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# Testing the Informational Efficiency of OTC Options on Emerging Market Currencies

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# Testing the Informational Efficiency of OTC Options on Emerging Market Currencies[1]

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**Abstract**



This paper analyzes the informational efficiency of OTC currency options on the Czech koruna and the Polish zloty correcting for the volatility risk premium and errors-in-variable problems, using state-of-the-art techniques (Chernov 2001). It finds that these markets are more efficient than mature markets possibly because of higher relative participation of informed dedicated investors, which offset the effects of relative illiquidity and higher transaction costs in these countries. Moreover, implied volatilities generally anticipate the direction of volatility correctly, with a bias to overpredicting volatility increases reflecting one-sided markets.

JEL Classification Numbers: C22, F31, G13

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## I. Introduction

Both academics and market practitioners have devoted significant time and effort to forecast future volatility in financial markets, as volatility is a major factor in accounting for the risk-return relationship in asset prices. While one strand of the literature has focused on modeling the statistical behavior of volatility using a time series method built upon the work of Engle (1982) and Bollerslev (1986), the other has relied upon the market information contained in option prices.

Following the introduction of the Black-Scholes-Merton option pricing formula and subsequent variations (Black and Scholes, 1973; Merton, 1973), it has been common practice among option traders to quote option prices as a function of their volatility forecast for the maturity period of the option, or to quote directly the volatility implied from using a benchmark pricing model. In an efficient market, option-implied volatilities should represent the market's expectations on future volatility accurately, provided that the pricing model used by the market is known and that the underlying data process satisfies the model's assumptions.

Under the conditions listed above, implied volatility should be an efficient predictor of future volatility, as it contains information beyond that already available in publicly available information such as past historical data. Hence, past historical data should not contribute significantly to forecast future volatility once implied volatility is used. In particular, it can be tested whether implied volatility is a significant, unbiased, and sufficient variable for forecasting future volatility. A relatively large body of work has tested the hypothesis above for a number of financial markets in mature markets. However, to our knowledge, the informational efficiency of implied volatility from option prices for emerging markets financial assets has not yet been tested, presumably because "nonmarket" factors may affect exchange rate patterns more directly.

Examples of these nonmarket forces include central bank interventions or changes in the stance of monetary policy. Furthermore, in emerging markets exchange rate flexibility has proved to be much more limited than in developed economies (Calvo and Reinhart, 2000); and the scale of of transactions is much more reduced. In consequence, transaction costs and lack of liquidity factors would likely prevent option prices from reflecting exchange rate expectations efficiently and without bias.[2] This paper investigates whether emerging markets currency option prices are efficient and unbiased despite imperfections in their underlying currency markets and other distorting factors. In principle, the latter would induce empirical results much different from those observed in mature markets.

This paper addresses the gap in the empirical literature as applied to emerging markets by examining the informational efficiency of currency option prices in two Eastern European

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[2] Constatinides (1994) noted that transaction costs do not necessarily have a first-order effect on option prices.

countries, the Czech Republic and Poland, during the two-year period January 1999–December 2000. In both countries, increased exchange rate flexibility and a rapid insertion in the global currency markets have facilitated the development of the currency derivatives market. Intensive central bank intervention in the foreign exchange market in the Czech Republic during the period analyzed was recognized and incorporated into the investors information set. While the derivative markets for these currencies are small and rather illiquid in absolute terms, they are not necessarily so if measured against the size of their spot foreign exchange markets.

The paper finds that currency option markets for both the Czech koruna (CZK) and the Polish zloty (PLN) behaved similarly to their mature markets counterparts. Specifically, we found that implied volatility, though informationally efficient, remains a biased predictor of realized exchange rate volatility against both the U.S. dollar (USD) and the euro (EUR). Another interesting finding of our study is that the numerical results are very similar to those reported recently by Chernov (2001a) in a comprehensive study of index and currency options in mature markets. This implies that OTC derivatives markets in emerging markets currencies may not differ significantly from those in mature markets when it comes to informational efficiency, regardless of the accepted view that there are more imperfections in the underlying currency markets. It some cases, the Czech koruna and the Polish zloty currency markets show even better results than in the Chernov study.

Besides testing for informational efficiency, as done in standard implied volatility studies, we also test whether implied volatility are directionally accurate, e.g., whether they can predict correctly changes in future realized volatility. While not the main focus of academic research, directional accuracy is useful to market participants for hedging purposes. We find that CZK/EUR implied volatility is useful to predict both volatility increases and declines, especially in the two-three month horizon, while the PLN/USD implied volatility predicts correctly only volatility increases. In general, implied volatility appears to overpredict increases in volatility. This may be explained partly by institutional features affecting financial markets in both countries and that may also be reflected in their exchange rate volatility patterns.

The rest of the paper is organized as follows. Section II reviews briefly the literature on implied volatility as an efficient forecast of future volatility. Section III describes institutional features in the Czech Republic and Poland that could impact informational efficiency and exchange rate volatility patterns. It also discusses issues related to currency derivatives markets in emerging markets. Section IV explains the data and empirical methodology used to evaluate the informational efficiency of implied volatility and its directional accuracy. Section V concludes.

## II. Literature Review

From an academic perspective, volatility forecasting using implied volatility is related to market efficiency, one of the cornerstones of financial theory. Market efficiency implies that the market's expectation of future volatility of the underlying asset is the option-implied volatility. The spectacular growth observed in the of options market in the past three decades has provided researchers with a plethora of data on which to test the informational efficiency of implied volatility. Empirical work has focused on one or more of the three following questions: (a) Do currency options provide information on realized volatility at all (informativeness property)? (b) Is information provided additional to that of historical volatility (informational efficiency)? and (c) if efficient, are option prices unbiased estimators (unbiasedness property)?

While earlier studies found that implied volatility was statistically significant, they have been criticized on grounds of the small datasets utilized and their focus on cross-sectional studies for a selected group of stocks.[3] Among recent studies on the S&P 100 index options, Day and Lewis (1992) and Lamoureux and Lastrapes (1993) showed that implied volatility was statistically significant but it did not capture all the information contained in past volatility data. Furthermore, Canina and Figlewski (1993) found that implied volatility was virtually uncorrelated with future volatility, and its forecast was dominated by the historical volatility rate. These authors attribute the poor forecasting performance of implied volatility to the fact that implied volatility is a "dirty" measure of expected volatility, as it reflects other factors such as supply and demand that are not explicitly accounted for by option pricing models.

The above studies used overlapping datasets that could yield unreliable estimates. Using a longer time series and nonoverlapping data, Christensen and Prabhala (1998) reversed the findings of Canina and Figlewski by showing that implied volatility outperformed past volatility in forecasting future volatility, and even subsumed the information contained in historical data. Fleming (1998) suggests that misspecification of the volatility process and/or the existence of early exercise opportunities may be responsible for the biased forecasts obtained using implied volatility. However, implied volatility was efficient with respect to its past forecast errors, and the errors were orthogonal to past information. Finally, Poteshman (2000) showed that a substantial fraction of the forecasting bias of implied volatility could be eliminated if realized volatility series were constructed using intraday prices in the index futures market rather than closing index levels and an option pricing model allowing non-zero market price of volatility risk were used.

In contrast to the empirical literature on index volatility forecasting, there is limited work on currency volatility forecasting using currency options implied volatility. Jorion (1995) was the first to analyze the information content of implied volatility in currency options, focusing on the deutsche mark, the Japanese yen, and the Swiss franc exchange rate vis-à-vis the U.S. dollar. He used implied volatilities obtained from short-term at-the-money options on currency futures traded in the Chicago Mercantile Exchange. In contrast to the results obtained for index options, Jorion found that the implied volatilities, though biased, outperform past historical data in predicting future exchange rate volatility. He attributed this finding to lower measurement errors in the currency markets.

In a very recent study, Chernov (2001a) studies the informational content of implied volatility using option data for the S&P 100 and Nasdaq 100 equity indices, as well as over-

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[3] The studies include those of Latané and Rendleman (1976), Chiras and Manaster (1978), and Beckers (1981).

the-counter currency options for the pound sterling, the Japanese Yen, and the Swiss Franc. In contrast to previous studies, Chernov defined realized volatility as the quadratic variation of realized returns to account for the volatility risk premium associated with either a stochastic volatility option pricing model or a multiple volatility and jump factors option pricing model. The estimation also corrects for the errors-in-variable problem arising from the fact that historical and realized volatility are estimates of the unobserved quadratic variation and spot volatility of the data generating process. After these corrections, Chernov could not reject the hypothesis that implied volatility was an unbiased and significant estimator of future volatility.

## III. Currency Market Developments and Market Infrastructure in the Czech Republic and Poland in 1999–2000

The main scope of this section is to describe both currency market developments and market infrastructure in the Czech Republic and Poland for the 1999-2000 period that may affect currency option prices and their informational content. In particular, it provides a framework to assess whether lack of liquidity, high transaction costs, and historical and institutional restrictions can impair the information content of currency options.

### A. Recent Developments

The evolution of Eastern European currencies in the last decade has been one of the most impressive features of their transition to become market economies. After a brief period of limited convertibility, these currencies have become increasingly traded in international markets to the point that cross-border investors and market-makers have developed up-to-date financial instruments, including options and other derivatives, to separate risks in their financial operations in Eastern Europe.

In the case of the Czech Republic and Poland, first-wave candidates to join the European Union, a relatively flexible exchange rate has increasingly facilitated the incorporation of market expectations in interest rate and exchange rate changes. The main differences in their relative development of their financial markets related to the development of derivatives operations are the following:

- **The Czech koruna shows a longer history of financial market development linked to the euro area than the Polish zloty, which is linked closely to the U.S. dollar.** In the Czech Republic, early integration with European financial markets favored stronger links with European currencies, in particular the deutsche mark. In Poland, hyperinflation in the early 1990s led to a high degree of dollarization as depositors held almost 40 percent of their deposits in foreign currency accounts, especially U.S. dollars.

- **Poland's debt market shows higher overall liquidity because of a larger stock of government debt**. Poland also started the transition period with a severe debt problem, with external debt amounting to 70 percent of GDP compared to 30 percent in the Czech and Slovak Republic. However, once major problems with debtors were overcome, the existence of a relatively liquid government debt market contributed to the rapid consolidation of the financial system. Availability of zloty-denominated bonds was about US$ 33 billion in 2000, the largest bond market in Eastern Europe, while that for Czech bonds was one of the smallest at about US$ 6 billion. Both are however smaller than other emerging markets such as South Africa (US$80 billion) and Turkey (US$50 billion). Czech bonds could be more liquid at times for longer maturities.

- **The Czech Republic has a longer history of derivative trading with European investors**. Both countries were affected by speculative capital flows since 1995, when they first issued Eurobonds. In the Czech Republic, favorable domestic-foreign interest rate differentials increased derivatives trading in koruna-denominated securities mainly through non deliverable forwards (NDFs) in London. Proprietary trading by banks rather than client-driven transactions experienced faster growth and accounted for the bulk of the transactions, with faster development of forward and swaps foreign exchange transactions in the Czech koruna relative to the Polish zloty.

- **Recent history shows more willingness to let the currency float in Poland**. The Czech central bank, after being forced to widen its exchange rate band by 0.5 percent to 7.5 percent in February 1996, adopted a managed floating regime on May 26, 1997, after ten days of unsustainable foreign exchange intervention, intensive short-selling and steep increases in interest rates. Increasing exchange rate pressure also forced Poland to allow the zloty to float on April 11, 2000 to facilitate a full-fledged inflation-targeting framework This event was preceded by a rebase of the zloty in January 1995; the set up of a crawling band of ± 7 percent in May 1995; successive widening of the exchange rate band to 10 percent in February 1998 and to 12.5 percent in October 1998 despite sterilization intervention and higher reserve requirements; and the removal of daily fixing by the Central Bank in January 1999.

The turbulence experienced by the Czech koruna and the Polish zloty during the late 1990s can be observed in Figures 1 and 2. Figure 1 shows the evolution of the exchange rate for both the Czech koruna and the Polish zloty against the U.S. dollar and the euro for 1997–2000. The series for the euro are extended before 1999 using the basket formula for the period before its inception on January 1, 1999. The 1997 crisis in the Czech Republic is clearly reflected in substantial exchange rate depreciation followed by appreciation in 1998 against both the U.S. dollar and the euro. The Czech koruna reflects the euro depreciation against the U.S. dollar. Intervention in the foreign exchange market under the prevailing managed floating regime became less intensive after 1997, and the Czech koruna appreciated against the euro for two years until the end of 2000. In the case of the zloty, some depreciation during 1997 was followed by a period of stability against the U.S. dollar (but not against the euro). The Russian crisis of 1998 resulted only in a short-lived exchange rate depreciation.

Figure 2 offers a glimpse of one-month and three-month exchange rate volatility. It is apparent that the Czech koruna shows less volatility fluctuations than the Polish zloty against both currencies, and a tendency to remain above a higher volatility plateau with respect to the U.S. dollar relative to the euro. The Polish zloty shows more fluctuations against the euro, especially looking at one-month volatility, and exchange rate volatility remains on average lower against the U.S. dollar relative to the euro.

In general, the Polish zloty shows more volatility fluctuations, with the Czech koruna reflecting the impact of central bank intervention to preserve exchange rate stability, especially against the euro. *Recent developments in the foreign exchange markets in the Czech Republic and Poland suggest more liquidity, higher exchange rate flexibility, and a closer link to the U.S. dollar for the zloty currency market and more financial development and integration with Europe for the koruna currency market. The relative weight of these factors on the efficiency of their currency option markets will be assessed in the empirical section.*

### B. Market Infrastructure

More than 75 percent of daily turnover in foreign exchange transactions in Eastern European currencies are conducted mainly in the London market (except for Hungary).[4] The main characteristics of these markets are the following:

- **Stronger link of the Czech koruna with the euro and of the Polish zloty with the U.S. dollar**. Consistent with exchange rate volatility patterns, the Czech koruna has long been in the zone of influence of the euro, closely related to the Deutsche mark, with main transactions conducted by domestic currency units within the major investment banks' trading groups. More market diversification is observed for the Polish zloty, with more transactions taking place in the U.S. dollar market.

- **Currency options are less important than other derivative instruments.** Interest rate swap and forward rate agreements (FRA) have developed strongly in the Czech koruna. In Poland, the non deliverable Forwards (NDF) market survived because of controls.[5] Other derivative instruments tend to focus on transactions with corporates rather than between market players. The currency option market started to operate in 1995. The small typical transaction size is larger for the Czech koruna for foreign exchange forwards, options and swaps (Table 1). Benchmark quotes for the Czech koruna are against the euro, while for the Polish zloty are against the U.S. dollar. Currency options are traded basically at the money, as liquidity in both currencies for trading options at strike prices other than at the money is low.

- **Foreign investors in general do not hedge domestic currency exposure except when market conditions are extremely uncertain**. Some investors prefer only to

[4] Cohrs and Dahmer (2000).

[5] Some restrictions on short-term capital flows still exist for operations in Polish Zloty. Specifically, transactions in derivative instruments not quoted on one of the country's exchanges require the explicit approval of the Polish National Bank. However, this is not strictly enforced.

hedge the euro exposure, hedging the approximate correlation with the domestic currencies (approximately 80 percent for the Czech koruna and 60 percent for the Polish zloty in recent years) by financing positions through a combination of euro and U.S. dollar funding. Generally, lack of liquidity in the market for forward and swaps at long maturities make hedging unduly costly. Zloty forward foreign exchange transactions for periods longer than six months are made difficult by lack of bank interest rate quotes for more than six months.

- **Dedicated investors favor Czech koruna instruments, while crossover investors favor Polish zloty instruments.** Relatively lower activity by foreign investors in the Czech Republic concentrates in buy-and-hold transactions. By contrast, foreign investors embark on more active proprietary trading in the Polish market relative to the rest of Eastern Europe, especially for 3-6 month transactions. European investors (particularly from Germany) are more likely to buy and hold bonds and hedge currency risk in periods of uncertainty (mainly by rolling short-term forwards). Non-European investors (particularly from the United States) engage in crossover transactions.

Table 1. Czech Koruna and Polish Zloty: Typical Transaction Size for Selected Cross-Border Financial Transactions
(In millions of U.S. dollars)

| | Czech koruna | Polish zloty |
|---|---|---|
| Foreign exchange spot | 10 | 5 |
| Foreign exchange forwards | 10 | 5 |
| Foreign exchange options | 10 | 5 |
| Swaps | 5 | 1 |
| Domestic debt | 1 | 3 |
| Currency-linked eurobond | 0.3 | 1.5 |

Based on the characteristics of the market infrastructure, the links of the zloty against the U.S. dollar are also important for the derivatives market relative to the koruna; currency options show limited development, with derivatives normally not used for hedging; and, the koruna market may be more isolated from exogenous events because of the larger presence of dedicated investors relative to the zloty market.

## IV. Informational Efficiency and Directional Accuracy of Implied Volatility

### A. Informational Efficiency

**Conceptual Considerations**

Academics consider that option-implied volatilities are good proxies for future volatility of the underlying asset. In consequence, a number of empirical studies have analyzed the informational efficiency of implied volatilities as predictors of future volatility. Usually, the studies have tested three different hypotheses about the information content of implied volatilities: informativeness, unbiasedness, and informational efficiency. The informativeness hypothesis states that implied volatilities provide useful information on future realized volatility. The unbiasedness hypotheses states that implied volatilities are unbiased estimators. Finally, the informational efficiency hypotheses states that implied volatilities contain information beyond that contained by historical data. These hypotheses would be clarified in the next section, once they are formulated in the context of the regression framework used in this paper.

This study uses option-implied volatilities from over-the-counter (OTC) currency options, as in Chernov (2001), rather than exchange-traded currency options as in Jorion (1995). Foreign exchange data usually conform better to the assumption of zero correlation between returns and spot volatility. This assumption is required to show that the Black-Scholes implied volatility is an unbiased forecast of future realized volatility in the stochastic volatility model of Hull and White (1987), which serves as the theoretical framework of our empirical analysis.[6] Another advantage of using currency option data is that the arbitrage between the option and the underlying asset is straightforward, unlike stock indices that require continuously buying and selling a number of stocks to maintain a delta neutral hedge.[7] Finally, implied volatilities are directly quoted for these currencies, and this ensures that the data is to some extent independent of the model and therefore helps avoid errors in computing implied volatilities.[8] However, because daily data is used, there is a high degree of implied volatility autocorrelation that may affect the results. Assuming that there are more frictions in these markets than in more developed markets (noncontinuous trading, bid-ask spreads, etc.), the bias problems should be more serious with the dataset used in this paper. If these factors were important, there would be available lucrative strategies for market makers profiting from the large bid-ask spreads in option markets,[9] which would be impossible to

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[6] Chernov (2001).

[7] Canina and Figlewski (1993).

[8] However, implied volatilities may have been set up having a specific model in mind (specifically Black-Scholes).

[9] Poteshman (2000).

incorporate into option pricing models and would render the analysis of option prices in emerging markets fruitless.

**Empirical Methodology**

The empirical methodology used in this study follows the one first proposed by Chernov (2001) closely. Given a forecasting horizon $k$, the standard regression used to evaluate the forecasting power of implied volatility is:

$$RV_{t,k} = a + b\, IV_{t,k} + c\, HV_{t-k,t} + e_{t+k}, \tag{1}$$

where $RV_{t,k}$ is the ex post realized volatility over the period $t$ to $t+k$, $IV_{t,k}$ is the implied volatility extracted from option prices at time $t$, $HV_{t-k,t}$ is the historical volatility over the preceding period $t-k$ to $t$, and $e_{t+k}$ is the forecasting error. Equation (1) permits testing three different hypothesis about implied volatility, which is widely believed to be the best forecast of future realized volatility. First, whether implied volatility contains useful information to forecast future realized volatility or equivalently, whether the coefficient $b$ is significantly different from zero. Second, whether implied volatility is an unbiased forecast or equivalently, whether $b=1$ and $a=0$. Finally, whether all the information needed to forecast realized volatility is captured by implied volatility or equivalently, whether $c=0$.

In this study both realized volatility and historical volatility could be estimated with their respective discrete time quadratic variation approximations:

$$HV_{t=k,t} \approx \frac{1}{k}\sum_{t=i}^{k-1} r_{t-i}^2 , \tag{2}$$

$$RV_{t,k} \approx \frac{1}{k}\sum_{t=i}^{k-1} r_{t+i}^2 , \tag{3}$$

where $r$ is the daily exchange rate return. There are some advantages in using quadratic variation process estimates for both volatility measures. First, under certain conditions, the quadratic variation process is an unbiased and highly efficient estimator of realized volatility, as shown by Andersen et al (2001), Barndorff-Nielsen and Shephard (2001, 2002), and Chernov (2001b). Second, the quadratic variation process is fully consistent with theoretical volatility measures derived from a number of continuous stochastic processes commonly used to model financial time series, including diffusion and jump-diffusion processes.[10] Finally, and equally important, the quadratic variation process is easy to calculate.

Nevertheless, because equations (2) and (3) are estimates of the true unobserved volatilities, their use introduces error-in-variables (EIV) problems. As noted by Chernov (2001), the EIV problem could introduce significant biases in the estimation of the implied volatility

[10] See Andersen et al (2002), Chernov (2001), and Foster and Nelson (1996).

coefficient in equation (1) if simple OLS estimation is used. This problem can be addressed if equation (1) is estimated by GMM, first proposed by Hansen (1982) while correcting for serial correlation and heteroskedasticity problems, a common feature of daily data, using the Newey-West kernel estimator. The set of moment conditions imposed in the estimation of equation (1) are:

$$E\left[\left(RV_{t,k} - a - bIV_{t,k} - cHV_{t-k,t}\right) \otimes Z_t\right] = 0, \tag{4}$$

where $Z_t$ is a set of instrumental variables, which in our analysis consist of lagged exchange rate returns.

**Data and Results**

The empirical methodology described above was applied to daily time series of over-the-counter (OTC) at-the-money (ATM) implied volatility quotes corresponding to currency options on the Czech k (CZK) and the Polish zloty (PLN) against the U.S. dollar (USD) and the euro (EUR) from a major player in the foreign exchange market. The data sample covers the period January 4, 1999 – December 29, 2000, with 1, 2, 3, 6 and 12 months time to maturity. The quotes were obtained from Deutsche Bank, London, as compiled from on-screen Reuters quotes of at-the-money call options prices offered by Cantor Fitzgerald International. Currency option quotes are expressed in implied-volatility units. Figures 3 and 4 show the evolution of one-month historical and implied exchange rate volatility. In general, both historical and implied volatility follow a similar pattern, as the spot market basically captures the same information available for agents in the currency option market.

It should be noted that the use of quoted implied volatilities offers a number of advantages. Errors in calculating implied volatilities are avoided, since currency options are quoted in units of volatility.[11] Because the volatility quotes correspond to OTC contracts corresponding to a fixed number of maturities quoted on a daily basis, there are no problems associated with the telescoping time to maturity and varying moneyness. These problems are described in more detail by Christensen and Prabhala (1998), Fleming (1998), and Poteshman (2000).

Equation (1) was estimated using OLS and GMM, to assess the bias associated with the EIV problem, and the results are summarized in Table 2. In general, Table 2 shows that regardless of the forecasting horizon and the estimation methodology used, implied volatility contains useful information about future realized volatility, as its coefficient is significant in almost all cases analyzed. There are three exceptions, all of them related to the Polish zloty. The appropriateness of the instrumental variables used in the GMM regressions is validated by the low and insignificant values of their corresponding $J$ statistics (not reported in the table for the sake of brevity) that imply that the overidentifying restrictions are satisfied. In

[11] Prices are obtained by replacing quoted volatilities in the option price formula first derived by Garman and Kohlhagen (1983).

contrast to the results obtained by Chernov (2001) for the Japanese yen and the Swiss franc against the U.S. dollar, the GMM estimates are very precise (see Table 3).
The table also shows that the EIV problem introduces substantial biases to the implied volatility coefficient, though the direction of the bias is not well determined. In most cases, especially for forecasting horizons up to 2 months, the implied volatility coefficient exhibits downward bias with the exception of the PLN/USD at 2 month horizon. From 3 month horizon onwards, there are some cases in which the implied volatility coefficient exhibits upward bias such as the CZK/USD, the CZK/EUR, and the PLN/EUR at 3 month horizon, the CZK/USD and PLN/EUR at 6 month horizon, and the CZK/USD and PLN/USD at 12 month horizon.

The EIV problem also affects the informational efficiency of implied volatility. On one hand, all OLS estimations show significant coefficients for the historical volatility variable which would tempt the reader to infer that implied volatility is informationally inefficient. On the other hand, historical volatility usually does not contain information beyond that contained by implied volatility once the EIV problem is corrected using GMM for forecasting horizons up to 6 months.

Both OLS and GMM estimates show that the constant term in regression (1) is insignificant, consistent with unbiased indicators. While all the OLS coefficient estimates are significantly lower than one, after correcting for the EIV problem we find two cases in which implied volatility is an efficient unbiased informative forecast of realized volatility, the CZK/EUR at 2 month horizon and the PLN/EUR at 1 month horizon.

### B. Directional Accuracy of Implied Volatility

To assess the usefulness of option prices to serve as a guide for hedging, we test overall predictability of implied volatilities distinguishing between "accurate forecasts" and "useful forecasts" following Levich,[12] i.e., useful forecasts would be those that lead to correct hedging decisions although the magnitudes were not accurately forecasted. If implied volatilities anticipate the direction of volatility correctly, it would be sufficient to justify the use currency options to hedge that risk. Table 4 shows summary results of the comparison of the implicit predictions of the direction of exchange rate volatility for four different option maturities. The following observations are worth mentioning:

- Except for the PLN/EUR exchange rate volatility, implied volatility appears more "accurate" in predicting volatility increases relative to decreases. This may reflect a more intensive use of derivatives at times of volatility increases, which makes the market more liquid in such events, or an overall tendency to implied-volatility overshooting in times of volatility increases.

- CZK/EUR currency option volatilities show the most balanced performance, with 97.7 percent significance of predictions for both volatility increases and decreases for

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[12] Levich (1998).

two- and three-month currency options, and a good performance predicting increases for other maturities. The PLN/USD currency option volatility shows an overwhelming good performance predicting volatility increases (practically 100 percent accuracy for all maturities), but not always an overall good performance (i.e., for volatility increases and decreases). The good performance predicting volatility increases apparently reflects the tendency to overpredict volatility increases.

- Even the less liquid PLN/EUR and CZK/USD dollar currency option volatilities show an overall good performance for one-, two- and three-month currency options, although biased to overpredict decreases in the case of the PLN/EUR and increases in the case of the CZK/USD dollar currency options.

## V. Conclusions

For both the Czech koruna and the Polish zloty, implied volatility, though informationally efficient, is still a biased predictor of realized exchange rate volatility against both the U.S. dollar and the euro. The classical interpretation of this failure, first put forward by Figlewski (1997), is that frictions in the options market prevent optimal forecasts of future volatility to be reflected in option prices. In addition, the bias exhibited by implied volatility can be explained in terms of the presence of a volatility risk premium (Lamoureux and Lastrapes, 1993) which has recently been analyzed explicitly by a number of authors.[13]

However, the evidence presented in this study suggests that market frictions rather than the volatility risk premium may be mainly responsible for the bias in the results, with tests showing higher overall informational efficiency than mature markets currencies. Intuitively, the volatility risk premium would increase with the forecasting horizon and the required risk compensation would imply that the implied volatility coefficient declines with maturity. These results hold for the OLS estimates but once the EIV problem is corrected in the GMM estimation, the declining trend disappears. Furthermore, the existence of negative implied volatility coefficients in all 12-month horizons implies a negative volatility risk premium which is difficult to justify economically.

Finally, currency option prices may be effective as a guide for hedging, especially at times of volatility increases. Implied volatilities generally anticipate the direction of volatility correctly, especially for CZK/EUR, probably reflecting that information content of option prices may be more relevant for dedicated investors despite low liquidity. Overprediction of volatility increases may reflect one-sided markets that become liquid in the expectation of volatility increases.

[13] Benzoni (1999), Chernov (2001), Chernov and Ghysels (2000), Jones (2002) and Pan (2000) among others.

Table 2. Informational Efficiency: Summary of Results.

| | | CZKUSD | | CZKEUR | |
|---|---|---|---|---|---|
| | Parameters | OLS | GMM | OLS | GMM |
| 1 Month | c | 0.00000113 | -0.0000117 | 0.00000143 | -0.0000191 ** |
| | t-statistic | (0.28275) | (-0.658938) | (1.009189) | (-4.455543) |
| | IVOL | 0.49583 ** | 0.719218 ** | 4.52E-01 ** | 1.468321 ** |
| | t-statistic | (14.59018) | (2.513768) | (14.07049) | (6.754946) |
| | HVOL | 0.064857 | -0.259326 | 0.152202 ** | -0.191931 |
| | t-statistic | (1.552293) | (-0.955965) | (3.444764) | (-1.915711) |
| 2 Month | c | 0.000011 ** | -0.0000183 | 0.0000172 ** | -0.0000179 ** |
| | t-statistic | (3.050499) | (-0.994043) | (13.36343) | (-4.284357) |
| | IVOL | 0.254178 ** | 0.549088 ** | 0.160146 ** | 0.988793 ** |
| | t-statistic | (9.364431) | (2.053672) | (5.361094) | (5.796043) |
| | HVOL | 0.308817 ** | 0.153586 | -0.237725 ** | 0.226372 ** |
| | t-statistic | (6.939641) | (0.553969) | (-4.709962) | (4.032746) |
| 3 Month | c | 0.00000483 ** | 0.0000151 | 0.00000817 ** | -0.00000915 ** |
| | t-statistic | (2.085607) | (1.170458) | (13.49785) | (-2.19029) |
| | IVOL | 0.4066 ** | 0.288824 ** | 0.190729 ** | 1.235011 ** |
| | t-statistic | (24.30923) | (2.143681) | (9.482724) | (5.232343) |
| | HVOL | 0.064639 ** | 0.024854 | 0.06925 ** | -0.466256 ** |
| | t-statistic | (2.189875) | (0.318535) | (5.289564) | (-2.330057) |
| 6 Month | c | 0.0000301 ** | -0.00000456 | -0.00000252 ** | 0.0000152 ** |
| | t-statistic | (7.971371) | (-0.335149) | (-2.474465) | (6.054522) |
| | IVOL | 0.227241 ** | 0.455773 ** | 0.535602 ** | -0.220609 ** |
| | t-statistic | (12.08072) | (4.729513) | (31.18812) | (-2.068494) |
| | HVOL | 0.041268 | 0.053634 | 0.136597 ** | 0.24841 ** |
| | t-statistic | (0.906046) | (0.444674) | (5.966615) | (3.715501) |
| 12 Month | c | 0.0000944 ** | 0.000501 ** | -0.0000333 ** | -0.0000168 |
| | t-statistic | (29.30582) | (8.272299) | (-6.798359) | (-1.63796) |
| | IVOL | 0.092929 ** | -4.038517 ** | 0.472509 ** | 0.628628 ** |
| | t-statistic | (4.886254) | (-7.250505) | (20.21428) | (2.440931) |
| | HVOL | -0.22445 ** | -0.318731 ** | 0.808415 ** | 0.22538 ** |
| | t-statistic | (-12.38595) | (-2.97781) | (9.90683) | (2.382302) |

* = 90 percent confidence level. ** = 95 percent confidence level.

Table 2. Informational Efficiency: Summary of Results (cont.).

| | | PLNUSD | | PLNEUR | |
|---|---|---|---|---|---|
| | Parameters | OLS | GMM | OLS | GMM |
| 1 Month | c | 0.00000233 | -0.0000237 * | 0.00000853 * | -0.0000394 |
| | t-statistic | (0.606786) | (-1.715776) | (1.83825) | (-1.252218) |
| | IVOL | 0.430436 ** | 0.678823 ** | 0.487085 ** | 1.067558 ** |
| | t-statistic | (16.59758) | (4.505621) | (13.70342) | (2.735844) |
| | HVOL | -0.087287 ** | -0.110311 | 0.076435 | -0.017338 |
| | t-statistic | (-2.425547) | (-1.262699) | (1.597825) | (-0.100988) |
| 2 Month | c | 0.0000358 ** | 0.000142 | 0.000078 ** | -0.000105 * |
| | t-statistic | (8.876402) | (1.098869) | (8.762204) | (-1.831683) |
| | IVOL | 0.158885 ** | -0.790107 | -0.009654 | 1.453888 ** |
| | t-statistic | (6.356533) | (-0.729912) | (-0.168681) | (2.532776) |
| | HVOL | -0.11006 ** | -0.103909 | -0.165035 ** | 0.542813 * |
| | t-statistic | (-2.492574) | (-0.812579) | (-2.038172) | (1.676236) |
| 3 Month | c | 0.0000397 ** | 0.00000203 | 0.0000713 ** | 0.000107 ** |
| | t-statistic | (15.19316) | (0.082018) | (25.55001) | (10.73431) |
| | IVOL | 0.080556 ** | 0.342283 | 0.067469 ** | -0.104939 |
| | t-statistic | (4.943613) | (1.639622) | (2.763091) | (-1.030572) |
| | HVOL | -0.263777 ** | -0.236238 ** | -0.290528 ** | -0.65132 ** |
| | t-statistic | (-6.936742) | (-2.013793) | (-9.230286) | (-6.034646) |
| 6 Month | c | 0.0000617 ** | 0.00000226 | 0.000121 ** | 0.000149 ** |
| | t-statistic | (24.54179) | (0.101844) | (17.12421) | (4.173822) |
| | IVOL | -0.049139 ** | 0.270516 ** | -0.181926 ** | -0.423893 ** |
| | t-statistic | (-3.7256) | (2.21707) | (-4.988752) | (-3.003687) |
| | HVOL | -0.509283 ** | 0.039208 | -0.587014 ** | -0.776232 |
| | t-statistic | (-13.39629) | (0.170778) | (-9.889307) | (-1.524378) |
| 12 Month | c | 0.00005 ** | 0.000123 ** | 0.0000828 ** | 0.000457 ** |
| | t-statistic | (20.64124) | (30.52646) | (13.30553) | (15.06855) |
| | IVOL | -0.08938 ** | -0.105352 ** | 0.075176 ** | 0.358169 ** |
| | t-statistic | (-5.993963) | (-2.907832) | (2.559565) | (3.231037) |
| | HVOL | 0.102048 ** | -1.219394 ** | -0.18566 ** | -5.565723 ** |
| | t-statistic | (3.535771) | (-11.75382) | (-3.801704) | (-14.97247) |

* = 90 percent confidence level. ** = 95 percent confidence level.

## Table 3. Chernov Estimations for the One-month Currency Options on the British Pound (GBP), Japanese Yen (JPY), and Swiss Franc (CHF) against the U.S. Dollar

| | GBP | | JPY | | CHF | |
|---|---|---|---|---|---|---|
| Parameters | OLS | GMM | OLS | GMM | OLS | GMM |
| c | 0.0055 | 0.0277 | 0.1137 ** | 0.1099 | 0.1233 * | 0.2372 |
| t-statistic | 0.679012346 | 0.586864407 | 11.84375 | 1.195865071 | 10.19008264 | 1.584502338 |
| IVOL | 0.9496 ** | 1.1121 * | 0.5523 ** | 1.0141 ** | 0.5849 ** | 1.0464 |
| t-statistic | 25.8746594 | 2.694693482 | 16.10204082 | 0.909180563 | 13.79481132 | 0.842308621 |
| HVOL | -0.0012 | -0.2359 | 0.1735 ** | -0.2608 | 0.1528 ** | -0.5467 |
| t-statistic | -0.052173913 | -0.665444288 | 8.183962264 | -0.324984424 | 6.643478261 | -0.530622149 |

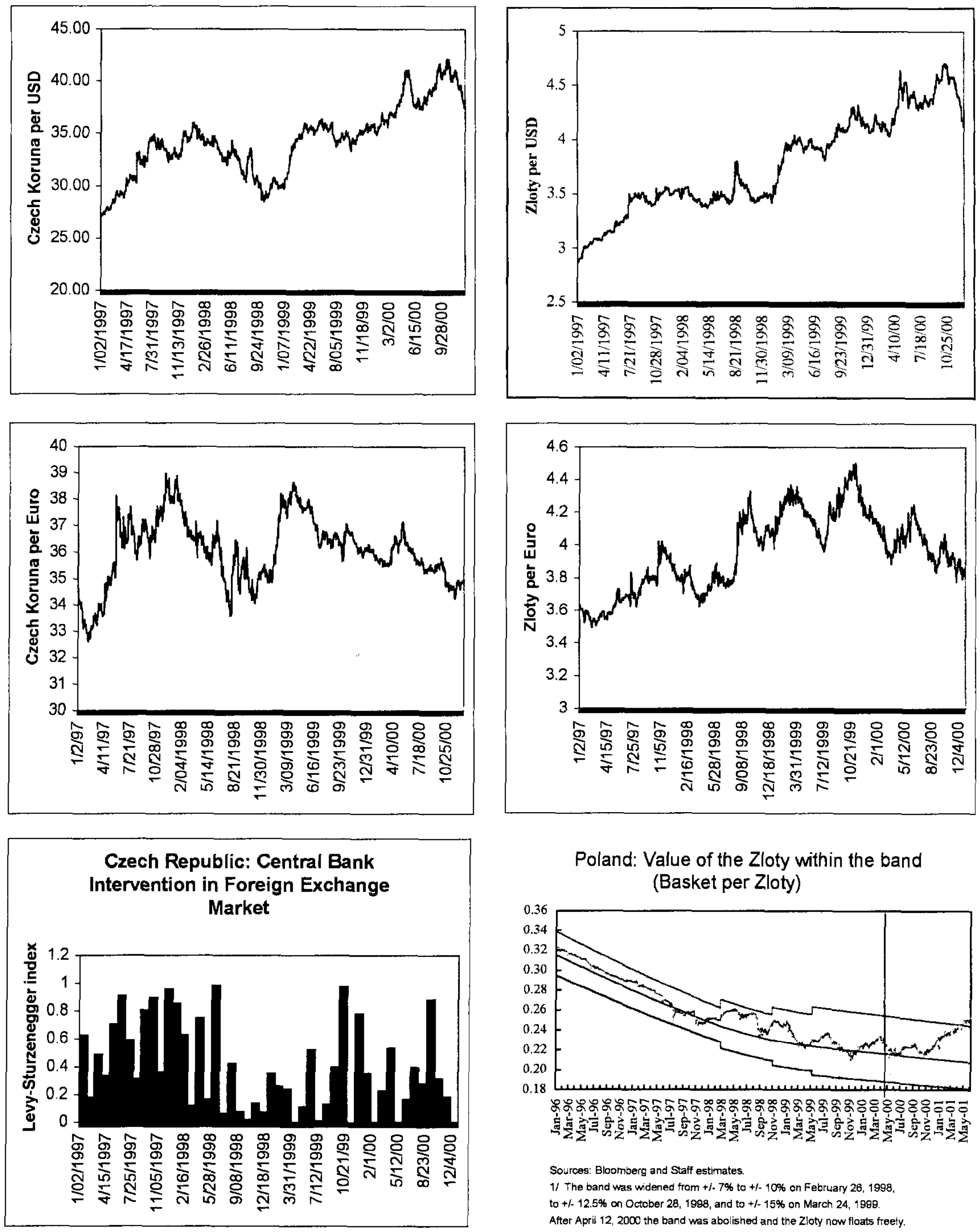
* = 90 percent confidence level. ** = 95 percent confidence level.

## Table 4. Czech Koruna and Polish Zloty: Success Rate of Implied Volatility to Forecast Volatility Changes

| | One-month volatility | | | Two-month volatility | | | Three-month volatility | | | Six-month volatility | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Volatility increases | Volatility decreases | Total | Volatility increases | Volatility decreases | Total | Volatility increases | Volatility decreases | Total | Volatility increases | Volatility decreases | Total |
| KORUNA/EURO | | | | | | | | | | | | |
| Episodes | 51 | 49 | 100 | 55 | 41 | 96 | 45 | 46 | 91 | 11 | 67 | 78 |
| Succesful Predictions | 70.6 | 57.1 | 64.0 | 87.3 | 73.2 | 81.3 | 100.0 | 71.7 | 85.7 | 81.8 | 40.3 | 46.2 |
| Wrong Predictions | 29.4 | 42.9 | 36.0 | 12.7 | 26.8 | 18.7 | 0.0 | 28.3 | 14.3 | 18.2 | 59.7 | 53.8 |
| ZLOTY/EURO | | | | | | | | | | | | |
| Episodes | 46 | 42 | 88 | 45 | 43 | 88 | 37 | 51 | 88 | 50 | 28 | 78 |
| Succesful Predictions | 60.9 | 92.9 | 76.1 | 46.7 | 86.0 | 65.9 | 40.5 | 80.4 | 63.6 | 32.0 | 60.7 | 42.3 |
| Wrong Predictions | 39.1 | 7.1 | 23.9 | 53.3 | 14.0 | 34.1 | 59.5 | 19.6 | 36.4 | 68.0 | 39.3 | 57.7 |
| KORUNA/USD | | | | | | | | | | | | |
| Episodes | 63 | 73 | 136 | 65 | 71 | 136 | 68 | 68 | 136 | 74 | 62 | 136 |
| Succesful Predictions | 88.9 | 49.3 | 69.1 | 80.0 | 39.4 | 58.6 | 85.3 | 32.4 | 58.8 | 79.7 | 29.0 | 56.6 |
| Wrong Predictions | 11.1 | 50.7 | 30.9 | 20.0 | 60.6 | 41.2 | 14.7 | 67.6 | 41.2 | 20.3 | 71.0 | 43.4 |
| ZLOTY/USD | | | | | | | | | | | | |
| Episodes | 66 | 92 | 158 | 81 | 73 | 154 | 68 | 81 | 149 | 70 | 66 | 136 |
| Succesful Predictions | 100.0 | 20.7 | 53.8 | 100.0 | 35.6 | 69.5 | 100.0 | 23.5 | 58.4 | 97.1 | 7.6 | 53.7 |
| Wrong Predictions | 0.0 | 79.3 | 46.2 | 0.0 | 64.4 | 30.5 | 0.0 | 76.5 | 41.6 | 2.9 | 92.4 | 46.3 |

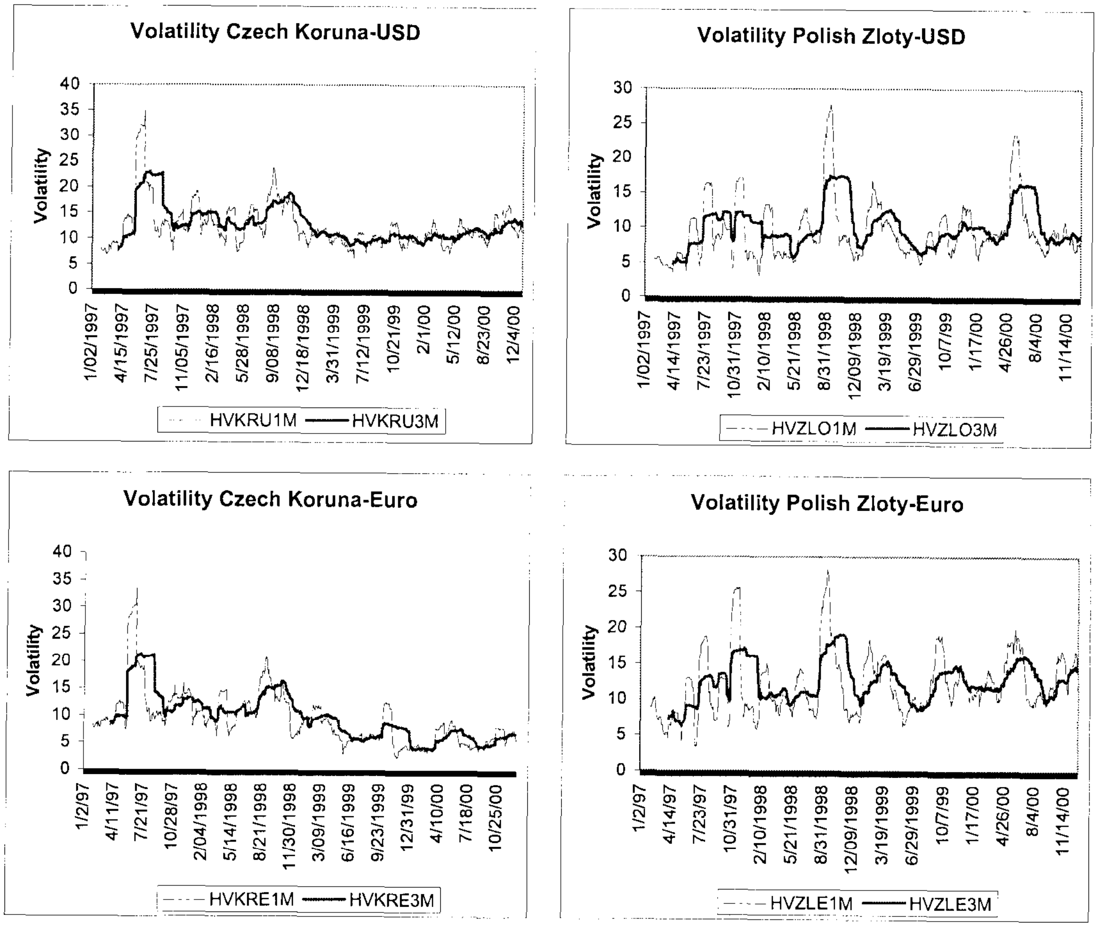
Shadow areas indicate significance beyond 2 standard deviations (97.7 percent confidence).

Figure 1. Czech Republic and Poland: Exchange Rates Relative to the U.S. Dollar and the Euro



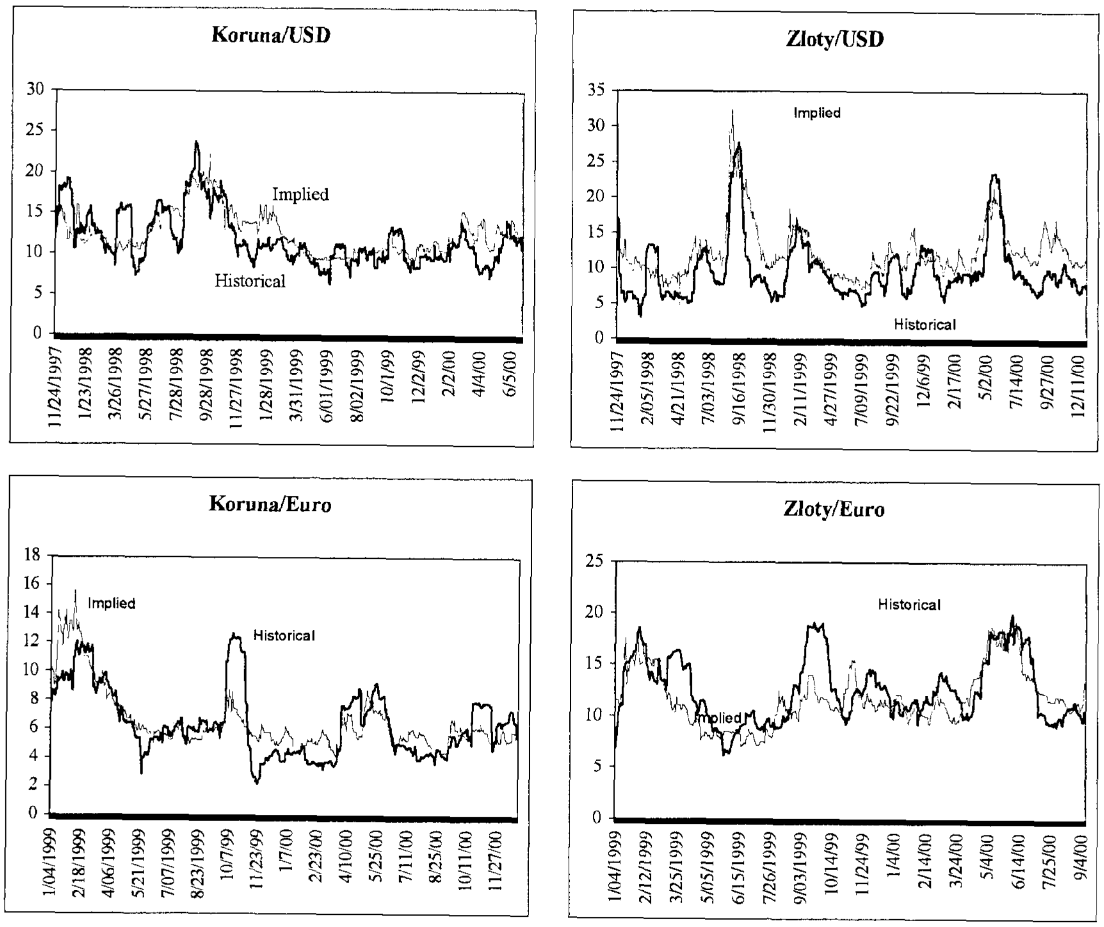

Sources: Bloomberg, Deutsche Bank; and staff calculations.

Figure 2. Czech Republic and Poland: One-Month and Three-Month Exchange Rate Volatility



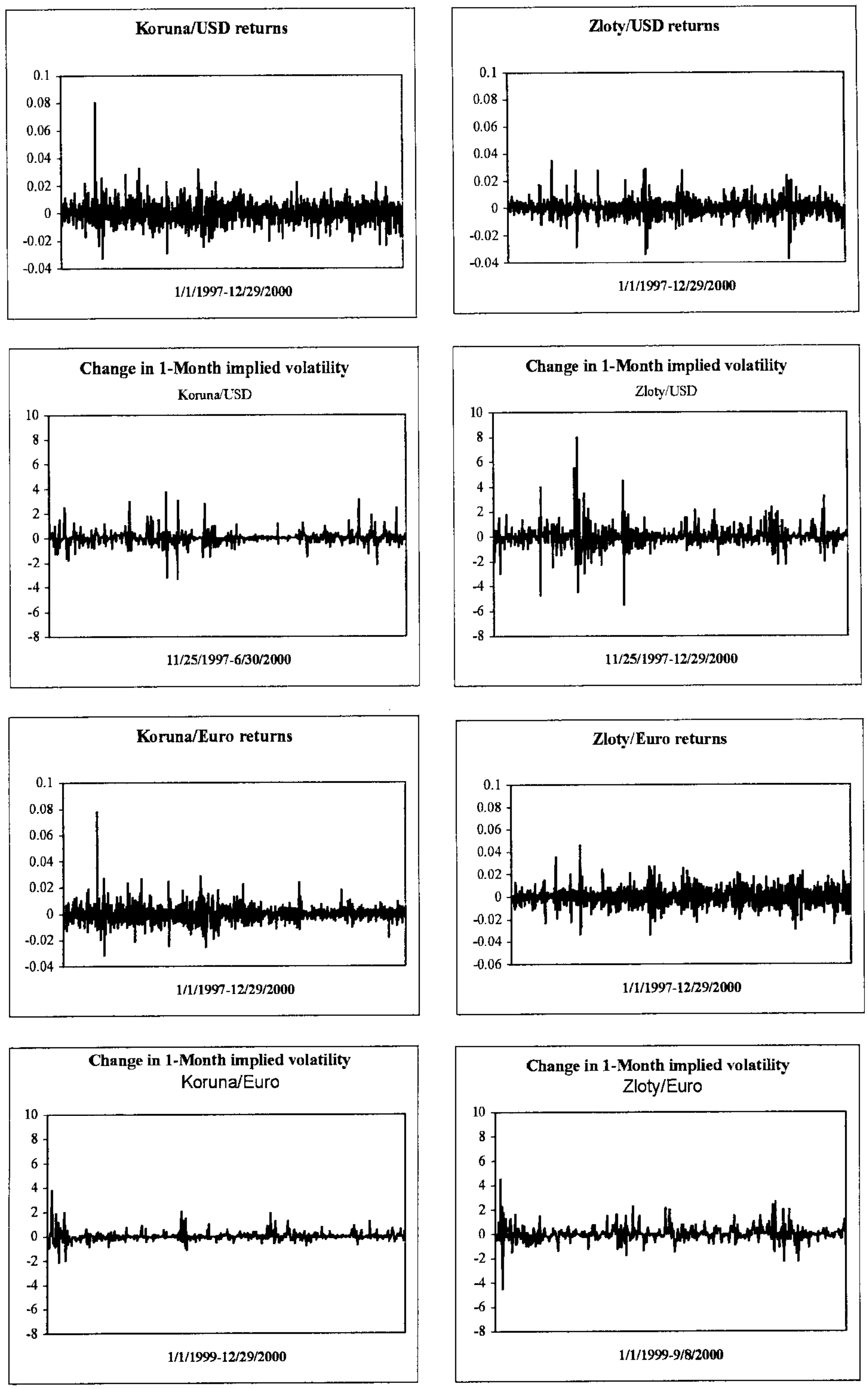

Sources: Bloomberg, Deutsche Bank; and staff calculations.

Figure 3. Czech Republic and Poland: One-Month Historical and Implied Volatility




Sources: Bloomberg, Deutsche Bank; and staff calculations.

Figure 4. Exchange Rate Returns and Changes in One-Month Implied Volatilities




Sources: Bloomberg, Deutsche Bank; and staff calculations.

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