Exchange Rate Volatility and Regime Change: A Visegrad Comparison

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Abstract

We analyze exchange rate volatility in the Visegrad Four countries during the period in which they abandoned tight regimes for more flexible ones. We account for path dependency, asymmetric shocks, and movements in interest rates. In addition, we allow for a generalized error distribution. The overall findings are that path-dependent volatility has a limited effect on exchange rate developments and that the introduction of floating regimes tends to increase exchange rate volatility. During the period of flexible regimes, volatility was mainly driven by surprises. Asymmetric effects of news tend to decrease volatility under the floating regime. Interest differentials impact exchange rate volatility contemporaneously under either regime, although we find no intertemporal effect of interest differentials.

Keywords: exchange rates, exchange rate regimes, volatility, transition, integration, European Union, nonlinearity, interest rate parity

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1. Introduction

The volatility of exchange rates under different regimes has been studied extensively in the literature.[1] Since the pioneering work of Mussa (1986), conventional wisdom indicates that exchange rate volatility is greater under a flexible regime than that under a fixed arrangement. However, the measurement of volatility has engendered much debate with the approach shifting from the use of standard deviations towards the use of foreign exchange options and conditional heteroskedasticity type models. Exchange rate volatility and its measurement take on new importance in the context of the transition process in the Central and Eastern European (CEE) countries and their integration into the European Union.

Since the early years of transition, most of the advanced reformers among CEE countries have developed independent, autonomous monetary policies. Concurrently, they have departed from fixed exchange rates by applying various exit strategies at different times and with different intensity and have moved towards a type of inflation targeting as a policy instrument, as Orlowski (2001) reports.[2] In addition, economic integration brought increased international trade openness. Égert and Morales-Zumaquero (2005) document that exchange rate volatility weakens exports with the impact varying across sectors and across CEE countries, and Babetskii (2005) shows that a decrease in exchange rate volatility has a positive effect on demand shock convergence. On the institutional level, exchange rate stability is defined as one of the Maastricht criteria for monetary integration.[3] Orlowski (2003) stresses that candidate countries for the Economic and Monetary Union (EMU) accession must demonstrate their capability to manage inflation and the exchange rate risk premium as a necessary prerequisite for successful monetary convergence. Hence, Orlowski (2004) argues that diminishing exchange rate risk is a key criterion for evaluating currency stability and, thus, the effectiveness of monetary convergence to the euro.

In this paper, we analyze exchange rate volatility in the four Visegrad countries, i.e., the Czech Republic, Hungary, Poland, and Slovakia, during the period in which they were abandoning tight regimes in favor of more flexible ones.[4] In analyzing exchange rate volatility, we account for path dependency, asymmetric shocks, and movements in interest rates. We find that introduction of floating regimes tends to increase exchange rate volatility, which conforms to conventional wisdom. Moreover, the degree of persistence in exchange rate volatility differs with respect to currency but remains at a similar level under the floating regime. Furthermore, the effect of asymmetric news tends to decrease volatility under the float. Finally, the interest rate influences exchange rate volatility in somewhat non-obvious ways in that, under both regimes, the contemporaneous effect of interest differentials impacts exchange rate volatility but the coefficients measuring the intertemporal effect of interest differentials are insignificant. In our empirical and methodological approaches, we focus on the comparative experiences of the new member states in European integration.

The rest of the paper is organized as follows. Section 2 provides an account of exchange rate developments and the arrangements in the Visegrad countries. Section 3 discusses exchange rate volatility and the sources of this volatility that are specific to the process of transition. Section 4 describes the methodology used to measure volatility while Section 5 provides details about the data and changes in exchange rate regime. In Section 6, we present our empirical results. We conclude with comments and policy implications.

2. Exchange Rates Arrangements in Central Europe

In CEE, the institutional design of exchange rate regimes has varied across countries since the beginning of transition.[5] Although we observe certain evolutionary similarities, the regimes adopted were heterogeneous so that we do not consider the Visegrad countries to be a homogenous group. The Czech Republic, Hungary, Poland, and Slovakia all adopted fixed exchange rates at the beginning of transition. The Czech and Slovak Republics, which until January 1, 1993 formed a federation and which shared a uniform exchange rate policy, fixed their currencies to a currency basket. At the beginning of transition, this basket consisted of five different currencies; later on, the peg used only the U.S. dollar and the

Deutsch mark. The weights of each currency in the basket were determined by the importance of that particular currency to the foreign trade of the country. The width of the band was set at ±0.5% from central parity. After their separation in 1993, Slovakia changed its band to ±7% and later the Czech Republic changed its band to ±7.5%. Central banks were obliged to intervene in the currency market to sustain the basket peg.

A similar institutional arrangement is found in Poland and Hungary. The only difference is that these two countries adopted a pre-announced crawling peg to the basket of currencies.[6] The central parity was not constant, as in the Czech Republic and Slovakia; rather, it was changed periodically and such devaluations were announced ahead of time. In some cases, the width of the band was changed during the period. Table A1 in the Appendix displays the details of all the adjustments that the central banks of the four CEE countries adopted in exchange rate management. The abundance of these adjustments is apparent in the cases of Poland and Hungary. Orlowski (2000a) investigates the influences of the various approaches to monetary policy in Poland, Hungary and the Czech Republic on the trend and the stability of real exchange rates from 1995 to 1999. His analysis casts doubt on the effectiveness of crawling devaluations. Apart from shifting to looser exchange rate regimes, the Visegrad countries share another similarity in that they adopt inflation targeting, albeit in various forms.

After the turmoil in financial markets in May 1997, the Czech Republic was the first Central European country to adopt a floating exchange rate regime. In October 1998, the National Bank of Slovakia followed this path. Poland in 2000 and Hungary in 2001 also left the fixed regime to adopt a floating or quasi-floating regime. Therefore, in general, the CEE countries move from a tight exchange regime to a looser one, as observed by Kočenda (2002) and Bofinger and Wollmershäuser (2001). However, when the exits from rigid exchange regimes are compared, those in Poland and Hungary are rather orderly in contrast with the disorderly exits in the Czech Republic and Slovakia. Detragiache, Mody and Okada (2005) claim that disorderly exit strategies occur in the presence of problems, e.g., real appreciation, falling reserves, a deteriorating fiscal position, and financial outflows due to low interest rate differential. In contrast, orderly exits occur in the absence of such macroeconomic problems.[7] Thus, the disorderly exits of the Czech and Slovak Republics can be explained, at least in part, by the financial crisis and the pre-election turmoil, respectively.

All four countries applied for EU membership in 1995 or 1996 and underwent a lengthy and thorough screening process. On May 1, 2004 they joined the EU and, as such, are required to become part of the EMU, or Eurozone, at some point in time. Although EU membership does not mean immediate participation in the Eurozone, membership does increase the pressure on new member countries to improve their institutions and maintain stable economic environments. Hence, membership is expected to foster euro-conversion-oriented development of their exchange rates.[8] The operations and timing of euro conversion is an intricate task; on this account, Slovakia is a frontrunner having entered the ERM II regime on November 27, 2005.

3. Exchange Rate Volatility: Transition Stages and Sources

For CEE countries, the effects of the transition process must be taken into account when analyzing exchange rate volatility and its sources. In the early stages of transition, the Visegrad countries experienced turbulent times that would tend to increase exchange rate risk, e.g., monetary separation in the Czech and Slovak Republics, banking crises, financial crises, and political crises. We present several important sources of volatility specific to these countries to characterize the systemic and institutional foundations of exchange rate risk. Although volatility depends on the exchange rate arrangements and their modifications described in Section 2, other factors also have an effect. Specifically, exchange rate risk has been rising in the Visegrad countries due mainly to questionable fiscal discipline. These countries are also susceptible to the contagion effects from international financial crises, which tend to increase exchange rate volatility as Orlowski (2003) discusses. Moreover, prior to 2004, the Visegrad countries were candidates for the EU so that they were subject to the same pressure on fiscal discipline as they are currently as full members. Effectively, these countries were on the path towards monetary integration prior to becoming members of the EU.

The overall monetary policy framework has an important impact on exchange rate volatility. After eliminating currency pegs, the Visegrad countries adopted direct inflation targeting. Svensson (1999) and Orlowski (2000b) define direct inflation targeting as a policy framework based on a pre-announced inflation target, on transparent strategies and tactics to support the target, and on policy responses to periodic deviations between inflation forecasts and the target. Orlowski (2001) provides a comprehensive account of direct inflation targeting. Hence, these countries gave up exchange rate stability as a target and focused more or less exclusively on inflation targets. Therefore, nominal exchange rates are likely to exhibit increasing volatility for at least two reasons. First, switching from currency pegs to flexible exchange rates and adopting DIT policies, at least for Poland and to a lesser degree for the Czech Republic, is accompanied by a benign neglect of exchange rate stability, as Orlowski (2005) discusses. Second, during periods of faster money growth, the pressure on domestic inflation rises contributing to exchange rate volatility, as evidenced in Hungary and Poland. Clearly, a converging economy should give priority to the objective of lowering inflation over exchange rate stability because price stability is a prerequisite for exchange rate stability, as shown empirically by Orlowski (2004).

Another source of exchange rate volatility is the increasing openness of an economy making trade integration in the Visegrad countries an important issue.[9] Shortly after the start of the transition process, these countries re-directed their foreign trade from the former Soviet bloc towards the EU. Over the years, foreign trade turnover increased dramatically so that the ratio of foreign trade turnover to GDP has reached values of around 80% for Poland to almost 150% for Slovakia. Égert and Morales-Zumaquero (2005) document a reverse link by analyzing the direct impact of exchange rate volatility on the export performance of ten CEE transition economies as well as its indirect impact via changes in exchange rate regimes. Their results indicate that the size and direction of the impact of foreign exchange volatility and of regime changes on exports are negative. In addition, these effects vary considerably across sectors and countries as well as specific periods. For our analysis, a high degree of openness is common to all four countries so that we expect to find its contribution to the evolution of volatility of exchange rates to be similar across countries.

More ambiguous are those impacts of the transition process due to institutional procedures connected with exchange rate management. The institutional framework is often related to exchange rate risk only indirectly because it includes aspects other than the exchange rate arrangement, e.g., the degree of credibility, the independence of the monetary authority, and the existence of targeting mechanisms. In addition, for the Visegrad countries, the process of EU accession, the eventual adoption of ERM II, and membership in the Eurozone must be considered. The likely expectation effects on exchange rates, which have been observed in the past transitions from ERMII to the Eurozone, are discussed in Vinhas de Souza (2002). For a sample of accession countries, he finds that a credible, independent central bank with a targeting mechanism under a floating exchange rate regime mimics the nominal variability properties of a fixed exchange rate regime. This result supports the hypothesis that the volatility of the exchange rate is affected by institutional factors other than the exchange rate regime.[10]

Specific sources of exchange rate volatility and their developments can be attributed to tighter versus looser exchange regimes. During the prevailing period when versions of the currency basket peg were used by the Visegrad countries, their banking sectors were less developed than those of European market economies. As privatization of large state-owned banks progressed and new commercial banks from abroad entered, the degree of competitiveness in the banking sector started to increase.[11] After privatization, commercial banks engaged more heavily in transactions with foreign exchange and the volumes traded surpassed several times those from earlier stages of transition. Although we cannot connect the switch of exchange regimes directly to banking sector improvements, we observe that the financial systems are able to better accommodate a wide range of shocks and are better fit to cope with the volatility of floating exchange rates at the same time.

A further source of volatility relates to the balance of payments. Early in the transition when they were using basket pegs, the Visegrad countries began to experience increases in their current account deficits. By using adjustable versions of basket pegs, Poland and Hungary avoided large real exchange rate appreciation. However, the Czech and Slovak Republics experienced real appreciation of their currencies so that managing their current accounts became harder and current account volatility could spill over to exchange rate volatility. In the Czech Republic, the increasing current account deficit along with the financial crisis of 1997 increased exchange rate volatility considerably and had a direct impact on the stance of the central bank towards exchange rate management. In addition, all four countries began to liberalize their capital accounts as part of their macroeconomic stabilization packages at the beginning of the transition. However, full scale liberalization occurred only several years later and was accompanied by increased capital account volatility. The deteriorating risk structure of capital inflows towards short-term money increased capital account volatility and spilled over to exchange rates. Over time, increased proportions of foreign direct investments improved the risk structure of the capital account and lowered its volatility. During the later stages of transition under the floating exchange rate regimes, capital account volatility was less important to exchange rate volatility. For the prospective Eurozone entrants, a robust monetary policy framework that shields their economies from the disruptive effects of capital account volatility by discouraging any presumption of implicit exchange rate guarantees is crucial, as Schadler (2004) argues.

4. The Empirical Methodology

Many early empirical studies use the standard deviation as a proxy for exchange rate volatility, e.g., Hallett and Anthony (1997), Andersen and Bollerslev (1998), Jorion (1995); and Scott and Tucker (1988). This approach assumes constant average daily returns, which is directly opposed to the interest rate parity condition. By using the standard deviation as a proxy for exchange rate volatility, spurious volatility may be detected due to movements in exchange rates that are generated by interest rate differentials. Hence, neglecting movements in interest rates leads to unreliable results. Therefore, in the spirit of the excess volatility debate, we consider whether and to what extent the volatility of exchange rates exceeds the volatility of interest rates.[12] To approximate an otherwise unobservable volatility, we follow an approach suggested by Andersen, Bollerslev, Diebold and Labys (2001).[13] Specifically, we fit a parametric econometric model of the autoregressive conditional heteroskedasticity (ARCH) type, due to Engle (1982), augmented by appropriate parameters to account for the effect of interest rate differentials on the volatility of exchange rates.

To augment our ARCH-type model, we use the concept of uncovered interest rate parity (UIP), which connects movements in exchange rates and interest rates and allows us also to distinguish the effect of interest rates on exchange rate volatility. Golinelli and Rovelli (2002) use a UIP model of exchange rates to analyze monetary policy rules for transition economies based on the strategy suggested by Svensson (2000) for a small open economy. This approach is particularly appropriate for the Visegrad countries that liberalized their capital accounts early in their transition and eased remaining barriers to financial transactions swiftly. Over time, capital mobility increased and political risk decreased in these countries providing a solid foundation for adopting the UIP framework.[14]

Golinelli and Rovelli (2005) find empirical support for the UIP model of exchange rates in the Visegrad countries in analyzing the process of disinflation in the Czech Republic, Hungary and Poland. They show that the current exchange rate depends on the current interest rate differential and on the expected future exchange rate, augmented by a risk premium. In addition, Chinn (2006) finds reasonable support for UIP in the Czech Republic and Hungary, as well as in other emerging markets. Orlowski (2004) proposes a model linking exchange rate volatility to differentials across the Eurozone in both inflation, as a target variable, and interest rate, as an instrument variable. Using a vector auto regressive specification, he shows that an increase in domestic interest rates relative to German rates contributes to currency appreciation for Czech Republic and Hungary but that the results are inconclusive for Poland. Thus, he concludes that changes in the value of the

Polish currency relative to the euro show a considerably weaker response to interest rate differentials than do the relative changes in the currencies of the Czech Republic and Hungary.[15]

The conventional notion of interest rate parity can be expressed as:

$$s_{t+1} - s_t = i_t - i_t^*, \tag{1}$$

where s_t denotes the natural logarithm of an exchange rate at time t and i_t and i_t^* are the domestic and foreign interest rates of equal maturity, respectively. For UIP, s_{t+1} indicates an expected exchange rate one period ahead. By contrast, for covered interest rate parity, s_{t+1} indicates a forward rate for one period ahead known at time t. Thus, equation (1) states that an intertemporal change in the exchange rate, under this theoretical condition, equals the interest rate differential.[16] Under the UIP condition, the exchange rate should adjust in every period so that the change is equal to the size of the interest rate differential. In contrast to this theoretical equality, the exchange rate is likely to show short-run deviations from UIP in practice and such deviations may be related to the size of the interest rate differential. Hence, such deviations may affect exchange rate volatility and corresponding movements in interest rates are also likely to affect the volatility of exchange rates.

Although the effect of movements in interest rates is ambiguous, Bilson (1999) shows that the volatility of exchange rates is related to the difference between the interest rates of the two currencies. To account for nonlinearity, an ARCH-type model should be augmented by the squared interest rate differential, i.e., $(i_t - i_t^*)^2$. However, this variable may not be sufficient because it captures only the contemporaneous effect of the differential and not its dynamics. Hence, we include the change in the interest rate differential squared, i.e., $(\Delta(i_t - i_t^*))^2$ as a second variable to account for intertemporal change.

To test empirically for exchange rate volatility, we employ an augmented generalized autoregressive conditional heteroskedasticity (GARCH) model due to Bollerslev (1986). In this extension of the GARCH model, the volatility, i.e., the conditional variance σ_t^2, is modeled not only as a function of past squared innovations and its own past variance, but also as a function of additional parameters. First, the mean extension includes a conditional variance in the mean equation so that we can analyze the process with the path-dependent rather than the zero-conditional mean. Second, the threshold extension accounts for asymmetric information.[17] Inclusion of a threshold dummy, d_t, enables us to make a distinction between positive and negative shocks to volatility or to allow innovations to have an asymmetric effect on conditional volatility. Third, we augment the variance specification by two parameters, i.e., the interest rate differential and its intertemporal change, to isolate the effect of movements in interest rates on exchange rate volatility.

We use the following specification of the augmented threshold GARCH-in-mean (TGARCH-M) model:

$$\begin{aligned} \Delta s_t &= a_0 + \sum_{i=1}^{k} a_i \Delta s_{t-i} + b \ln \sigma_t^2 + \lambda \cdot SD_t + \varepsilon_t ;\ \varepsilon_t \sim N(0, \sigma_t^2) \\ \sigma_t^2 &= \omega + \sum_{i=1}^{p} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2 + \xi d_{t-1} \varepsilon_{t-1}^2 + \delta_1 (i_t - i_t^*)^2 + \delta_2 (\Delta(i_t - i_t^*))^2 \end{aligned} \tag{2}$$

where Δs_t is the difference of the log of the exchange rate between time t and t-1, i.e. the change in the exchange rate over two consecutive trading days and k, p and q are the numbers of lags chosen by the Schwarz-Bayesian lag selection criterion. The log of the conditional variance in the mean equation, i.e. $\ln \sigma_t^2$, allows for an exponential rather than quadratic effect of observed volatility. The threshold dummy variable d_{t-1} is equal to 1 if $\varepsilon_{t-1} < 0$, i.e., a negative shock or good news, and 0 otherwise, i.e., a positive shock or bad news.[18] The variables $(i_t - i_t^*)$ and $(\Delta(i_t - i_t^*))$ are the annualized interest rate differential and the change in the interest rate differential, respectively. The shock dummy, i.e. SD_t, in the mean equation accounts for a few infrequent outliers of appreciation and depreciation movements of the currencies.

In the above specification, the ARCH term, i.e. $\alpha\varepsilon_{t-1}^2$, reflects the impact of news or surprises from previous periods that affect exchange rate volatility. A significant and positive value for α that is less than one characterizes the extent to which shocks do not destabilize volatility. When α is greater than one, shocks from the past are destabilizing.[19] The GARCH term, i.e. $\beta\sigma_{t-1}^2$, measures the impact of the forecast variance from previous periods on the current conditional variance, or volatility. Hence, a significant value for β that is close to one indicates a high degree of persistence in exchange rate volatility. The sum of both coefficients, i.e., α plus β, indicates the speed of convergence of the forecast of the conditional volatility to a steady state. The closer its value is to one, the slower is the convergence. The TARCH asymmetric term, i.e. $\xi d_{t-1}\varepsilon_{t-1}^2$, measures and accounts for the effect of the difference between good and bad news. The value of a statistically significant leverage coefficient, i.e. ξ, indicates the magnitude of the leverage effect and the sign indicates the effect's direction. A positive value of ξ indicates an increase in the subsequent volatility of the exchange rate and vice versa. Furthermore, a negative value of this coefficient means that negative shocks tend to increase the subsequent volatility of the exchange rate more than do positive innovations of an equal magnitude. Finally, the coefficients δ_1 and δ_2 capture the contemporaneous and intertemporal effects of the interest rate differential on exchange rate volatility. The smaller is the size of the interest rate differential, the smaller should be its effect on subsequent volatility.

Based on the Akaike information criterion (AIC) and the Schwarz-Bayesian information criterion (SBIC) and the significance of the coefficients, we select a specific version of the baseline model that corresponds best to the data on each currency and regime. This model selection strategy results in specifications that vary in terms of parameters across currencies as well as regimes.[20] In tables with numerical estimates we indicate the parameter that does not appear in a particular regression by including a dash instead of the coefficient value. The standardized residuals from such a specification are free from ARCH effects. Estimation of the model uses a log-likelihood function, i.e. $\ln L_t = -0.5(\ln(2\pi\sigma_t^2) + \sum_{t=t_0}^{T} \varepsilon_t^2 / \sigma_t^2)$, as in Bollerslev (1986). The maximum-likelihood estimates are obtained by using the numerical optimization algorithm described by Berndt, Hall, Hall, and Hausman (1974). To avoid the risk of overestimating volatility, we do not impose the normality condition on distribution as do many earlier studies. Rather, we allow for the generalized error distribution (GED) following Nelson (1991). The volatility of the exchange rate series is likely to follow a leptokurtic data distribution that is reflected by an actual GED parameter considerably lower than 2, which is the value in the case of normal distribution. Leptokurtosis implies that daily exchange rate volatility tends to concentrate around the mean during tranquil market periods but that shocks to volatility are large during turbulent times.[21]

5. The Data and Regime Switches

We use daily nominal exchange rates expressed in terms of the euro[22] to calculate changes in the exchange rates over two consecutive periods in the currencies of the Visegrad countries.[23] The interest rates of the Bundesbank initially and those of the European Central Bank (ECB) later in the period are used as the foreign interest rate. We use daily interest rates of one-month maturity to calculate the interest rate differentials. In the literature, shorter maturities may be used but the one-month rate is the maturity published in each country for the longest period. Moreover, this rate is close to the standard reference interest rate used by most central banks. All data are assembled from statistics provided by the central banks of these countries for considerable periods before and after the regime change. For Slovakia, we use interest rate data for the period from July to October 1997 from the ECOWIN Database because they are not readily available from the central bank. The length of the data period varies across countries depending on the extent of the particular regime.

Aside from loosening their exchange rate regimes, the Visegrad countries have another common factor that could influence exchange rate volatility, namely the credibility of the arrangement. The theoretical model of Krugman (1991) indicates that widening the fluctuation band should lead to an increase in the credibility of the band and, consequently, to a reduction in the volatility of the exchange rate. However, credibility could be influenced by factors other than the width of the fluctuation band, e.g., the interest rate differential, the inflation rate differential, and the level of foreign reserves. The Visegrad countries exhibit a high level of credibility because they either did not change the central parity or did so in pre-announced steps. Including countries that were forced to re-align their central parity unexpectedly and frequently would make it difficult to include a credibility variable in our model. By choosing countries with similar levels of credibility, we diminish the effect of credibility on the exchange rate in our analysis.

Since we want to analyze exchange rate volatility in conjunction with a move from a tighter to a looser exchange rate regime, the date of such a changeover is the natural choice for the break point. However, the timing of the switch should be consistent with the departure from a monetary policy based on the exchange rate and not simply with the formal adoption of a pure float. Hence, we must scrutinize each currency for an accurate date for the changeover. The choice for the Czech and Slovak currencies is relatively uncomplicated. After substantial periods of a currency basket peg, the national banks of both countries introduced a floating regime on May 26, 1997 in the Czech Republic and on October 2, 1998 in Slovakia.

In Poland, the National Bank of Poland (NBP) effectively abandoned monetary policy based on the exchange rate in May 1995, which is long before the switch to a pure float in April 12, 2000. In 1995, the NBP enacted a crawling devaluation regime with a wide band of permitted fluctuations. Such a wide band allowed the NBP to refrain from large foreign exchange market interventions so that it was capable of absorbing nominal shocks, particularly those stemming from the Asian and Russian financial crises. After adopting a direct inflation targeting strategy in January 1999, the NBP gave up foreign exchange interventions almost entirely and loosened its exchange rate policy further when it introduced a wide fluctuation band of ± 15% on March 25, 1999. Therefore, we chose January 7, 1999 as a more appropriate choice for regime switching in Poland than the date on which the float was formally introduced.[24]

The National Bank of Hungary (NBH) followed an ERM II shadowing strategy and adopted the forint/euro reference rate on January 1, 2000. The band was widened from ±2.25% to ± 15% on May 4, 2001 and the NBH adopted inflation targeting at this time. Although the crawling peg was abandoned later only in October 2001, when the rate of crawl was set to zero, the rate of crawl was low prior to this time. Practically, the daily devaluation of the central parity between May and October 2001 amounted to 0.00654%, which resulted in a total devaluation of 1.12% according to Crespo-Cuaresma, Égert, and MacDonald (2005). Because the overall impact of the crawl has been negligible in Hungary, we consider May 4, 2001 being the effective date of the switch in the exchange in our analysis.

A change in exchange rate regime, or an important modification, represents a shock to currency markets. During the time before and shortly after the change, traders and central banks react differently than during a normal period. Hence, the exchange rate series has different statistical properties and contains many outliers during this period. Basically, the observations do not come from the usual data-generating process. Therefore, we exclude data for one month before the change of regime and one month after. Thus, our results should not contain any bias due to turbulent times. The basic statistics for exchange rate changes are found in Table 1a and for interest rates in Table 1b along with the specifics about the time periods.

In addition, the data for each country and regime include several observations that are clearly outside the normal data-generating process. These outliers usually correspond to a truly sudden change in a variable, to factors such as the release of an unexpected macroeconomic indicator, or to short-term political turmoil such as the resignation of a minister. A standard GARCH model computes the next period's variance by squaring this period's shock. For very large shocks, this approach produces dramatic increases in variance that distort the coefficients. Friedman and Laibson (1989) argue that large shocks constitute extraordinary events; hence, they propose truncating their influence on the conditional variance. Charles and Darné (2005) argue that the presence of outliers may have undesirable effects on the estimates of the equation parameters that govern the dynamics of volatility. We account for these extreme events by including in the mean equation a shock dummy variable, denoted SD_t, rather than by truncating the data. Using the classification described in Doornik and Ooms (2005), this type of dummy variable accounts for additive outliers that affect only the level but not the variance. In other words, these outliers do not influence the lagged disturbances that enter the conditional variance and, therefore, the variance equation remains free from any outliers that would affect the values of the coefficients.[25] The shock dummy takes a value of one if the size of the daily change in the exchange rate is higher than five times the standard deviation of the sample and zero otherwise. The number of such shocks tends to be small in most countries, ranging from 2 to 6. The exception is the Hungarian forint under a floating regime for which we find shocks more often than in the other three countries. Hence, we consider observations that are higher than two times the standard deviation in Hungary during this period. Table A2 of the Appendix presents the details on outliers; clearly, they are infrequent compared to the sample sizes of data.

6. The Empirical Findings

In this section, we comment first on the results for each currency based on the reported numerical estimates and then provide a brief overall comparison. In the tables we report the coefficients, standard errors and marginal effects in terms of probabilities. We insert a dash in places where parameters do not appear in the particular regression according to the model selection strategy outlined in section 4.

As a complement to the numerical estimates, we provide graphical representations in which we plot the conditional variance for each of the four currencies. The time-varying path of volatility provides numerous insights into the responses of exchange rate risk to various general, as well as specific, external shocks. Under the fixed regime, we find that volatility tends to be lower. However, we identify outbursts of volatility under both fixed and float regime periods. The Asian crisis in 1997, the Russian crisis in August 1998, and the Brazilian crisis in January 1999 resulted in large shifts that can be traced uniformly for all currencies.

Table 2 contains the results for the Czech Republic. A small, negative, and significant coefficient of the log of the conditional variance in the mean equation implies that exchange rate fluctuations depend on the prevailing exchange rate risk under the tight regime. The negative coefficient means that an increase in volatility contributed to the currency's appreciation in terms of the euro but that this effect was limited. We find no effect of volatility in the mean under the floating regime, which indicates that volatility containment is not an important issue under the current Czech regime. The estimated conditional variance equation shows that exchange rate risk is persistent under the tight regime because the GARCH term coefficient, i.e., β, is close to unity at 0.9307. This degree of persistence declines somewhat under the float to 0.8910. Further, unanticipated news or surprises about volatility tend to increase the exchange rate risk at about an equal degree under both regimes as documented by the ARCH term coefficients, i.e., α, of 0.0612 and 0.0672, respectively. The sum of the ARCH and the GARCH term coefficients is very close to unity under the tight regime at 0.9919 but declines somewhat under the float to 0.9582. On this basis, we argue that the exchange rate risk of the Czech koruna is converging to a steady state but very slowly. Asymmetric shocks do not seem affect the currency’s volatility since the TARCH term coefficient, i.e. ξ, is insignificant under both regimes. By contrast, the impact of interest rate differential on volatility, i.e. δ_1, is evidenced under both regimes. Although the effect is fairly small, it increases about four times under the float from 0.0002 to 0.0009. Intertemporal changes in the interest differential do not affect exchange volatility.

Figure 1 depicts the developments in the conditional volatility for the Czech Republic to allow us to consider specific factors influencing the currency. The effect of the Asian crisis was coupled with a local financial crisis that erupted on May 26, 1997. The increasing current account deficit and the massive outflow of short-term capital prompted the Czech National bank (CNB) to relax the fixed exchange regime towards a float because it was not willing to waste foreign exchange reserves on futile interventions. A subsequent credit crunch on commercial banks also impact at this time. A political crisis arose in 1998 when the government was recalled by the President for the first time in the history of the country and early elections were called in 1999 that also affected volatility considerably. Such heightened volatility vanishes only slowly, as the Figure depicts. A further increase in volatility began in 2002 and continued into 2003 due most likely, to the significant deterioration in Czech fiscal discipline during this period.

Table 3 contains the results for Slovakia, which are different from those for the Czech Republic. During specification selection our model reduces from TGARCH-M to TGARCH under both regimes. The absence of the conditional variance in the mean equation implies that exchange rate fluctuations are not affected by the prevailing exchange rate risk under either regime. Hence, exchange rate volatility has been contained. Another difference from the Czech case is the originally higher degree of persistence in volatility measured by the GARCH term, i.e., β, at 0.9389, which decreases under the float to 0.8525. Under the tight regime, the volatility of the Slovak koruna is affected less by unexpected shocks than is its Czech counterpart because the ARCH term, i.e., α, is lower at 0.0442. Under the float the comparison changes. Unexpected shocks tend to increase the exchange rate risk, as the first-order ARCH term coefficient of 0.2390 indicates. However, this effect is dampened by more distant shocks, as evidenced by the negative second-order ARCH term coefficient of -0.0986. Most likely, the National Bank of Slovakia (NBS) managed purposeful adjustments to these shocks. A disturbing finding is the high sum of the ARCH and GARCH coefficients; it is virtually unity under the tight regime at 0.9831 and under the float at 0.9929. Hence, the exchange rate risk of the Slovak koruna is converging to a steady state at an extremely slow rate and not decreasing. As in the Czech case, asymmetric shocks do not appear to affect the currency's volatility because the TARCH coefficients, i.e. ξ, are insignificant under both regimes. The effect of the interest rate differential, i.e. δ_1, is insignificant under the tight regime but it becomes significant under the float and increases in magnitude. We find no effects of the changes in the interest differential.

Figure 2 depicts the development of the volatility of the Slovak koruna. During the fixed exchange rate regime, volatility gradually rises starting at the beginning of 1997. This date coincides with an increase in the fluctuation band to ± 7.5% and with the beginning of excessive budgetary spending by the government. The Russian financial crisis in May 1997 coupled with the crisis in the Czech Republic created pressure for exchange rate depreciation. However, the NBS maintained the fixed regime at the expense of a high interest rates and a loss of foreign exchange reserves. The pressure on the exchange rate decreased gradually towards the end of 1997. During the course of 1998, increasing government deficits to around 6% of GDP put pressure on the demand for the koruna and resulted in very high interest rates that enabled the NBS to support the existence of the fixed regime for almost an additional year. However, shortly before parliamentary elections in September 1998, abandoning the fixed regime was clearly inevitable. This expectation increased volatility and, a few days after the election results were announced, the fixed exchange rate regime was replaced with a floating one. The burgeoning economic crisis and the change in exchange rate regime increased volatility at the end of 1998. Unfortunately, the new government did not start the reform process as quickly as was expected by financial markets. In May 1999 on the heels of strong depreciation pressure, the government announced a series of measures that helped to stabilize the economy. After this date, the majority of the spikes in volatility are connected either with political turmoil[26] or with central bank intervention on the foreign exchange market. In addition to these internal factors, the Slovak foreign exchange market is often affected by regional news or sentiment. Hence, problems experienced by the other Visegrad countries apply to Slovakia.

Table 4 presents the results for the Polish currency. The significant coefficient of the conditional variance in the mean equation under the tight regime implies that exchange rate fluctuations were affected by the prevailing exchange rate risk; no evidence is found under the float. Thus, exchange rate volatility has been well contained since the regime was relaxed. The degree of the persistence of this volatility as measured by the sum of the

GARCH term coefficients, i.e., sum of β_1 and β_2, is markedly lower under the tight regime at 0.5061 than under the float at 0.7760. Under the tight regime, persistence is dampened by the negative first-order GARCH term coefficient of –0.1499 but this impact is outweighed by the positive second-order term coefficient of 0.6560.[27] Of the four countries, the persistence of the Polish zloty is the lowest. Under both regimes, the currency has been affected by unexpected shocks. However, the effect is greater under the tight regime than under the float as denoted by the values of the ARCH term coefficients, i.e. α's, at 0.3164 and 0.1535, respectively. Such an effect is divided into two periods, where the second-order ARCH effect is even stronger than the first-order one, indicating a cumulative effect of the shocks and some degree of memory on the market. More disturbing is that the sum of the ARCH and GARCH term coefficients increased greatly from one regime to the next. The sum's relatively low value of 0.8225 under the tight regime increased but stayed below one at 0.9295 under the float. Thus, convergence of the zloty toward a steady state slowed down considerably under the float. Asymmetric shocks also affect the currency's volatility. The TARCH term coefficient, i.e., ξ, is positive under the tight regime at 0.0134 and negative under the float at -0.1611. Thus, asymmetric shocks tend to increase the currency's volatility under the former regime and decrease it under the latter one, although the dampening effect is more than ten times stronger. Under both regimes, the effect of the interest rate differential, i.e. δ_1, is significant and of almost equal magnitude. As before, we find no effect of the change in the interest differential.

Figure 4 depicts exchange rate volatility in Poland over time. The effect of the Asian crisis in 1997 was limited because the outburst of volatility did not last long, as Gelos and Sahay (2001) also show. The heightened volatility in September 1998 can be attributed to the official strategy of de-coupling the Polish financial markets and institutions from the Russian crisis. According to Orlowski (2004), the monetary authorities presented compelling evidence of immunity to possible contagion effects by emphasizing the better institutional advancement of the Polish financial system and the higher quality of assets held by the country's financial institutions. During the float period, volatility spikes in July 2000 and again in summer 2001 due to uncertainties about parliamentary approval of the budget. If the budget proposals did not get approved, Poland would have to borrow additional funds in eurobond markets. Official government statements triggered speculative actions against the Polish zloty so that volatility increased as a consequence. More recently in early 2005, the spike was related to the zloty's appreciation because the conditional variance equation contains interest rate differentials as regressors. The NBP had been slowly reducing interest rates in 2005, while the zloty was appreciating significantly in euro terms. The appreciation was due to extensive selling of the proceeds from eurobonds on foreign exchange markets in exchange for domestic currency by the Ministry of Finance.[28]

Table 5 presents the results for Hungary. Under the fixed regime, volatility does not have an effect on the development of exchange rates. In contrast, the effect of the log of the conditional variance in the mean equation is evident under the floating regime. The negative coefficient of -0.0013 indicates that the increase in volatility contributed to the currency's appreciation in terms of the euro. However, this effect was limited as the small size of the coefficient indicates. The estimated conditional variance equation shows that exchange rate risk was not as persistent under the tight regime as it was in the Czech or Slovak cases because the GARCH term coefficient, i.e., β, is considerably below unity at 0.7981. However, the degree of persistence increases somewhat under the float to 0.8555. Unanticipated news or surprises about volatility that are captured by the ARCH term coefficient, i.e., α, have a tendency to increase exchange rate risk under the tight regime by about three times more than under the float. The sum of the ARCH and GARCH term coefficients is above unity under the tight regime at 1.1031 but it declines below one under the float to 0.9615. Therefore, the exchange rate risk of the forint has been converging to a steady state only under the float regime but such convergence is again slow. Asymmetric shocks captured by the TARCH term, i.e., ξ, do affect the currency's volatility strongly under both regimes. The negative coefficients indicate that asymmetric shocks tend to dampen the volatility, albeit less under the float than under the tight regime. The impact of the interest rate differential on volatility, i.e., δ_1, is evident under both regimes; this effect is small but its importance increases dramatically under the float as the coefficient increases about eight times from that in the tight regime. Again, intertemporal change in the interest differential does not affect exchange volatility.

Figure 3 depicts exchange rate volatility in Hungary over time. The effects of two major crises, one in 1997 and the other in 1998, are clearly visible during the fixed regime period. In addition, the Brazilian currency devaluation and crisis in 1999 also affect the volatility of the forint. After the basket was reduced to a peg to the euro in January 2000 volatility decreases dramatically. With the widening of the fluctuation band in May 2001, volatility rises considerably. In 2003, three major events prompted outbursts of volatility. A jump in volatility in January 2003 is associated with an attack against the forint at its strong end. A significant jump in volatility in mid-2003 coincides with a badly coordinated devaluation of the central parity of the forint against the euro on June 4, 2003 by 2.26% accompanied by confusing statements from the NBH and the government, which led to significant depreciation and elevated volatility after this date. Finally, in December 2003, an attack against the forint at its weak end prompted the largest jump in volatility during the period of the semi-floating regime.

In summary, the volatility in the exchange rates of the Visegrad countries followed different patterns, which challenges the common conception that the four countries form a homogenous group. This finding is corroborated by the correlations for exchange rate volatility presented in Table 6, which are calculated over the common sample for all currencies under specific exchange rate regimes. The sample consists of 160 and 958 observations for the fixed and floating regimes, respectively. The correlation is low in both regimes but smaller under the float. Many correlation coefficients are negative. Some co-movements in volatility can be identified in both regimes, e.g., the Czech and Slovak korunas and the Polish zloty and the Slovak koruna. Hence, we conclude that exchange rate volatility has been driven mainly by country-specific factors rather than by common causes for the Visegrad countries.

We also find that volatility increased or remained about the same after tight regimes were replaced with more flexible ones. These findings are consistent with the stylized fact that volatility is greater under a floating than under a fixed exchange rate. Since all four countries practiced inflation targeting during the flexible regime period, this result is also supportive of theoretical argument put forth by Leitemo (2004) that such targeting leads to excessive volatility in interest rates and exchange rates.[29] Entry to the ERM II with a wide band of ± 15% should lead to lower volatility in these countries so that the potential conflict with inflation targeting may not materialize.[30] The crucial issue is the choice of the reference exchange rate for each currency to the euro at time of entry. An inappropriate reference rate, which does not reflect macroeconomic conditions or market sentiment, would generate pressures that would tend to increase volatility and potentially violate ERM II boundaries.

7. Conclusion

We analyze the volatility of exchange rates in the Visegrad countries, namely, the Czech Republic, Hungary, Poland, and Slovakia under two exchange rate regimes. We use an augmented path-dependent threshold GARCH specification to evaluate the dependency of the exchange rate on its volatility and to uncover the impacts of external shocks and interest rates on exchange rate volatility. In addition, we analyze the persistence of volatility and the tendency of these currencies' volatility to converge towards a steady state. Our results indicate that daily fluctuations of the Czech and Polish currencies depended on the prevailing exchange rate risk under the fixed exchange rate regime. Although the Hungarian currency is affected by its volatility under the floating exchange rate regime, we find no evidence of this effect for Slovakia. These findings imply that exchange rate risk has not been well contained in the past in the tight regime for these three countries but that only the Hungarian currency is affected by such risk under the current flexible regime. In all three cases, volatility contributes to the appreciation of the currency, which is considered less harmful than its impact under conditions of depreciation.

Our estimates of conditional volatility indicate that volatility tends to increase after the switch to a more flexible regime. This finding is consistent with the stylized fact that exchange rate volatility is greater under a float than under a fixed regime. In general, our findings indicate that the width of a fluctuation band, either narrow or broad, does not have an unambiguous influence on exchange rate fluctuation. Nonetheless, the type of regime is likely to be the strongest factor affecting exchange rate volatility because of the role played by the interest rate. Furthermore, we find that the impact of external shocks, i.e., news or surprises, on exchange rate volatility differs across countries. Hence, we conclude that volatility has been driven primarily by country-specific effects.

The extent to which the volatility was driven by shocks increased after the switch to the float for the Czech and Slovak korunas but it is lower for the Hungarian forint and the Polish zloty in the flexible regime. Hence, the central banks of Poland and Hungary face a more favorable situation because their currencies are better able to contain external shocks, possibly due to more developed financial markets. Regarding the persistence of volatility, we find that it decreased for the former currencies, i.e., the korunas, but increased for the latter ones, i.e., the zloty and the forint. Although a decrease in persistence can be considered a positive sign, the level of persistence is roughly equal for all four currencies under the float so that, on this score, no one of them is in a more favorable position. Finally, we find that the asymmetric effect of past shocks yields mixed results under the tight regime but it has a suppressing impact on the Hungarian and Polish currencies under the float.

Two of our findings for these four countries require further explanation. First, we find that the contemporaneous effects of interest rate differentials on exchange rate volatility are small, although clearly present, and they increase under the float for all countries. However, we find no evidence of any effects of changes in interest rate differentials. To explain this latter result, we consider monetary policy and the level of interest rates in the Visegrad countries. During the period of the tight regime, these countries did not conduct independent monetary policy for the most part. After the switch to a flexible regime, monetary policy became more independent in all countries with the interest rate used as its key instrument. In addition, the level of interest rates for the Visegrad countries was relatively high during the tighter regime period. A high interest rate should cause appreciation of the currency, *ceteris paribus*, although only within the bands of the currency basket and crawling pegs. However, if a high nominal interest rate reflects high expected inflation, Frankel (1993) argues that the currency should lose value in the future. Therefore, if the level of the interest rate, or its differential, reflects an uncertain economic situation and high inflation as it did in these countries, the impact of the interest rate differential becomes reality as in our findings.

Second, we find that convergence of exchange rate volatility to the steady state is somewhat problematic. When the two regimes are compared, the convergence rate is either higher or lower depending on the currency. In general, convergence is relatively slow and about equal for three of the currencies. The exception is the Slovak koruna, whose volatility does not tend to converge to the steady state after the switch to the float. Our findings suggest that policy makers in all four countries should work to contain exchange rate volatility by improving institutions that support better-functioning financial markets and by eliminating the other sources of volatility.

Due to the openness of the Visegrad economies and their dependency on foreign trade, the higher exchange rate volatility accompanying the switch to the float may have negative effects on international trade, as documented by Égert and Morales-Zumaquero (2005). Increased exchange rate volatility may also dampen the pass-through from the exchange rate to inflation, which may have a potentially negative impact on the ongoing process of convergence in prices to EU15 levels. Specifically, increased volatility associated with a more flexible exchange rate regime together with the inflation targeting may sever the link between the exchange rate and prices by disconnecting primarily non-tradable goods from the exchange rate, as Coricelli, Jazbec, and Masten (2006) discuss. Hence, policy makers in the Visegrad countries should set a high priority on containing exchange rate volatility.

Finally, by connecting the spikes in volatility to real events, we conclude that volatility is not a completely exogenous process. Budgetary imbalances are the most critical issue for the Visegrad countries because they affect not only exchange rate volatility but also the entire process of conversion to the EMU, as Kočenda, Kutan, and Yigit (2005) discuss. Uncertainty about fiscal discipline is a common exogenous factor behind exchange rate volatility for these countries. Therefore, central banks should set low inflation targets, work on gaining credibility, and stabilize nominal interest rates at low levels. A stable interest rate propagates less volatility in the exchange rate and achieving stable low inflation also promotes a less volatile exchange rate, as Orlowski (2004) discusses. However, this policy may risk generating expectations of a nominal exchange rate appreciation, which may paradoxically increase exchange rate volatility. To avoid such an outcome, a consistent framework for monetary policy decisions is required. More importantly, central banks should increase the transparency of their policy decisions and targets by providing more information to markets, as Woodford (2005) argues. By reducing the frequency of unexpected news and surprises with respect to monetary policy, this communication reduces the major factors that drive exchange rate volatility in the Visegrad countries. Therefore, coordination of monetary and fiscal policies would help to reduce exchange rate volatility in these four countries but this is a considerable task for policymakers currently.

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Table 1a

Basic Statistics: Daily returns of local currency with respect to the Euro

	Fixed exchange rate regime				Floating exchange rate regime			
	Czech koruna	Slovak koruna	Polish zloty	Hungarian forint	Czech koruna	Slovak koruna	Polish zloty	Hungarian forint
No. of Obs.	1048	779	553	1136	1922	1594	1538	958
Mean	1.15E-05	-3.53E-05	1.99E-04	2.64E-04	-1.04E-04	-5.41E-05	-5.03E-05	1.34E-05
Std. Deviation	0.0029	0.0034	0.0063	0.0024	0.0044	0.0030	0.0072	0.0057
Minimum	-0.0130	-0.0384	-0.0327	-0.0143	-0.0269	-0.0155	-0.0582	-0.0246
Maximum	0.0207	0.0157	0.0463	0.0164	0.0311	0.0248	0.0630	0.0691
Start	05.01.1993	07.07.1995	12.08.1996	01.08.1996	01.07.1997	01.12.1998	02.02.1999	02.07.2001
End	29.04.1997	28.09.1998	30.12.1998	27.04.2001	28.06.2005	28.06.2005	28.06.2005	28.06.2005

Table 1b

Basic Statistics: One-month interest rate on local currency

	Fixed exchange rate regime				Floating exchange rate regime			
	Czech koruna	Slovak koruna	Polish zloty	Hungarian forint	Czech koruna	Slovak koruna	Polish zloty	Hungarian forint
No. of Obs.	1048	779	553	1136	1922	1594	1538	958
Mean	11.1%	16.7%	22.4%	16.7%	6.1%	8.0%	11.3%	9.6%
Std. Deviation	2.3%	8.1%	2.6%	4.1%	4.5%	3.6%	5.2%	1.9%
Minimum	6.2%	5.1%	16.1%	9.3%	1.8%	2.2%	5.2%	4.2%
Maximum	20.0%	62.5%	27.3%	23.9%	22.7%	30.0%	21.8%	15.2%
Start	05.01.1993	07.07.1995	12.08.1996	01.08.1996	01.07.1997	01.12.1998	02.02.1999	02.07.2001
End	29.04.1997	28.09.1998	30.12.1998	27.04.2001	28.06.2005	28.06.2005	28.06.2005	28.06.2005

Table 2

Results of the TGARCH-M Volatility Estimation: Czech Koruna

	Fixed regime			Floating regime		
	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
a_0	-0.0042	0.0021	0.0448	-0.0002	0.0001	0.0041
b	-0.0003	0.0002	0.0458	-		
λ	0.0167	0.0021	0.0000	0.0237	0.0014	0.0000
ω	0.0000	0.0000	0.1192	0.0000	0.0000	0.0011
α	0.0612	0.0190	0.0013	0.0672	0.0197	0.0007
β	0.9307	0.0224	0.0000	0.8910	0.0224	0.0000
ξ	-0.0274	0.0200	0.1697	0.0107	0.0229	0.6407
δ_1	0.0002	0.0001	0.0986	0.0009	0.0003	0.0064
GED parameter	1.3672	0.0734	0.0000	1.2490	0.0487	0.0000
Num. of obs	1048			1922		
Adjusted R^2/DW	0.129/1.961			0.107/1.982		
Log Likelihood	4776.383			8044.795		
AIC/SIC	-9.098/-9.056			-8.363/-8.340		
sum (α+β)	0.9919			0.9582		

Notes: DW indicates the Durbin-Watson statistics. AIC and SIC stand for the Akaike and Schwarz-Bayesian information criteria, respectively. A dash indicates where parameter does not appear in the particular regression.

Table 3

Results of the TGARCH Volatility Estimation: Slovak Koruna

	Fixed regime			Floating regime		
	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
a_0	-0.0001	0.0001	0.2377	-0.0001	0.0000	0.0217
a_1	-			0.0518	0.0215	0.0158
λ	0.0153	0.0046	0.0009	0.0165	0.0013	0.0000
ω	0.0000	0.0000	0.2480	0.0000	0.0000	0.0058
α_1	0.0442	0.0213	0.0376	0.2390	0.0592	0.0001
α_2	-			-0.0986	0.0568	0.0822
β	0.9389	0.0321	0.0000	0.8525	0.0317	0.0000
ξ	-0.0063	0.0262	0.8085	-0.0532	0.0361	0.1404
δ_1	0.0000	0.0000	0.4904	0.0005	0.0003	0.0612
GED parameter	1.3799	0.0991	0.0000	1.0817	0.0546	0.0000
Num. of obs	779			1593		
Adjusted R^2/DW	0.207/1.881			0.091/1.902		
Log Likelihood	3457.762			7282.359		
AIC/SIC	-8.857/-8.809			-9.130/-9.097		
sum (α+β)	0.9831			0.9929		

Notes: DW indicates the Durbin-Watson statistics. AIC and SIC stand for the Akaike and Schwarz-Bayesian information criteria, respectively. A dash indicates where parameters do not appear in the particular regression.

Table 4

Results of the TGARCH-M Volatility Estimation: Polish Zloty

	Fixed regime			Floating regime		
	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
a_0	-0.0058	0.0032	0.0752	-0.0002	0.0002	0.1344
a_1	-			-0.0622	0.0239	0.0093
a_2	-			-0.0806	0.0251	0.0013
a_3	-			-0.0585	0.0242	0.0158
b	-0.0005	0.0003	0.0795	-		
λ	0.0232	0.0018	0.0000	0.0355	0.0017	0.0000
ω	0.0000	0.0000	0.9713	0.0000	0.0000	0.0004
α_1	0.1260	0.0568	0.0264	0.1535	0.0379	0.0001
α_2	0.1904	0.0563	0.0007	-		
β_1	-0.1499	0.0721	0.0376	0.7760	0.0549	0.0000
β_2	0.6560	0.0756	0.0000	-		
ξ	0.0134	0.0666	0.8408	-0.1611	0.0404	0.0001
δ_1	0.0016	0.0008	0.0599	0.0015	0.0007	0.0339
GED parameter	1.0333	0.0775	0.0000	1.4778	0.0732	0.0000
Num. of obs	553			1535		
Adjusted R^2/DW	0.273/1.972			0.134/1.957		
Log Likelihood	2227.365			5592.681		
AIC/SIC	-8.016/-7.930			-7.273/-7.234		
sum (α+β)	0.8225			0.9295		

Notes: DW indicates the Durbin-Watson statistics. AIC and SIC stand for the Akaike and Schwarz-Bayesian information criteria, respectively. A dash indicates where parameters do not appear in the particular regression.

Table 5

Results of the TGARCH-M Volatility Estimation: Hungarian Forint

	Fixed regime			Floating regime		
	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
a_0	0.0001	0.0000	0.0000	-0.0149	0.0044	0.0007
b	-			-0.0013	0.0004	0.0008
λ	0.0143	0.0014	0.0000	0.0118	0.0005	0.0000
ω	0.0000	0.0000	0.0062	0.0000	0.0000	0.0085
α	0.3050	0.0541	0.0000	0.1060	0.0301	0.0004
β	0.7981	0.0248	0.0000	0.8555	0.0408	0.0000
ξ	-0.2089	0.0593	0.0004	-0.1345	0.0375	0.0003
δ_1	0.0001	0.0000	0.0036	0.0009	0.0004	0.0410
GED parameter	1.1381	0.0593	0.0000	1.3727	0.0996	0.0000
Num. of obs	1136			958		
Adjusted R^2/DW	0.128/1.915			0.616/1.923		
Log Likelihood	5690.182			4094.326		
AIC/SIC	-10.004/-9.968			-8.529/-8.483		
sum (α+β)	1.1031			0.9615		

Notes: DW indicates the Durbin-Watson statistics. AIC and SIC stand for the Akaike and Schwarz-Bayesian information criteria, respectively. A dash indicates where parameter does not appear in the particular regression.

Table 6

Correlations for Exchange Rate (TARCH-M) Volatility

	Czech koruna	Slovak koruna	Polish zloty	Hungarian forint
Fixed exchange rate regime				
Czech koruna	1			
Slovak koruna	0.117	1		
Polish zloty	-0.247	0.432	1	
Hungarian forint	-0.313	0.030	0.488	1
Floating exchange rate regime				
Czech koruna	1			
Slovak koruna	0.246	1		
Polish zloty	0.096	0.199	1	
Hungarian forint	0.012	-0.019	-0.045	1

Notes:

i. Correlation coefficients are calculated over the common sample for all currencies under specific exchange rate regime.

ii. The length of the sample is 160 and 958 observations for fixed and floating regimes, respectively.

Figure 1

Conditional Variance: Czech Koruna

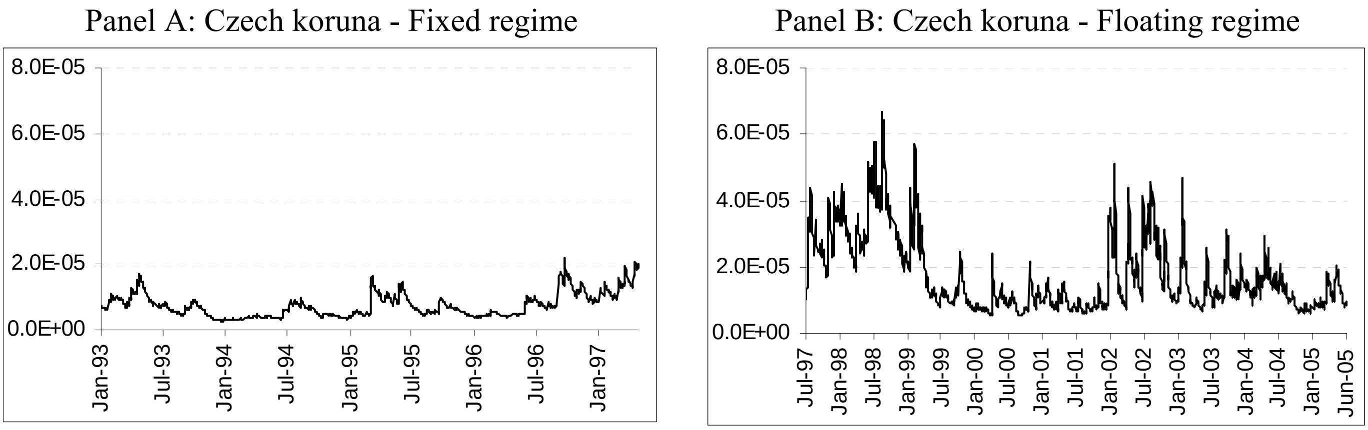


Figure 2

Conditional Variance: Slovak Koruna

Panel A: Slovak koruna - Fixed regime

Panel B: Slovak koruna - Floating regime

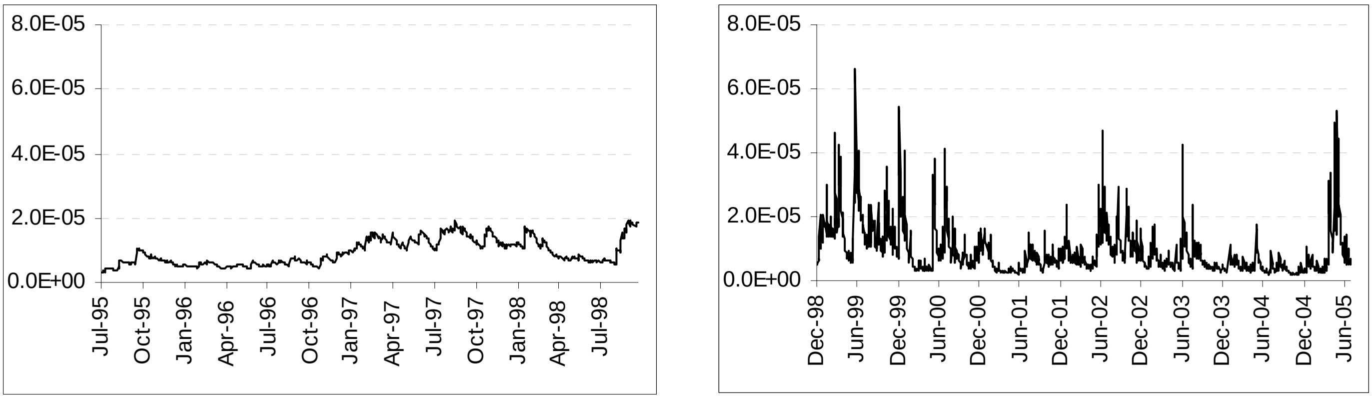


Figure 4

Conditional Variance: Polish Zloty

Panel A: Polish zloty - Fixed regime

Panel B: Polish zloty - Floating regime

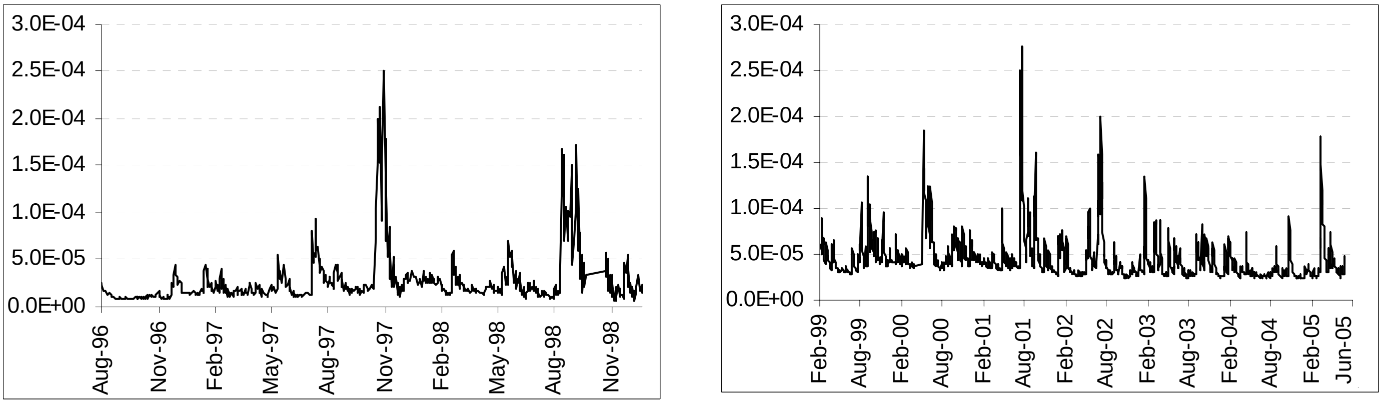
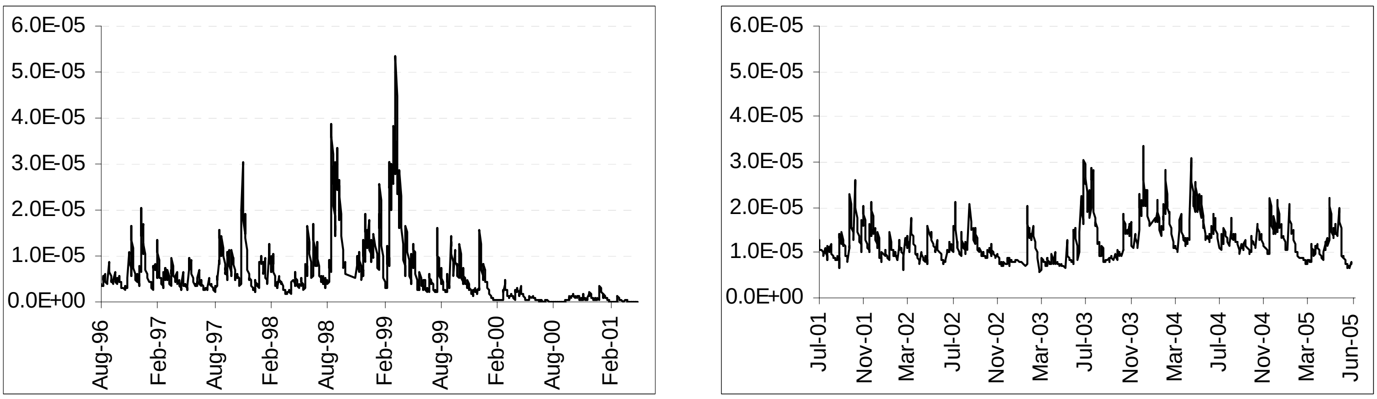


Figure 5

Conditional Variance: Hungarian Forint

Panel A: Hungarian forint - Fixed regime

Panel B: Hungarian forint - Floating regime



Appendix

Table A1

Exchange Rate Regime Development

A: Czech Republic

Changes to koruna exchange regime

1 January 1991	Currency basket peg regime, Basket: 45.52% DEM, 31.34% USD, 12.35% ATS, 4.24% GBP, 6.55% CHF
2 January 1992	Change in Basket composition: 36.15% DEM, 49.07% USD, 8.07% ATS, 2.92% FRF, 3.79% CHF
8 February 1993	Split of Czechoslovak currency – Czech koruna. No change in basket composition or band width
3 May 1993	Basket 65% DEM, 35% USD, Band ±0.5%
28 February 1996	Widening band to ±7.5%
26 May 1997	Introduction of managed float with reference currency DEM and later EUR

B: Slovakia

Changes to koruna exchange regime

1 January 1991	Currency basket peg regime, Basket: 45.52% DEM, 31.34% USD, 12.35% ATS, 4.24% GBP, 6.55% CHF
2 January 1992	Change in Basket composition: 36.15% DEM, 49.07% USD, 8.07% ATS, 2.92% FRF, 3.79% CHF
8 February- 1993	Split of Czechoslovak currency – Slovak koruna, Basket: 36.16% DEM, 49.06% USD, 8.07% ATS, 2.92% FRF, 3.79% CHF, Band ±1.5%
10 July 1993	Devaluation 10%
14 July 1994	Basket changed: 60% DEM, 40% USD
1 January 1996	Band ±3%
31 July 1996	Band ±5%
1 January 1997	Band ±7%
2 October 1998	Introduction of managed float
1 January 1999	Reference currency EUR

C: Poland

Changes to zloty exchange regime

1 January 1990	Exchange rate fixed to dollar. 1USD=9500 ZLP
16 May 1991	Exchange rate fixed to a currency basket (45% USD, 35% DEM, 10%GBP, 5% FRF, 5% CHF), devaluation to 1USD=11100ZLP (16.84%)
14 October 1991	Crawling peg to the currency basket: monthly rate 1.8%, margin +/- 0.6%
26 February 1992	Devaluation by 12% + maintain crawling peg 1.8%
27 August 1993	Devaluation by 7.4% + Crawling rate 1.6%
13 September 1994	Crawling peg 1.5 % monthly
30 November 1994	Crawling peg 1.4%
16 February 1995	Crawling peg 1.2 %
6 March 1995	NBP margin +/- 2%
16 May 1995	Introduction of crawling band +/-7%, crawling rate 1.2%, interbank rates subject to free market forces and NBP intervention
22 December 1995	Revaluation by 6%
8 January 1996	Crawling peg 1.0%
26 February 1998	Crawling peg 0.8% and band +/- 10%
17 July 1998	Crawling peg 0.65%
10 September 1998	Crawling peg 0.5%
28 October 1998	Band +/- 12.5%
1 January 1999	Change in currency basket: euro 55%, dollar 45%
25 March 1999	Crawling peg 0.3%, band +/- 15%
7 June 1999	NBP is not obliged to perform transactions with commercial banks during fixing
12 April 2000	Floating exchange rate

D1: Hungary

Changes in basket and width of the forint intervention band

26 February 1990	USD 42,6%, DEM 25,6%, ATS 10,4%, CHF 4,9 %, ITL 3,8%, FRF 3,5 %, GBP 2,9%, SEK 2,0%, NLG 1,7%, FIM 1,5%, BEC 1,1%
14 March 1991	USD 50,9%, DEM 23,1%, ATS 8,1%, CHF 3,9%, ITL 3,5%, FRF 3,6%, GBP 2,7 %, SEK 1,5%, NLG 2,7%
9 December 1991	USD 50% , ECU 50%
1 July 1992	Band width ± 0.3%
2 August 1993	USD 50% , DEM 50%
16 May 1994	USD 30% , ECU 70%
1 June 1994	Band width ± 0.5%
5 August 1994	Band width ± 1.25%
22 December 1994	Band width ± 2.25%
1 January 1997	USD 30% , DEM 70%
1 January 1999	USD 30% , EUR 70%
1 January 2000	EUR 100%
4 May 2001	Band width ± 15.00%

D2: Hungary

Official devaluations of forint

31 January 1990	1.0%
6 February 1990	2.0%
20 February 1990	2.0%
7 January 1991	15.0%
8 November 1991	5.8%
16 March 1992	1.9%
24 June 1992	1.6%
9 November 1992	1.9%
12 February 1993	1.9%
26 March 1993 2	.9%
7 June 1993	1.9%
9 July 1993	3.0%
29 September 1993	4.5%
3 January 1994	1.0%
16 February 1994	2.6%
13 May 1994	1.0%
10 June 1994	1.2%
5 August 1994	8.0%
11 October 1994	1.1%

29 November 1994	1.0%
3 January 1995	1.4%
14 February 1995	2.0%
13 March 1995	9.0%
16 March 1995	1.9% (daily devaluation: 0.060%)
29 June 1995	1.3% (daily devaluation: 0.042%)
2 January 1996	1.2% (daily devaluation: 0.040%)
1 January 1997	1.2% (daily devaluation: 0.040%)
1 April 1997	1.1% (daily devaluation: 0.036%)
15 August 1997	1.0% (daily devaluation: 0.033%)
1 January 1998	0.9% (daily devaluation: 0.030%)
15 June 1998	0.8% (daily devaluation: 0.026%)
1 October 1998	0.7% (daily devaluation: 0.023%)
1 January 1999	0.6% (daily devaluation: 0.020%)
1 July 1999	0.5% (daily devaluation: 0.0163%)
1 October 1999	0.4% (daily devaluation: 0.0133%)
1 April 2000	0.3% (daily devaluation: 0.0098%)
1 April 2001	0.2% (daily devaluation: 0.00654%)
1 October 2001	No devaluation
4 June 2003	One time 2.25% devaluation of central parity

Table A2

Shocks to Exchange Rates

	Total number of observations	Criterion for shock	Exchange rates		
			Depreciative shocks	Appreciative shocks	Total
Fixed exchange rate regime					
Czech koruna	1048	>5*SD	4	0	4
Slovak koruna	779	>5*SD	2	1	3
Polish zloty	553	>5*SD	3	2	5
Hungarian forint	1136	>5*SD	3	1	4
Floating exchange rate regime					
Czech koruna	1922	>5*SD	2	4	6
Slovak koruna	1593	>5*SD	3	1	4
Polish zloty	1535	>5*SD	2	2	4
Hungarian forint	958	>2*SD	19	14	33

Note: SD indicates the standard deviation.

Endnotes

[1] Mussa (1986), Stockman (1988), and Papell (1992) are examples of pioneering work.

[2] These events occurred relatively swiftly, often during turbulent periods of economic developments and conflicting monetary policies, which undoubtedly affected exchange rate volatility.

[3] The Maastricht criteria require that a country's currency should have participated without stress in the Exchange Rate Mechanism (ERM) for at least two years prior to being allowed to adopt the euro.

[4] As early as December 1991, the former Czechoslovakia, Poland and Hungary signed the European Agreement with the European Union. These countries have striven to establish a workable framework for international trade and cooperation in order to facilitate the transition process. Their effort was institutionalized in March 1993 in the form of the Central European Free Trade Agreement (CEFTA). In addition to the four Visegrad countries, the agreement was later signed by Slovenia, Bulgaria and Romania. On a broader scale, these four countries established a framework for political cooperation by signing the Visegrad agreement. In 1995 or 1996, each country applied for EU membership and they all became members in 2004.

[5] Bofinger and Wollmershäuser (2001) provide a comprehensive overview of this topic. Égert (2003) provides a critical survey of the literature on equilibrium exchange rates in the CEE accession countries. His paper covers the behavior of exchange rates under various regimes.

[6] Szapary and Jakab (1998) review Hungary's experience with the pre-announced crawling band exchange rate system from 1995 to 1997. Kemme and Teng (2000) provide a comprehensive analysis of exchange rate policies in Poland and their effect on export growth.

[7] Kočenda (2005) documents the existence of several key problems inherent to disorderly exits in the Czech Republic and Slovakia prior to the relaxation of exchange rate regimes.

[8] A looser exchange regime with the euro as a reference currency should be a credible peg with respect to the euro that allows for changes in the domestic currency in response to the market. Indeed, if a currency fluctuates within a ±15% band with respect to the euro, it implicitly follows the ERM II condition even if the country does not participate formally in

this mechanism. Orlowski (2001) proposes a sequence of steps towards monetary convergence to the euro zone based on autonomous monetary policy rather than on an early application of the euro-peg. He warns that a premature peg to the euro may lead to real currency appreciation, large capital inflows, and costly sterilization.

[9] Hau (2002) analyzes the link between the openness of an economy and real exchange rate movements for 48 countries and finds that trade integration and real exchange rate volatility are linked structurally and exhibit a negative correlation.

[10] We would like to thank Lucio Vinhas de Souza for pointing out this issue. As we discuss relative to the credibility issue, we chose the CEE countries having institutional frameworks that evolved similarly over the last 10 years. This framework consists of not only a common change from fixed to floating exchange rate regime but also similarities in the quality of the monetary authorities, the transition experience, the timing of EU accession process, EU entry, and the expected date of euro zone membership.

[11] To make this point, Kočenda (2001) and Kutan and Yigit (2004) document the continuously decreasing interest rate spreads.

[12] We thank an anonymous referee for this point.

[13] Andersen, Bollerslev, Diebold and Labys (2001) list three ways to approximate an otherwise unobservable volatility, namely by fitting parametric econometric models such as GARCH, by calculating direct indicators of volatility such as ex post squared or absolute returns, or by calculating volatility implied by option prices. In addition, the authors propose a new volatility measure, which they call realized volatility that is computed by summing intraday squared returns so that it is limited to data with intraday frequency.

[14] Chinn (2006) argues that capital account controls and political risk are the two main obstacles that prevent the UIP condition from holding in emerging markets.

[15] Since the NBP remains committed to a fully flexible exchange rate system while the CNB follows a managed float strategy and the NBH has applied an ERM II shadowing regime since October 2001, this result is expected.

[16] By following Svensson (1993) and Rose and Svensson (1994) and separating the interest rate differential into a domestic and foreign component, we could have allowed these two rates to have different impacts on the exchange rate. We decided to use this differential under the assumption that a change in the domestic or the foreign interest rate would have the same impact on the exchange rate and that only the level of the interest rate differential plays an important role.

[17] The GARCH specification implies that innovations have a symmetric impact on volatility. Whether the innovation variable, i.e. ε_t, is positive or negative makes no difference on the expected variance in the ensuing period because only the size of the innovation matters. In essence, good news and bad news have the same effect. The theory of the leverage effect, first described in Black (1976) in connection with the stock market, suggests that positive and negative innovations have a different impact. Hence, a large unanticipated drop in the market is expected to lead to higher volatility than would a large unanticipated increase of comparable magnitude.

[18] The specification of volatility with a threshold or leverage effect, represented by the dummy variable d_{t-1}, was introduced by Glosten, Jagannathan, and Runkle (1993) and applied to exchange rates in the transition context by Kočenda (1998) and Orlowski (2003). In the case of the exchange rate, the leverage effect represents the fact that a decrease in the price of a foreign currency in terms of a domestic currency, or a domestic currency's appreciation, tends to increase the subsequent volatility of the domestic currency more than would a depreciation of equal magnitude.

[19] This condition is sufficient but not necessary. For a destabilizing effect, we need only that $\alpha + \beta \geq 1$, which is less strict.

[20] In some instances the TGARCH-M specification reduces to TGARCH. Further, the parameter for the change in the interest rate differential was excluded from the model specification uniformly across all currencies.

[21] Orlowski and Rybinski (2006) use a similar approach.

[22] In 1999, a common European currency, the euro, replaced the national currencies of those countries that became members of the EMU for banking or essentially non-cash transactions. Since 2002, all transactions, including those made in cash, use euros. For the sake of consistency, we use the official fixed parity rate of 1 euro to 1.95583 Deutsch marks to recalculate exchange rates for the pre-1999 period.

[23] We concentrate on the four Visegrad countries for econometric reasons. Given our focus on volatility under different exchange rate regimes, we need reasonably long periods of experience under both regimes in each country. Considering the other post-transition accession countries, the three Baltic countries maintained fixed-type regimes for a long period without any reasonable experience with floating exchange rate regimes. In addition, Slovenia maintained a floating exchange rate regime *de iure* and a tightly managed crawling band regime *de facto* throughout most of this period and had a very short period of a fixed exchange rate regime during its early transition.

[24] We are grateful to an anonymous referee for clarifying this issue.

[25] This approach to the detection of outliers is similar to the methods used in Doornik and Ooms (2005) for GARCH models and in Giordani, Kohn and van Dijk (2006) or Battaglia and Orfei (2005) for general nonlinear time series models.

[26] The events are a referendum on early elections in November 2000 and April 2004, the presidential election in May 1999 and April 2004, regular parliamentary elections in September 2002, and political instability in June 2003.

[27] A negative coefficient on the first-order GARCH term occurs infrequently in empirical work. We attribute our finding to the fact that the exchange rate of the Polish zloty was heavily managed during the period of the tight regime. Since the second-order GARCH term is positive and larger that the first-order term and the remaining coefficients in the variance specification are also positive, the conditional variance is non-negative and well defined.

[28] We thank Lucjan Orlowski for sharing his insights on this topic with us.

[29] Leitemo (2004) studies the dynamics of interest rates and exchange rates as a game between monetary and fiscal policymakers in which the monetary policymaker targets inflation. In the Nash game, a conflict over the appropriate size of the output gap leads to excessive volatility of interest rates and exchange rates.

[30] Orlowski and Rybinski (2006) discuss the implications of ERM II for the monetary policy framework in Poland.