Exchange Rate Regimes and Volatility: Comparison of the Snake and Visegrad

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Abstract

Recent developments in exchange rates of the Central European countries (Visegrad Group) and selected group of the European Union countries (Snake) participating in the former European Monetary System was analyzed. We compared volatilities in currencies of both groups under specific exchange rate regimes. Currencies of the Snake countries exhibit lower volatility than currencies of the Visegrad Group under both fixed and floating regimes. After the change in exchange regime has taken place, volatility decreased uniformly in the Snake currencies. Results for the Visegrad Four currencies were in general inconclusive due to the lack of statistical significance. Limited evidence showed either moderate increase or unchanged volatility after the regime was modified.

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

JEL Classification: C14, C22, C51, E43, F31, F33, F36, P59

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1. Introduction

This paper analyzes volatility of the exchange rates of the Central European countries and compares it to volatility of exchange rates of the European Union countries participating in the former European Monetary System. Since exchange rate stability was defined as one of the prerequisites for monetary integration in Europe, the topic is important for prospective candidates from transition countries. Further, realized volatility under specific exchange rate regimes can be used to compare prospects of candidate countries for exchange rate policies during the pre-accession period.

The European Monetary System (EMS) was established in March 1979 as a way to stabilize exchange rates volatility within the countries of European Community (EC). According to the EMS, the EC countries agreed to limit fluctuations to their bilateral exchange rates in an obligatory way by interventions of national central banks that was known as the Exchange Rate Mechanism (ERM). From the beginning, all EC countries were members of the EMS but only eight of them initially participated in the ERM: Belgium, the Netherlands, Luxembourg, Denmark, France, Germany, Ireland, and Italy. Spain joined the ERM in 1989 followed by the United Kingdom and Portugal in 1990 and 1991, respectively. Only Greece remained out of the mechanism. However, after the major exchange rate crisis in September 1992, the United Kingdom and Italy stopped participating. After another crisis in August 1993, the ERM was redesigned to allow for wider fluctuation bands.

Thus, European Monetary System was created as a first step towards the full monetary integration of countries participating in this system (originally eleven countries). The essential feature of this system was that all countries adhering to the Exchange Rate Mechanism (ERM) fixed their currencies to all other currencies and then their exchange rate could fluctuate in range of ±2.25% from central parity.[1] Central banks of participating countries were obliged to keep their currencies within defined band. However, after many attacks and high market pressures (1992-1993), some central banks have to re-align the value of central parity and finally all central banks broaden the fluctuation band to ±15%. Despite that the exchange rate regime was formally still fixed, the width of the band (30% in absolute value) warrants to consider it as a floating regime. Therefore we consider the first part of EMS history dating from March 1979 to 1993 as a period with fixed exchange rate within a narrow band, and from 1993 up to 1999 (introduction of Euro) as a period with floating exchange rate. We hypothesize that volatility of exchange rates of the EMS member countries during the period of fixed regime should be different than volatility during the quasi-float regime from 1993 till 1999. Volatility during the latter period could be used as a proxy to measure exchange rate stability during such period. Thus, it could be used as a complementary measure of stability stipulated in one of the Maastricht criteria.

In Central Europe the institutional design of exchange rate regimes has varied across countries since the beginning of transition. The degree of exchange rate regime homogeneity is not comparable to that of the former EMS but we can observe certain evolutionary similarities. The exchange rates of the Czech Republic, Poland, Hungary, and Slovakia were from the beginning of transition process fixed. Czech and Slovak republics fixed their currencies to currency basket. Till January 1, 1993 both republics formed a federation and shared uniform exchange rate policy. Thus, at the beginning of transition, this currency basket consisted of five different currencies, later of US dollar and German mark. The weights of each currency in a basket were based on importance of a currency in foreign trade of a particular country. The width of the band was set at ±0,5% from central parity. After the separation Slovakia changed the band to ± 7% and later the Czech Republic changed it to ±7.5%. Central banks were obliged to intervene in the currency market to sustain the basket peg. The similar institutional evolution was encountered in Poland and Hungary. The only difference is that these two countries adopted pre-announce crawling peg to the basket of currencies. The central parity was not constant, as in case of the Czech Republic or Slovakia, but was changed each month. The periodic devaluations were announced ahead of time. In some cases the width of band has been changed throughout the time as well. Intricacy of such institutional design can be seized from the Table 1 that displays in an extensive detail all adjustments that central banks of four CEE countries adopted in exchange rate management. Abundance of these steps is unreservedly apparent in cases of Poland and Hungary.[2]

After turmoil on financial markets, the Czech republic adopted floating exchange rate regime in May 1997 as the first country in Central Europe. In October 1998, National Bank of Slovakia followed by adopting this regime as well. Later, Poland and Hungary left the fixed regime and adopted also floating one. Therefore, we can see a general tendency of easing

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[1] Wider band (±6%)was provided for Italy during the earlier stage of the system, as well as for Spain and Portugal.

[2] For additional details on regimes in transition countries see Tomczynska (1998).

from tight exchange regime to (more) loose exchange regime (Kocenda, 2002). Further, tendency to allow the markets to determine the price of national currency has been same for both the former EMS and Central European countries. The two groups are thus natural candidates for comparative purposes from exchange regime perspective. Nevertheless, there is another important motivation. All four central European countries have applied for European Union membership and already declared a wish to be part of Euro zone sooner or later. The membership alone does not mean an immediate participation in monetary union (or Euro zone). However, the EU membership will increase pressure to keep up institutional and economic environment and should even foster the Euro-conversion oriented development of exchange rates of Central European countries. Looser exchange regime with the Euro as a reference currency should be considered as pursuit of a credible peg of a domestic currency with respect to Euro that allows for necessary responses to market. As a matter of fact, if a currency fluctuates within a ±15% band with respect to Euro, then it implicitly follows the ERM II even it does not participate formally.

The uncertainty related to exchange rate volatility has been recognized as having damaging effects on working of the whole economic system.[3] Therefore, central banks adopt non-floating exchange rate regimes with aim at domestic currency stability. Computing degree of realized volatility is a usual way to assess evolution and performance of exchange rate system. For comparative purposes diffusion function can serve such intent. Specification of the diffusion function in models describing the evolution of exchange rates has been recognized in the finance literature as one of the most important features for derivative pricing. However, diffusion function is not important only for derivative pricing. The shape of the function can tell a lot about the characteristics of market and market expectations. Differences or similarities in shape of the curve of diffusion function can serve for their comparison. If diffusion functions of two different currencies are similar, we could say that these currencies are similar in terms of risk. Differences in shapes, on the other hand, would indicate differences in market environment and expectations. Similarly, shape of a drift function in financial models is also important. Usually it is modeled as mean reverting. In a case of currency prices, the mean (to which price reverts) is modeled as the interest rate

[3] It has been recognized in the finance literature that for correct derivative pricing, the one of the most important features is the specification of the diffusion function in models describing the evolution of exchange rate. Usual way how to assess the performance of particular exchange rate is calculating its volatility exhibited. The motivation is that uncertainty, materialized through volatility of exchange rate, has negative effect on functioning of whole economic system.

differential. Therefore, the shape of drift function can be understood as the way the currency complies with interest rate parity. Moreover from shape of this function we can figure out how quickly, if ever, the price process adapts to deviations from interest rate parity.

The remainder of article is as follows. In section 2 we introduce the methodology used. The section 3 describes the data, while in Section 4 we present results. The brief comments conclude. Technical details are given in Appendix.

2. Methodology

The currency markets of Central Europe are usually not well covered in empirical finance literature. The research dealing with emerging markets concentrates mainly on the "old" emerging markets, e.g. Indonesia, Mexico, Thailand etc. and “new” emerging markets are largely neglected. The lack of studies thus offers a few hints on specifications of the drift and diffusion functions and miss-specification problem can be an important issue.

The diffusion function can be estimated using the most general parametric specification of Ait-Sahalia (1996) that was developed to model the behavior of interest rates. The general parametric model gives more precise estimates on smaller data samples. In general, a continuous time models for interest rate typically rest on one or more stationary diffusion processes with dynamics represented by Itô stochastic differential equation:

$$dr_t = m(r_t)dt + s(r_t)dW_t,$$

where function $m(r_t)$ is drift function, $s(r_t)$ is diffusion function, and $\{W_t, t \geq 0\}$ is a standard Brownian motion. Usually, functions for drift and diffusion are parameterized. Particular models differ in shape of drift, but mainly in shape of diffusion function. Ait-Sahalia (1996) model offers quite rich parametric specification. The model has following specification:

$$m(r,q) = a_0 + a_1 r_t + a_2 r_t^2 + \frac{a_3}{r_t}$$

$$s^2(r,q) = b_0 + b_1 r_t + b_2 r_t^{b_3}$$

By imposing restrictions on parameters’ values such specification could encompass many earlier models. For example, restriction $a_2 = a_3 = b_1 = b_2 = b_3 = 0$, would yield Vasicek (1977) model. On the other hand, Cox, Ingersoll and Ross (1985) model can be obtained by imposing restriction $b_3 = 1$.

Recently Elerian, Chib and Shephard (2001) introduced a new methodology to estimate nonlinear stochastic differential equations when observations are discretely sampled.

This methodology is able to increase precision of estimates in cases where one is left with low number of observations. They compare estimates from their specification with that of Ait-Sahalia (1996) and find that their estimates perform well even in smaller data samples.

Ait-Sahalia (1996) argues that his specification can be extended to estimate mean and volatility of exchange rates. We do not find enough theoretical motivation behind such specification to apply it in its entirety on exchange rates. Rather, we develop a model in spirit of interest rate parity that has theoretical foundation in it. The formal derivation of the model specification is given in the Appendix. We use the specification that models change in exchange rate in the following form for drift and diffusion functions:

$$m(\Delta S, q) = a_1 \left(i_t - i_t^*\right) + a_2 \left(i_t^{\,2} - i_t^{*2}\right) + a_3 \left(i_t^{\,3} - i_t^{*3}\right) \tag{1}$$

$$s^2(\Delta S, q) = b_0 + b_1 \left(i_t - i_t^*\right) + b_2 \left(i_t - i_t^*\right)^2 \tag{2}$$

where S is a log price of foreign currency in terms of domestic one, i_t is domestic interest rate, i_t^* is foreign interest rate.

The richly specified m and s^2 functions of the spot exchange rate have not been previously introduced in the related literature. Moreover, the empirical evidence so far suggests that miss-specification of the models in the literature is caused jointly by the linearity of the drift and constant diffusion. These are the two reasons why we decide for the rich nonlinear parametric specification of the drift (mean) and diffusion (volatility) functions derived on the basis of interest rate parity.

The estimation of the model is performed in two steps using the feasible least squares.[4] First we estimate the discretized version of the drift equation (1) in the form:

$$E\left[\ln\left(S_{t+1}\right) - \ln\left(S_t\right) \mid S_t\right] = a_1 \left(i_t - i_t^*\right) + a_2 \left(i_t^{\,2} - i_t^{*2}\right) + a_3 \left(i_t^{\,3} - i_t^{*3}\right) + e_t \tag{3}$$

The squared residuals e_{t+1}^2 from this first-stage regression are then regressed by least squares, with a discretized version of the diffusion equation (2) in the form:

$$E\left[e_{t+1}^2 \mid S_t\right] = b_0 + b_1 (i_t - i_t^*) + b_2 (i_t - i_t^*)^2 . \tag{4}$$

The second-stage regression for the drift uses the fitted values from the diffusion regression to form the weighting matrix for the generalized least-squares estimation of discretized drift. The first-stage residuals scaled by the fitted standard errors (standardized residuals) $e_{t+1} \big/ \sqrt{b_0 + b_1(i_t - i_t^*) + b_2(i_t - i_t^*)^2}$ should be white noise.

3. Data

For the purpose of comparative analysis we use two groups of countries with similar economic and institutional development with respect to exchange rate regime. In case of the EMS countries we use the group of countries that adopted tight exchange rate regime even prior to EMS. The group of countries, so-called "Snake", consists of Germany, the Netherlands, Belgium, and Denmark; it also included France on several occasions. In 1973, these countries fixed their exchange rates with each other while jointly floating against other countries. In 1979 these countries were among the founders of the EMS and during its history never deviated from the ERM. For this reason we consider this group as a benchmark cases.[5] In 1993 all countries widened their fluctuation band and from this year we can consider the floating exchange rate system.

As for the Central European countries we chose the so-called Visegrad Four group that consists of the Czech Republic, Hungary, Poland, and Slovakia. As early as December 1991, the former Czechoslovakia, Poland and Hungary signed the so-called "European Agreements" with the European Union. These countries have striven to establish a workable framework for international trade and co-operation 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), that was signed also by Slovenia.[6]

We use the nominal exchange rates expressed in terms of Deutsche mark (or Euro) to calculate changes in exchange rate over two consecutive periods. We use interest rates of one-month maturity to calculate needed interest rate differentials. In literature we may find also

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[4] The estimation procedure is same as in Ait-Sahalia (1996).

[5] Kocenda and Pappel (1997) find out that countries which continuously participated in the narrow ERM band show a dramatically higher convergence rate of inflation during the ERM period than those staying outside the mechanism. They explain this fact by institutional reasons.

[6] Kocenda (2001) examines the macroeconomic convergence of Central European countries. He finds that the group of five countries that signed the original CEFTA agreement display similar and relatively high degrees of convergence in most variables. He attributes this finding to two factors. First, international trade within CEFTA

shorter maturities used. However, one-month maturity is the maturity that is published in each country for the longest period. It is also a standard reference interest rate for most of central banks.

The motivation for our comparison lies in a change from one exchange rate regime to another. The date of change from fixed to floating exchange rate regime is our anchor date. For Snake countries it is uniformly August 2, 1993. However, for Visegrad Four countries the day when countries change their exchange rate regime was always different. The national banks introduced floating regime on the following dates: May 26, 1997 in the Czech Republic, on October 2, 1998 in Slovakia, and on April 12, 2000 in Poland. In case of Poland, we can consider a close parallel to the post-1993 development of the EMS. Poland introduced a wide fluctuation band of ± 15.0% (same as the EMS) on March 25, 1999. The same development is found in Hungary where the band was widened also to ± 15.0% on May 4, 2001 and no further monthly devaluations were implemented.

Since the decisive point in time is the date of change from fixed to floating regime, the time span for Snake countries begins on January 1, 1988 (5 years prior to change) and last till December 31, 1998 (5 years after the change). As for the Visegrad Four countries we use the maximum length available prior and post the change of regime, namely the data beginning in January 1993 to July 2002.

4. Empirical Results

4.1 Correlation analysis

We first perform a simple correlation analysis among pairs of currencies. We take into account two forces that drive the exchange rate evolution: (1) institutional setup, e.g. either fixed or floating regime, and (2) market environment. We isolate their influences by the following manner.

The first is the institutional setup. We arrange all exchange rates time series in such a way that the days of introduction of the floating regime exactly overlap. This way we shift the time series in a way that they do not coincide with respect to the real time, but they do with respect to exchange rate regime. The graphs of shifted time series are in Figure 1.A. We calculate the corresponding correlation coefficients for the sample with maximum overlap. The results are in Panel A of Table 2.

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framework serves as a natural means of coordinating economic development. Second, the prospective accession to the EU serves as an institutional means of coordination in order to satisfy a set of pre-accession criteria.

The second approach is the market environment. For this case we use time series without any shifts and we pair them in real time in their full available length, separately for two defined groups of countries. Graphs of the series are in Figure 1.B. The correlations are calculated and results presented in Panel B of Table 2.

The third point is the combination of the above: institutional setup and market environment. All time series are taken in real time and correlations are calculated for the period when all countries in a group had the same exchange rate regime. The situation is simple for the Snake countries, because we cannot separate institutional setup from market environment. All five countries had floating regime introduced on the same date. The time series of exchange rates of Snake countries are in Figure 2. The correlation coefficients are in Table 3. In case of the Visegrad Four countries the arrangement is different since the floating regime was introduced at different dates. The period of overlapping currency basket peg regime is from Januar1, 1993 to May 27, 1997 and period of floating regime is from May 4, 2001 to July, 31, 2002. The correlation coefficients are presented in Panel C of Table 2.

In order to compute correlations for both the mean and volatility we transform our daily data to monthly frequencies. This enables us to compute correlations, not only among the means but also among volatilities within particular group. When comparing an absolute level of correlation among the Visegrad Four currencies, in most cases the largest values are found when an institutional set-up and market do overlap. This finding is consistent both for mean as well as volatility. In case of the Snake countries we have an institutional and market overlap by definition. The values of correlation coefficients for drift and volatility are very similar to the values of Visegrad Four currencies.

4.2 Model estimation

We have estimated model for mean and volatility as specified by equations (3) and (4). First we present results for the Visegrad Four currencies, separately for the periods of different exchange rate regimes. The results are in Table 4. Then we present results for the Snake currencies in Table 5.

Because of the change in exchange rate regime, we expect the parameters of the drift and diffusion to be different during different regimes. More preciously, the particular parameterization is not time-homogenous. For example, the coefficient a_1 of the process estimated during float should be higher than that estimated over the fixed regime. Unfortunately, lack of statistical significance precludes making any unambiguous conclusion with this respect for both groups of currencies. The lack of significance is present for other coefficients of the mean function as well.

Most important and illustrative part of estimation are the values of coefficients in volatility function. Among them the coefficient $ß_0$ plays the pivotal role. This coefficient captures the extent of volatility that does not depend on fluctuations in interest rate differential. The other coefficients ($ß_1$ and $ß_2$) portray the volatility movements dependent on these fluctuations. The statistical significance of coefficients $ß_0$ allows inferring several interesting conclusions. Volatility during fixed regime period is uniformly higher in Visegrad Four currencies than in the Snake currencies. Volatility during floating regime period is also uniformly higher in Visegrad Four currencies than in the Snake currencies.

When we compare changes in volatility magnitude in between periods of fixed and floating regime the findings render interpretation for all Snake currencies, but only half of Visegrad Four currencies due to lack of significant coefficients in floating regime period. The Snake currencies exhibit uniformly substantial decrease of volatility. As for the Visegrad Four currencies the Czech koruna shows moderate increase in volatility and Slovak koruna shows a marginal decrease in volatility. Results for Hungarian forint and Polish zloty are inconclusive due to lack of statistical significance.

5. Conclusions

We analyzed volatility of the exchange rates of the Central European countries (Visegrad Group) and selected group of the European Union countries (Snake) participating in the former European Monetary System. We compared volatilities in currencies of both groups under specific exchange rate regimes. Currencies of the Snake countries exhibit lower volatility than currencies of the Visegrad Group under both fixed and floating regimes. After the change in exchange regime has taken place, volatility decreased uniformly in the Snake currencies. Results for the Visegrad Four currencies were in general inconclusive due to the lack of statistical significance. Limited evidence showed either moderate increase or unchanged volatility after the regime was modified. Our findings can be used to compare prospects of candidate countries for exchange rate policies during the pre-accession period.

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Appendix

In the Appendix we derive the mean and volatility specifications. We begin with the conventional notion of the interest rate parity in a form:
$\frac{F}{S}\left(1+i^*\right)=\left(1+i\right)$, where S is exchange rate at time t, F is exchange rate at time $t+1$, , i is domestic interest rate, and i^* is foreign interest rate. Taking the natural log of the above results in

$ln\frac{F}{S}=ln\frac{(1+i)}{\left(1+i^*\right)}$, that can be further rewritten as $ln\,F-ln\,S=ln(1+i)-ln\left(1+i^*\right)$.

Taylor expansion of $ln(1+x)=x-\frac{x^2}{2}+\frac{x^3}{3}-\frac{x^4}{4}+\frac{x^4}{5}+....\ \ if\ -1<x\leq 1$ can be used express the interperiod change in exchange rate as

$d\,ln\,S=i-\frac{i^2}{2}+\frac{i^3}{3}+o\left(i^4\right)-\left(i^*-\frac{i^{*2}}{2}+\frac{i^{*3}}{3}+o\left(i^{*4}\right)\right)$. After rearranging the terms and neglecting the forth and higher order terms we obtain the expression of interperiod change in exchange rate as a function of domestic and foreign interest rate:
$d\,ln\,S=i-i^*-\left(\frac{i^2-i^{*2}}{2}\right)+\left(\frac{i^3-i^{*3}}{3}\right)$. This is our mean (drift) equation.
In order to derive the specification for volatility we start with previously defined equation derived from interest rate parity, $ln\frac{F}{S}=ln\frac{(1+i)}{\left(1+i^*\right)}$, and define the variance of both sides as

$\text{var}\left(\ln\frac{F}{S}\right)=\text{var}\left(\ln\frac{(1+i)}{\left(1+i^*\right)}\right)$.

Let's denote: $s^2=\text{var}(d\ln S)=\text{var}\left(\ln\frac{F}{S}\right)$. Further, since $\text{var}(g(x))\cong g'^2(m)\text{var}(x)$, then in our case $g(x)=\ln(x)$, $g'(x)=1/x$, and $s^2=\left(\frac{\overline{\left(1+i^*\right)}}{(1+i)}\right)^2\text{var}\left(\frac{(1+i)}{\left(1+i^*\right)}\right)$.

Let's denote $K=\left(\frac{\overline{\left(1+i^*\right)}}{(1+i)}\right)^2$. Then expression for volatility will be

$s^2=K\,\text{var}\left(\frac{(1+i)}{\left(1+i^*\right)}\right)=K\,\text{var}\left(1+\frac{i-i^*}{1+i^*}\right)=K\,\text{var}\left(\frac{i-i^*}{1+i^*}\right)\approx K\,\text{var}\left(i-i^*\right)$. When we expand the expression for variance of interest rate differentials we obtain
$s^2=K\,\text{var}\left(i-i^*\right)=K\left[\left(i-i^*\right)-\overline{\left(i-i^*\right)}\right]^2=K\left[\left(i-i^*\right)^2-2*\left(i-i^*\right)\overline{\left(i-i^*\right)}+\overline{\left(i-i^*\right)}^2\right]$.
Finally, expression for volatility of exchange rate changes as a function of interest rate differentials is written as $s^2=K\left[\left(i-i^*\right)^2-2*\left(i-i^*\right)\overline{\left(i-i^*\right)}+\overline{\left(i-i^*\right)}^2\right]$.

This implies the following regression specification of volatiltiy as

$$s'^{2}(S,q) = b_0 + b_1\left(i_t - i_t^*\right) + b_2\left(i_t - i_t^*\right)^2,$$

where $s'^{2} = s^{2} \Big/ \left(\frac{\overline{(1+i^*)}}{(1+i)}\right)^2$, $b_0 = \overline{(i-i^*)}^2$, and $b_1 = -2*\overline{(i-i^*)}$.

Hence, our specification of mean and volatility results in to the following pair of equations:

$$m(\Delta S,q) = a_1\left(i_t - i_t^*\right) + a_2\left(i_t^2 - i_t^{*2}\right) + a_3\left(i_t^3 - i_t^{*3}\right)$$

$$s^{2}(\Delta S,q) = b_0 + b_1\left(i_t - i_t^*\right) + b_2\left(i_t - i_t^*\right)^2$$

Table 1
Exchange Rate Regime Development

A: 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%

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% (rate of daily devaluation: 0.060%)
29 June 1995	1.3% (rate of daily devaluation: 0.042%)
2 January 1996	1.2% (rate of daily devaluation: 0.040%)
1 January 1997	1.2% (rate of daily devaluation: 0.040%)
1 April 1997	1.1% (rate of daily devaluation: 0.036%)
15 August 1997	1.0% (rate of daily devaluation: 0.033%)
1 January 1998	0.9% (rate of daily devaluation: 0.030%)
15 June 1998	0.8% (rate of daily devaluation: 0.026%)
1 October 1998	0.7% (rate of daily devaluation: 0.023%)
1 January 1999	0.6% (rate of daily devaluation: 0.020%)
1 July 1999	0.5% (rate of daily devaluation: 0.0163%)
1 October 1999	0.4% (rate of daily devaluation: 0.0133%)
1 April 2000	0.3% (rate of daily devaluation: 0.0098%)
1 April 2001	0.2% (rate of daily devaluation: 0.00654%)
1 October 2001	No devaluation

B: Czech Republic
Alterations of koruna exchange regime

1 January 1991	Fixed exchange rate 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

C: Poland
Changes of 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: crawling rate 1.8% monthly, NBP 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

D: Slovakia
Alterations of koruna exchange regime

1 January 1991	Fixed exchange rate 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, Band +/-7%
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

Table 2
Correlation Matrices: Visegrad Four

A: Institutional Overlap (Monthly)

Drift

	CZK	SKK	PLN	HUF
CZK	*1*			
SKK	0.485	*1*		
PLN	-0.555	-0.587	*1*	
HUF	-0.503	-0.681	0.787	*1*

Volatility

	CZK	SKK	PLN	HUF
CZK	*1*			
SKK	0.625	*1*		
PLN	0.065	0.052	*1*	
HUF	0.414	0.279	0.199	*1*

B: Market Overlap (Monthly)

Drift

	CZK	SKK	PLN	HUF
CZK	*1*			
SKK	-0.085	*1*		
PLN	0.520	-0.497	*1*	
HUF	0.540	-0.354	0.891	*1*

Volatility

	CZK	SKK	PLN	HUF
CZK	*1*			
SKK	0.395	*1*		
PLN	0.311	0.322	*1*	
HUF	0.119	0.217	0.338	*1*

C: Institutional and Market Overlap (Monthly)

Drift

	CZK	SKK	PLN	HUF
CZK	*1*			
SKK	-0.392	*1*		
PLN	0.791	-0.614	*1*	
HUF	0.890	-0.473	0.946	*1*

Volatility

	CZK	SKK	PLN	HUF
CZK	*1*			
SKK	0.543	*1*		
PLN	0.480	0.406	*1*	
HUF	0.352	0.386	0.464	*1*

Table 3
Correlation Matrix: Snake

Drift

	BEF	FRF	NLG	DKK
BEF	*1*			
FRF	0.597	*1*		
NLG	0.004	-0.487	*1*	
DKK	0.668	0.931	-0.474	*1*

Volatility

	BEF	FRF	NLG	DKK
BEF	*1*			
FRF	0.388	*1*		
NLG	0.253	0.219	*1*	
DKK	0.592	0.473	0.313	*1*

Table 4

Mean and Volatility coefficients: Visegrad Four

A: Fixed regime

	Alpha 1	Alpha 2	Alpha 3	Beta 0	Beta 1	Beta 2
CZKDEM	-0.047	-0.913	-4.783	2.8E-06 [1]	5.3E-06	1.1E-04
	(0.031)	(0.682)	(3.301)	(4.1E-7)	(8.1E-6)	(1.4E-4)
SKKDEM	0.013	0.176	0.517	2.7E-06 [1]	-5.6E-06	1.0E-05
	(0.016)	(0.174)	(0.439)	(7.0E-7)	(5.6E-6)	(4.0E-5)
PLNDEM	-0.014	-0.337	-1.355	4.6E-05 [1]	2.1E-04 [1]	1.2E-03 [1]
	(0.111)	(1.072)	(2.733)	(9.8E-6)	(6.3E-5)	(3.9E-4)
HUFDEM	-0.037 [5]	-0.595 [5]	-2.074 [5]	3.4E-06 [1]	-3.7E-05 [1]	-2.5E-04 [1]
	(0.018)	(0.283)	(1.022)	(5.9E-7)	(5.0E-6)	(3.9E-5)

B: Floating regime

	Alpha 1	Alpha 2	Alpha 3	Beta 0	Beta 1	Beta 2
CZKDEM	0.025	0.818	4.962	3.7E-06 [1]	-2.2E-05 [5]	-7.5E-05
	(0.030)	(0.639)	(3.206)	(3.7E-7)	(9.4E-6)	(1.4E-4)
SKKDEM	-0.034	-0.578 [10]	-2.204 [10]	2.6E-06 [1]	8.4E-06 [10]	1.5E-04 [1]
	(0.023)	(0.352)	(1.202)	(4.1E-7)	(5.4E-6)	(5.8E-5)
PLNDEM	-0.118	-0.269	2.040	2.5E-05	1.1E-04	1.9E-03
	(0.219)	(3.075)	(11.611)	(2.2E-5)	(2.3E-4)	(2.1E-3)
HUFDEM	-0.492	-12.268	-82.134	4.9E-05	-8.9E-04	-1.4E-02
	(1.069)	(31.936)	(217.476)	(5.2E-5)	(8.5E-4)	(1.4E-2)

Table 5

Mean and Volatility coefficients: Snake

A: Fixed regime

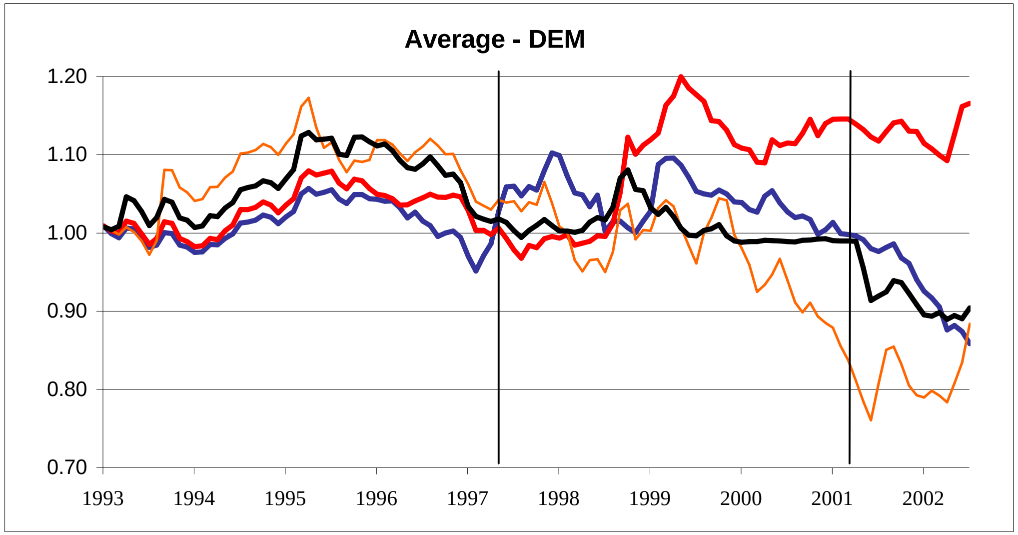
	Alpha 1	Alpha 2	Alpha 3	Beta 0	Beta 1	Beta 2
BEFDEM	-0.050	-2.084	-18.695	1.9E-07 [1]	-5.0E-07	5.3E-05
	(0.043)	(1.844)	(15.414)	(1.1E-8)	(1.0E-6)	(3.5E-5)
FRFDEM	0.140	2.551	10.662	4.1E-07 [1]	-1.8E-06	-3.2E-05
	(0.125)	(2.196)	(9.443)	(3.7E-8)	(2.4E-6)	(1.0E-4)
NLGDEM	-0.433	-10.622	-65.810	9.3E-08 [1]	-2.4E-06	7.2E-04
	(0.812)	(19.828)	(119.669)	(6.1E-9)	(1.7E-6)	(5.4E-4)
DKKDEM	0.051 [5]	0.733 [1]	2.353 [1]	4.9E-07 [1]	-2.1E-06 [5]	-1.7E-05
	(0.024)	(0.284)	(0.765)	(4.6E-8)	(1.0E-6)	(1.1E-5)

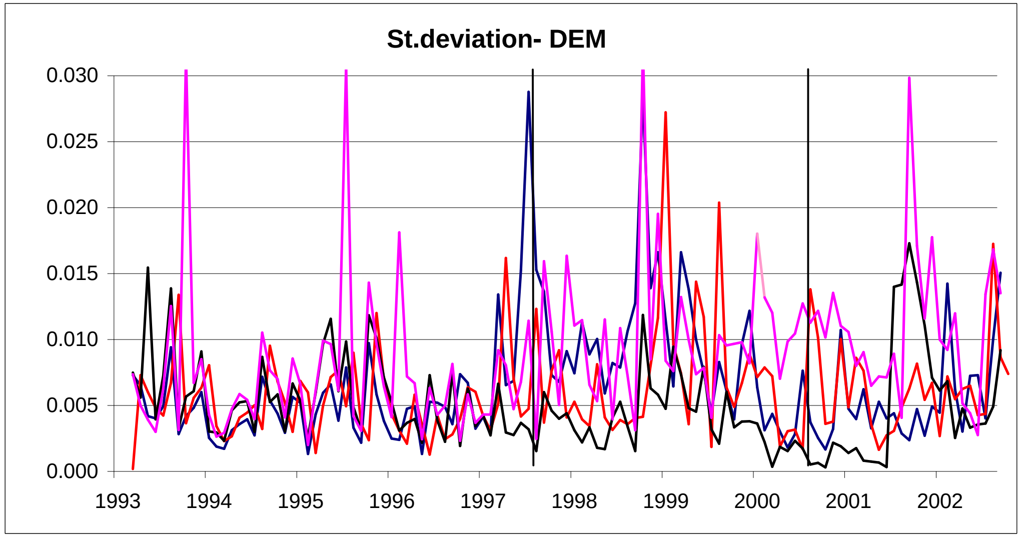
B: Floating regime

	Alpha 1	Alpha 2	Alpha 3	Beta 0	Beta 1	Beta 2
BEFDEM	0.598 [1]	24.494 [1]	204.881 [1]	8.1E-08 [1]	1.0E-05 [1]	7.8E-03 [1]
	(0.043)	(1.413)	(11.169)	(4.7E-9)	(9.6E-7)	(8.1E-5)
FRFDEM	-0.135	-4.808	-54.362 [10]	2.1E-07 [1]	-3.1E-05 [1]	-1.4E-03 [1]
	(0.093)	(3.335)	(29.390)	(2.4E-8)	(3.0E-6)	(1.9E-4)
NLGDEM	0.002	0.623	11.651	4.8E-08 [1]	1.1E-06	8.2E-05
	(0.083)	(3.897)	(42.506)	(2.8E-9)	(1.1E-6)	(4.1E-4)
DKKDEM	-0.216 [1]	-8.281 [1]	-81.712 [1]	1.0E-07 [1]	-5.0E-06 [5]	-2.1E-04
	(0.042)	(1.364)	(11.220)	(2.0E-8)	(1.9E-6)	(1.5E-4)

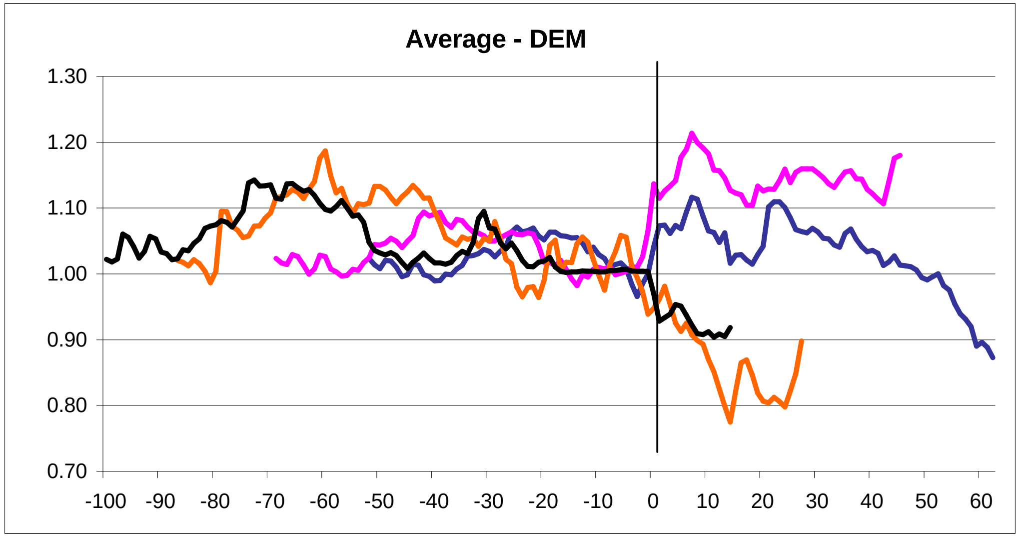
Figure 1
Visegrad Four series

A: Real time series





B: Shifted series



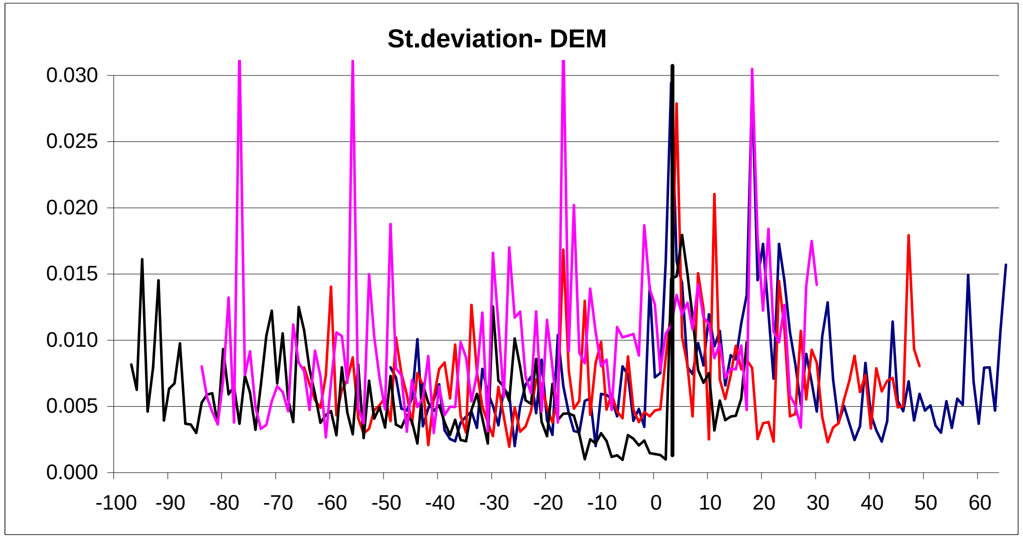


Figure 2
Snake real time series