13 (5.52)		3.78 (9.71)	
	3.18 (5.49)			-1.95 (6.09)
Rate cut Czech Rep.	-9.32 (16.35)	2.58* (1.21)		
	-3.79 (16.71)		8.59 (8.85)	
	-8.83 (16.11)			0.42 (5.39)
Rate cut Hungary	-0.25 (1.52)	0.69* (0.30)		
	-0.23 (1.51)		-6.15* (2.87)	
	-0.25 (1.53)			-2.80* (1.23)

A star (*) denotes statistical significance at 5% level.

The results are reported in Table 4. Regarding the euro exchange rates (Table 4a), neither the movements in short-term interest rates nor the changes in the moments of the RNDs increased the probability of changes in the Polish monetary policy stance. However, implied standard deviation on the CZK/EUR rate signals increased probability of an interest rate cut the following day. For Hungary, while changes in short-term interest rates do not signal increased probability of policy moves, all moments of the RND move systematically the day prior to the interest rate cuts. More precisely, the general uncertainty, or risk aversion (as measured by implied standard deviation) tends to increase, while the relative likelihood of near-term forint weakness (as measured by implied skewness) and the probability of extreme movements (as measured by implied kurtosis) tend to decline.

Turning to the moments implied by US dollar-based RNDs (see Table 4b), the increased implied standard deviation on the CZK/USD RNDs is the only movement that suggests an increase in the probability of interest rate cuts by the Czech National Bank.

Table 4b: Logit estimation of determinants of interest rate cuts: USD exchange rates

	Explanatory variable			
	Δr_{t-1}	$\Delta Stdev_{t-1}$	$\Delta Skew_{t-1}$	$\Delta Kurt_{t-1}$
Rate cut Poland	3.17 (5.50)	4.03 (7.09)		
	3.25 (5.52)		1.78 (8.31)	
	2.96 (5.51)			-2.30 (6.26)
Rate cut Czech Rep.	-9.32 (16.35)	2.58* (1.21)		
	-8.89 (17.65)		0.02 (2.32)	
	-11.11 (16.69)			-15.67 (18.23)
Rate cut Hungary	-0.30 (1.39)	0.54 (0.84)		
	-0.26 (1.43)		0.16 (8.11)	
	-0.27 (1.42)			-1.67 (4.36)

A star (*) denotes statistical significance at 5% level.

5. Robustness check: findings for the USD/EUR currency pair

As a final step, we repeat the dummy variable and news impact estimations using the moments on the USD/EUR currency pair. Apart from providing a robustness check for the results using the moments of the RNDs on the NMS currencies, the results may also provide some further information about the differences in results between the estimates that used different base currencies above, for example, the differences between results obtained for

CZK/EUR and CZK/USD currency pairs. Since the sample period applied above includes only few interest rate decisions for the Fed and the ECB, we extend the sample period here to begin from January 2001; all policy decisions within this sample period were also interest rate cuts.

Table 5. Regression coefficients for USD/EUR (standard errors in parenthesis)

	$D^{-}_{FED,\,CUT}$	$D^{+}_{FED,\,CUT}$	$D^{-}_{ECB,\,CUT}$	$D^{+}_{ECB,\,CUT}$	$NEWS_{FED}$	$NEWS_{ECB}$
USD/EUR STDEV	**0.0011*** **(0.0003)**	-0.0003 (0.0003)	0.0001 (0.0002)	-0.0002 (0.0002)	-	-
USD/EUR SKEW	0.004 (0.012)	0.008 (0.013)	-0.001 (0.008)	0.010 (0.009)	-	-
USD/EUR KURT	0.003 (0.008)	0.004 (0.009)	-0.0004 (0.006)	0.006 (0.006)	-	-
USD/EUR STDEV	-	-	-	-	**-0.004*** **(0.002)**	0.002 (0.002)
USD/EUR SKEW	-	-	-	-	-0.014 (0.094)	0.058 (0.072)
USD/EUR KURT	-	-	-	-	-0.009 (0.064)	0.015 (0.049)

A star (*) denotes statistical significance at 5% level.

The first observation from Table 5 is that in most cases, the coefficients are smaller for the implied moments on the USD/EUR currency pair than for the NMS currencies. The implied standard deviation on the USD/EUR tends to increase prior to Fed and ECB policy decisions, and to re-bound thereafter (however, the coefficient of the lagging dummy variable is not significant at 5% level). No other moments did yield statistically significant coefficients. Regarding the surprise impacts, news on Fed policy decisions (larger-than-anticipated interest rate cut) coincide with an increase in implied standard deviation on the USD/EUR currency pair, but no systematic movement could be detected in any other implied moments. These results suggest that the implied moments on the NMS currencies are relatively more sensitive to changes to monetary policy stance, which could reflect at least three different factors. First, in small open economies the market could perceive the changes in relative monetary policy stance as a rather more important determinant of exchange rate sentiment than in the case of large economic areas. Second, the volatility in the NMS currencies is generally higher than in the major currencies, partially explaining why the implied RNDs could be more responsive to news. Finally, the liquidity in the OTC market is certainly more limited for the NMS currencies implying that reactions to monetary policy news could be more extreme.

Combining the results from Tables 3 and 5, an interesting finding is that the surprise components of the ECB monetary policy moves are generally preceded by high implied standard deviation on RNDs on all bilateral euro exchange rates covered by our study (including the US dollar). On the other hand, surprise components of the Fed interest rate reductions were associated with increased implied standard deviation of the US dollar exchange rate against the euro and the Hungarian forint, but decreased implied standard deviation against the Polish zloty and the Czech koruna. The rather short sample period employed in our analysis is the most likely reason to this somewhat inconsistent finding.

6. Conclusion

This paper focused on changes in the foreign exchange market sentiment as captured by prices on options on exchange rates of the largest new EU member states Poland, the Czech Republic and Hungary. Using the method developed by Malz (1997), we estimated the daily risk-neutral density (RND) functions for the Polish zloty, the Czech koruna and the Hungarian forint exchange rates against the euro and the US dollar. Test results suggest that apart from the extreme tails, the estimated density functions provide good predictions of the true distributions. We then analysed the individual moments implied by those distributions, and studied whether they tend to change systematically around the times of monetary policy events.

The results show that, given the caveats associated with the RND methodology, the estimated RND functions are useful in analysing changes in the FX market conditions in several respects. The changes in shapes of the daily RNDs, and the density bands that plot the daily RNDs over time, provide illustrative case studies about the changes in assessment around the times of various episodes. The econometric analysis revealed that at least some of the implied moments on the RNDs on all exchange rates covered in this study tend to move systematically around dates of monetary policy changes. In particular, uncertainty or risk aversion, as measured by implied standard deviation on the CZK/USD and HUF/USD exchange rates, increased prior to monetary policy changes in the Czech Republic and Hungary. Moreover, the surprise components associated with the changes in ECB monetary policy stance coincided with an increase in implied standard deviation in all bilateral euro exchange rates, including the USD/EUR. We also found that in our sample period, the lagged changes in implied moments on the RNDs of the HUF/EUR currency pair were capable of predicting increased probability of interest rate reductions by the Hungarian central bank.

All in all, the results confirm the usefulness of the RND approach in analysing market sentiment and risk aversion in currencies of small open economies that are often characterised by higher volatility than major currencies and also tend to be more systematically affected by monetary policy news. Our results were particularly encouraging in the case of the Hungarian forint-euro exchange rate that throughout the sample period was characterised a fixed exchange rate with a wide fluctuation band. This suggests that the options market could be particularly reactive to events in such regimes. Given that the ERM II mechanism, where a minimum two year's participation is required prior to the entry to the EMU Stage Three, is structurally rather similar than the current Hungarian unilateral regime, monitoring currency options market in the cases where data is available would seem useful in analysing pressures in the ERM II.

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Appendix 1: Descriptive statistics of the options data

	PLEUSTDEV	PLEUSKEW	PLEUKURT
Mean	0.140661	0.614062	4.410759
Median	0.138793	0.633782	4.42848
Maximum	0.216681	0.812282	4.679237
Minimum	0.102203	0.395152	4.02189
Std. Dev.	0.023467	0.112593	0.165364
Skewness	0.802271	-0.408249	-0.380925
Kurtosis	3.790259	1.946812	2.069354
Jarque-Bera	46.2531	25.67616	20.91425
Probability	0	0.000003	0.000029
Sum	48.80922	213.0793	1530.533
Sum Sq. Dev.	0.19055	4.38631	9.461413
Observations	347	347	347

	PLUSSTDEV	PLUSSKEW	PLUSKURT
Mean	0.136322	0.555052	4.286869
Median	0.135785	0.577995	4.2573
Maximum	0.188114	0.914427	4.871565
Minimum	0.099079	0.200148	3.939951
Std. Dev.	0.019214	0.168191	0.206091
Skewness	0.246644	-0.241096	0.698551
Kurtosis	2.508451	2.242254	2.82104
Jarque-Bera	7.01162	11.66336	28.68417
Probability	0.030022	0.002933	0.000001
Sum	47.3038	192.6031	1487.544
Sum Sq. Dev.	0.127732	9.787735	14.69581
Observations	347	347	347

	CZEUSTDEV	CZEUSKEW	CZEUKURT
Mean	0.701627	0.349983	4.421882
Median	0.659647	0.351987	4.458398
Maximum	1.152383	0.808215	5.04963
Minimum	0.494345	-0.027043	3.39973
Std. Dev.	0.149896	0.17107	0.26472
Skewness	1.331436	0.333168	-0.666845
Kurtosis	4.21425	3.162029	3.390202
Jarque-Bera	123.8398	6.799114	27.91886
Probability	0	0.033388	0.000001
Sum	243.4645	121.444	1534.393
Sum Sq. Dev.	7.774247	10.12569	24.24655
Observations	347	347	347

	CZUSSTDEV	CZUSSKEW	CZUSKURT
Mean	0.874947	0.043556	3.560626
Median	0.883904	0.024605	3.564964
Maximum	1.021193	0.422437	3.841386
Minimum	0.674093	-0.174221	3.413313
Std. Dev.	0.066222	0.1562	0.096724
Skewness	-0.400802	0.986849	0.304385
Kurtosis	3.047376	3.429558	2.59978
Jarque-Bera	9.322934	58.99	7.674138
Probability	0.009453	0	0.021557
Sum	303.6067	15.11395	1235.537
Sum Sq. Dev.	1.517353	8.441824	3.237047
Observations	347	347	347

	HFEUSTDEV	HFEUSKEW	HFEUKURT
Mean	6.499014	0.939752	5.375837
Median	5.638871	0.970391	5.33214
Maximum	14.93928	1.679692	7.379522
Minimum	3.024873	-0.181271	3.90882
Std. Dev.	2.54037	0.395704	0.7083
Skewness	0.877206	-0.724932	0.461073
Kurtosis	3.080817	3.049094	3.050134
Jarque-Bera	44.59659	30.4278	12.33105
Probability	0	0	0.002101
Sum	2255.158	326.0939	1865.416
Sum Sq. Dev.	2232.905	54.17712	173.5846
Observations	347	347	347

	HFUSSTDEV	HFUSSKEW	HFUSKURT
Mean	7.915309	0.370449	4.141795
Median	7.804372	0.127927	3.973129
Maximum	11.68782	1.112454	5.227977
Minimum	5.853273	-0.157574	3.604659
Std. Dev.	1.059358	0.39904	0.434404
Skewness	0.720135	0.537802	0.786164
Kurtosis	3.792139	1.633773	2.500391
Jarque-Bera	39.06437	43.7148	39.35305
Probability	0	0	0
Sum	2746.612	128.5458	1437.203
Sum Sq. Dev.	388.295	55.09454	65.29245
Observations	347	347	347

Appendix 2: Tests of the accuracy of the density forecasts

Table A.2.1: Test statistics from the unconditional normal tests (P-vales in parenthesis)

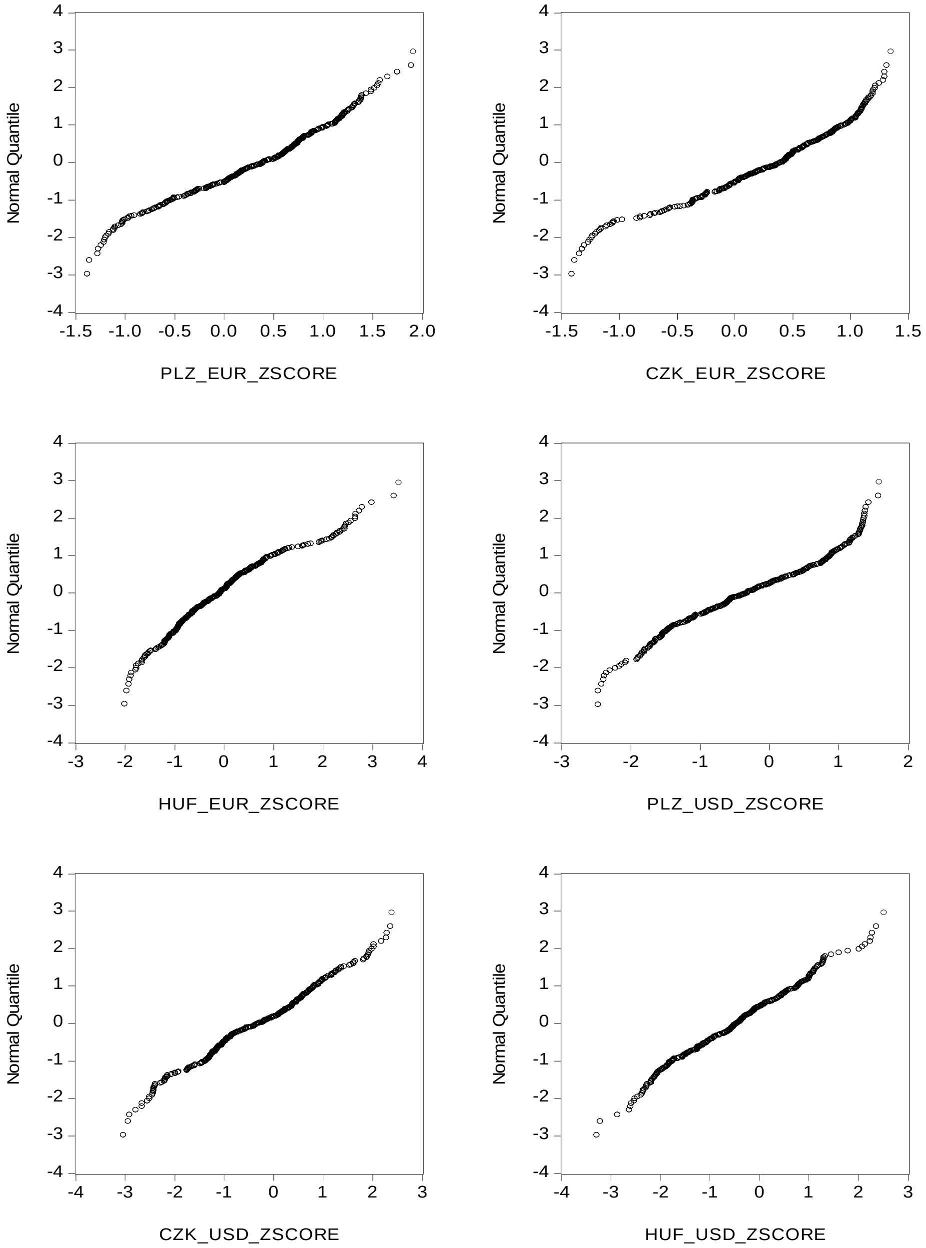
	PLZ/EUR	CZK/EUR	HUF/EUR	PLZ/USD	CZK/USD	HUF/USD
D+	0.896 (0.2009)	1.715 (0.0028)	1.387 (0.0213)	2.929 (0.000)	3.530 (0.000)	3.741 (0.000)
D-	3.670 (0.000)	4.022 (0.000)	1.121 (0.0811)	0.119 (0.972)	0.189 (0.9312)	0.044 (0.996)
D	3.670 (0.000)	4.022 (0.000)	1.387 (0.0426)	2.939 (0.000)	3.530 (0.000)	3.741 (0.000)
V	4.577 (0.000)	5.751 (0.000)	2.514 (0.0002)	3.056 (0.000)	3.727 (0.000)	3.794 (0.000)
W	4.802 (0.000)	5.941 (0.000)	0.578 (0.0254)	3.020 (0.000)	3.281 (0.000)	6.530 (0.000)
C-M	1.604 (0.000)	2.855 (0.000)	0.382 (0.0011)	0.653 (0.000)	0.938 (0.000)	1.128 (0.000)
A-D	24.046 (0.000)	30.026 (0.000)	4.576 (0.0046)	18.441 (0.000)	21.634 (0.000)	40.802 (0.000)

Table A.2.2: Test statistics for the moments of the probability transform functions (T-values in parenthesis)

	PLZ/EUR	CZK/EUR	HUF/EUR	PLZ/USD	CZK/USD	HUF/USD
Mean	0.294 (1.778)	**0.269*** **(2.023)**	-0.001 (-0.004)	-0.323 (-1.419)	-0.338 (-1.267)	**-0.494*** **(-1.968)**
Variance	**-0.476*** **(-4.534)**	**-0.597*** **(-5.55)**	0.179 (0.590)	0.029 (0.190)	0.351 (1.164)	0.273 0.922
Skewness	-0.330 (-0.582)	-0.641 (-0.932)	0.776 (1.106)	-0.036 (-0.079)	0.003 (0.005)	0.107 0.170
Kurtosis	-0.602 -(0.737)	-0.120 (-0.082)	0.418 (0.308)	**-1.021*** **(-2.228)**	-0.552 (-0.648)	-0.435 -0.409

A star (*) denotes statistical significance at 5% level.

Chart A.2.1: QQ plots on the estimated RNDs against theoretical distributions



Charts

Chart 1: Developments in the major acceding currencies against the euro

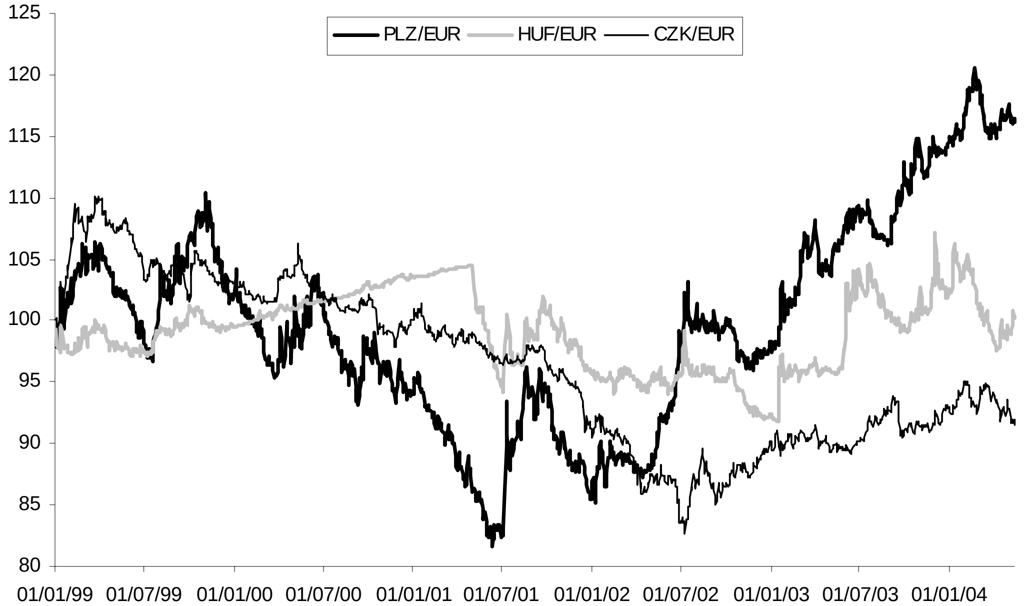


Chart 2: Developments in the major acceding currencies against the USD

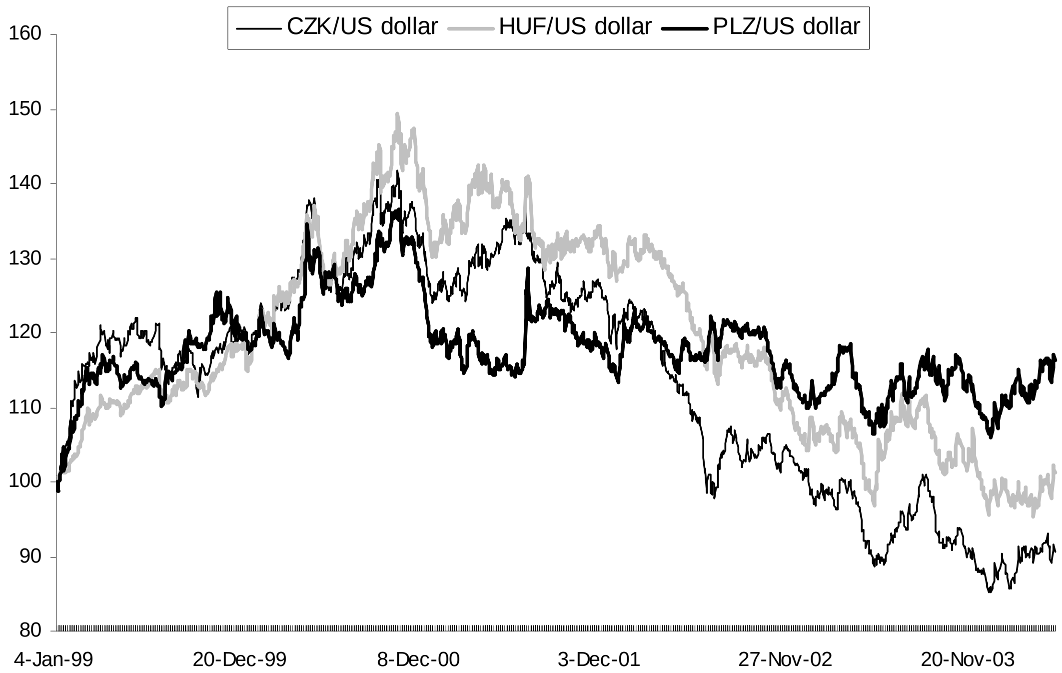


Chart 3: PLZ/EUR densities

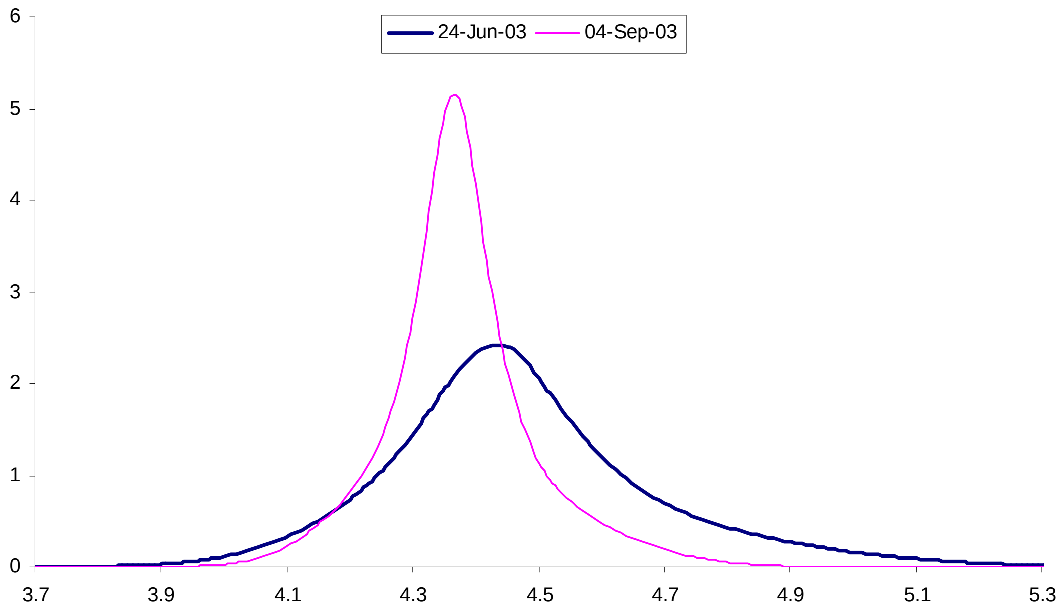


Chart 4: CZK/EUR densities

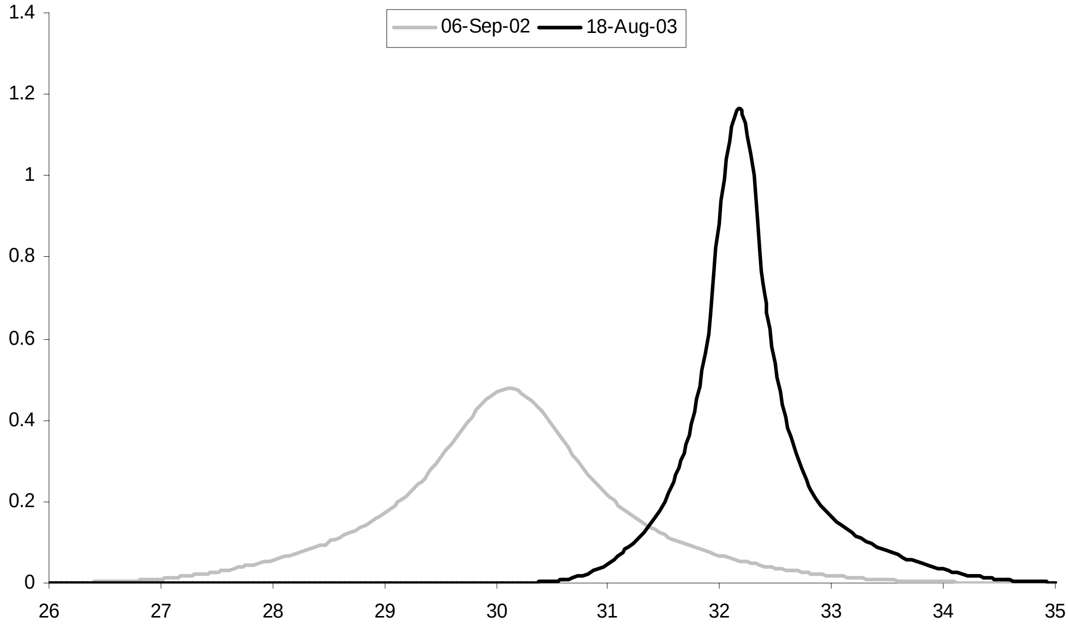


Chart 5: HUF/EUR densities

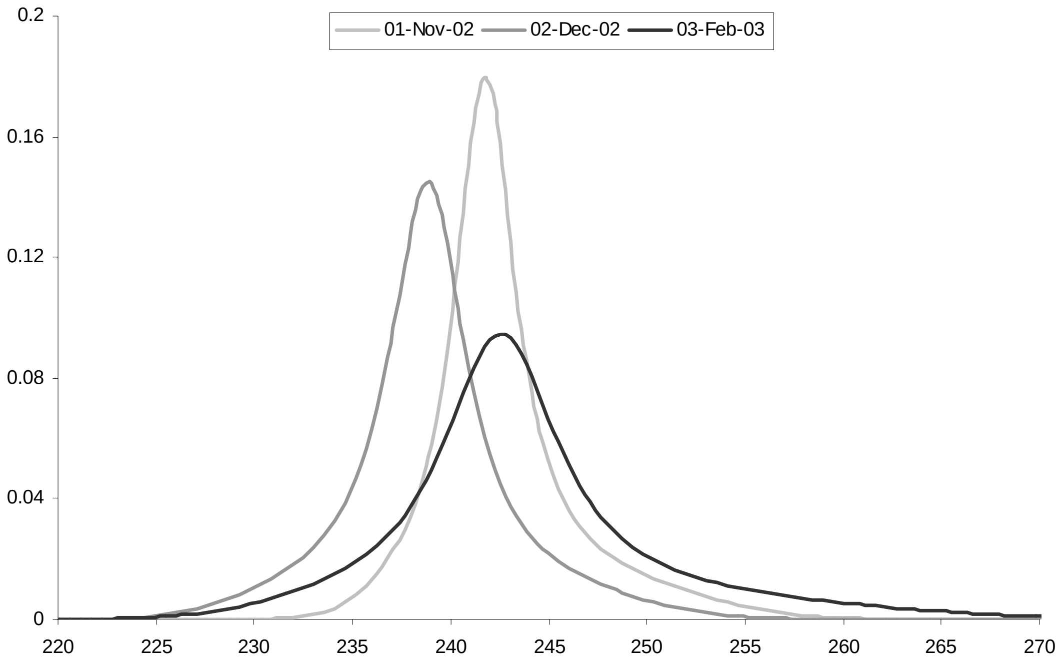


Chart 6: PLZ/USD densities

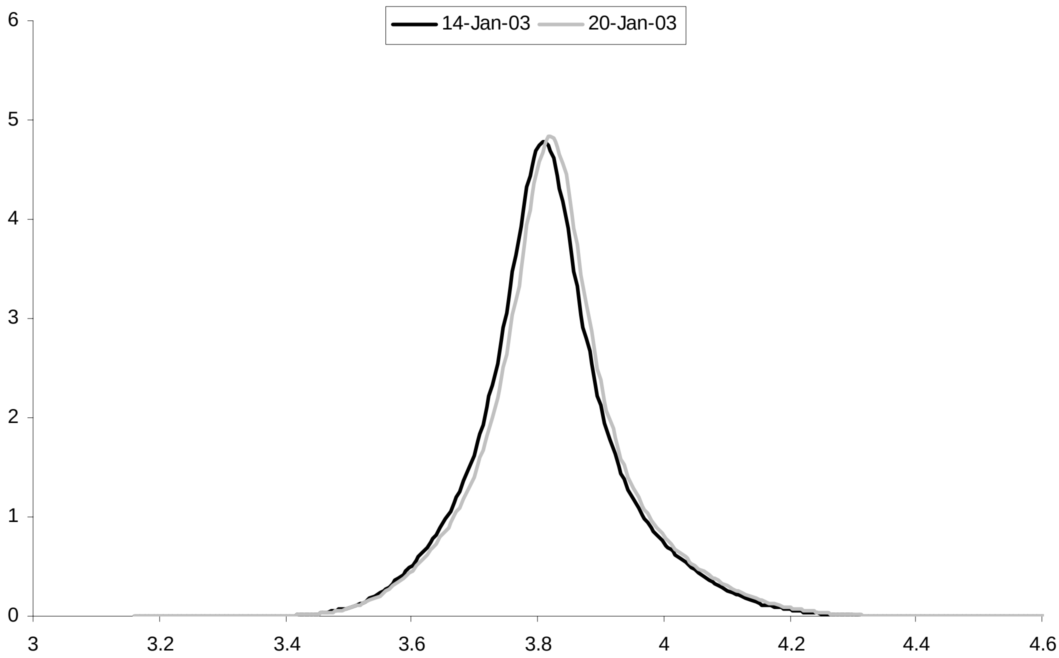


Chart 7: CZK/USD densities

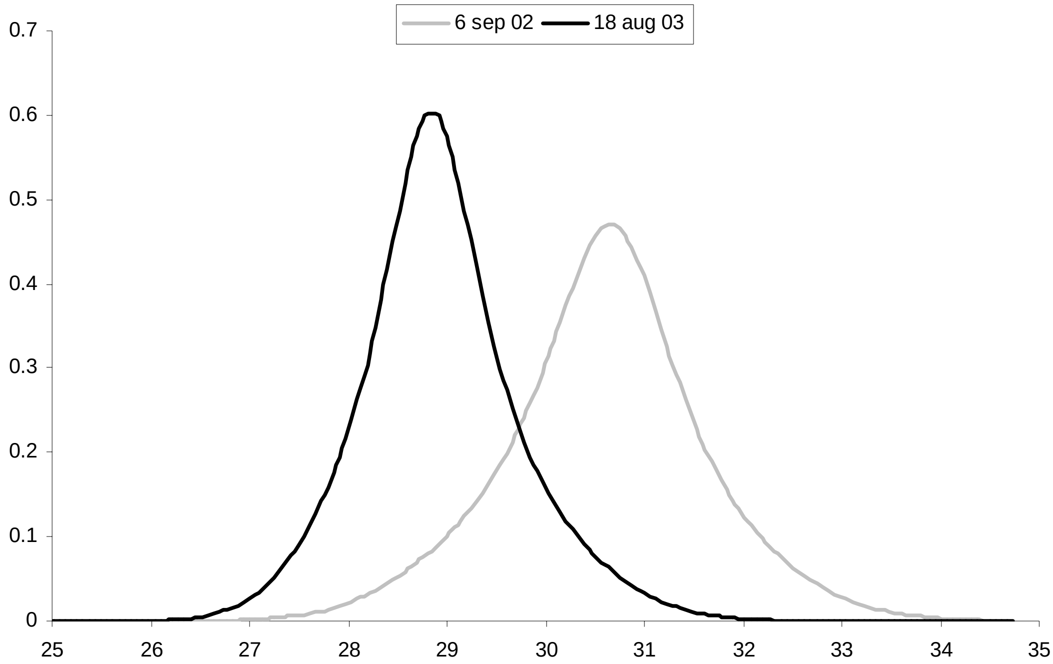


Chart 8: HUF/USD densities

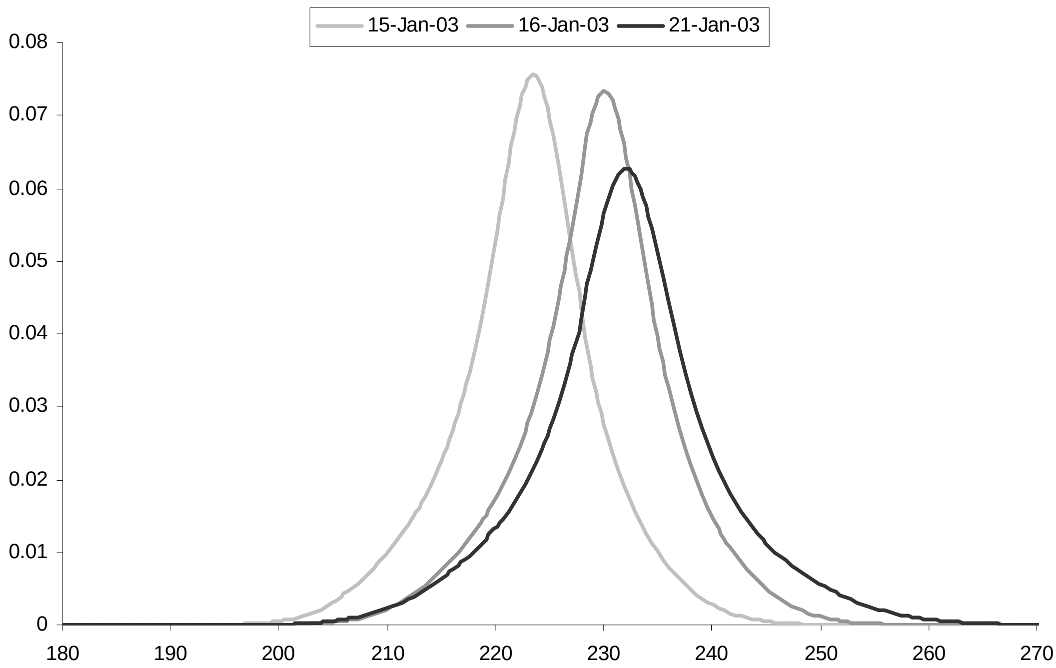


Chart 9: PLZ/EUR density bands

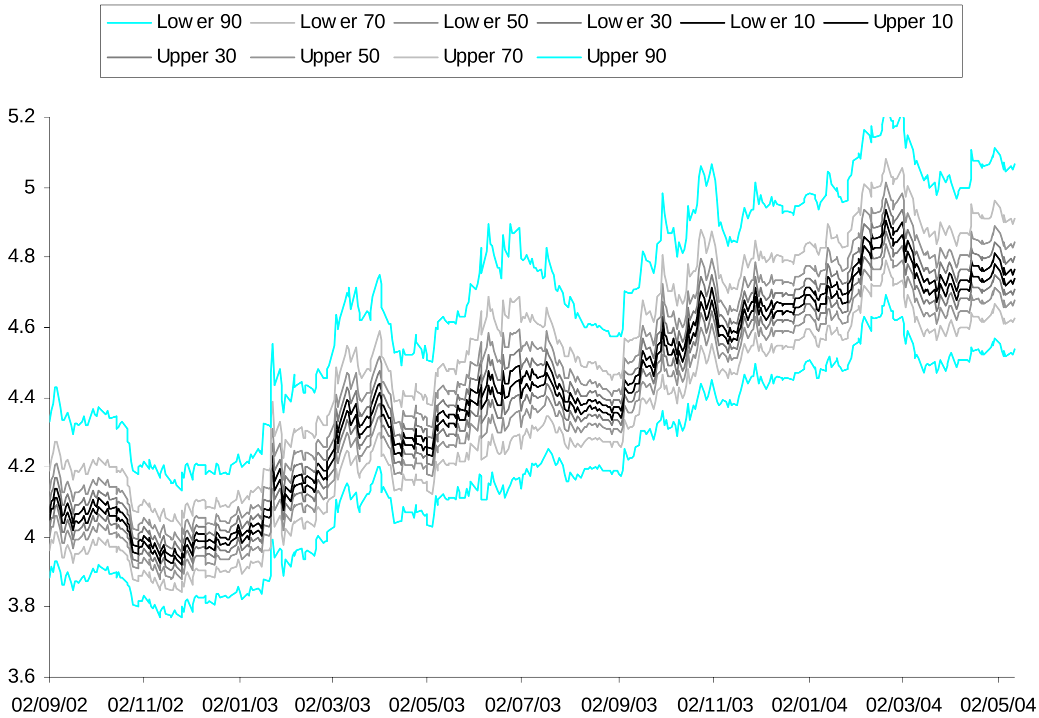


Chart 10: CZK/EUR density bands

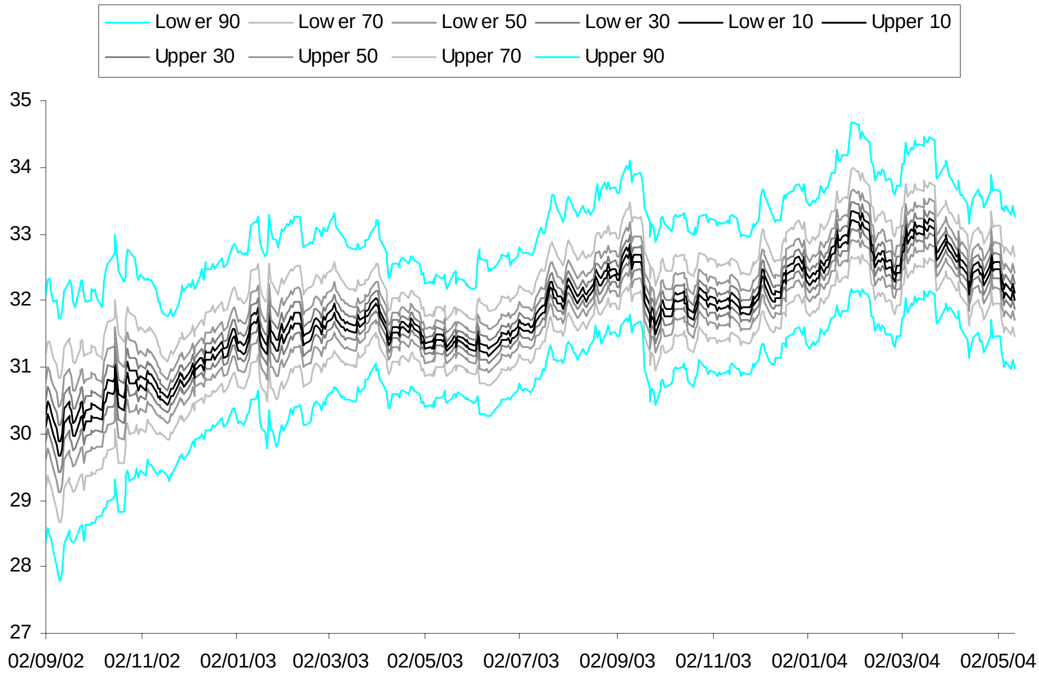


Chart 11: HUF/EUR density bands

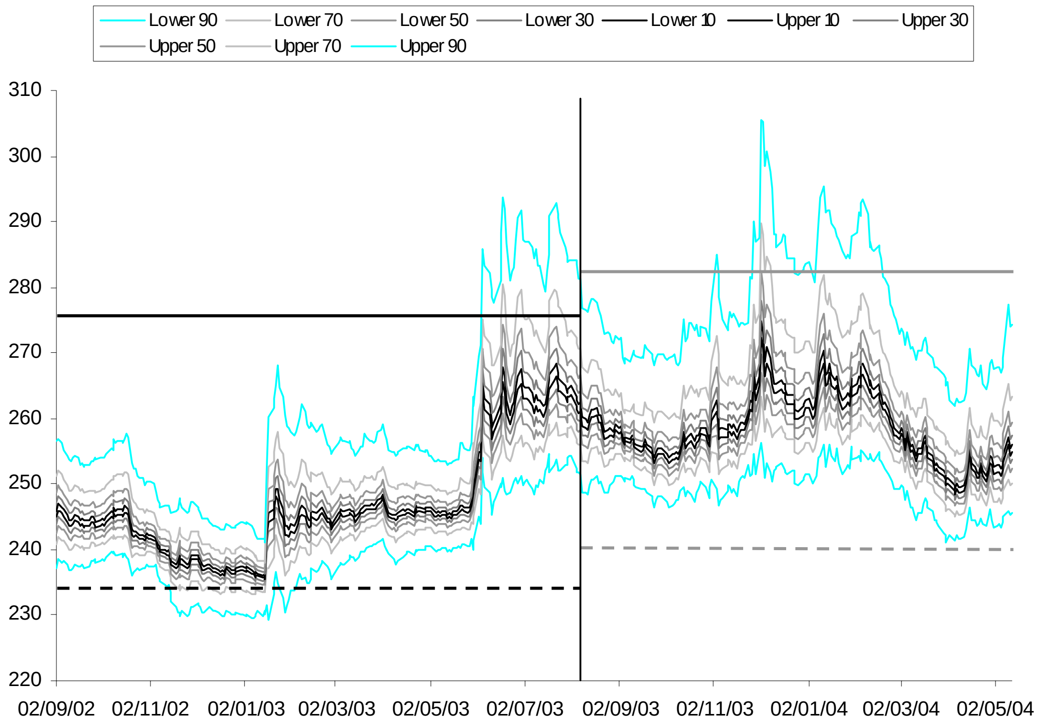


Chart 12: PLZ/USD density bands

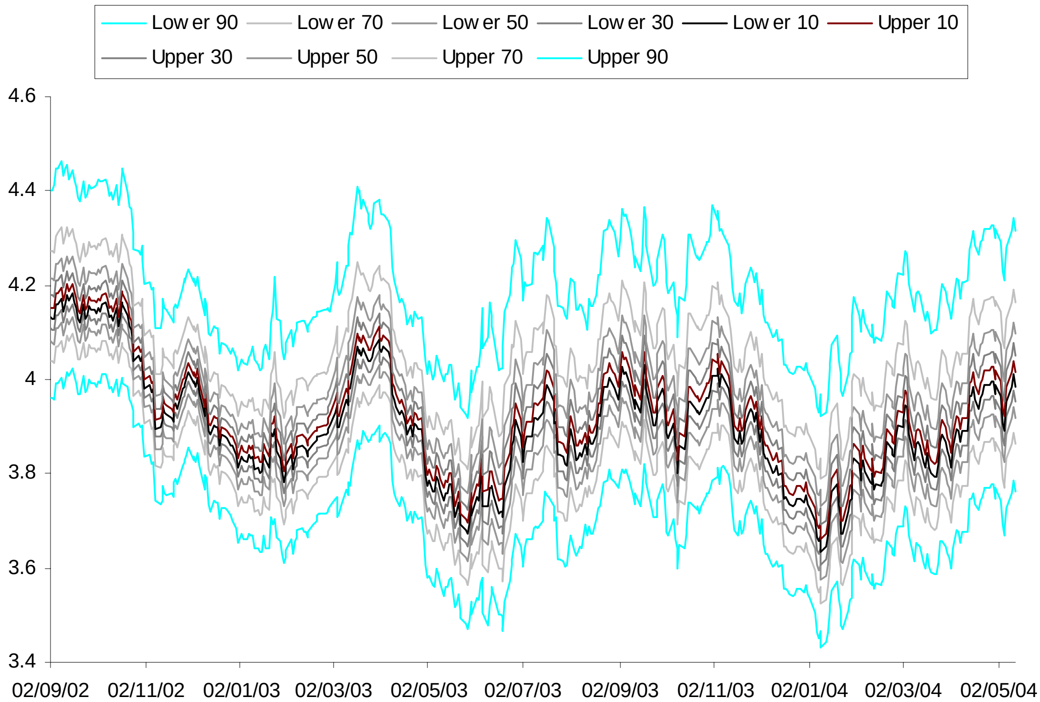


Chart 13: CZK/USD density bands

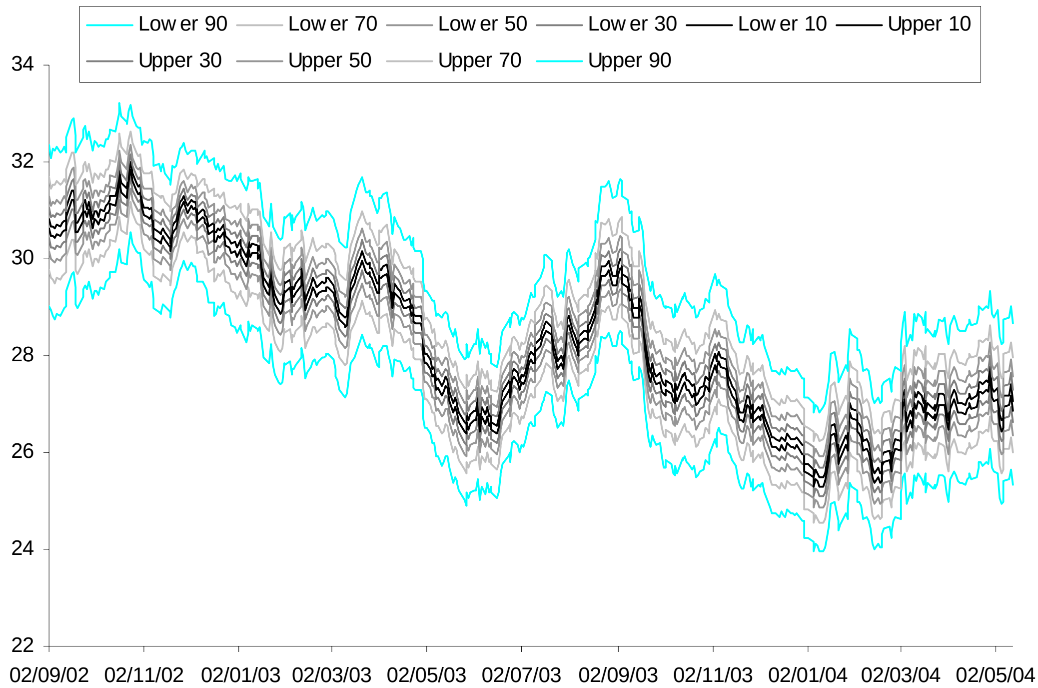


Chart 14: HUF/USD density bands

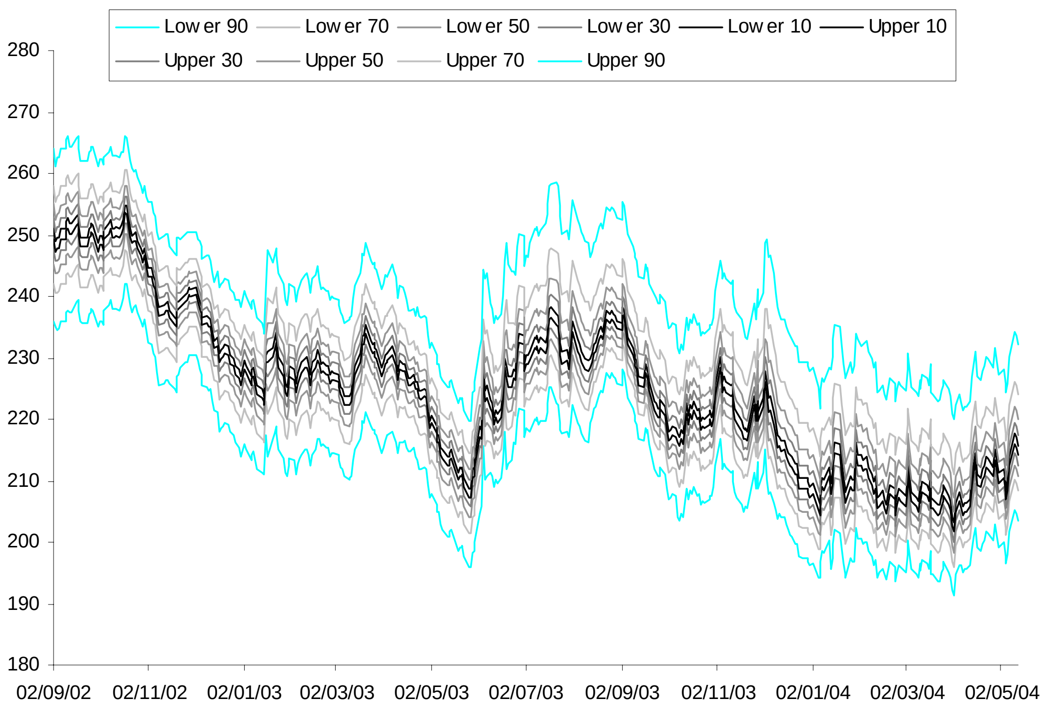
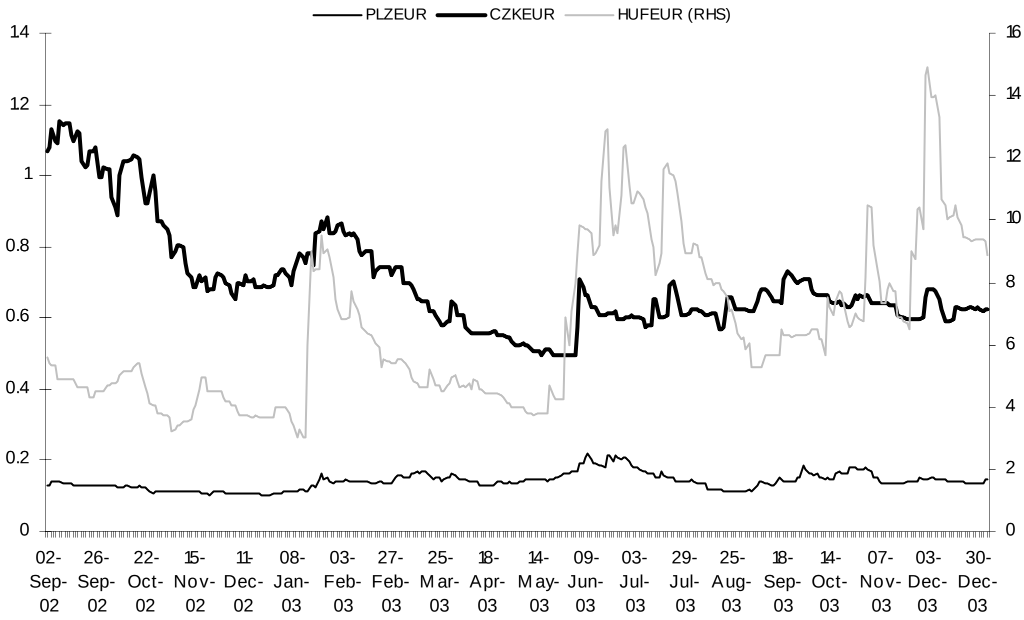
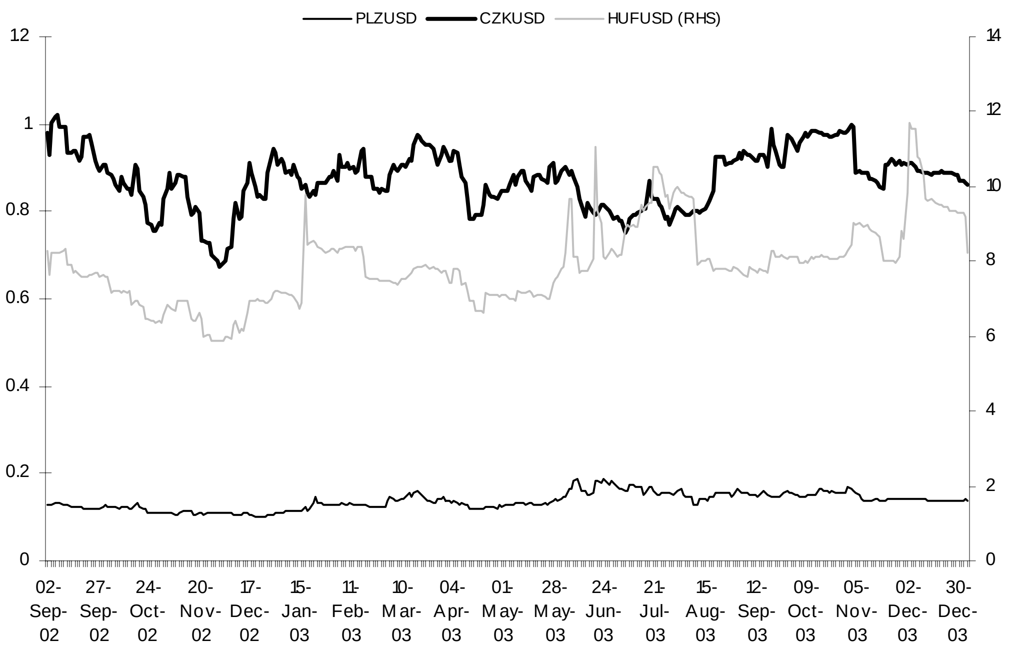


Chart 15: Standard deviations against the euro



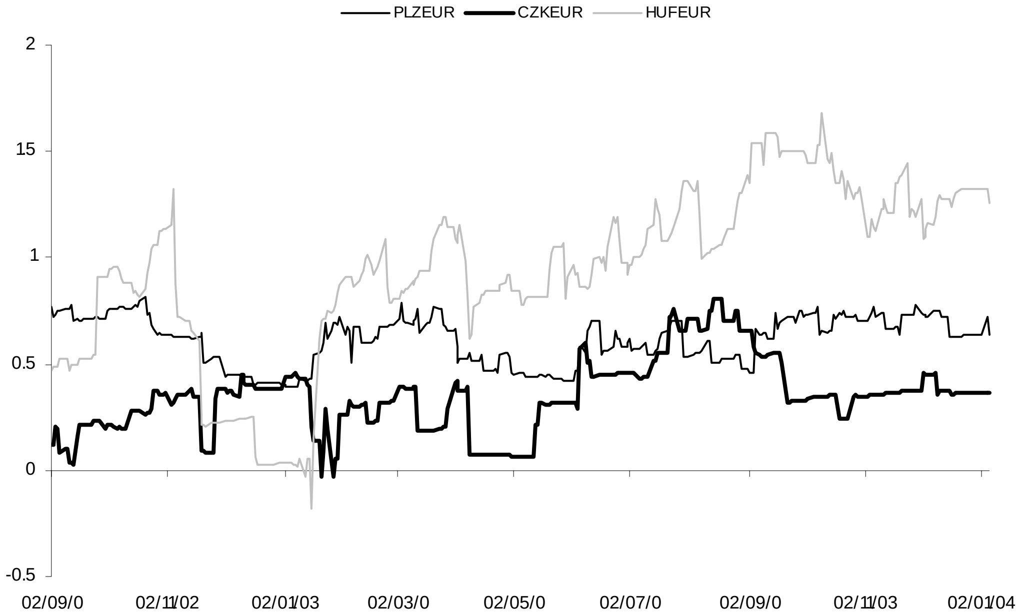
Source: Citibank and ECB calculations

Chart 16: Standard deviations against the US dollar



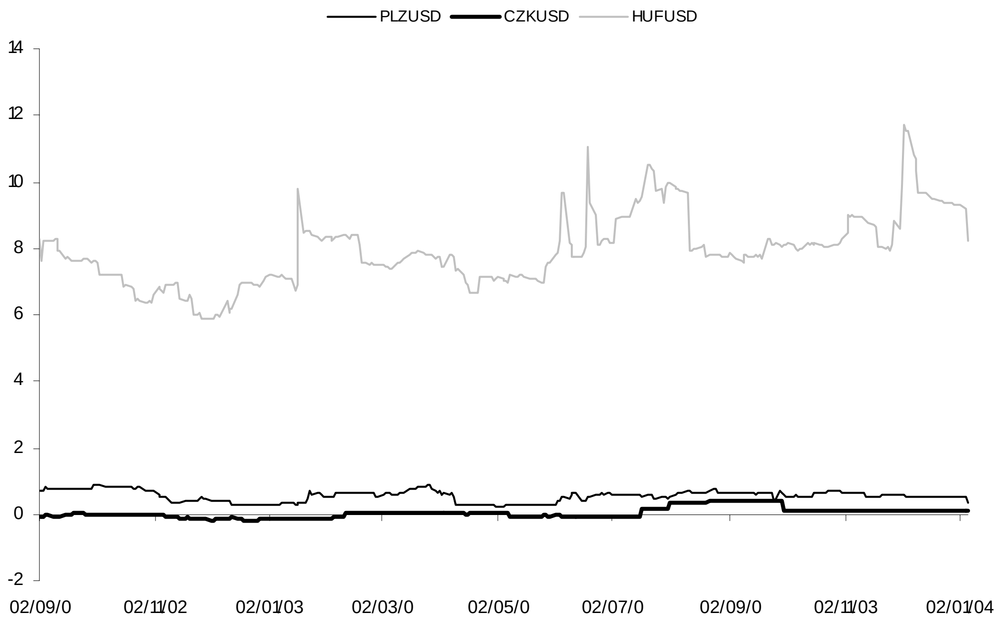
Source: Citibank and ECB calculations

Chart 17: Skewnesses against the euro



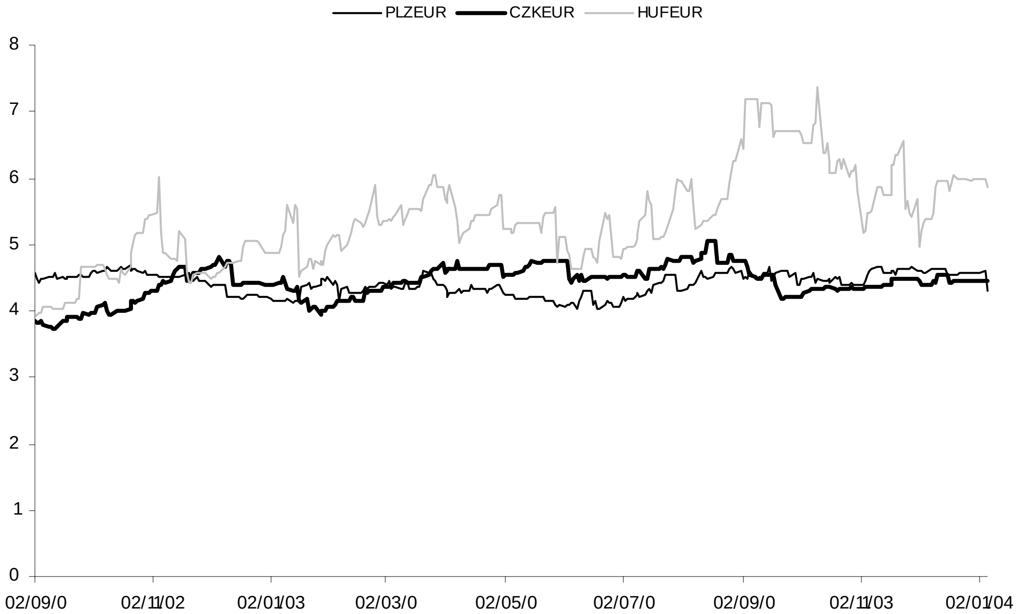
Source: Citibank and ECB calculations

Chart 18: Skeweness against the US dollar



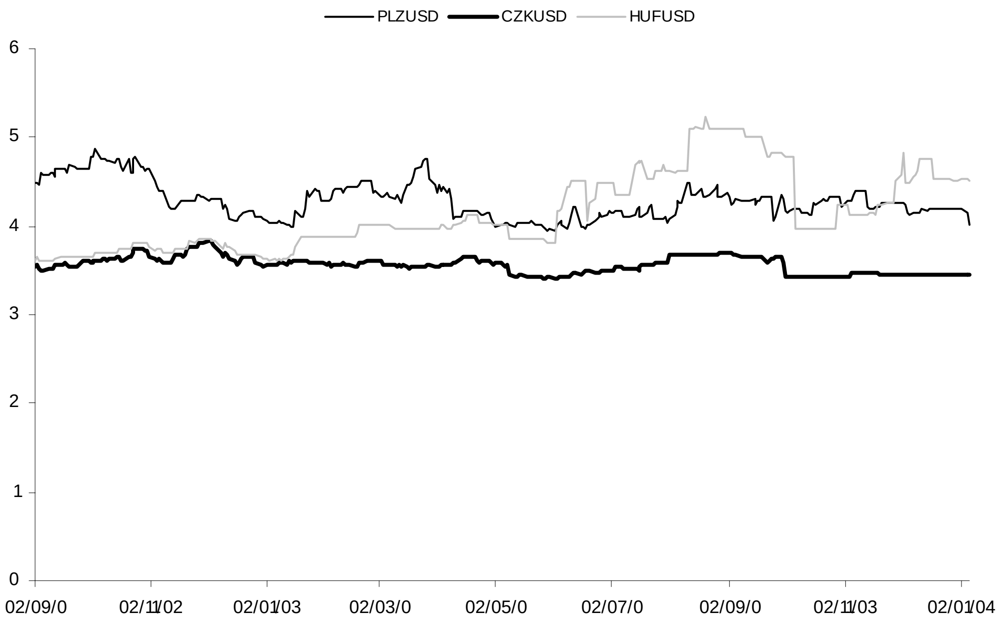
Source: Citibank and ECB calculations

Chart 19: Kurtosis against the euro



Source: Citibank and ECB calculations

Chart 20: Kurtosis against the USD



Source: Citibank and ECB calculations

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