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# Czech Koruna and Polish Zloty Currency Options: Information Content and EU-accession Implications

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## IMF Working Paper

Monetary and Exchange Affairs Department

# Czech Koruna and Polish Zloty Currency Options: Information Content and EU-accession Implications

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Authorized for distribution by Elizabeth Milne

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## Abstract



Currency option implied volatility predicts more efficiently exchange rate volatility for the Polish zloty relative to the Czech koruna, reflecting differences in the frequency of central bank intervention in the foreign exchange market. A GARCH model shows a positive impact of the introduction of the Euro on exchange rate volatility for the Polish zloty (negative for the Czech koruna), related to its larger exposure to external shocks. For countries in transition to Euro integration, the implied trade-off between isolation from shocks and efficient signaling must be addressed based on the risk of exchange rate misalignment at the time of monetary conversion.

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## I. Introduction

Concerns about the eventual adoption of the Euro by economies in transition have been related to the potential introduction of instability in industrial economies as a result of further widening of the income gap between country members that would use the currency in an expanded Euro area. Some of these risks are related to exchange rate volatility factors in economies in transition prior to their adoption of the Euro. The analysis of the impact of the introduction of the Euro in 1999 on the foreign exchange markets in transition economies in Eastern Europe may shed some lights about related risk prospects. These prospects are closely linked to the risks of exchange rate misalignment at the time of inception.

This paper analyzes the foreign exchange markets in the Czech Republic and Poland, in particular the determinants of exchange rate volatility in 1997-1999, period that comprises the Russian turmoil and the introduction of the Euro. The paper compares their corresponding exchange rate regimes in terms of their implications on actual and expected exchange rate volatility. The paper aims at evaluating the potential trade-offs entailed in their decision of adopting the Euro in the next 3-5 years. Although in principle a more flexible exchange rate regime facilitates a better exchange rate alignment, the costs of exposure to external shocks may justify more active central bank intervention, particularly if the impact of intervention on expectations and adequate pricing is not significant, and if there is a need to use the exchange rate as a nominal anchor. In that sense, the recent decision to float the Polish zloty would reflect the perception of relatively low costs of exposure to external shocks based on their past experience of exchange rate band widening, relative to perceived larger costs of an eventual exchange rate misalignment, and a further commitment to use monetary policy to pursue further reductions of inflation.

Implied volatility embedded in currency option prices is used as market predictor of exchange rate volatility. In addition to the analysis of its properties, its predictive power is compared with a GARCH model of conditional volatility.[2] Moreover, the paper tests if implied volatility provides additional information content to explain exchange rate returns in the spot market.

As for the GARCH model, the paper tests asymmetric volatility responses at times of exchange rate depreciation compared to appreciation. More intense volatility persistence is expected at times of exchange rate depreciation for weak currencies, given their limited demand compared with hard currencies. By using dummy variables, the paper also evaluates the impact on exchange rate volatility of the impact of the Russian turmoil and the introduction of the Euro among other variables.

[2] Generalized Auto Regressive Conditional Heteroskedasticity models (GARCH models) are used to analyze high-frequency data showing volatility cluster patterns. The relative performance of currency option implied volatility and GARCH modeled volatility for both countries is shown in the Appendix.

The paper finds greater volatility persistence in the Czech Republic related to frequent central bank intervention in the foreign exchange market, and greater exchange rate volatility fluctuations in Poland related to the widening of the exchange rate band. The Russian turmoil does not have systematic impact on volatility, unlike the introduction of the Euro that has a positive impact on exchange rate volatility in Poland and a negative impact in the Czech Republic. Currency option implied volatility appears to be a more efficient market predictor in Poland relative to the Czech Republic, for which the GARCH model predictor seems relatively more efficient. However, in either case efficiency is not sufficient to eliminate the need to include information from historical volatility to project future volatility. Changes in implied volatility contain information affecting spot exchange rate returns. Finally, volatility persistence is found to be larger for periods of exchange rate depreciation, as expected.

The paper is divided as follows: Section II summarizes the characteristics of exchange rate volatility in the spot and currency option market for both currencies, to analyze the context before and after the introduction of the Euro. In Section III, a GARCH model is constructed to analyze the features of exchange rate volatility and the relative contribution of different factors including the introduction of the Euro. Section IV summarizes the main conclusions.

## II. Historical and Implied Volatility

### A. Background

Through 1999, Euro volatility showed an upward trend that contrasted with the evolution of the Czech koruna and the Polish zloty. (See Charts 1-3) This is consistent with the fact that neither of the two countries adopted a policy of absolute flexibility up to 1999[3]. In the Czech Republic, managed floating was introduced after four years of having pegged the Koruna to a basket of two currencies, the deutsche mark (65 percent) and the US dollar (35 percent). After that, the central bank has intervened heavily in the market guided by the evolution of the real exchange rate. In Poland, increased flexibility in the foreign exchange market has resulted from the setting and further widening of an exchange rate band and a moderation of the rate of crawl that reduced the need for central bank intervention (see Chart 2). The exchange rate band was set at ±7 percent in May 1995, and increased to ±10 percent in February 1998, ±12.5 percent in October 1998 and ±15 percent in March 1999. The monthly rate of crawl was reduced to one percent in January 1996, to 0.8 percent in February 1998, to 0.65 percent in July 1998, to 0.5 percent in September 1998 and to 0.3 percent in March 1999. In both countries, increased aperture of the capital account has allowed more participation of domestic and foreign players, and the use of more developed financial instruments, including currency derivatives.

[3] Poland decided to float the Zloty in April 2000.

Exchange rate policy in both currencies has incorporated the parity against the Euro as one of its main components (until the recent decision to float the currency, the zloty central parity was based on a partial peg to the Euro). A more accelerated convergence of interest rate and inflation to Euro levels should in itself favor a stronger correlation between these currencies and the Euro in the period prior to their formal incorporation to the EU. Moreover, the Euro market has become even more important for exports from both countries in the aftermath of the Russian crisis of 1998.

### B. Volatility Trends

The economic environment prior to the introduction of the Euro in the world currency market differed for the Czech Republic and Poland. The Czech Republic experienced a severe slowdown in 1997, followed by a tight monetary policy combined with sizeable purchases of foreign exchange to prevent the appreciation of the koruna. This policy continued until June 1998, when elections took place. In the case of Poland, the economy continued expanding until 1998, when uncertainties following the Russian crisis led to a slowdown of economic activity. In the face of more acute uncertainties concerning the external sector for Poland, related to the larger share of exports to Russia relative to the Czech Republic, the government reacted to the Russian crisis by expanding further the exchange rate band and by opening further the capital account in the first quarter of 1999.

Chart 3 shows the evolution of 30-day historical and implied exchange rate volatility. [4] The reported implied volatilities are used to determine option prices using the Black-Scholes-Garman-Kohlhagen model. This makes identifying the most appropriate derivative pricing model unnecessary.[5] In general both historical and implied volatility follow a similar pattern, with some apparent visual evidence of implied volatility preceding moves in the spot market. The peak volatility jump occurs at the time of the 1997 internal crisis for the Czech Republic and at the time of the Russian crisis for Poland (in both cases followed by the most acute volatility decline). Volatility appears to smooth out over time after a more moderate jump that followed the introduction of the Euro for both the Czech Republic and Poland.

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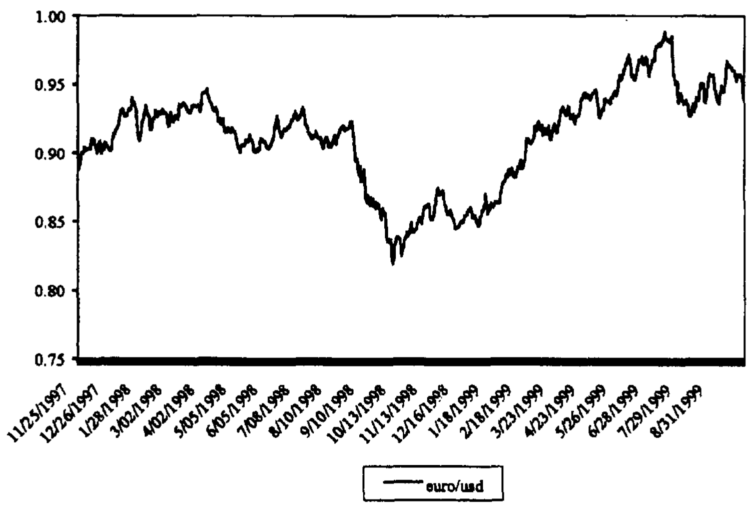
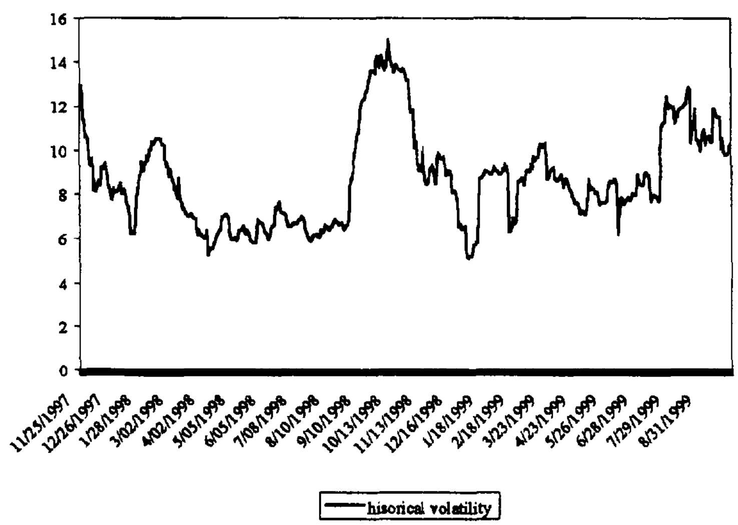
[4] Implied volatility data is taken from quotes by Cantor Fitzgerald International for at the money currency options, as reported by Reuters.

[5] Extensive literature has been devoted to the analysis of the most appropriate derivative pricing model. See for example Dumas, Fleming and Whaley (1996) or Guo (1998).

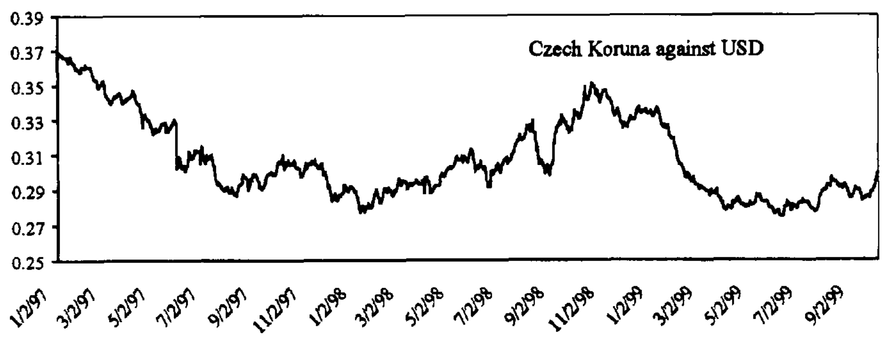
Chart 1. Euro Exchange Rate and Historical Volatility, 1997-99



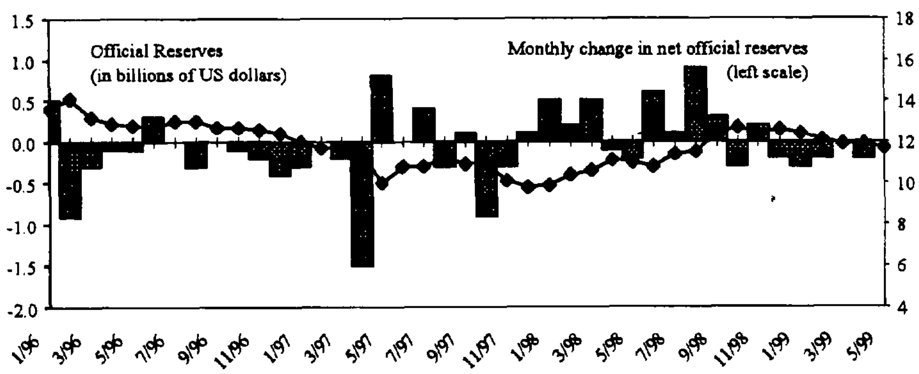



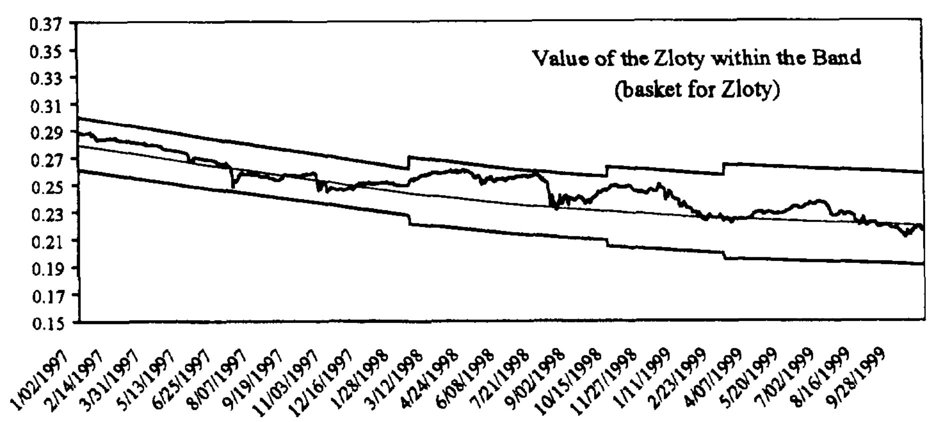

Source: European Central Bank and staff estimates. For the period prior to the introduction of the Euro, the series constructed by the European Central Bank was used.

Chart 2. Czech Republic and Poland: Exchange Rate Evolution, 1997-99




Czech Koruna Central Bank Intervention in The Foreign Exchange Market

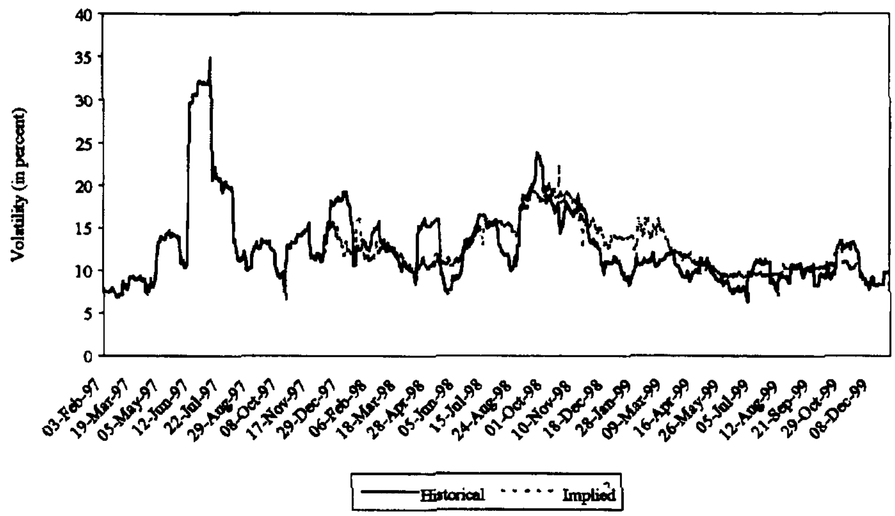


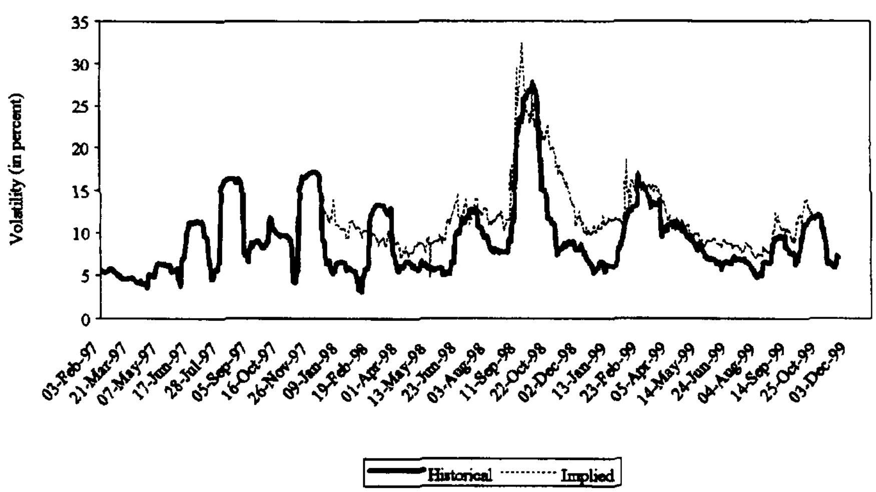

Source: Central Banks of Czech Republic and Poland.

Chart 3. Czech Republic and Poland: 30-day Exchange Rate Volatility, 1997-99

Czech Republic




Poland




Source: Cantor Fitzgerald and staff estimates.

Chart 4 allows for a visual inspection of the evolution of historical, actual and implied volatility for end-of-quarter information from June 1998 to September 1999. Volatility cones are constructed based on maximum and minimum volatility shown in historical data between January 1997 and September 1999. [6] The cone shape results from the larger dispersion in short-term historical volatility relative to volatility for larger maturities. The corresponding graphs within the chart should be followed from right to left: The extreme right shows information one year before the option exercise date and the extreme left one month before the exercise date. Two differences with respect to the original methodology are worth noting: Each quadrangle shows the evolution of implied volatility for different options with the same exercise date as opposed to the original approach that use the same contracts with different times to expiration. Also, actual volatility of the corresponding period ahead is incorporated together with historical volatility. [7] The main inferences that result from visual inspection are the following:

- **In both countries, actual volatility remained around the middle of the volatility range up to June 1998.** In the Czech Republic, this period was marked by significant intervention in the foreign exchange market and monetary tightening, prior to the elections of June 1998. In Poland, this occurred in spite of the widening of the exchange rate band that had taken place in February 1998. Implied volatility seems to anticipate quite well exchange rate volatility up to June 1998, with one-month and six-month options showing larger deviations for Poland.

- **Implied volatility was generally above historical volatility throughout the period preceding the Russian crisis**, but to a much larger extent in Poland relative to the Czech Republic, as illustrated by a jump of implied volatility beyond the upper limit of the volatility cone for September 1998.

- **Implied volatility anticipates the decline in actual volatility between December 1998 and March 1999.** In the same period, while volatility remains low in the Czech Republic, in Poland actual volatility increased to the middle of the volatility range. This coincides with the introduction of the Euro, which in Poland was accompanied by a further widening of the exchange rate band to 15 percent and measures opening further the capital account.

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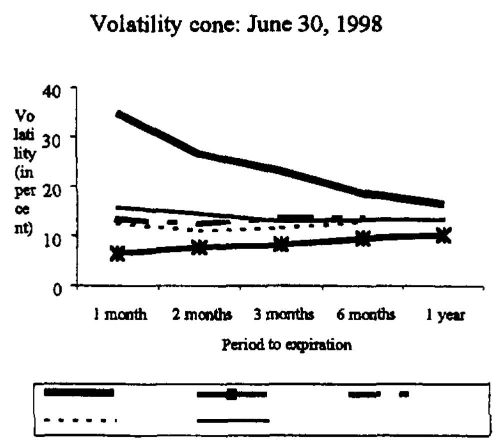
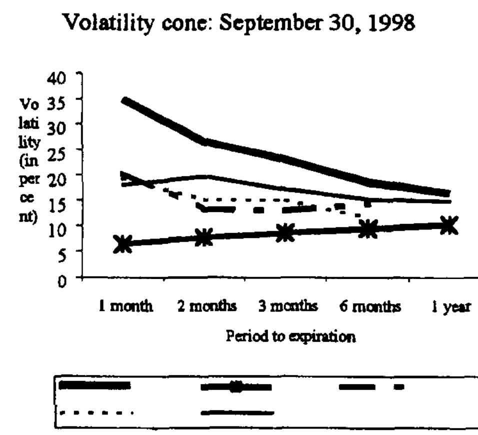
[6] Burghardt and Lane (1990)

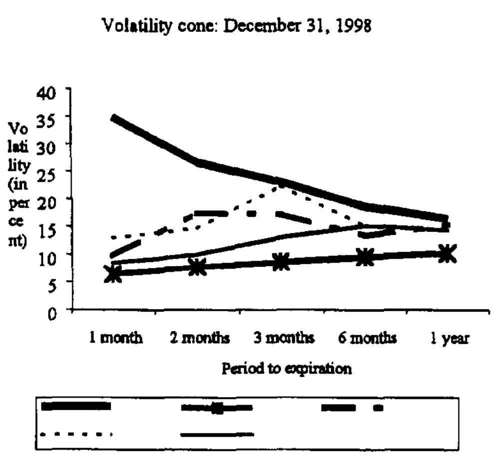
[7] The Burghardt-Lane methodology is designed to identify if options were cheap or dear, not if predictions were efficient or not, which is why it does not incorporate actual volatility separated from historical volatility.

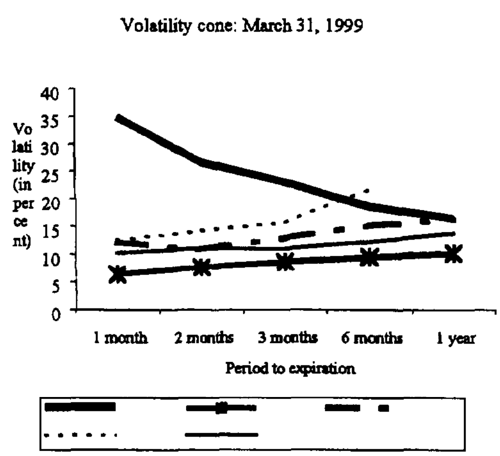
## Chart 4. Czech Republic and Poland: Volatility Cones

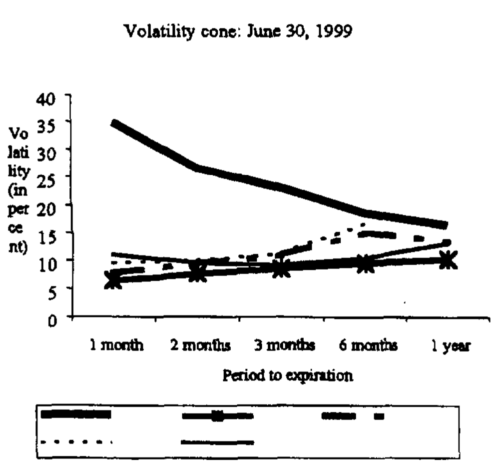
4a: Czech Republic

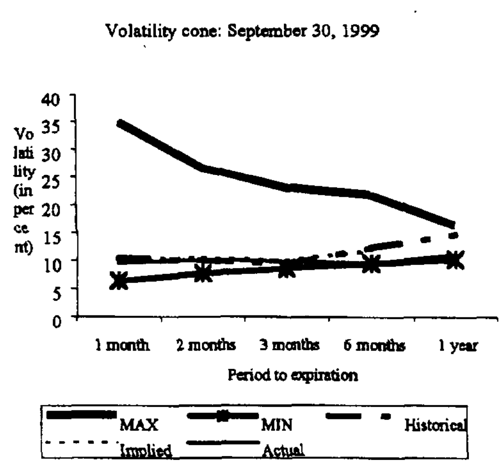


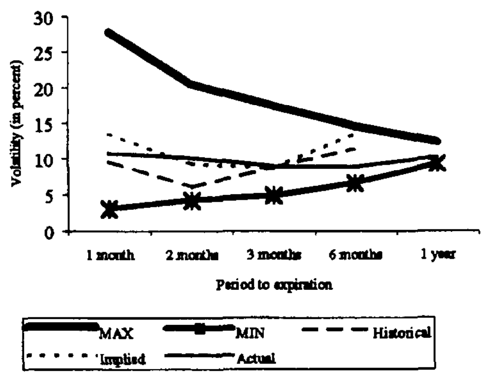




Source: Staff estimates

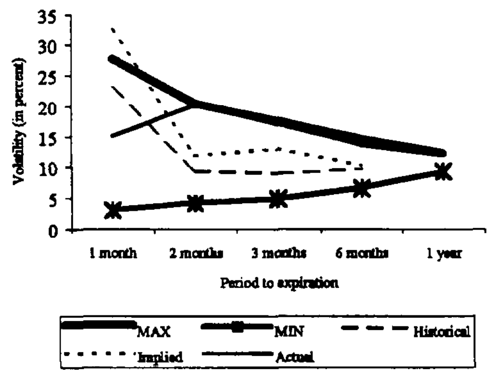
## Chart 4. Czech Republic and Poland: Volatility Cones

4b: Poland

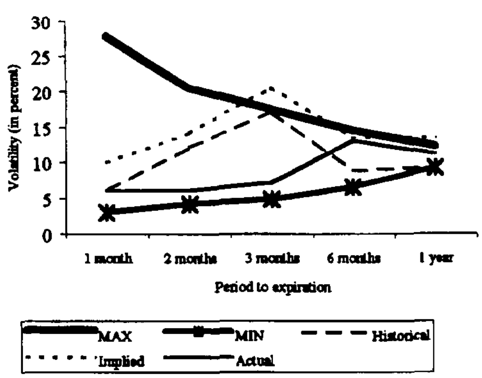
Volatility cone: June 30, 1998



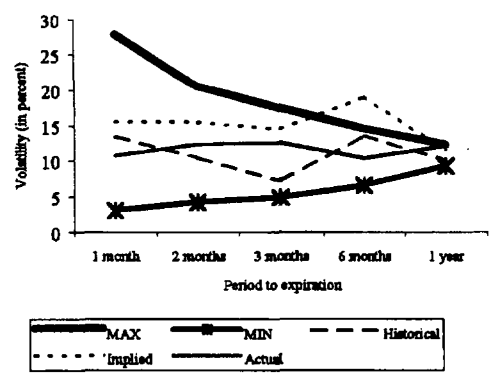

Volatility cone: September 30, 1998



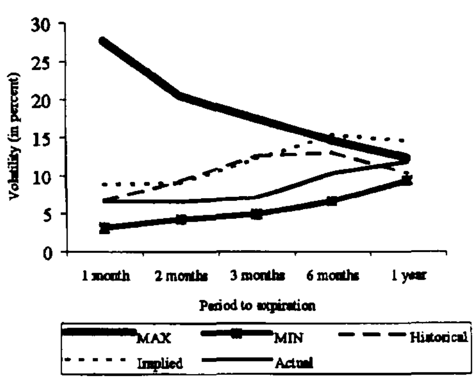

Volatility cone: December 31, 1998



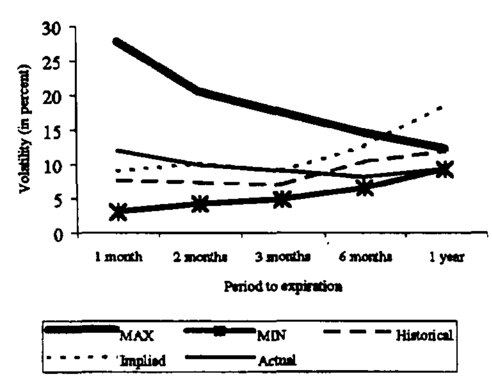

Volatility cone: March 31, 1999




Volatility cone: June 30, 1999




Volatility cone: September 30, 1999




Source: Staff estimates.

- Implied volatility moves closer to historical volatility for the post-turmoil period that is for options with exercise date June 30, 1999 and September 30, 1999.

Both implied and actual volatility shows much more variation in Poland relative to the Czech Republic. However, a visual inspection is insufficient for a comprehensive analysis of the predictive power embedded in their corresponding currency option implied volatility.

### C. Overall Predictive Power of Currency Option Implied Volatility

Table 1 shows that average exchange rate volatility is notably lower for Poland, while deviations (volatility fluctuations) are smaller for the Czech Republic. Squared deviations standardized by the corresponding average volatility show a better absolute performance of implied volatility in the Czech Republic relative to Poland. However, this is strongly conditioned by limited volatility fluctuations in the Czech Republic[8]. A better use of this indicator is to show differences in performance for different maturities. Options with shorter maturity are, in principle, more efficient predictors of volatility for the Czech Republic, while six-month option implied volatility shows the smallest deviation for Poland. [9] This may be related to a better anticipation of near-term central bank intervention in the foreign exchange market in the Czech Republic. For Poland, the results suggest more efficiency in the options market, with implied volatility for options with higher maturity incorporating more information relative to noise.

Table 2 reports the relative accuracy of prediction of the direction of changes in volatility. The results correspond to mid-week implied predictions of future volatility changes for options with maturity between one and six months. A successful outturn would be the accurate prediction of an increase or a decrease in actual volatility in the corresponding period ahead. For $IV_0$ and $HV_0$ representing implied and historical volatility at time zero and $IV_t$ and $HV_t$ the same variables at time t, a successful outturn would take place when $IV_0 - HV_0$ has the same sign as $HV_t - HV_0$.

Results show close to 100 percent accuracy of predictions of changes in volatility for periods of volatility increase for all periods in the case of Poland and especially for recent periods in the case of the Czech Republic. This means that in general the market is not taken by surprise by volatility increases. The opposite seems to be true for volatility decreases, which could reflect a higher risk premium after episodes of volatility increases leading to

[8] In other words, it is more likely to show smaller deviations when predicting a variable that does not show large fluctuations.

[9] One-year options are reported but not analyzed in light of reported distortions resulting from lack of liquidity in the market for options of this maturity.

volatility overshoots. It may also reflect decreased liquidity in the option market after volatility spikes.

Table 1. Implied Forecasted Volatility minus Actual Volatility
Standardized Average Square Deviations

| | 1 month | 2 month | 3 month | 4 month | 5 month |
|---|---|---|---|---|---|
| **Czech Republic** | | | | | |
| Square deviation | 10.137 | 8.365 | 12.090 | 17.781 | 9.762 |
| Average volatility | 12.828 | 13.191 | 13.401 | 13.669 | 13.818 |
| Standardized deviation | 0.790 | 0.634 | 0.902 | 1.301 | 0.706 |
| **Poland** | | | | | |
| Square deviation | 34.122 | 30.296 | 28.242 | 26.467 | 43.043 |
| Average volatility | 9.275 | 9.661 | 9.943 | 10.555 | 10.905 |
| Standard deviation | 3.679 | 3.136 | 2.840 | 2.608 | 3.947 |

Source: Staff estimates

Table 3 shows indicators of volatility stickiness measured as one-week changes in implied volatility with a different sign than one-week changes in actual volatility in the corresponding period ahead. Volatility overshoots in option prices in times of turmoil would lead to volatility adjustments in the opposite direction to match actual volatility, resulting in'upward stickiness.' Using the same notation as before, upward stickiness would take place when $IV_0 - IV_{-1}$ is negative while $HV_t - HV_{t-1}$ is positive.

This 'upward stickiness' is larger than 50 percent in all cases except for six-month options for Poland after the Russian crisis. This means that there are more periods when implied volatility needs to be adjusted downwards rather than upwards for both currencies. Upward stickiness has in general increased after the Russian crisis, more clearly for the Czech Republic, while for Poland again six-month options show the opposite trend. This means that the tendency to overshoot option prices has intensified after the Russian crisis, to a larger extent in the Czech Republic, where paradoxically central bank intervention aimed at limiting exchange rate volatility.

TABLE 2. Czech Republic and Poland:

SUCCESS RATE OF IMPLIED VOLATILITY
TO FORECAST VOLATILITY CHANGES
(11/25/99-9/30/99)

2a: Czech Republic

| | 1-month volatility | | | 2-month volatility | | | 3-month volatility | | | 6-month volatility | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Volatility increases | Volatility decreases | Total | Volatility increases | Volatility decreases | Total | Volatility increases | Volatility decreases | Total | Volatility increases | Volatility decreases | Total |
| **Episodes** | 38.0 | 54.0 | 92.0 | 37.0 | 50.0 | 87.0 | 34.0 | 55.0 | 89.0 | 24.0 | 42.0 | 66.0 |
| **Successful predictions (%)** | 81.6 | 53.7 | 65.2 | 75.7 | 48.0 | 59.8 | 70.6 | 49.1 | 57.3 | 70.8 | 54.8 | 60.6 |
| Pre-Russia crisis | 78.9 | 83.3 | 81.1 | 52.6 | 83.3 | 67.6 | 44.4 | 73.3 | 57.6 | 36.4 | 68.2 | 57.6 |
| Post-Russia crisis | 75.0 | 31.3 | 40.0 | 100.0 | 33.3 | 50.0 | 100.0 | 46.2 | 65.0 | 100.0 | 0.0 | 55.0 |
| Post Euro | 86.7 | 45.0 | 62.9 | 100.0 | 23.5 | 56.7 | 100.0 | 37.0 | 52.8 | 100.0 | 72.7 | 76.9 |
| **Wrong predictions (%)** | 18.4 | 46.3 | 34.8 | 24.3 | 52.0 | 40.2 | 29.4 | 50.9 | 42.7 | 29.2 | 45.2 | 39.4 |
| Pre-Russia crisis | 21.1 | 16.7 | 18.9 | 47.4 | 16.7 | 32.4 | 55.6 | 26.7 | 42.4 | 63.6 | 31.8 | 42.4 |
| Post-Russia crisis | 25.0 | 68.8 | 60.0 | 0.0 | 66.7 | 50.0 | 0.0 | 53.8 | 35.0 | 0.0 | 100.0 | 45.0 |
| Post Euro | 13.3 | 55.0 | 37.1 | 0.0 | 76.5 | 43.3 | 0.0 | 63.0 | 47.2 | 0.0 | 27.3 | 23.1 |

Source: Staff estimates.

## TABLE 2. Czech Republic and Poland:

SUCCESS RATE OF IMPLIED VOLATILITY
TO FORECAST VOLATILITY CHANGES
(11/25/99-9/30/99)

2b: Poland

| | 1-month volatility | | | 2-month volatility | | | 3-month volatility | | | 6-month volatility | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Volatility increases | Volatility decreases | Total | Volatility increases | Volatility decreases | Total | Volatility increases | Volatility decreases | Total | Volatility increases | Volatility decreases | Total |
| **Episodes** | 39.0 | 53.0 | 92.0 | 45.0 | 42.0 | 87.0 | 31.0 | 52.0 | 83.0 | 26.0 | 44.0 | 70.0 |
| **Successful predictions (%)** | 100.0 | 17.0 | 52.2 | 100.0 | 47.6 | 74.7 | 100.0 | 21.2 | 50.6 | 96.2 | 4.5 | 38.6 |
| Pre-Band widening | 100.0 | 50.0 | 69.2 | 100.0 | 62.5 | 76.9 | NA | 0.0 | 0.0 | 100.0 | 0.0 | 7.7 |
| Pre-Russia | 100.0 | 9.1 | 62.5 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 | 75.0 | 95.8 | NA | 95.8 |
| Post-Russia crisis | 100.0 | 15.4 | 60.0 | 100.0 | 33.3 | 60.0 | 100.0 | 35.7 | 55.0 | 100.0 | 10.5 | 15.0 |
| Post Euro | 100.0 | 9.5 | 48.7 | 100.0 | 35.3 | 63.3 | 100.0 | 31.6 | 50.0 | NA | 0.0 | 0.0 |
| **Wrong predictions (%)** | 0.0 | 83.0 | 47.8 | 0.0 | 52.4 | 25.3 | 0.0 | 78.8 | 49.4 | 3.8 | 95.5 | 61.4 |
| Pre-Band widening | 0.0 | 50.0 | 30.8 | 0.0 | 37.5 | 23.1 | NA | 100.0 | 100.0 | 0.0 | 100.0 | 92.3 |
| Pre-Russia crisis | 0.0 | 90.9 | 37.5 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 25.0 | 4.2 | NA | 4.2 |
| Post-Russia crisis | 0.0 | 84.6 | 40.0 | 0.0 | 66.7 | 40.0 | 0.0 | 64.3 | 45.0 | 0.0 | 89.5 | 85.0 |
| Post Euro | 0.0 | 90.5 | 51.3 | 0.0 | 64.7 | 36.7 | 0.0 | 68.4 | 50.0 | NA | 100.0 | 100.0 |

Source: Staff estimates.

## III. A Model Of Exchange Rate Volatility

A GARCH model is used to analyze the conditional variance of exchange rate returns. GARCH models help to analyze high-frequency information under the hypothesis that the variance of a given variable is an average of an (unconditional) long-term average, the forecasted variance from the previous period (the GARCH term), and volatility observed in the previous period (the ARCH term). This modeling is consistent with volatility clustering, where large changes in returns are likely to be followed by further large changes. The more persistent the changes in conditional volatility, the closer to one the sum of the coefficients for the ARCH and GARCH terms would be.

The model used in the paper also tests for an asymmetric GARCH process, with a lower persistence of volatility following unexpected appreciation relative to unexpected depreciation. [10] The corresponding models to test these hypotheses are TARCH and EARCH models, for which a leverage effect can be tested (good news leading to declines in volatility persistence). The leverage effect is quadratic for TARCH models and exponential for EARCH models. This paper shows only results from the TARCH model, as the additional complication of using EARCH models did not contribute to a significant improvement of the results.[11]

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[10] For hard currencies, symmetry is the norm. However, for weak currencies, volatility should increase more acutely in the event of exchange rate depreciation as demand for a weak currency may eventually go down to zero.

[11] Once the GARCH model is set up, an encompassing model would help measuring the relative performance of the market predictor (implied volatility) against the model predictor (GARCH conditional volatility). The results are shown in attached appendix.

TABLE 3. Czech Republic and Poland:

VOLATILITY STICKINESS

(11/25/99-9/30/99)

3a: Czech Republic

| | 1-month volatility | | 2-month volatility | | 3-month volatility | | 6-month volatility | |
|---|---|---|---|---|---|---|---|---|
| | Upward stickiness | Downward stickiness | Upward stickiness | Downward stickiness | Upward stickiness | Downward stickiness | Upward stickiness | Downward stickiness |
| Episodes | 45.0 | 47.0 | 37.0 | 50.0 | 37.0 | 46.0 | 28.0 | 42.0 |
| Stickiness Index | 62.2 | 44.7 | 59.5 | 36.0 | 59.5 | 41.3 | 60.7 | 50.0 |
| Pre-Russia crisis | 56.3 | 64.7 | 37.5 | 41.2 | 50.0 | 53.3 | 52.9 | 62.5 |
| Post-Russia crisis | 62.5 | 23.1 | 75.0 | 46.2 | 71.4 | 50.0 | 50.0 | 47.1 |
| Post Euro | 66.7 | 41.2 | 76.9 | 25.0 | 66.7 | 23.5 | 85.7 | 33.3 |

Source: Staff estimates.

TABLE 3. Czech Republic and Poland:

VOLATILITY STICKINESS

(11/25/99-9/30/99)

3b: Poland

| | 1-month volatility | | 2-month volatility | | 3-month volatility | | 6-month volatility | |
|---|---|---|---|---|---|---|---|---|
| | Upward stickiness | Downward stickiness | Upward stickiness | Downward stickiness | Upward stickiness | Downward stickiness | Upward stickiness | Downward stickiness |
| Episodes | 44.0 | 48.0 | 39.0 | 48.0 | 46.0 | 38.0 | 35.0 | 35.0 |
| Stickiness Index | 59.1 | 29.2 | 56.4 | 31.3 | 50.0 | 42.1 | 48.6 | 37.1 |
| Pre-Band widening | 75.0 | 20.0 | 50.0 | 0.0 | NA | NA | NA | NA |
| Pre-Russia crisis | 41.7 | 33.3 | 46.7 | 33.3 | 47.1 | 57.1 | 62.5 | 33.3 |
| Post-Russia crisis | 60.0 | 20.0 | 66.7 | 35.8 | 40.0 | 50.0 | 45.5 | 44.3 |
| Post Euro | 66.7 | 33.3 | 62.5 | 30.4 | 57.9 | 30.0 | 43.7 | 34.8 |

Source: Staff estimates.

### A. Characteristic of Exchange Rate Returns

Exchange rate returns (DLKORUNA and DLZLOTY) are defined as the differential of the logarithms of the exchange rate for two consecutive periods. The exchange rate is defined in terms of units of domestic currency per US dollar, which means that an increase in the exchange rate return imply a depreciation of the domestic currency (the return on holding USD against the domestic currency). Table 4 shows the unconditional distribution statistics for the corresponding exchange rate returns. Foreign exchange markets for both currencies appear reasonably efficient, as the median and mean value of returns are close to zero. The corresponding distributions do not appear normal as the coefficient for skewness are significantly above zero and the one for kurtosis significantly above three, which is confirmed by the high value of the Jarque-Bera coefficient.

Table 4. Unconditional Distribution Statistics
Exchange Rate Returns
(sample period: January 1, 1997–September 30, 1999

| | Koruna/USD | Zloty/USD |
|---|---|---|
| Mean (in percent) | 0.000 | 0.030 |
| Median (in percent) | 0.000 | 0.000 |
| Standard deviation (in percent) | 0.008 | 0.648 |
| Maximum | 0.032 | 2.890 |
| Minimum | -0.029 | -3.349 |
| Skewness | 0.207 | 0.419 |
| Kurtosis | 4.271 | 8.090 |
| Jarque-Bera test for normality | 35.974 | 535.656 |

Source: Staff estimates.

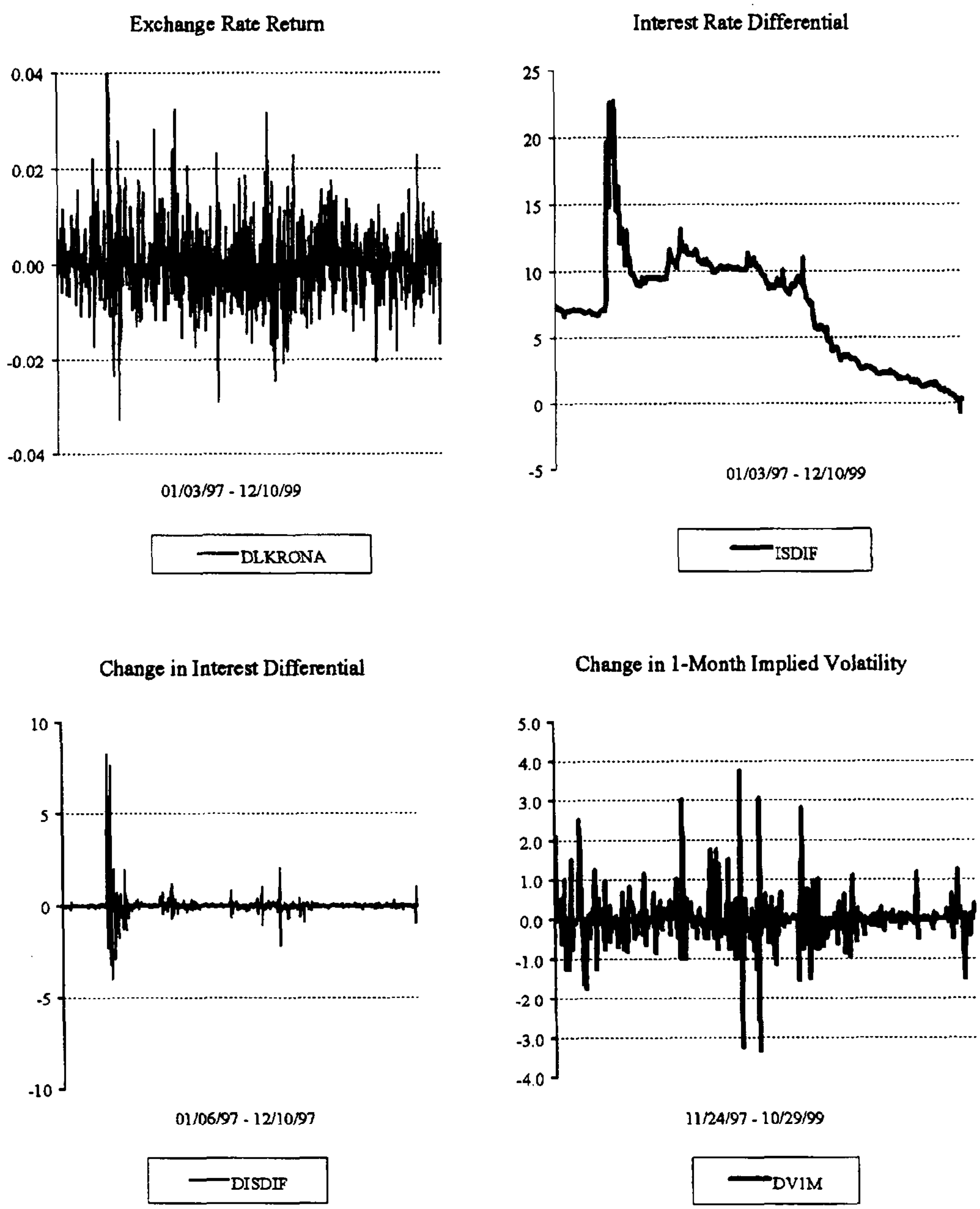
Chart 5 shows evidence of volatility clustering of exchange rate returns and the evolution of variables that could partly explain the behavior of exchange rate returns. Volatility persistence reflected in volatility clustering presumably results from slow adaptation to news and differences in the interpretability of information.[12] The appropriate representation of the mean exchange rate returns matters only to the extent that it may facilitate a more accurate modeling of conditional variance.[13]

[12] Diebold and Lopez (1995).

[13] It is not unusual to represent the mean equation as a pure random walk. In any case, to the extent that the expected value of the change in interest rate differentials and implied volatilities is zero, the mean equation do not have practical predictive power.

## Chart 5. Czech Republic and Poland: Volatility Indicators

5a: Czech Republic



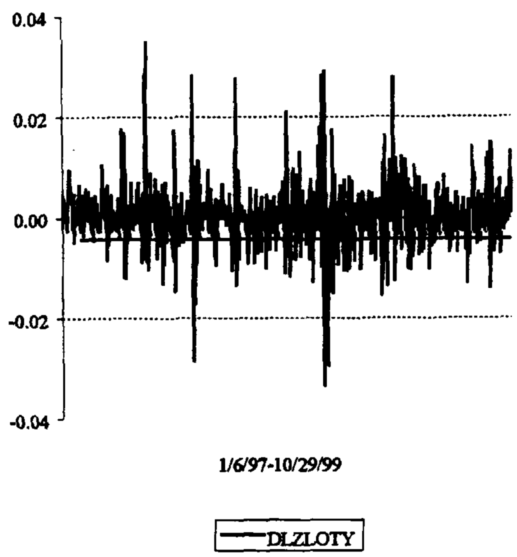

Source: Bloomberg and staff estimates.

**B.**

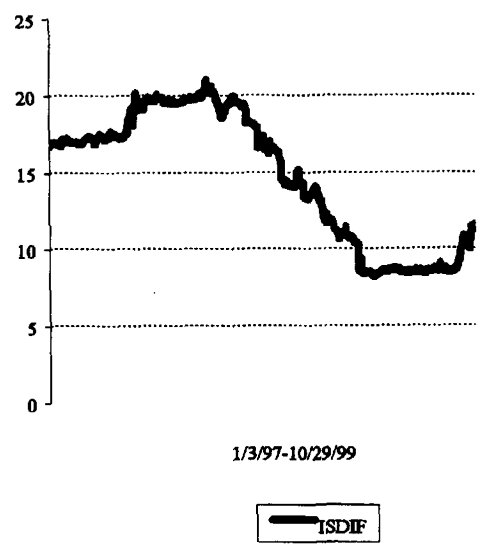
## Chart 5. Czech Republic and Poland: Volatility Indicators

5b: Poland

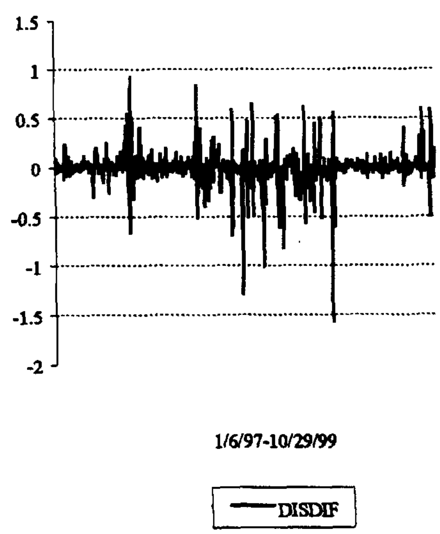
Exchange Rate Return



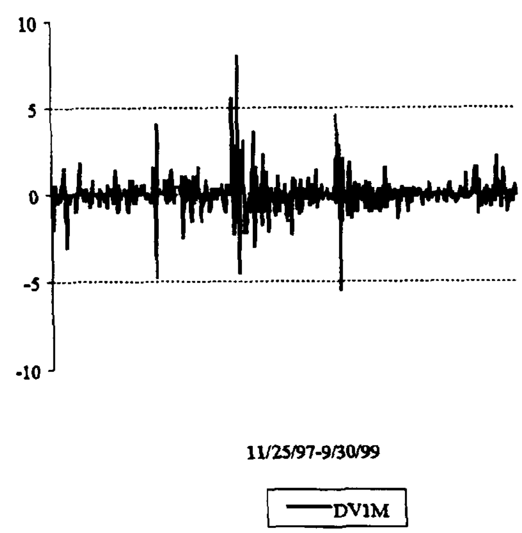

Interest Rate Differential




Change in Interest Differential




Change in 1-month Implied Volatility




Source: Bloomberg and staff estimates.

## B. GARCH Model

### Explanatory variables of mean and variance of exchange rate returns

Exchange rate returns may be explained by news embedded in changes in interest rate differentials with the US and changes in implied volatility in the currency option market. The relative performance of these variables in the mean equation will test if agents operating in the currency option market are better informed than agents operating in the spot market. By using the differential in implied volatilities, the problem of using a moving average variable in the mean equation is minimized. The corresponding variables used in the model are the three-month interbank interest rate differential with the US rates (DISDIF) and changes in 1-month implied volatilities (DV1M). The use of interbank interest rates is justified by the fact that the interbank market is deeper and more liquid than other markets.

The impact of changes in interest rate differentials may have different signs depending on alternative hypotheses. On the one hand, changes in the differential may precede a partial adjustment of the exchange rate in periods when liquidity demand switches towards foreign exchange. This would imply that the correlation with exchange rate returns would be positive (a higher differential would anticipate an exchange rate depreciation). Alternatively, changes in the interest rate differential may reflect domestic liquidity gaps, which would also affect the foreign exchange market. In this case, lower liquidity would lead to a higher interest rate differential, which in turn would lead to a short-term decline in the demand for foreign exchange. The correlation with exchange rate returns would be negative in this case.

Changes in one-month option volatility are expected to contain more information about factors that have a potential short-term impact, and which are also expected to affect the spot market in the near term (relative to other maturities). Larger implied volatility (news leading to the expectation of higher volatility) should be reflected by larger exchange rate movements, in addition to constitute an implicit forecast of larger one-month volatility for the period ahead.

The sample period is January 1, 1997 to September 30, 1999, except for the equations where changes in implied volatility are incorporated, as this information is only available from November 25, 1997. The model tests the significance of the following variables in explaining the evolution of the unconditional variance:

- MONDAY: Takes the value of one on Mondays and zero otherwise, to account for the implicit three-day volatility over weekends.

- BAND1: Takes the value of one from February 26, 1998 to October 29, 1998 and zero otherwise, to account for the widening of the exchange rate band to 10 percent in Poland.

- BAND2: Takes the value of one from October 29, 1998 until the end of the sample period, to account for the widening of the band to 12.5 percent in October 98 and 15 percent in March 99 in Poland.

- RUSSIA: Takes the value of one from August 17, 1998 to February 17 1998 and zero otherwise, to account for the peak of the Russian crisis.

- EURO: Takes the value of one from January 1, 1999 until the end of June, to account for the introduction of the Euro.[14]

In evaluating the different specifications, preference is given to models with a distribution of residuals closer to normal and mean exchange rate returns closer to zero. With the probable exception of MONDAY, the design of dummy variables naturally entails some degree of arbitrariness. In particular, EURO may also comprise the impact of measures in Poland that enhanced the flexibility of the capital account and the initial impact of further widening of the exchange rate band to ±15 percent in March. However, the number of dummy variables was limited to avoid more confusing results. Also, to incorporate only systematic effects, dummy variables were restricted to take the value of one for a period no shorter than six months.

Table 5 shows the unit root tests for the variables included in the mean exchange rate return equation. All relevant variables are stationary as expected and required. To test if the currency option market incorporates information faster than the spot market, because of higher quality of information in that market, Granger Causality Tests are performed. Table 6 shows that the test strongly rejects that exchange rate returns drive implied volatilities, and it accepts that changes in implied volatility Granger-causes changes in exchange rate returns. This means that news that affect first currency option prices cause fluctuations in the spot market, and therefore changes in implied volatility can be incorporated as an independent variable in the mean equation for exchange rate returns.

[14] Volatility of the EURO was introduced explicitly as an independent variable, but it proved to be insignificant.

TABLE 5. Czech Republic and Poland:
Augmented Dickey-Fuller Unit Root Test

| | No trend No intercept | No trend with intercept | With trend and intercept |
|---|---|---|---|
| **Czech Republic** | | | |
| DLNKORUNA | -9.208 | -9.196 | -9.189 |
| ISDIF * | -2.139 | -0.188 | -2.334 |
| DISDIF | -9.504 | -9.831 | -9.830 |
| DV1M | -11.769 | -11.765 | -11.748 |
| **Poland** | | | |
| DLNZLOTY | -9.559 | -9.625 | -9.673 |
| ISDIF * | -2.406 | -1.358 | 0.692 |
| DISDIF | -8.570 | -8.799 | -8.948 |
| DV1M | -9.687 | -9.677 | -9.667 |

* Accepts unit root at 99% confidence level.

TABLE 6. Czech Republic and Poland:
Pairwise Granger Causality Tests

**Czech Republic**

Date: 1/11/00
Sample: 11/25/97 - 9/30/99
Lags: 2
Obs: 481

| Null Hypothesis: | F-Statistic | Probability |
|---|---|---|
| DV1M does not Granger Cause DLNKORUNA | 1.147 | 0.318 |
| DLNKORUNA does not Granger Cause DV1M | 8.255 | 0.000 |

**Poland**

Date: 1/7/00
Sample: 11/25/97 - 9/30/99
Lags: 2
Obs: 480

| Null Hypothesis: | F-Statistic | Probability |
|---|---|---|
| DV1M does not Granger Cause DLZLOTY | 0.631 | 0.533 |
| DLZLOTY does not Granger Cause DV1M | 10.103 | 0.000 |

TABLE 7. Czech Republic and Poland:

GARCH AND TARCH MODELS FOR EXCHANGE RATE RETURNS

7a: Czech Republic

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | | (exchange rate expressed as koruna per US$) | | |
| **Mean equation** | | | | |
| Constant | 2.1700000 | | | |
| | (-0.061877) | | | |
| disdif | | 0.007713 | 0.007341 | 0.007352 |
| | | (-4.013263) | (3.610434) | (3.727743) |
| disdif(-2) | | -0.004309 | -0.004441 | -0.004072 |
| | | (-3.175160) | (-3.350131) | (-3.172539) |
| dvlm | | | | 0.001458 |
| | | | | (2.307311) |
| dvlm(-2) | | | | -0.001067 |
| | | | | (-1.877180) |
| **Covariance equation** | | | | |
| Constant | 5.64000000 | 5.36000000 | 4.97000000 | 4.92000000 |
| | (1.361139) | (-1.904775) | (2.340379) | (2.185279) |
| ARCH(1) | 0.058821 | 0.057107 | 0.084396 | 0.085022 |
| | (2.789764) | (-2.976339) | (3.3167036) | (3.093199) |
| ARCH(1) (RESID<0) | | | -0.063910 | -0.062076 |
| | | | (-1.909914) | (-1.875509) |
| GARCH(1) | 0.806381 | 0.856651 | 0.869045 | 0.867507 |
| | (10.48770) | (-14.9987) | (19.09966) | (16.96534) |
| MONDAY | 1.310000 | | | |
| | (1.203660) | | | |
| RUSSIA | 2.390000 | | | |
| | (-0.908374) | | | |
| EURO | -2.950000 | -1.650000 | -2.010000 | -2.030000 |
| | (-1.630402) | (-1.367027) | (-1.891263) | (-1.880663) |
| R square | -0.000004 | 0.048606 | 0.048526 | 0.061631 |
| Adjusted R square | -0.012609 | 0.038634 | 0.036533 | 0.045726 |
| F-statistics | | 4.873945 | 4.046110 | 3.875055 |
| **Residuals tests** | | | | |
| Mean | 0.003239 | 0.015311 | 0.012306 | 0.011296 |
| Standard deviation | 1.003773 | 1.001351 | 1.001035 | 1.001512 |
| Skewness | 0.106769 | 0.033636 | 0.006801 | -0.062637 |
| Kurtosis | 3.659495 | 3.625744 | 3.559597 | 3.518673 |
| Jarque-Bera | 9.670698 | 7.971140 | 6.305853 | 5.706172 |

TABLE 7. Czech Republic and Poland:

GARCH AND TARCH MODELS FOR EXCHANGE RATE RETURNS

7b: Poland

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | | (exchange rate expressed as zlotys per US$) | | |
| **Mean equation** | | | | |
| Constant | 0.000455 | 0.000554 | 0.000291 | |
| | (3.50903) | (3.01831) | -1.290278 | |
| disdif(-1) | | -0.002393 | -0.003197 | -0.003443 |
| | | (-2.020362) | (-2.553119) | (-2.747557) |
| disdif(-2) | | 0.003535 | 0.002731 | 0.002516 |
| | | (2.991715) | (2.127587) | (1.991654) |
| dv1m | | | 0.001674 | 0.001668 |
| | | | (7.400542) | (7.500374) |
| dv1m(-1) | | | 0.000718 | 0.000699 |
| | | | (3.326629) | (3.245562) |
| **Covariance equation** | | | | |
| Constant | 0.00000364 | 0.00000673 | 0.000004 | 0.00000421 |
| | (2.757657) | (6.940414) | (2.153838) | (2.26729) |
| ARCH(1) | 0.150403 | 0.393208 | 0.131868 | 0.113064 |
| | (8.955156) | (5.025354) | (1.3898396) | (1.375759) |
| ARCH(2) | | 0.186651 | 0.161997 | 0.172724 |
| | | (4.206881) | (2.586633) | (2.849196) |
| ARCH(1) (RESID<0) | | -0.436339 | -0.156201 | -0.147023 |
| | | (-5.656129) | (-1.619884) | (-1.727095) |
| GARCH(1) | 0.60029 | 0.300316 | 0.373081 | 0.353192 |
| | (16.16518) | (4.877948) | (3.370372) | (3.279124) |
| MONDAY | | | 0.0000246 | 0.0000256 |
| | (5.418695) | (5.142104) | (6.380034) | (6.742561) |
| BAND1 | 0.00000391 | 0.00000913 | 0.00000772 | 0.00000819 |
| | (2.772685) | (3.731847) | (3.431799) | (3.712272) |
| BAND2 | -0.00000255 | | | |
| | (-4.399735) | | | |
| RUSSIA | -0.00000118 | | | |
| | (-2.867351) | | | |
| EURO | 0.00000151 | 0.00000919 | 0.00000765 | 0.00000809 |
| | (2.780818) | (2.696412) | (2.451548) | (2.507459) |
| R square | -0.000044 | 0.002349 | 0.123226 | 0.119942 |
| Adjusted R square | -0.011376 | -0.011883 | 0.100792 | 0.099345 |
| F-statistics | | 0.16504 | 5.492938 | 5.823257 |
| **Residuals tests** | | | | |
| Mean | 0.007586 | -0.019303 | 0.006944 | 0.062116 |
| Standard deviation | 1.282937 | 1.238474 | 1.000952 | 0.999048 |
| Skeweness | 0.567713 | 0.380929 | 0.254276 | 0.250995 |
| Kurtosis | 6.0841 | 5.780068 | 4.674012 | 4.631923 |
| Jarque-Bera | 321.7758 | 246.5064 | 61.47389 | 58.54624 |

The main conclusions from Table 7 are the following:

- Unconditional means returns equal zero. For the Czech Republic this happens in the most basic GARCH formulation (column 1), while for Poland this happens once implied volatility is incorporated into the equation.

- Changes in the interest rate differential show low explanatory power but significant coefficients. The liquidity effect (leading to exchange rate appreciation) is larger and more immediate for Poland, which may reflect a more liquid foreign exchange market in the Czech Republic.

- Contemporaneous and one-lag changes in implied volatilities improve markedly the explanatory power of the mean equation, confirming that they provide additional information content. In the case of the Czech Republic, a peculiar negative two-day impact of implied volatility may reflect central bank reactions to movements in the foreign exchange market.

- The residuals are far from normally distributed in both cases, although results improve with a better specification and are in general closer to normality for the Czech Republic. This may imply that the sample is still limited to extract final conclusions. To that extent, the results should be seen as preliminary evidence.

- The fact that MONDAY appears to be non-significant for the Czech Republic is an indication that the central bank intervention in the foreign exchange market may be overshadowing seasonal effects.

- In the basic model (column 1 in table 7a and 7b), the coefficients for RUSSIA are not significant for the Czech Republic and enter with the wrong sign for Poland. This suggests that the Russian crisis resulted mainly on a short-lived volatility spike, without impact on the conditional variance.

- BAND2 shows the wrong sign in the basic equation for Poland, and proved to be insignificant when included in other specifications. This means that the previous widening of the band may have been sufficient to incorporate most of potential flexibility in the market.

- For ARCH effects, one lag appears sufficient for the Czech Republic while an additional lag was found significant for Poland. In both cases, an asymmetric specification proved to be significant. Considering the final specifications (column 4 in Tables 7a and 7b), volatility persistence is larger when the exchange rate depreciates relative to when it appreciates.

- The impact of the EURO has different signs in both countries, with a negative impact on conditional volatility for the Czech Republic and a positive impact for Poland. This may be related to a larger susceptibility to shocks and a larger incorporation of potential volatility in expectations in Poland. In the Czech Republic, the result appears to be the counterpart of effective isolation as a consequence of central bank intervention, with domestic factors apparently dominant following uncertainty surrounding the electoral process of 1998.

- Volatility is more persistent in the Czech Republic, with a sum of GARCH and ARCH coefficients equal to 0.95 against 0.64 for Poland. It also shows a much larger coefficient for the GARCH term (forecast persistence).

Overall, for the Czech Republic, central bank intervention seems to isolate somewhat the foreign exchange market from external events, as shown by the lower volatility jump following the Russian crisis and the opposite sign observed in Poland for the impact of the introduction of the Euro. By contrast, central bank intervention does not seem to lead to lower volatility or lower volatility persistence. Economic policy in Poland, with an almost non existent degree of central bank intervention and wide exchange rate bands, made it more vulnerable to volatility increases in the face of exogenous events.[15]

It should be noted that a positive impact of the introduction of the Euro on exchange rate volatility in Poland may have also resulted from the further aperture of the capital account in the first quarter of 1999. Even a delayed impact of the Russian crisis may have played a role, for example in the face of increasing expectations of a lasting impact in the balance of payments. However, the fact that attacks on the exchange rate band during the Russian crisis vanished soon after the turmoil was over suggest that volatility driven by these events may have been largely incorporated and anticipated by the market before the Euro was introduced.

Comparing the relative performance of implied volatility with the GARCH model, it is found that the dynamic GARCH variance performs better than other variables (See Appendix). In addition, historical volatility shows that some volatility reversal is captured neither by the GARCH model nor by implied volatility. The explanations for this may be that GARCH models capture only immediate daily persistence, and that, in periods of regime shifts, ARCH models tend to overestimate the true variance of the process.

## IV. Summary and Conclusions

Exchange rate flexibility has been a salient feature of transition in Eastern European countries, particularly in the Czech Republic and Poland. However, by relying on exchange rate bands rather than on managed floating, the exchange regime in Poland has become closer to a floating regime relative to the Czech Republic. More recently, flexibility was further increased by the adoption of a floating regime. This has improved the absorption of

[15] However, no formulation of central bank intervention appeared significant to explain conditional volatility.

information in market expectations, particularly in the currency option market. Central bank intervention seems to have led to higher volatility persistence in the case of the Czech Republic, but larger flexibility in Poland may have led to much higher sensitivity of exchange rate volatility to exogenous volatility shocks such as the introduction of the Euro in 1999.

Further flexibility could be more favorable to incorporate Euro-induced volatility to domestic markets prior to the adoption of the Euro, if this turmoil is not expected to be too disruptive for domestic financial markets. By contrast, central bank intervention may minimize volatility fluctuations prior to the adoption of the Euro, if inadequate signals are not expected to risk exchange rate misalignment at the time of adoption of the Euro. The experience in the Czech Republic shows that central bank intervention has effectively isolated foreign exchange markets from external shocks, but has also consistently obscured the formation of expectations. However central bank intervention may be considered a valid alternative in the transition period if the risk of introducing exchange rate misalignment is considered low.

For currency option markets, Poland shows more appropriate option pricing and more information content from the options market translated into the spot foreign exchange market. Asymmetric volatility persistence is found, with larger persistence in times of unexpected exchange rate depreciation relative to unexpected appreciation. Both countries show a tendency to price overshoots in times of turmoil followed by consecutive periods of volatility declines. Because of the higher volatility persistence and the relative lower efficiency in the options market, a GARCH model shows more forecasting power for the Czech Republic, although it is also highly significant for Poland.

Other asymmetric responses are evident for volatility increases relative to volatility decreases. In general, the market is not taken by surprise by volatility increases. The opposite seems to be true for volatility decreases, which could reflect a higher risk premium and lower liquidity after episodes of volatility increases leading to volatility overshoots.

In spite of the large impact of the Russian crisis especially in Poland, this event does not show a systematic impact on volatility. Given that after the Russian turmoil the Euro market has become more important for both the Czech Republic and Poland, Euro-induced shocks are expected to show increasing importance in the preparation period for the adoption of the Euro as a national currency. A policy decision on the appropriate exchange rate regime for the transition period would soon become more urgent.

## Encompassing Volatility Forecast Model

The encompassing principle of Hendry and Richard (1982) helps to evaluate the relative predictive power of the implied variances estimated from the GARCH model compared to implied volatility and historical volatility. The encompassing principle deals with the ability of a model to explain the behavior embodied in the relevant characteristics of rival models. Ordinary least squares are used with the caveat that the coefficients would be unbiased but inconsistent (because of overlapping information in the data set). However, it should provide sufficient information for the purposes of this paper.

Table 8 shows the results of this exercise for in-sample data. The test is performed on the dynamic forecast of conditional variance from the GARCH model (that assumes that errors are unknown. Therefore, the persistence differential coefficient is given the value of 0.5). The constant in the mean equation is omitted as it was found insignificant.

The main results are:

- For both countries, the dynamic GARCH variance performs better than other variables. For Poland, the GARCH variance performs better than other variables in all cases. For the Czech Republic, implied volatility is surprisingly more significant for one- month forecasts.
- Implied volatility is significant for Poland for all cases except six-month forecasts. Discarding it as an explanatory variable results in a significant loss of explanatory power.
- Historical volatility shows a significant negative coefficient for all cases except for the two-month predictions of volatility in the Czech Republic. This implies that some volatility reversal is captured neither by the GARCH model nor by implied volatility. This can be explained by the fact that GARCH models capture only immediate daily persistence. Also, in periods of regime shifts such as speculative attacks or widening or narrowing of the exchange rate bands, ARCH models tend to overestimate the true variance of the process[16], which maybe captured by this negative coefficient.

Chart 6 shows these results in a graphical way. The GARCH term is more stable than actual volatility, and the volatility reversal is visually evident. Implied volatility increases above historical volatility in times of turmoil, which gives support to the hypothesis of volatility overshooting.

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[16] Jochum, C and Kodres, L. (1997)

TABLE 8. Czech Republic and Poland:

ENCOMPASSING VOLATILITY FORECAST MODEL

## 8a: Czech Republic

| | One month | Two months | Three months | Six months |
|---|---|---|---|---|
| GARCH model | 0.094289 | 0.719511 | 1.378139 | 1.708707 |
| | (0.964014) | (11.56424) | (21.28143) | (69.07167) |
| Implied Volatility | 0.741271 | 0.206582 | 0.093697 | -0.319905 |
| | (6.590330) | (3.389936) | (1.668203) | (-13.65941) |
| Historical Volatility | -0.144950 | 0.057066 | -0.441642 | -0.264132 |
| | (-2.559376) | (0.849403) | (-6.431158) | (-8.530433) |
| R square | 0.116029 | 0.403546 | 0.491604 | 0.886279 |
| Adjusted R square | 0.112177 | 0.400816 | 0.489154 | 0.885631 |
| F-statistics | 30.12377 | 147.8314 | 200.6464 | 1367.748 |
| Number of observations | 462 | 440 | 418 | 354 |
| | **Excluding implied volatility** | **Excluding historical volatility** | **Excluding implied volatility** | **Excluding implied volatility** |
| GARCH model | 0.691485 | 0.746445 | 1.418432 | 1.674792 |
| | (17.97349) | (13.94830) | (23.09229) | (55.06070) |
| Implied Volatility | | 0.237229 | | |
| | | (4.832133) | | |
| Historical Volatility | 0.088997 | | -0.381292 | -0.567106 |
| | (1.929723) | | (-6.711711) | (-21.24068) |
| R square | 0.032384 | 0.402561 | 0.488879 | 0.825829 |
| Adjusted R square | 0.030280 | 0.401197 | 0.487653 | 0.825334 |
| F-statistics | 15.39498 | 295.129 | 398.8532 | 1686.997 |

TABLE 8. Czech Republic and Poland:

ENCOMPASSING VOLATILITY FORECAST MODEL

8b: Poland

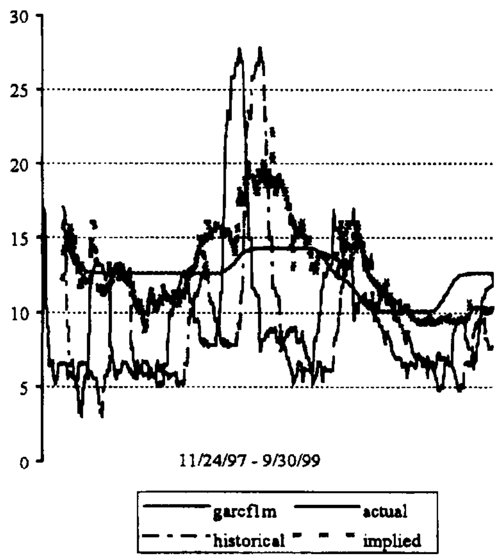
| | One month | Two months | Three months | Six months |
|---|---|---|---|---|
| GARCH model | 0.683601 | 0.863243 | 0.969904 | 1.733821 |
| | (-11.0038) | (16.13209) | (1846031) | (39.90147) |
| Implied Volatility | 0.583612 | 0.674284 | 0.496445 | 0.283046 |
| | (8.213133) | (10.26721) | (8.896206) | (8.731676) |
| Historical Volatility | -0.399596 | -0.642244 | -0.508475 | -0.856452 |
| | (-5.711969 | (-9.759703) | (-8.703392) | (-18.26114) |
| R square | 0.169687 | 0.261135 | 0.26669 | 0.558081 |
| Adjusted R square | 0.166069 | 0.257753 | 0.263165 | 0.555563 |
| F-statistics | 46.9018 | 77.22373 | 75.64557 | 221.6319 |
| Number of observations | 462 | 440 | 419 | 354 |
| | | **Excluding implied volatility** | | |
| GARCH model | 1.028485 | 1.167873 | 1.211252 | 1.832377 |
| | (47.35789) | (23.56642) | (24.70491) | (39.63724) |
| Historical Volatility | | -0.095387 | -0.116413 | -0.585548 |
| | | (-2.217972) | (-2.785492) | (-15.11131) |
| R square | 0.109255 | 0.082901 | 0.127181 | 0.46209 |
| Adjusted R square | 0.109255 | 0.080808 | 0.125088 | 0.460562 |
| F-statistics | | 39.59314 | 60.7623 | 302.385 |

Finally, the encompassing model was applied to out-of-sample data corresponding to the last quarter of 1999. Chart 7 shows that three-month volatility shows an initial increase in the Czech Republic but remains rather constant for both countries throughout the quarter. Forecasts based on the GARCH model appear closer to the actual outcome for the Czech Republic, while the encompassing equation and implied volatility show a better performance for Poland. It should be mentioned that this comparison is somewhat biased to disfavor implied volatility, as in this case only data for end-September contains all relevant information for the following quarter. Finally, the negative correlation between historical and actual volatility (volatility reversal) is again evident.

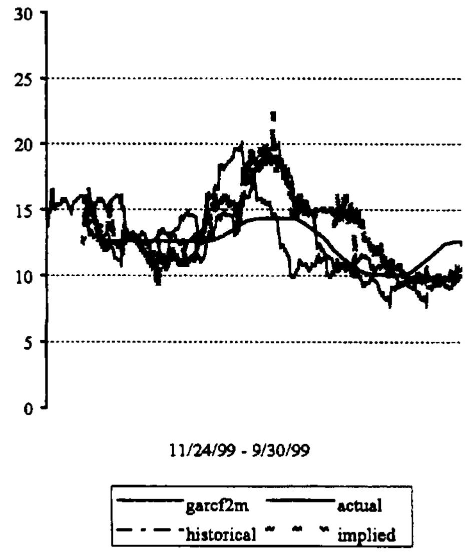
## Chart 6. Czech Republic and Poland: In-Sample Dynamic Forecast - Encompassing Equation

6a: Czech Republic

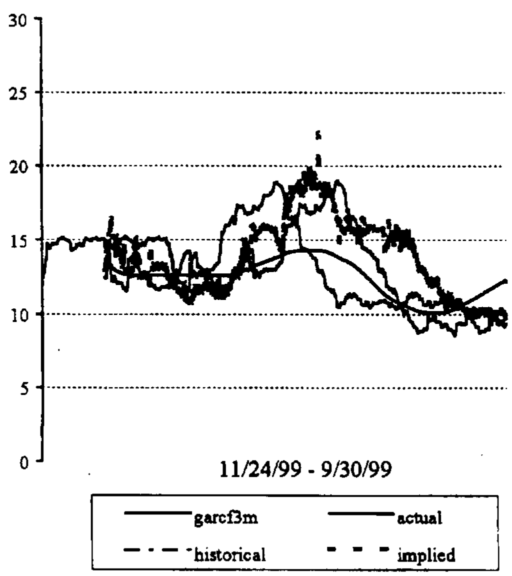
Projected one-month volatility



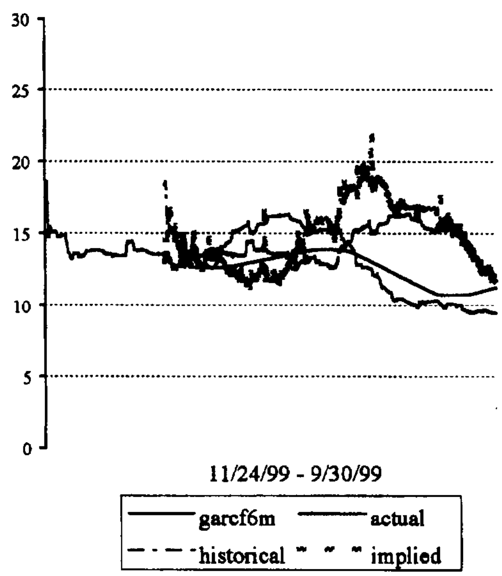

Projected 2-month volatility




Projected 3-month volatility




Projected 6-month volatility

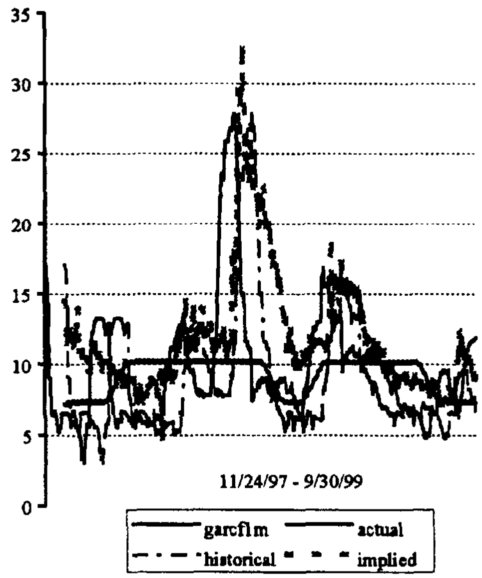



Source: Bloomberg and staff estimates.

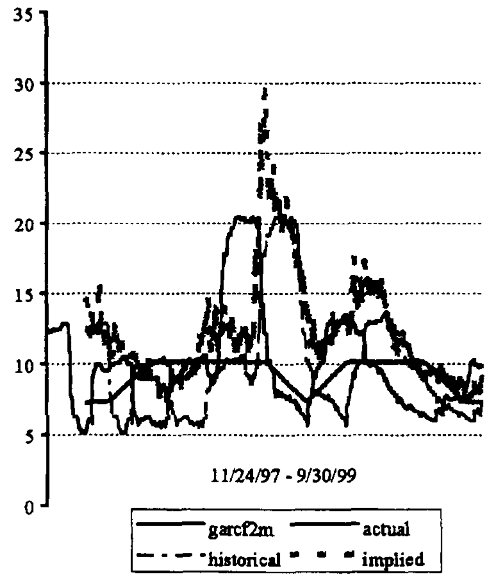
## Chart 6. Czech Republic and Poland: In-Sample Dynamic Forecast - Encompassing Equation

6b: Poland

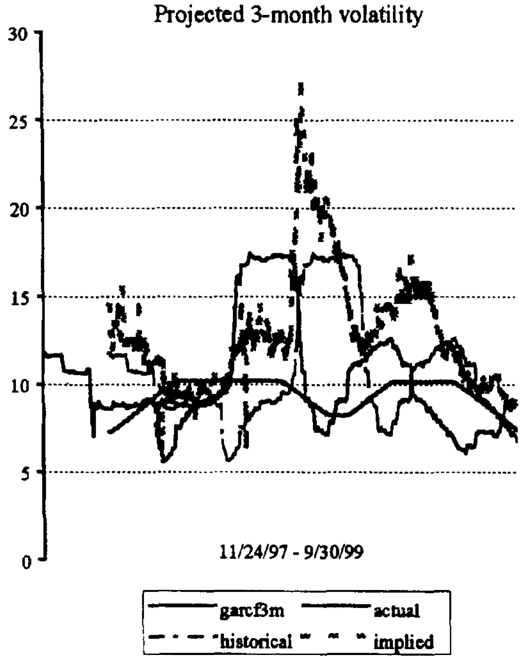
Projected one-month volatility



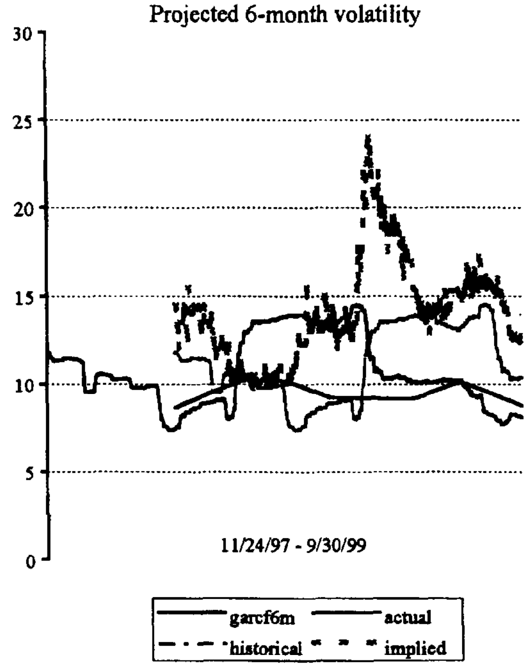

Projected 2-month volatility




Projected 3-month volatility

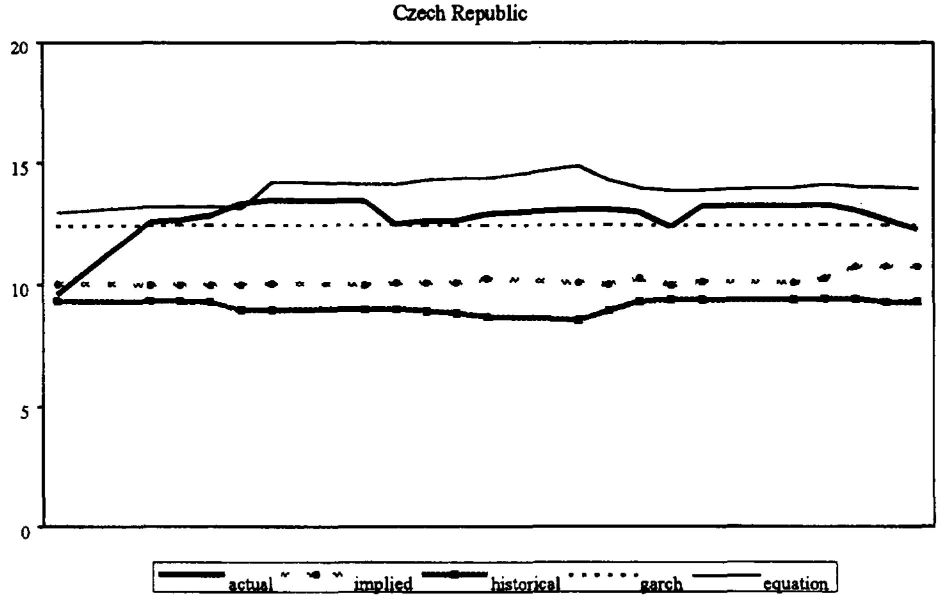


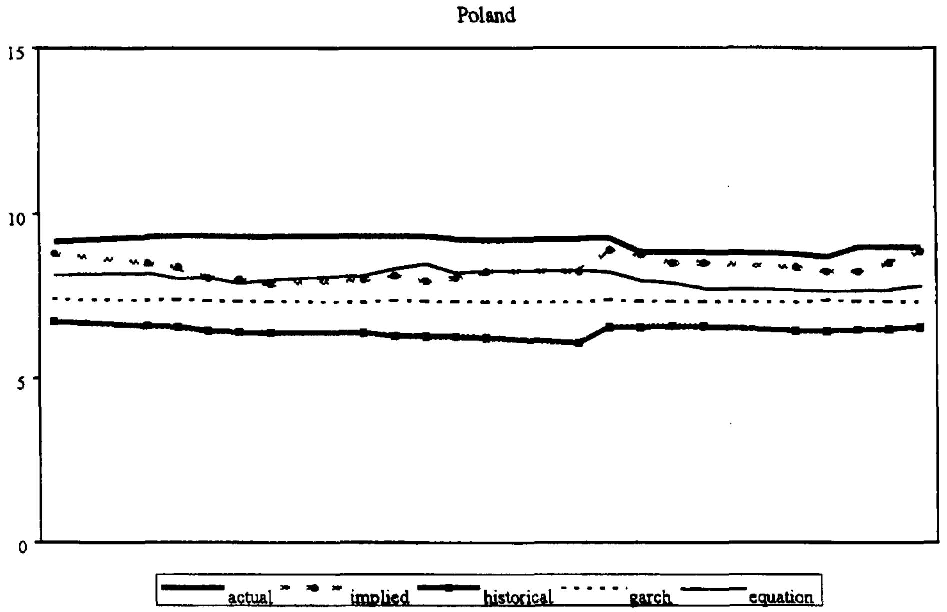

Projected 6-month volatility




Source: Bloomberg and staff estimates.

## Chart 7. Czech Republic and Poland: Out-of-Sample




Source: Staff estimates.

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