Volatility Regimes
in Central and Eastern European
Countries' Exchange Rates

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Abstract:

The choice of an exchange rate arrangement affects the volatility of the exchange rate: higher flexibility goes ahead with increasing volatility and vice versa (Flood and Rose 1995, 1999). We investigate the exchange rate volatility of six Central and Eastern European countries (CEEC) between 1994 and 2004. The analysis merges two approaches, the GARCH-model (Bollerslev 1986) and the Markov Switching Model (Hamilton 1989). We discover switches between high and low volatility regimes which are consistent with policy settings for Hungary, Poland and, less pronounced, the Czech Republic, whereas Romania and Slovakia do not show a clear picture. Slovenia, finally, shows some kind of anticipation of the wide fluctuation margins in ERM2.

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1 Introduction

Central and Eastern European countries (CEEC) have experienced remarkable changes in their settings of exchange rate arrangements as well as in monetary policy. They are often regarded as examples for the hollowing out of intermediate exchange rate regimes (see for a general discussion of the hollowing the middle hypothesis inter alia Obstfeld and Rogoff 1995, Fischer 2001). Most countries started with more or less pronounced intermediate exchange rate regimes, and then have chosen different ways of adjusting them on their way in transition. The credibility of these arrangements was crucial for their success (for the need of credibility see for instance De Grauwe and Grimaldi 2002). Similar problems of the credibility of the exchange rate regime[1] are known from the history of the exchange rate mechanism (ERM) of the European monetary system (EMS) between 1979 and 1999. There are, however, two main differences: First, the CEEC form a much more heterogeneous group than the former participants in the ERM regarding their exchange rate policy, because the ERM was supposed to be symmetric and the legal conditions were identical for all members. The CEEC in contrast have chosen very different exchange rate policies from the beginning and were not affected by any legal restrictions as they opted unilaterally for their policy settings. Second, the EMS members did not experience such remarkable changes in their policy settings than the CEEC. The ERM did not perform any major modifications in its modus operandi. The only real change was the widening of the intervention band after the second EMS crisis in

1 The credibility of the exchange rate system can of course not be separated from the credibility of the monetary policy.

1993. For the CEEC we can observe an increasing degree of exchange rate flexibility between 1994 and 2004, too[2]. Increased flexibility of the exchange rate, however, may not necessarily lead to higher volatility. Krugman (1991) argues that widening the fluctuation band will make it more credible, because it gets less likely that the fluctuation margins are reached and consequently volatility decreases. In contrast, Flood and Rose (1995, 1999) conclude that fixed exchange rate regimes are in general less volatile than floats.

Therefore, taking a closer look at the exchange rates' behaviour in the CEEC should provide some interesting insights. Kočenda (2005) argues that a lack of coincidence between policy changes and structural breaks in the exchange rate behaviour may hint at policy settings which are not consistent with the opinion of market participants and therefore low credibility of the system. This is in line with the observation that, if the costs of changing an exchange rate regime are high, a country may uphold an exchange rate regime, although it is not the optimal choice or even unsustainable in the long run (Eichengreen and Masson 1998; Juhn and Mauro 2002).

Empirical results by Berger et al. (2000) indicate that not only the type of the exchange rate regime affects volatility, but even a "wrong" choice of a peg (that is the choice of a peg by a country for which a flexible exchange rate would be more appropriate) induces higher exchange rate volatility than a peg which is in line with the macroeconomic condition. Volatility can be seen as a measure of credibility of policy settings and has been investigated for exchange rates in the EMS (Frömmel and Menkhoff 2001) as well as for interest rates in the EMS (Dahlquist and Gray 2000, Sarantis and Piard 2001, Arestis and Mouratidis 2004). It serves as "a symbolic and visible measure of the government's success in macroeconomic management." (Dut-

[2] When the first countries joined ERM2, this tendency was stopped and changed its direction. Slovakia and Slovenia, which had officially announced quite flexible exchange rate arrangements then started to peg the Slovak koruna and the Slovenian tolar to the Euro within a band of ±15 per cent.

tagupta et al. 2004). Wilfling (2002) shows that there were significant anticipation effects prior to the introduction of the Euro, reflected by a change in the volatility regime.

Changes in exchange rate volatility may have different reasons: It is well known that the choice of an exchange rate regime strongly influences exchange rate volatility[3]. Frömmel and Menkhoff (2003) additionally identify changes in monetary policy settings as a determinant of volatility switches.

There are, however, few works which investigate structural breaks in the exchange rates of Central and Eastern European transition economies. Kočenda (1998) compares GARCH estimates for the Czech Koruna before and after the exchange rate band was widened in 1996 and finds significantly differing volatility patterns. Kóbor and Székely (2004) apply a simple Markov Switching Model to the exchange rates of the so-called Visegrád Group (Czech Republic, Hungary, Poland and Slovakia) between 2001 and 2003 and find frequent regime switches. Their sample period, however, does not include any change of the officially announced exchange rate system. Kočenda (2005) tests for one-time structural breaks in the mean process of the exchange rates of a broad set of Central and Eastern European countries (CEEC). He finds a break for most countries. Linking them to changes in exchange rate arrangements hints at imperfect timing of official regime switches. Frömmel and Schobert (2006) test for the Visegrád countries, Slovenia and Romania for changes in (partly implicit) basket compositions and find several significant structural breaks.

Besides the credibility problem of intermediate exchange rate regimes, there is another, econometric reason to investigate structural breaks in exchange rate volatil-

[3] See inter alia for the change to flexible exchange rates in major industrial countries Flood and Rose (1995, 1999) and for the introduction of the European Monetary System Hughes Hallett and Anthony (1997).

ity: The well-known and popular GARCH model, based on the seminal works by Engle (1982) and Bollerslev (1986), has turned out to become the workhorse in estimating volatility. It is widely used[4] and provides accurate forecasts (Andersen and Bollerslev 1998). However, problems in estimating GARCH models may arise if the underlying volatility process is subject to structural breaks, especially shifts in the overall level of volatility. The empirical literature shows (see for instance Klaassen 2002) that the sum of the estimated GARCH coefficients is very close to or even exceeds one, implying that the variance process is (almost) non-stationary. Klaassen (2002) argues that this high persistence of volatility shocks in single-regime GARCH models is due to neglecting regime changes, that is the model is misspecified. In this case the persistence of volatility shocks is systematically overestimated (Lamoureux and Lastrapes 1990; Timmermann 2000, Caporale et al. 2003). A common way to deal with such structural breaks is to introduce dummy variables for subperiods reflecting the change in volatility level. In most cases, however, it is not possible to determine the date of the shift sufficiently accurately, or the date itself is subject to the analysis and cannot be determined exogenously. Therefore we apply a Markov Switching GARCH model (MS-GARCH) for modelling the structural break endogenously. This model merges the classical GARCH model (Bollerslev 1986) with the Markov switching model (Hamilton 1989).

Thus, the contribution of this paper to the empirical literature on CEEC's exchange rates is twofold:

First, we investigate structural breaks in exchange rate volatility over a sample which covers almost the whole process of transition for a broad set of six Central and

4 For surveys see, inter alia, Bollerslev, Chou and Kroner (1992), Bollerslev, Engle and Nelson (1994), Franses and van Dijk (2000), Poon and Granger (2003).

Eastern European Countries: the Czech Republic, Hungary, Poland, Romania, Slovenia and Slovakia. Except Romania they are all member of the European Union (EU) and will subsequently join the European Monetary Union (EMU) during the next years[5]. Romania will probably join EU in 2007. We do not consider other new central European member or candidate countries because they have opted for very fixed exchange rate regimes without major changes[6]. Therefore we cover all countries which have recently joined the European Union and those who will do in the near future, except for those with rigid exchange rate systems.

Second, we apply sophisticated econometric methods by using a Markov switching GARCH model with t-distributed errors. The Markov switching GARCH model allows searching for detecting one or several structural breaks without giving any predetermined date. Compared to a simple GARCH model with homoskedastic error distribution within each regime we are able to take GARCH effects into account, which could otherwise be spuriously interpreted as regime switches. Therefore it allows distinguishing daily volatility changes from permanent shifts and provides additional benefit compared to the use of a plain Markov switching model. Furthermore the use of the student t-distribution leads to more stable results in terms of regime persistence than the commonly applied normal distribution. Although Markov switching models have been applied to the question of credibility of monetary policy in a number of studies[7], most of them apply to the former EMS and little work has been done on CEEC yet. Arestis and Mouratidis (2005) consider a synthetic interest differential between four accession countries and members of EMU as a measure of

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5 Slovenia and Slovakia among our country sample have recently joined the exchange rate mechanism 2 (ERM2) of the European monetary system, which is according to the Maastricht treaty a prerequisite for joining EMU. As all new member countries are obliged to join EMU as soon as possible, other countries will follow. For entry scenarios see inter alia De Grauwe and Schnabl (2004b, 2005).

6 Bulgaria, Estonia and Lithuania have currency boards since the early 1990s, Latvia has pegged its exchange rate to the special drawing right and since 2005 to the Euro.

7 See Dahlquist and Gray (2000), Sarantis and Piard (2001), Tronzano (2001), Tillmann (2003), Arestis and Mouratidis (2004), Ledesma-Rodriguez et al. (2005).

credibility of monetary policy. We will, in contrast, directly use exchange rate volatility as a measure of credibility, thus investigating the credibility of the exchange rate arrangement rather than that of interest rate policy. We will, however keep in mind, that both issues cannot be considered separately.

The structure of the paper is as follows: Section 1 has motivated the use of regime switching models for the analysis of the credibility of exchange rate arrangements in CEEC. Section 2 highlights the economic background of the CEEC. Section 3 introduces the Markov Switching GARCH model, whereas Section 4 presents the data and estimation results, and Section 5 summarises the main results.

2 Exchange Rates of Central and Eastern European Countries

Post communist countries often started the process of transition by opting for a stabilization strategy in terms of a fixed exchange rate. Table 1 shows the evolution of (official) exchange rate regimes, which have been more often subject to changes than the monetary policy strategies[8]. Changes in the exchange rate regime are changes of currency weights in basket pegs or of the devaluation rate (Hungary 01/01/1997, 01/01/2000, 01/05/2001; Poland 01/01/1999), changes of the bandwidth (Czech Republic 01/03/1996; Hungary 01/05/2001; Poland 16/05/1995, 25/02/1998; Slovakia 01/01/1997) or complete changes of the regime, i.e. introduction of a managed float or float (Czech Republic 27/05/1998; Poland 12/04/2000, Slovakia 01/10/1998). The question which of the changes are the relevant ones is mainly an empirical one.

[8] Some authors, however, argue that there exist a significant discrepancies between official and de facto exchange rates (Levy-Yeyati and Sturzenegger 2005; in particular for CEEC Frömmel and Schobert 2006). For determinants of regime discrepancies see von Hagen and Zhou (2005).

As table 1 shows, the Visegrád Group had very rigid systems in 1994. Subsequently, these fixed exchange rate regimes became more flexible (Sachs 1996) and after widening the bands, the Czech Republic (1997), Poland (2000) and Slovakia (1998) declared managed or freely floating exchange rates. Hungary kept the forint fixed versus the Euro, but substantially widened the band to ±15% thus mirroring the exchange rate regime envisaged in the Exchange Rate Mechanism 2 (ERM2). The strategies of these countries add the benefits from pegging to the anchor currency in the beginning, which reduced inflation and stimulated growth (Szapáry and Jakab 1998; De Grauwe and Schnabl 2004a) to the ability to cope better with volatile capital movements later (Corker et al. 2000). In contrast, Romania and Slovenia have opted from the beginning for managed floats and officially never changed their official exchange rate system[9].

The evolution of exchange rate regimes in the CEEC is in line with the bipolar view (Fischer 2001), which has emerged as some kind of mainstream opinion of exchange rate policy. The basic idea of the bipolar view is, that adjustable pegs may be very costly and unsustainable given that capital mobility is high. Therefore, they will be replaced in the long run by either hard pegs, such as currency boards and currency unions, or by flexible exchange rates.

The empirical literature, however, shows that “what countries say they are doing may not be what they are doing” (Ishii and Habermeyer 2002, p.344). It has been widely accepted that monetary authorities suffer from the so called fear of floating (Calvo and Reinhart 2002). According to this classification the Slovenian exchange rate regime can be considered as a crawling peg, although authorities officially announced a managed float, whereas the evidence for Romania is weak (Frömmel and Schobert 2006).

[9] Slovenia, however, pegged the tolar to the Euro in 2004 joining ERM2.

Significant changes in the economic conditions also took place in the monetary policy settings. Frömmel and Menkhoff (2003) show, that changes in the monetary policy may lead to structural breaks in exchange rate volatility. Therefore, even if the focus is solely on exchange rate volatility, it is necessary to take into account the monetary policy regimes as well. Table 2 shows the development of the monetary policy strategies since 1994. The picture is similar for most of the countries: In the early years targeting of monetary aggregates and/or the exchange rate were dominating. During time most countries moved towards inflation targeting, starting with the Czech Republic, Poland and Slovakia in 1998 and ending with Hungary in 2001.

3 The Markov Switching GARCH Model

The Markov Switching GARCH (MS-GARCH) model has been independently introduced by Cai (1994) and Hamilton and Susmel (1994). It is completely characterised by the four elements mean process, state process, variance process and the distribution of the error term. For the *mean process* we rely on a simple random walk, since the analysis focuses solely on the variance dynamics of the exchange rate. That is for the log of the exchange rate p_t the exchange rate return $r_t = p_t - p_{t-1}$ is given by (conditional on the state variable s_t which may take the values 1 or 2)

(1) $$r_t = \begin{cases} \mu_1 + \varepsilon_t, s_t = 1 \\ \mu_2 + \varepsilon_t, s_t = 2 \end{cases}$$

with conditional means μ_i , $i \in \{1,2\}$ and an error term ε_t which will be discussed in more detail later.

The *state process* s_t follows a time-discrete Markov process with two possible states.[10] The dynamics of this process is given by the transition matrix P and the probability distribution in t = 1:

(2)
$$P = \begin{bmatrix} p_{11} & p_{21} \\ p_{12} & p_{22} \end{bmatrix},$$

with $p_{ij}=P(s_t=j|\, s_{t-1}=i)$, $\pi_1=\{P(s_1=1|\Phi_0),P(s_1=2|\Phi_0)\}$

Φ_t is the set of available information at time t, i.e. the set of all realisations of the returns process up to time t and the vector ϑ of parameters, $\Phi_t = \{r_t, r_{t-1}, .., r_1; \vartheta\}$ (see Hamilton 1994, p. 237). π_1 denotes the steady state probabilities of the Markov process (Hamilton 1994):

(3)
$$P(s_1 = 1 | \Phi_0) = P(s_1 = 1) = \frac{1 - p_{22}}{2 - p_{11} - p_{22}},$$

and

$$P(s_1 = 2 | \Phi_0) = P(s_1 = 2) = 1 - P(s_1 = 2)$$

If there is no a-priori preference for one of the possible states, one could also consider $P(s_1=1|\Phi_0) = P(s_1=2|\Phi_0) = 0.5$. Starting with the initial probabilities several series of probabilities can be calculated recursively:

The *filter probabilities* $P(s_t=i|\Phi_t)$ are the probabilities of being in state i, taking into account all the information up to time t, that is based on the information set Φ_t (see Kim and Nelson 1999, p. 63):

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[10] The model can be easily generalised to k states, as well as the mean process can be modified. This will, however, not lead to substantial changes in the model, so we rely on the simple model as described in the main text.

$$P(s_t = 1 \mid \Phi_t) = \frac{f_1(r_t) \cdot P(s_t = 1 \mid \Phi_{t-1})}{f_1(r_t) \cdot P(s_t = 1 \mid \Phi_{t-1}) + f_2(r_t) \cdot P(s_t = 2 \mid \Phi_{t-1})}$$

(4) and

$$P(s_t = 2 \mid \Phi_t) = 1 - P(s_t = 1 \mid \Phi_t)$$

where $f_i(r_t)=f(r_t|s_t=i)$, $i\in\{1,2\}$ are the densities of the return distribution, conditional on the state variable s_t.

The *ex-ante probabilities* $P(s_{t+1}=i|\Phi_t)$, are the probabilities of being in regime i in the next period, based on today's information Φ_t (see Kim and Nelson 1999, p. 63):

$$P(s_{t+1} = 1 \mid \Phi_t) = \sum_{i=1}^{2} P(s_t = i \mid \Phi_t) \cdot p_{i1}$$

(5) and

$$P(s_{t+1} = 2 \mid \Phi_t) = 1 - P(s_{t+1} = 1 \mid \Phi_t)$$

Both series of probabilities are estimated recursively when calculating the likelihood function of the model. In contrast, the *smoothed probabilities* $P(s_t=i \mid \Phi_T)$, based upon all information on its entire dataset, require an additional filter procedure. Alternative filters have been provided by Hamilton (1989), Diebold, Lee and Weinbach (1994), Kim (1994) and Gray (1996). For our calculations we shall use the filter by Kim (1994).[11]

Major differences between different regime switching GARCH models follow the specification of the *variance process*, i.e. the conditional variance $\sigma_t^2=Var(\varepsilon_t|s_t)$. It is a good starting point to consider the conditional variance along the lines of Bollerslev's

[11] For a detailed derivation of the filter see Kim and Nelson (1999), chapter 4.3.1.

(1986) original GARCH model and to consider the regime dependent equation for the conditional variance:

(6) $$\sigma_{t,}{}^2 = \omega_{s_t} + \alpha_{s_t}\varepsilon_{t-1}{}^2 + \beta_{s_t}\sigma_{t-1}{}^2$$

The coefficients $\omega_{s_t}, \alpha_{s_t}$ and β_{s_t} correspond to respective coefficients in the one-regime GARCH model, but may differ depending on the present state.

In equation (6) the term $\varepsilon_{t-1}{}^2$ can be easily calculated as:

(7) $$\begin{aligned}\varepsilon_{t-1}{}^2 &= (r_{t-1} - E[r_{t-1} \mid \Phi_{t-2}])^2 \\ &= \left(r_{t-1} - \left[P(s_{t-1} = 1 \mid \Phi_{t-2}) \cdot \mu_1 + \overbrace{P(s_{t-1} = 2 \mid \Phi_{t-2})}^{=1-P(s_{t-1}=1\mid\Phi_{t-2})} \cdot \mu_2 \right] \right)^2\end{aligned}$$

where Φ_t is again the set of available information at time t.

In contrast to $\varepsilon_{t-1}{}^2$ the term $\sigma_{t-1}{}^2$ in equation (6) requires additional considerations. When calculating $\sigma_{t-1}{}^2$ problems arise due to its path-dependence (Cai 1994; Hamilton and Susmel 1994; Gray 1996; Klaassen 2002): The present conditional variance $\sigma_t{}^2$ depends not only on $\varepsilon_{t-1}{}^2$ and $\sigma_{t-1}{}^2$, but also through $\sigma_{t-1}{}^2$ on $\varepsilon_{t-2}{}^2$ and $\sigma_{t-2}{}^2$ and so forth. As $\sigma_1{}^2$ to $\sigma_t{}^2$ are also influenced by the respective value of s_t, today's conditional variance $\sigma_t{}^2$ depends on the whole path of the state process $s_1,..,s_t$ and the number of possible paths grows exponentially in t. Even on shorter series it is not convenient to integrate all the paths.

This problem will not occur if the term $\beta_{s_t}\sigma_{t-1}{}^2$ is abandoned, so in case the model reflects a pure ARCH model, or if there will be just the last few days taken into consideration (Cai 1994; Hamilton and Susmel 1994).

Another, more appealing approach proposed by Gray (1996) is to follow the Markov switching model as a mixture of distributions and use in equation (6) the expected volatility, based upon the ex-ante probabilities $P(s_{t-2}|\ \Phi_{t-2})$, rather than the actual volatility. This leads to:

$$
\begin{aligned}
\sigma_{t-1}{}^2 &= E[r_{t-1}{}^2 \mid \Phi_{t-2}] - \left(E[r_{t-1} \mid \Phi_{t-2}]\right)^2 \\
&= P(s_{t-1}=1 \mid \Phi_{t-2}) \cdot (\mu_1{}^2 + \sigma_{1,t-1}{}^2) + P(s_{t-1}=2 \mid \Phi_{t-2}) \cdot (\mu_2{}^2 + \sigma_{2,t-1}{}^2) \\
&\quad - \left\{P(s_{t-1}=1 \mid \Phi_{t-2}) \cdot \mu_1 + P(s_{t-1}=2 \mid \Phi_{t-2}) \cdot \mu_2\right\}^2
\end{aligned} \tag{8}
$$

Furthermore, Klaassen (2002) suggests replacing the ex-ante probability in equation (8) by the filter probability to use as much information as possible for estimation. In this case equation 8 emerges to:

$$
\begin{aligned}
\sigma_{t-1}{}^2 &= P(s_{t-1}=1 \mid \Phi_{t-1}) \cdot (\mu_1{}^2 + \sigma_{1,t-1}{}^2) + P(s_{t-1}=2 \mid \Phi_{t-1}) \cdot (\mu_2{}^2 + \sigma_{2,t-1}{}^2) \\
&\quad - \left\{P(s_{t-1}=1 \mid \Phi_{t-1}) \cdot \mu_1 + P(s_{t-1}=2 \mid \Phi_{t-1}) \cdot \mu_2\right\}^2
\end{aligned} \tag{9}
$$

As Klaassen (2002) states, the choice of the specification (8) or (9) only marginally affects the results. Therefore I rely on Gray's specification.

We model the conditional *distribution of the error term* as t-distribution, which is quite popular in the traditional single-regime GARCH literature (see, for instance, Bollerslev, Chou and Kroner 1992), but has been less widely used in the regime switching GARCH context so far (Klaassen 2002). The fatter tails of the t-distribution (in comparison to the normal distribution) significantly improve the ability of the model to distinguish the different regimes (Klaassen 2002): E.g. in the low volatility regime a single large innovation does not cause the model to switch to the high volatility regime and the estimated regimes become much more stable. Hence, the distribution of the returns takes the following form:

(10)
$$f(r_t) = \begin{cases} f_1(r_t) = t_{\nu_1,\mu_1,\sigma_{1,t}^2}(r_t), \text{if } s_t = 1 \\ f_2(r_t) = t_{\nu_2,\mu_2,\sigma_{2,t}^2}(r_t), \text{if } s_t = 2 \end{cases}$$

$$P(s_t = j \mid s_{t-1} = i) = p_{ij}\text{ , for } i,j \in \{1,2\}$$

where $t_{\nu_i,\mu_1,\sigma_{1,t}^2}(r_t)$ is the probability density function of the decentralised t-distribution with degrees of freedom ν_i, mean μ_i and variance $\sigma_{i,t}^2$ for the regimes $i\in\{1,2\}$.

The use of a Markov switching model may not be obvious, if only one regime change is found. However, the Markov switching GARCH model provides some benefit compared to a model with one deterministic break point: First, prior to the date of the break it allows to model the uncertainty of a future breakpoint by taking "into account the possibility of the change from regime 1 to regime 2" (Hamilton 1994, p. 695). Second, after the break point it incorporates the possibility that the regime changes again back to the initial situation and therefore may reflect the expectations of market participants. The latter argument is sometimes found in the literature (Wilfling 2002). However, even in the case of exactly one permanent break point the Markov switching model is not misspecified, as this is included in the model as a special case: the transition probability p_{21} would simply be zero, i.e. regime 2 is an absorbing state[12].

[12] Hamilton (1993) states: "Some might object that a change in regime could be represented as a *permanent* change…, rather than the cycling and back and forth between states 1 and 2 that seems to be implicit in (1.2) [i.e. the Markov chain]. However the specification (1.2) allows the possibility of a permanent change as a special case if p_{21}=0." (p. 235).

Calculating and maximising the constrained maximum likelihood function is performed using GAUSS (edition 3.5). The transition probabilities p_{11} and p_{22} are constrained to the interval [0.001, 0.999]. Indeed, in section 4 some of the estimated transition probabilities are close to 0.999. This is, however, not necessary, as the model will not break down in the presence of an absorbing state, but seems to make some sense: Even if there is only one change from a volatile to a more tranquil period, a shift back would be likely if the sample was longer. Hamilton explicitly proposes this as the more appealing alternative to modelling the Markov switching model with an absorbing state: “Alternatively [remark: to using a Markov chain with an absorbing state 2] , we could have p_{21} quite close to zero, with the implication that in a sample of given size T we would likely see only a single shift, though that at some point in the future we should see a return to regime 1. “ (Hamilton 1993, p. 235).

4 Data and Estimation Results

We use daily data of six CEEC, the Czech Republic, Hungary, Poland, Romania, Slovenia and Slovakia from January 1, 1994 to March 31, 2004. As the euro is the main anchor currency for these countries, see table 1, we focus on the volatility of exchange rates versus the euro (respectively the Deutsche mark prior to 1999). The data is provided by the respective national central banks and Thomson Financial DataStream. The use of daily data refers to exchange rate volatility as a high-frequency concept[13].

[13] „Volatility is a ‚high-frequency concept’ referring to movements in the exchange rate over comparatively short periods of time. Misalignment, on the other hand, refers to the capacity of an exchange rate to depart from its fundamental equilibrium value over a protracted period of time.” (Artis and Taylor 1988, p188).

Table 3 provides estimation results for the Markov switching GARCH model and for comparison a single regime GARCH model. It is obvious that for the single regime GARCH model some problems arise regarding the persistence of the variance process: For all exchange rates the sum $\alpha+\beta$ is very close to one, for the Hungarian forint and the Slovenian tolar it even significantly exceeds 1, implying a non-stationary process.

In contrast, for the MS-GARCH model $\alpha+\beta$ in no case but regime 2 for the Slovenian tolar, i.e. the process is variance stationary. Generally the volatility persistence is higher in the high volatility regime 2 than in the low volatility regime 1, that is the higher volatility in regime 1 is partly driven by a high degree of volatility persistence. This observation is in line with recent empirical studies (Chaudhuri and Klaassen 2001; Klaassen 2002; Wilfling 2002), which allow – in contrast to earlier studies (Cai 1994; Hamilton and Susmel 1994) – independent GARCH coefficients in both regimes. Only for the Romanian leu the persistence in the low volatility regime is higher. The sum $\alpha+\beta$ differs remarkably between the regimes. The difference is highest for the Romanian leu (0.375 in regime 1, 0.961 in regime 2). As an interim summary, our results support the view by Klaassen (2002), who argues that the high persistence of volatility shocks in single-regime GARCH models is due to neglecting regime changes, that is the single-regime GARCH model is misspecified[14].

Moreover the choice of the t-distribution for the error terms is justified by the fact that all estimated degrees of freedom, for the single-regime GARCH as well as for the MS-GARCH model, are comparatively small. For the MS-GARCH model they are between ν_2=2.673 for the Hungarian forint and ν_1= 7.206 for the Romanian leu.

[14] Only for the Slovenian tolar, however, the estimated coefficients reach the boundary $\alpha+\beta\leq 1$.

These values imply a distribution with finite variance (as all degrees of freedom exceed 2) but much higher kurtosis compared with the normal distribution[15].

Another important feature of the estimation is the high persistence of the regimes: the transition probabilities p_{11} and p_{22} are close to 1 and never smaller than 0.984. This high regime persistence, which is also visible in Figure 1 showing the smoothed probabilities $P(s_t \mid \Phi_T)$, is due to the choice of the t-distribution as conditional distribution for the error term (Klaassen 2002).[16]

Figure 1 shows the probability of being in the high volatility regime. The results indicate different characteristics of the countries. Hungary and Poland show the most clear-cut results, i.e. regime changes occur in coincidence with changes in the exchange rate regime. In the case of *Poland* the volatility was initially low, when the zloty was pegged to a broad basket of anchor currencies, with a fluctuation range of ±1 per cent in the beginning. Remarkably the extension of the range to ±7 per cent in 1995 did not lead to a substantial change in the volatility characteristics, although the filter probability (the dotted line) shows some more peaks after the change between 1995 and 1998. The results indicate that the most important change in the exchange rate regime in terms of volatility was the broadening of the range to ±10 per cent on February 25, 1998, which leads to a permanent transition to the high-volatility regime. At the same time Poland changed its monetary policy strategy to inflation targeting, as suggested by Eichengreen (1999, p.C9). In contrast, the changes in the Poland's basket of anchor currencies on January 1, 1999, had only limited effect on the exchange rate volatility: The smoothed probability of the high volatility regime in-

[15] The t-distribution can be approximated with the normal distribution for much higher degrees of freedom (Greene 2000, p 68), usually the normal distribution is supposed to be a good approximation for $\nu>30$.

[16] See Section 3. We have done all estimations for normal distributed error terms, too. This leads to less stable regimes and less pronounced overall results. The estimation output is not given here, but available from the authors on request.

creased to a value very close to one, and there are hardly any declines in the filter probability. The same applies to the period of Poland's independently floating exchange rate from 2000 on. Poland may be seen as the most successful country in our sample introducing greater exchange rate flexibility during a period of capital inflows (Eichengreen 1999).

The estimation provides similarly clear results for *Hungary*. The initial volatility of the forint versus the Deutsche mark was comparatively high, although Hungary followed a very strict exchange rate peg with fluctuation margins of ±2.25 per cent only. This result, however, is puzzling at first sight only: Until January 2000 Hungary had pegged the forint to a basket of the ECU (since 1997 Deutsche mark) and US dollar and then switched to a pure euro peg, thus significantly lowering the volatility against the Deutsche mark respectively the euro. Therefore there was a sharp decline in volatility in early 2000. The situation changed again when Hungary substantially widened the fluctuation band from ±2.25 to ±15 per cent in May 2001 accompanied by the introduction of an inflation targeting strategy instead of pure exchange rate targeting. In contrast, the transition from the crawling peg to a horizontal one few months later had no effect on volatility. Summing up so far Poland as well as Hungary show a remarkable coincidence between changes in exchange rate volatility and changes in exchange rate and monetary policy.

Although the Czech Republic and Slovakia show a similar evolution in the official exchange rate regime as Hungary and Poland, the relationship between the volatility regimes and the exchange rate arrangement is – especially for Slovakia – less pronounced. While the Czech koruna stayed in the low volatility regime until the fluctuation margins were widened to ±7.5 per cent in March 1996, the probability of the high volatility regime increased steadily from then and was around 0.6 when the

Czech Republic abandoned the peg and introduced a managed float in May 1997. The Czech Republic's exit from its peg took place in a severe exchange rate crisis (for details see Begg 1998; Böhm and Źdárský 2005). Our results support the impression of a "not peaceful exit" (Asici and Wyplosz 2003) from the peg and confirm the general picture of increased volatility after disorderly exits as drawn in Duttagupta et al. (2004). After the crisis and abandoning the peg the koruna's volatility swung back to the low volatility regime in 1999 and again experienced some turmoil in 2002.

The figure looks similar for *Slovakia*, starting with quite volatile exchange rates which calmed down after the turbulent first years. Dealing with substantial current account deficits Slovakia widened the band to ±7 per cent in January 1997, this was accompanied by a sudden transition to the high volatility regime. After Slovakia was not able to maintain its peg in 1998 (Mayes 2002) and changed to a managed float, there was no clear effect on the volatility regime: the exchange rate changed frequently and irregularly between the high and the low volatility state. Compared to Hungary, Poland and even the Czech Republic, the volatility of the Slovak koruna therefore shows the least distinguished and clear-cut evolution. Obviously there is little coincidence between monetary and exchange rate policy and the exchange rate behaviour.

Romania and Slovenia form a special group among our sample, as they never changed their official exchange rate system. *Romania* reflects this well, showing no clear pattern in exchange rate volatility, which oscillates between the two regimes and does not show any clear picture. *Slovenia*, in contrast, starts in the low volatility regime, and then switches permanently to the high volatility regime in early 2001. This may be interpreted as leaving the very strict implicit de facto peg to the euro (Frömmel and Schobert 2006) and preparation to joining ERM2 in 2004 with a much wider band of fluctuation.

Finally, it must be stated that exchange rate volatility is only one indicator for uncertainty and credibility. Therefore all results have to be considered precautionary, but seem to be reasonable at the same time.

5 Conclusions

In this paper we show first, that the application of a standard single-regime GARCH model leads to variance processes which are at least almost non-stationary, whereas the use of a Markov switching GARCH model substantially improves the results. Second, changes in the regimes of exchange rate volatility for most CEEC in our sample coincide with changes in the exchange rate system and monetary policy. This result is most pronounced for Hungary and Poland. The results indicate that an increase in the flexibility of the exchange rate regime leads to an increase in exchange rate volatility. Both countries do not show any severe mismatch between policy settings and market expectations and provide some evidence for the success of gradually increasing exchange rate flexibility for exiting a peg (Eichengreen, 1999, p.C9). Furthermore it is possible to identify the most influential policy changes in terms of the volatility against the Deutsche mark respective the euro: these are for Hungary the switch from a basket peg to a pure peg to the euro on January 1, 2000, and the introduction of inflation targeting and widening of the fluctuation margins to ±15 per cent on May 1, 2001, and for Poland the widening of the band to ±7 per cent February, 1998. For the Czech Republic we find a less precise, but still visible coincidence of volatility regimes and policy settings: Prior to the introduction of wider fluctuation margins (±7.5 per cent) exchange rate volatility was remarkably low. With the Czech exchange rate crisis the probability of the high volatility regime increased steadily and reached its peak just after the peg was abandoned. From there, during the managed float shifts start to become irregular. For Slovakia after an initial slowdown in volatility we detect a sharp rise upwards in the probability of the high volatility regime during the turmoil in the Slovak foreign exchange market and the Russian crisis between 1996 and 1998 and no clear tendency afterwards. The latter also applies to the volatility of the Romanian leu over the whole period, whereas the Slovenian tolar shows an increasing degree of flexibility prior to Slovenia's entrance to ERM2 (although the official regime never changed).

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TABLE 1. Official monetary policy regimes since 1994

Czech Republic		Hungary		Poland	
1994-1997	Targeting of the exchange rate and monetary aggregates (credit volume and M2)	1994-2001	Targeting of the exchange rate	1994-1998	Targeting of the exchange rate and
1998-2001	Net inflation[1] targeting	2001-	Inflation targeting (CPI annual average)	1998-	Inflation targeting (end of year CPI inflation)
2002-	Headline inflation targeting with linear and declining target band				

Romania		Slovakia		Slovenia	
1994-	No official commitment to a monetary policy strategy	1994-1998	Exchange rate targeting	1994-1995	Base money targeting
		1998-	No commitment, informal inflation targeting	1996	Targeting of base money and M1
				1997-	Targeting of M3[2]

[1] Headline inflation minus regulated prices and changes in indirect taxes

[2] In Slovenia also including foreign exchange deposits of private households

TABLE 2. Official exchange rate regimes since 1994

Czech Republic		Hungary		Poland	
01/01/1994-29/02/1996	**Basket peg**: 65% DEM, 35%USD, Band: ±0.5%	01/01/1994-31/12/1996	**Crawling peg:** 70% Ecu, 30% USD, Band: ±2.25%	01/01/1994-15/05/1995	**Crawling peg:** 45% USD, 35% DEM, 10% GBP, 5% FRF, 5% CHF Band: ±1 %
01/03/1996-26/05/1997	Band: ±7.5%	01/01/1997-31/12/1999	70% DEM, 30% USD	16/05/1995-24/02/1998	Band: ±7%
27/05/1997-present	**Managed float**	01/01/2000-30/04/2001	100% EUR	25/02/1998-31/12/1998	Band: ±10%
		01/05/2001-30/09/2001	Band ±15%	01/01/1999-11/04/2000	45% USD, 55% EUR
		01/10/2001-present	**Horizontal peg:** 100% EUR, Band: ±15%	12/04/2000-present	**Free float**

Romania		Slovenia		Slovak Republic	
01/01/1994-present	**Managed float**	01/01/1994 -26/6/2004	**Managed float**	01/01/1994-31/12/1996	**Basket peg:** 60% DEM, 40%USD, Band: ±1.5%
		27/6/2004	**Peg:** 100% EUR, ±15% (ERM2)	01/01/1997-30/09/1998	Band: ±7%
				01/10/1998-24/11/2005	**Managed flo-at**
				25/11/2005 -present	**Peg:** 100% EUR, ±15% (ERM2)

Notes

1. Source: IMF, Exchange Rate Arrangements and Restrictions, various issues.
2. Until 16.3.1995, the NBH devalued in discrete steps.
3. Since 2001 the Hungarian forint (HUF) is pegged at a rate of 276.1 HUF/EUR.

TABLE 3: Results of GARCH estimations for EU accession countries

Single regime GARCH

	CZK	HUF	PLZ	ROL	SIT	SKK
μ	-0.011**	0.013***	0.022***	0.073***	0.005***	-0.009*
	(0.005)	(0.002)	(0.008)	(0.011)	(0.000)	(0.004)
ω	0.002***	0.000	0.007***	0.015***	3.37E-6**	0.004***
	(0.001)	(0.000)	(0.002)	(0.004)	(1.62E-6)	(0.001)
α	0.085***	0.304***	0.136***	0.097***	0.507***	0.109***
	(0.013)	(0.041)	(0.018)	(0.014)	(0.065)	(0.018)
β	0.907***	0.828***	0.857***	0.882***	0.720***	0.858***
	(0.012)	(0.012)	(0.016)	(0.014)	(0.015)	(0.019)
$\alpha+\beta$	0.992	1.132	0.993	0.979	1.227	0.967
ν	4.608	2.877	4.735	4.501	3.170	4.080

MS GARCH (low volatility regime)

	CZK	HUF	PLZ	ROL	SIT	SKK
Regime 1 (high volatility)						
μ_1	-0.013**	0.012***	0.046***	0.058***	0.018	-0.015***
	(0.006)	(0.002)	(0.010)	(0.011)	(0.002)	(0.005)
ω_1	0.011***	0.001	0.016**	0.003	0.001	0.007
	(0.003)	(--)	(0.007)	(0.002)	(0.001)	(0.005)
α_1	0.122***	0.407***	0.106***	0.013	0.443***	0.120
	(0.029)	(0.148)	(0.033)	(0.010)	(0.079)	(0.051)
β_1	0.698***	0.409***	0.785***	0.948***	0.556***	0.670***
	(0.063)	(0.067)	(0.060)	(0.013)	(0.079)	(0.153)
$\alpha_1+\beta_1$	0.820	0.816	0.891	0.961	0.999	0.790
volatility	0.063	0.005	0.144	0.075	1.389	0.033
ν_1	4.548	2.976	3.908	3.901	3.021	3.973

Table 3 to be continued on next page

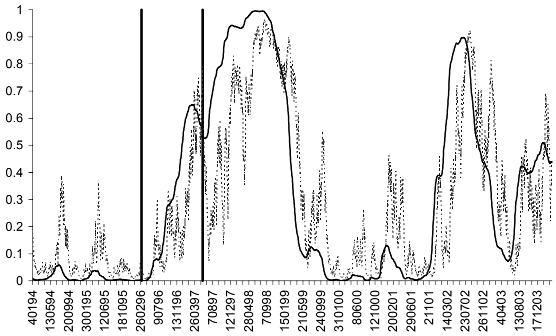
Table 3 continued

Regime 2 (high volatility regime)	**CZK**	**HUF**	**PLZ**	**ROL**	**SIT**	**SKK**
μ_2	-0.004	0.017**	-0.016	0.213***	0.009***	0.005
	(0.014)	(0.006)	(0.013)	(0.051)	(0.001)	(0.010)
ω_2	0.037**	0.047***	0.028**	0.587***	0.005*	0.030***
	(0.016)	(0.074)	(0.011)	(0.076)	(0.003)	(0. 014)
α_2	0.059	0.209***	0.149***	0.269***	0.999[1]	0.084**
	(0.035)	(0.074)	(0.031)	(0.074)	(--)	(0.037)
β_2	0.893***	0.712***	0.809***	0.106	0.000[1]	0.670***
	(0.055)	(0.058)	(0.047)	(0.054)	(--)	(0.113)
$\alpha_2+\beta_2$	0.952	0.921	0.958	0.375	0.999	0.754
volatility	0.754	0.596	0.646	0.938	5.079	0.165
ν_2	5.694	2.673	5.788	7.206	2.129	4.699
p_{11}	0.998	0.997	0.999	0.998	0.999	0.992
p_{22}	0.995	0.998	0.999	0.984	0.994	0.991

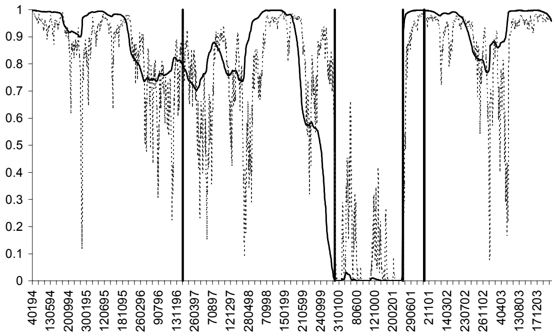
Asterisks refer to the level of significance, ***: 1 per cent, **: 5 per cent, *: 10 percent; asymptotic standard errors in parentheses.
Single regime GARCH model: $r_t = \mu + \varepsilon_t; \varepsilon_t \sim t_{\nu,\mu,\sigma_t^2}(r_t); \sigma_t^2 = \omega + \alpha \cdot \varepsilon_{t-1}^2 + \beta \cdot \sigma_{t-1}^2$
MS-GARCH-Model according to the description in the main text.
Volatility: $\omega/(1-\alpha-\beta)$ [for the MS-GARCH-model separate calculation for each of the regimes]

[1] Coefficient estimates reach boundary.

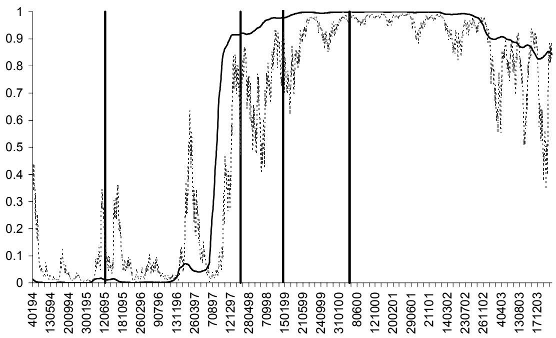
FIGURE 1:Filter- and smoothed probabilities for EU accession countries



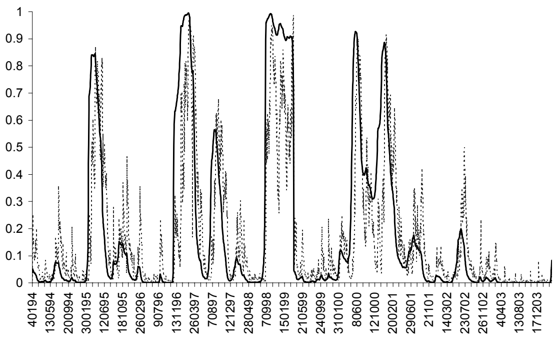
CZK/DEM



HUF/DEM



PLZ/DEM



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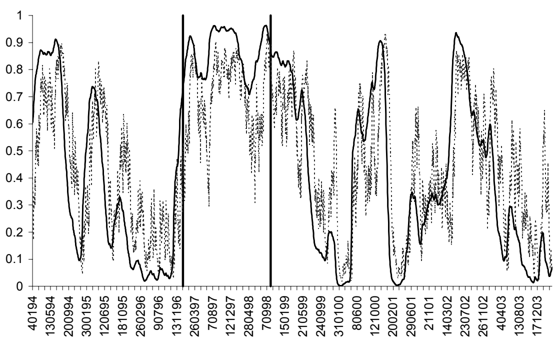
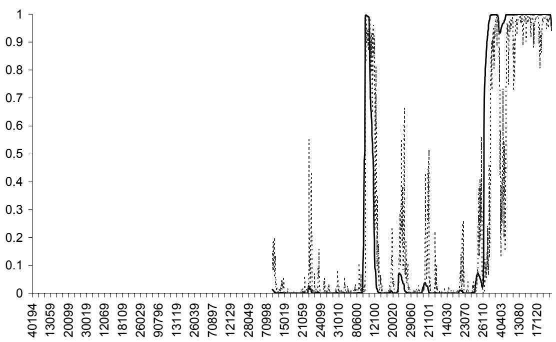


SKK/DEM



SIT/DEM

The bold lines are the smoothed probabilities $P(s_t=1 \mid \Phi_T)$ of being in the high volatility regime, the dotted lines reflect the filter probabilities $P(s_t=1 \mid \Phi_t)$ of being in the high volatility regime 1. The vertical lines represent changes in the exchange rate system of the respective country.