Exchange rate in transition

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To Monika

Preface

In this book several econometric techniques are used to perform quantitative research of the exchange rate in transition. This is an empirical work based on related economic theory. While the stress is put on the exchange rate of the Czech koruna, the subject is analyzed from a broader perspective of other transition countries as well. I have used parts of the original text in my class Econometrics IV (Applied Time Series) that I teach at CERGE of Charles University.

I am grateful to many people for their help. I am indebted to a colleague and friend of mine, Jan Hanousek, who carefully reviewed the text. I had the benefit of comments and suggestions from (in alphabetical order): Parker Ballinger, Štepán Cábelka, W. Davis Dechert, John Fahy, Randall Filer, Jan Hanousek, Martin Kupka, Lubomír Lízal, David Papell, Christof Ruehl, Raúl Susmel, and František Turnovec.

Contents

1 Introduction

At this point, nearly a decade into transition, the Czech Republic has completed the early stages of the process. The country has launched various privatization programs and has adopted an extensive range of measures to implement monetary and fiscal policies that would suit the needs of the overall transformation. Aside from private investors, numerous international organizations have become involved to aid the process. Naturally, the country recorded both achievements and failures.

Any country in transition must undergo a stage of macroeconomic stabilization, which is inevitably accompanied by large shocks to macroeconomic fundamentals. The nature and magnitude of these disruptions affect the progress of economic development. Research into the success of the stabilization programs in transition economies is especially important for policymakers. Owing to the relative openness and the close economic relations among transition economies in Central and Eastern Europe and between these countries and the European Union, the exchange rate and the exchange rate regime play an important role in economic development.

The stability of the exchange rate and a type of its regime are important elements in the overall monetary policy of each country. The significance of the matter is even more accentuated in the case of transition economies because international lending institutions like the International Monetary Fund, the World Bank, and the European Bank for Reconstruction and Development provide credit subject to macroeconomic stability and a stable exchange rate. This is true no matter what kind of regime is adopted.

The following chapters analyze the role of the exchange rate and its regime in the Czech Republic, its influence on financial market, and the evolution of exchange rates among the Central and Eastern European countries from the beginning of the transformation until recently. The overall analysis is based on an economic theory and applies both classical and advanced econometric techniques. Thus, the theoretical approach allows the formulation of qualified empirical conclusions.

Chapter 2 concentrates on a conditional variance analysis of the exchange rate of the Czech koruna. Several detailed studies have applied the generalization of the autoregressive conditional heteroskedastic (ARCH) model to assess the changing variances of exchange rates and their distribution. Knowledge of the exchange rate behavior has important implications for the decisions made in an international financial environment. The opening of new emerging markets in Central and Eastern Europe has increased interest in exploring the behavior of the exchange rates of the region. Central and Eastern European economies are undergoing a unique transformation and for these reasons their exchange rate arrangements differ from those in the developed economies.

This chapter examines the behavior of the exchange rate of the Czech koruna when pegged to a currency basket. This is a significant contribution to the field because, so far, no research has applied the ARCH model to such an exchange rate. The exchange rates are described both narratively and from a statistical point of view. A short explanation is provided on how the exchange rate movement is related to the currency basket peg. The peg is supposed to limit the overall instability of the currency, and hence, stabilize the exchange rate. This is conditional on the central bank keeping the index of the currency basket within a narrow band without subjective tampering. If inconsistency occurs, the pegged rates do not fully reflect the underlying processes in free exchange rates and further analysis is futile.

The tests that discover similarities between a pegged exchange rate system and the behavior of free floating exchange rates are presented, supporting the employment of an ARCH model. The GARCH(1,1) model with daily dummy variables in both mean and variance equations is applied to model the conditional variance in exchange rates in order to account for heteroskedasticity. Estimates of the models are presented separately for the mean and variance equations along with statistical tests that show comparable as well as differing results from referenced studies. A separate section elaborates on the nonlinearity in exchange rate movement and uses an advanced nonparametric BDS statistic to test the results. The quantitative results are applied to the behavior of exchange rates and central bank policy.

Chapter 3 extends the analysis from the previous chapter and presents a modification of the technique used. This part examines the behavior of the exchange rate of the Czech koruna when pegged to a currency basket under different fluctuation bands. The currency basket peg is supposed to limit the overall instability of the currency. Such limiting means stabilizing the exchange rate and lowering its volatility. Again, this is conditional on the central bank keeping the index of the currency basket within a narrow band. The purpose of the analysis is to show how the volatility of the exchange rate is affected by allowing for a wider fluctuation band.

The GARCH-L(1,1) model with a dummy variable for the volatility response to the koruna's appreciation in a variance equation is applied in order to model conditional variance in exchange rates. This is done in order to account for the change in the width of the fluctuation band. Estimates of the models are presented for the mean and variance equations. The results show that, contrary to conventional wisdom, the volatility of the various exchange rates decreased after a much wider fluctuation band was introduced to limit movements of the currency basket index.

The previous two chapters present an economic and institutional background of the exchange rate regime that has governed the behavior of the Czech koruna since the early 90's. Since the exchange rate regime is an important element in the overall monetary policy of every country, it substantially influences financial market. This influence is often likely to be an indirect one *via* interest rates. Such an influence is discussed in chapter 4 where we analyze the linkages between interest rates, as well as interest rates and exchange rates, and compare the results of the periods before 1997 with those in the year, when the country experienced financial crisis. The concept of Granger causality within the framework of the bivariate Vector Autoregressive model is used as an econometric tool to test the respective hypotheses.

The relatively stable environment of the fixed exchange rate regime and semi-regulated interest rates provided a soft environment for the evolution of links among key interest rates and the exchange rate. The bonds among interest rates tended to evolve in a weak economic sense. During the turbulent times of the financial crisis, the prevailing links among interest rates tended to gain strength and the money market became more efficient than ever before. The evolution of the linkages also showed that interest rates influenced the exchange rate during the year of crisis. The exchange rate was found to influence only the short-term interest rates.

The broader perspective of exchange rate analysis among Central and Eastern European countries is discussed in chapter 5. Here we address the question of whether the transition countries have achieved exchange rate development that would eventually lead to greater similarities with the countries within the European Union.

The transition process in Central and Eastern Europe provides a unique opportunity to carry out a quantitative analysis of exchange rate convergence within distinctive groups of the Central and Eastern European countries. Transposed from the original application to growth of output, the convergence of exchange rates should be reflected in a reduction of the exchange rate differentials across countries over time. The panel unit-root test is the econometric tool used to test our hypothesis.

In the case of the Central and Eastern European countries, a relevant and related question arises. With so many varieties of exchange rate regimes, does the degree of convergence depend on a particular exchange rate regime? Or, in other words, is convergence faster in countries that favored some kind of tight exchange regime as opposed to a rather free one?

Investigating to what extent the exchange rate regime is partially susceptible to supporting convergence, or to preventing it, can enhance our knowledge of how transition economies function not only from an academic point of view. It can also provide concrete evidence and enhanced policy tools for addressing the issue of European Union accession. The results of the analysis support convergence in general. However, the findings seem to indicate that the answer to the question of convergence is far from obvious and may not be the same for all countries (or groups of countries).

2 Conditional variance analysis of the exchange rate

2.1 Exchange rate environment

In 1991, former Czechoslovakia officially started its economic transformation. From this time the role of the exchange rate could no longer be disfigured as in the former centrally planned economy. However, a certain reduction in the relative volatility of exchange rates was desirable in order to promote export, direct foreign investments and generally favorable economic development during the transition to a free market economy. With the absence of fully functioning financial markets, the newly emerged private sector was extremely vulnerable to exchange rate fluctuations. The fixed exchange rate provided a less volatile environment according to policy makers at that time.

The shock of the transition needed to be buffered, and therefore, to introduce a floating exchange rate system would have been premature. A floating exchange rate regime requires that no restrictions on financial capital movement be imposed. This necessitates a strong mature economy with sufficient reserves of convertible currencies. During the early stages of economic reform, the country did not meet these conditions and an eventual bank run could have caused vast damage. The situation resulted in a temporary anchor of the currency basket peg. We will define currency basket and describe its properties in the next section. Further, additional detailed discussion on the role of fixed exchange rates can be found in Svensson (1994).

In the beginning of 1993 Czechoslovakia was split into two independent nations. Monetary separation of the Czech and Slovak republics followed shortly after the formal division of the state. From this point on the Czech koruna has remained for several years more or less stable, unlike its Slovak counterpart, which has devalued to a certain extent over time. Full convertibility of the koruna was implemented on October 1, 1995, and meant that the koruna could be traded for foreign exchange without restrictions by both companies and citizens. However, this step was not paired with any change in the exchange rate regime and the koruna remained pegged to the currency basket. Thus, after this date, the exchange rate of the koruna was still not completely free to float as the currencies of developed economies. We now proceed to statistical description of exchange rates in question as well as of a currency basket.

2.2 Data and the currency basket

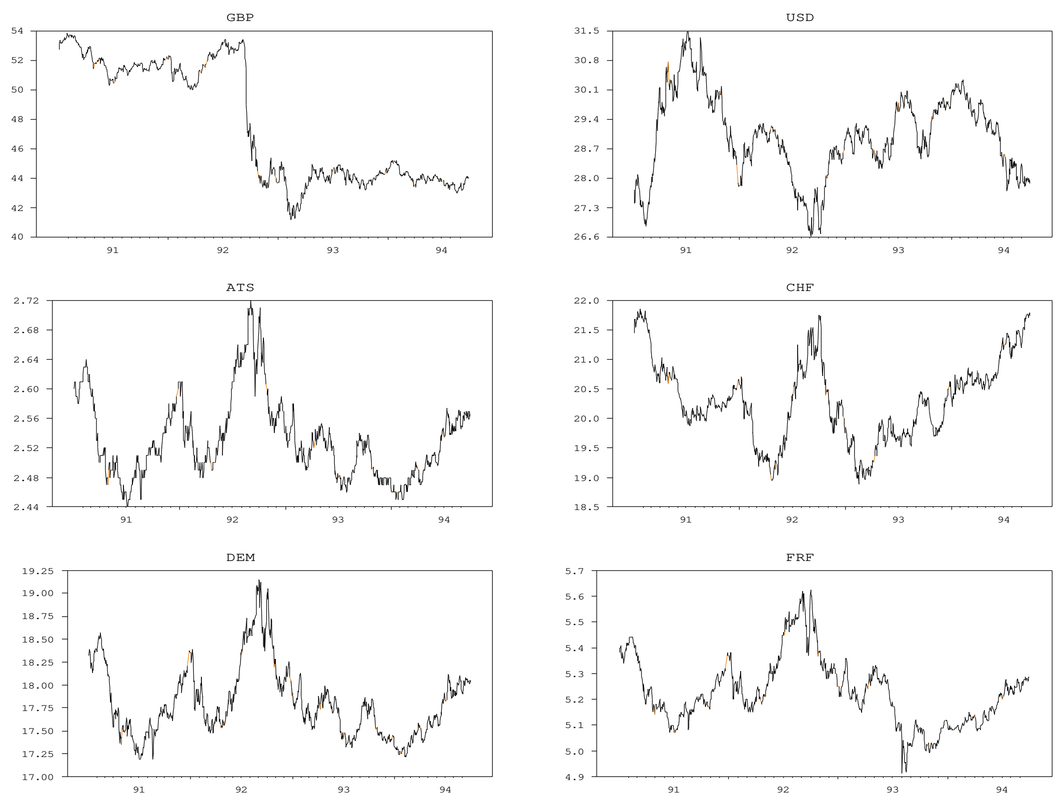
The data consists of daily midpoint exchange rates of the Czech koruna (CZK) to six major currencies during the period from January 2, 1991 to September 30, 1994. The split-up of the former Czechoslovakia on January 1, 1993 generated two separate currencies (Czech koruna and Slovak koruna) which replaced the former Czechoslovak koruna. The entire series is referred to as the Czech koruna because it (CZK) followed the former stable path of the old Czechoslovak koruna. After the monetary separation the Slovak koruna has devaluated considerably. The data was supplied by the Czech National Bank (CNB), Prague. Six major currencies were selected for this study because of their importance in international trade and their inclusion in the currency basket to which the Czech koruna is pegged. The rates of foreign currencies in terms of the Czech koruna are: British Pound (GBP), Austrian Shilling (ATS), Deutsche Mark (DEM), U.S. Dollar (USD), Swiss Franc (CHF), and French Franc (FRF). There are a total of 953 daily observations for each currency.

Table 2.1 contains the summary statistics of the data. The means are fairly small. However, their negative sign implies that the koruna has, on average, slightly depreciated over time. The low variance indicates a stable evolution.

Table 2.1 Summary statistics of log price changes:
$r_t = \log(R_t/R_{t-1})*100$

Statistics	GBP	ATS	DEM	USD	CHF	FRF
Mean	-0.02163	-0.00242	-0.00416	0.00534	-0.00156	-0.00447
Variance	0.23785	0.12908	0.11577	0.22176	0.20454	0.12005
Skewness	-1.68703	-0.40586	-0.57688	0.34574	-0.16915	-0.76434
Kurtosis	16.2077	2.35196	3.21914	1.65811	2.57694	6.27226
Maximum	1.99089	1.53259	1.28961	2.45490	2.28472	1.49497
Minimum	-4.9373	-1.19121	-1.73237	-1.69109	-2.34774	-2.75034

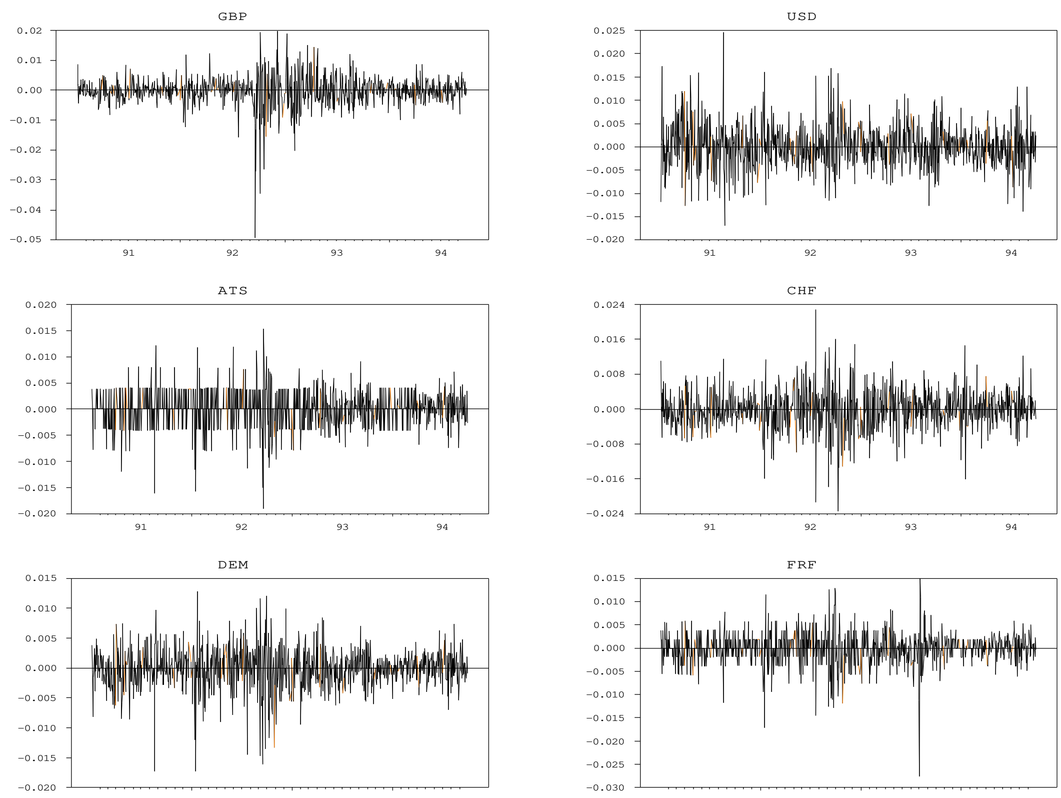
Figure 2.1 Evolution of Exchange Rates: Nominal Levels



The range of daily changes is relatively small with one exception. A drop of almost 5 percent of GBP coincides with the time when GBP left the European Monetary System. Unconditional distributions for the three rates show a typical property of a fat tail implying the non-normal distribution as indicated by the fourth moment.

Figure 2.1 shows the evolution of the respective exchange rates over the entire period. The data are not stationary but are a first-order integrated process. The rate of change is calculated by taking the logarithmic difference between two consecutive business days. Figure 2.2 represents the logarithmic first order differences of exchange rates. It serves as a visual test for stationarity and illustrates the periods of volatility.

Figure 2.2 First Logarithmic Differences of Exchange Rates



In order to address properly the question of how the exchange rate behaved during the researched period we introduce a short description of the monetary instrument called currency basket. The currency basket was primarily meant to be a nominal anchor that allows, under a prudent policy, to keep a relatively stable nominal exchange rate. Currency is pegged to a currency basket when it is bound to several currencies *via* exchange rates in certain proportions. The currency basket is, according to the International Monetary Fund, categorized as a type of fixed exchange rate arrangement. The CNB introduced the basket system at its current general level at the beginning of 1991 and constructed the basket as a weighted average of nominal exchange rates. The use of weighted average mathematically creates a slight discrepancy by not fully exploiting the importance of the respective currencies, which are represented by their weights. This would be eliminated by using a geometric average instead.

The change in the value of the currency basket is measured by its index $I(t,w)$, which the CNB defines as

$$I(t,w) = \sum_{j=1}^{N} w_j \left[R_j(t) / R_j(0) \right] \tag{2.1}$$

where w_j is a weight ($\sum w_j = 1$), $R_j(t)$ is the domestic exchange rate at time t, and $R_j(0)$ is the domestic exchange rate at time 0, i.e. the base exchange rate. Both rates are at nominal levels. In order to peg the home currency to a currency basket, the index must be fixed. In this case it means that the index is set to be equal to one ($I(t,w) = 1$). It should be stressed that the index is calculated from daily midpoint exchange rates and, for the purpose of this analysis, serves only as an illustration of how the index evolved over time.

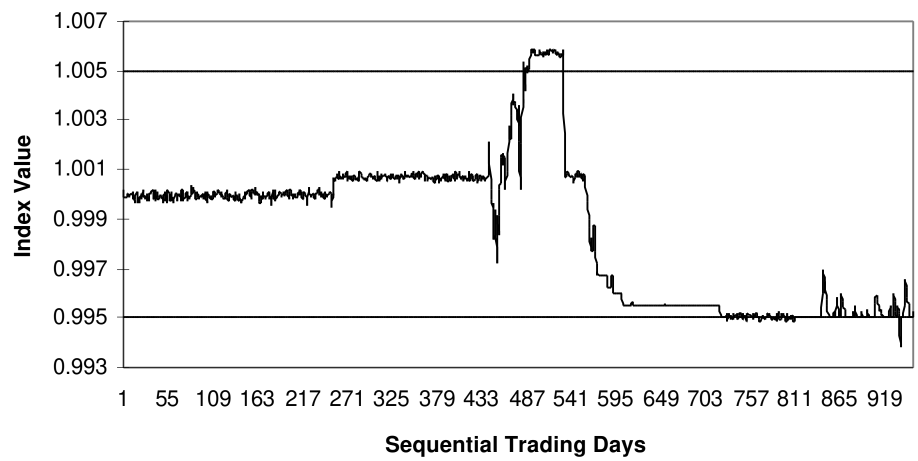
Table 2.2 Basket Composition, Currency Weights, and Base Rates across Periods

Period		GBP	ATS	DEM	USD	CHF	FRF
Jan. 1,1991 - Jan. 1, 1992	Weight	0.0424	0.1235	0.4552	0.3134	0.0655	-
	Base Rate	52.50	2.59	18.23	28.00	21.34	-
Jan. 2, 1992 – May 2, 1993	Weight	-	0.0807	0.3615	0.4907	0.0379	0.0292
	Base Rate	-	2.61	18.35	27.84	20.57	5.37
May 3, 1993 - Jun. 26, 1997	Weight	-	-	0.6500	0.3500	-	-
	Base Rate	-	-	17.995	28.443	-	-

Weights sum up to 1 and represent relative importance of particular currency in the balance of payments.
Base rates are constant over respective period.

Table 2.2 illustrates three changes in weights and base rates that took place during the four-year period. The weights represent relative importance of the particular foreign currency in the turnover of the Czech balance of payments excluding banking operations. The fluctuation band imposed on the basket was set at ± 0.5%. The CNB managed to keep the index of the basket within the band during all three periods. The index was held on average at 0.9999, 1.0011, and 0.9952 for the respective periods. However, minor mismanagements occurred as can be seen in Figure 2.3 that shows the evolution of the currency basket index over the entire period.

Figure 2.3 Evolution of the Currency Basket Index



2.3 Process underlying exchange rate movement

2.3.1 Theoretical background

Many economic and especially financial variables reflect the stylized facts attributed to Mandelbrot (1963). These are: (1) unconditional distributions have thick tails, (2) variances change over time, and (3) large (small) changes tend to be followed by large (small) changes of either sign. These stylized facts are especially appealing in the context of high frequency financial data such as exchange rates and stock prices.

The distribution and statistical properties of exchange rates are of considerable interest since the time when exchange rates of major currencies started to float. The importance of this knowledge has very practical implications: the effects of exchange rates movement on international trade and capital flows, mean-variance analysis of international asset portfolios, and the pricing of options on foreign currencies. The opening of new emerging markets in Central Europe has led to interest in the behavior of exchange rates of these economies since they broaden frontiers to international investments. To know the statistical properties and to define the behavior of the particular currency may lower the risk involved in international financial activity.

The fat tails of the exchange rates distributions imply increased uncertainty, and this feature attracts attention. In order to account for leptokurtosis, two different explanations were suggested in literature, namely by Friedman and Vandersteel (1982). One idea suggests that the rates are independently drawn from a fat tail distribution that is fixed over time. The other view favors distributions that vary over time. Hsieh (1988) found a strong statistical evidence to discriminate between the two competing theories. His evidence points to the rejection of the first hypothesis because of changing means and variances of daily rates. This feature can be best described by accounting for the conditional autoregressive heteroskedasticity in modeling the variance that was first introduced by Engle (1982).

So far, research interest has concentrated on free-floating exchange rates. It is clear that it is not much useful to study firmly fixed exchange rates in a time series context since they represent just series of equal numbers over a period of time. However, the behavior of semi-fixed exchange rates that can be observed in case of the currency basket arrangement, does not offer such a clear explanation. At first, due to the condition that the basket index be kept at some constant relative to its construction and deviation is allowed only within the band, exchange rates are to closely follow their "master" currencies in many respects. On the other hand, exchange rates are likely to be exposed to the subjective actions of a central bank that may try to manipulate certain exchange rates within or outside the limits of the basket. The reason would be to pursue its own targeting policy or to smooth outside negative influences in order to maintain relative stability of exchange rates. Volatile periods may emerge from both motives mentioned above. The consistent monetary policy of the central bank with respect to the stable index is therefore imperative in order to produce mathematically consistent semi-fixed exchange rates. Fortunately, this is the case for the Czech koruna.

Milhøj (1987) modeled the distribution of daily deviations of the U.S. Dollar to Special Drawing Rights (SDR) using a simple ARCH model. SDR has been a composite of currencies since July 1, 1974. However, the U.S. Dollar is not pegged to this basket and thus such a modeling does not involve semi-fixed exchange rate. Therefore, the exchange rate of the Czech koruna to other currencies represents an interesting modeling challenge.

2.3.2 Autoregressive conditional heteroskedasticity

The original ARCH model framework of Engle (1982) suggests that current volatility depends on past squared innovations in order to explain the tendency of large residuals to cluster together. Bollerslev (1986) extended the framework into a generalized autoregressive conditional heteroskedasticity model (GARCH) where current volatility depends not only on past squared residuals but also on lagged autoregressive component, e.g. lagged own variances. By deriving residuals ε_t from an underlying process, which are conditioned by the information set Ω_t, a GARCH(p,q) process is given by

$$\varepsilon_t \mid \Omega_{t-1} \sim N(0,\sigma_t^2) \tag{2.2}$$

with conditional autoregressive variance specified as

$$\sigma_t^2 = \omega + \sum_{j=1}^{p} \alpha_j \varepsilon_{t-j}^2 + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2 \, . \tag{2.3}$$

Conditional variance may be denoted by h_t in the part of the literature. We feel that use of σ_t^2 to denote conditional variance is sufficiently illustrative. As for the ARCH model, by far the most popular model of this type that has been used to describe financial data volatility is the generalized specification GARCH(1,1).

Whether the ARCH process described above is present in the data can be detected by subsequent tests. In order to remove any linear structure in the data, an autoregressive filter is applied. Each series is modeled as an autoregressive process of the form

$$r_t = a_0 + \sum_{i=1}^{10} a_i r_{t-i} + \varepsilon_t \qquad (2.4)$$

where ε_t is independently and identically distributed (iid). The Akaike Information Criterion (AIC) method of Akaike (1974) was employed to determine the appropriate number of lags.

Table 2.3 shows the results of two independent test performed on residuals from the mean equation (AR(10)) to detect presence of an ARCH process described above. A Lagrange-multiplier test suggested by Engle (1982), tests a null hypothesis that no ARCH process is present in the data. The values of LM(10) are distributed according to the chi-squared distribution with 10 degrees of freedom and the null hypothesis can be decisively rejected at any confidence level for all six rates.

A Ljung-Box (1974) test against higher order serial correlation was performed for up to the tenth order. The values of Ljung-Box Q statistic are distributed asymptotically according to the chi-squared distribution with 10 degrees of freedom. The values for the first moments are extremely low and are not statistically significant at any reasonable level for any of the six currencies. This fact indicates that there is no higher order serial correlation present in the data. On the other hand, the values of the Ljung-Box Q statistic for absence of serial correlation in squared residuals are high enough above a 1% significance level to indicate the presence of serial correlation here. The absence of serial dependence in the first conditional moments and its strong presence in the conditional second moments indicate an ARCH process.

Table 2.3 Testing for conditional heteroskedasticity and serial correlation

Statistics	GBP	ATS	DEM	USD	CHF	FRF
LM(10)	77.00	114.44	82.34	51.06	77.49	96.01
Q(10)	0.3536	0.0964	0.0936	0.282	0.0104	0.1987
$Q^2(10)$	110.05	156.94	130.32	64.97	94.24	135.09
Skewness	-1.441	-0.404	-0.674	0.326	-0.179	-0.854
Kurtosis	14.600	2.394	3.523	1.815	2.561	6.474

LM: Lagrange multiplier test by Engle (1982), Q: Ljung-box test against higher order serial correlation by Ljung-Box (1978), χ^2 critical value at 1% level with 10 d.f. is 23.21

Despite the fact that the tests were performed using the autoregressive process with 10 lags, the results of both tests are not sensitive to any particular choice of lags, as they were replicated for control purpose with different structures.

The values of the unconditional sample kurtosis exceed a normal value in the case of three currencies. This fact, along with the results of previous tests, shows that an autoregressive process appears to account for the serial correlation properties of the daily data. However, it does not adequately describe the heteroskedasticity or the large kurtosis present in the daily rates. The next step is to employ an ARCH model with conditionally distributed errors and daily dummy variables in both conditional mean and conditional variance equations.

2.4 Conditional variance

2.4.1 Modelling

Brock, Hsieh, and LeBaron (1993), p. 130, point out that a prevalent view in literature is that exchange rates follow a random walk. However, no strong statistical evidence has emerged to confirm or refute this view so far. Research done with exchange rates and security prices uses random walk as well as different univariate processes. When taking into account a basket pegged character of the exchange rates in the data set, a possibility of a specific underlining process cannot be overlooked.

An autoregressive process was chosen as a proxy to model the underlying process in the data. The AIC method was employed to determine the appropriate number of lags. AR(10) structure was also the efficient way to filter the data so that the model yielded residuals free of autocorrelation and seasonality as well. To capture plausible changes of the distribution in different days during a business week, appropriate day-of-the-week dummy variables were employed. The specification of the model resulted into the following mean equation

$$\begin{aligned} \mathrm{r_t} = \mathrm{a_0} + \sum_{\mathrm{i=1}}^{10} \mathrm{a_i} r_{t-i} + \gamma_1 d_{MO,t} + \gamma_2 d_{TU,t} + \gamma_3 d_{WE,t} + \\ + \gamma_4 d_{TH,t} + \gamma_5 d_{HO,t} + \varepsilon_t \end{aligned} \tag{2.5}$$

where, $\varepsilon_t \mid \Omega_{t-1} \sim D(0, \sigma_\mathrm{t}^2)$, and a conditional variance equation

$$\begin{aligned} \sigma_\mathrm{t}^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{\mathrm{t-1}}^2 + \phi_1 d_{MO,t} + \phi_2 d_{TU,t} + \\ + \phi_3 d_{WE,t} + \phi_4 d_{TH,t} + \phi_5 d_{HO,t} \end{aligned} \tag{2.6}$$

where $d_{MO,t}$, $d_{TU,t}$, $d_{WE,t}$, $d_{TH,t}$ are dummy variables for Monday, Tuesday, Wednesday, and Thursday, and $d_{HO,t}$ is the number of holidays (excluding weekends) between successive business days.

The restrictions on the parameters in the variance equation require that $\omega > 0$, $\alpha \geq 0$, and $\beta \geq 0$. Further, when $\alpha + \beta < 1$, then the unconditional variance is finite and stationarity is ensured by not having unit root as shown by Bollerslev (1986).

Estimation of the model is performed by using a log-likelihood function of the form

$$L = \left(-\tfrac{1}{2}\ln\sigma_t^2 - \tfrac{1}{2}\left(\varepsilon_t^2 / \sigma_t^2\right)\right). \tag{2.7}$$

Coefficients of the day-of-the-week dummies were expected to be fairly small and therefore non-negativity restrictions were not imposed on them. The maximum likelihood estimates are obtained by using a numerical optimization algorithm described by Berndt, Hall, Hall, and Hausman (1974).

Table 2.4 Estimating the mean equation for GARCH(1,1) $r_t = a_0 + \sum_{i=1}^{10} a_i r_{t-10} + \sum_{j=1}^{5} \gamma_j d_{jt} + \varepsilon_t$

Estimates and statistics	GBP	ATS	DEM	USD	CHF	FRF
a_0	-0.000529	-0.000123	-0.000208	-0.000243	-0.000581	-0.000284
	(0.000355)	(0.000261)	(0.000248)	(0.000343)	(0.000331)	(0.000252)
a_1	0.0270	-0.1070[a]	-0.0446	-0.0155	-0.0564	0.0024
	(0.0326)	(0.0328)	(0.0327)	(0.0326)	(0.0329)	(0.0327)
a_2	0.0569[c]	-0.0271	0.0304	0.0460	-0.0190	-0.0217
	(0.0326)	(0.0330)	(0.0337)	(0.0326)	(0.0328)	(0.0327)
a_3	0.0302	0.0489	-0.0227	-0.0154	-0.0307	0.0122
	(0.0326)	(0.0330)	(0.0327)	(0.0326)	(0.0328)	(0.0326)
a_4	0.0451	0.0397	0.0592	0.0448	0.0466	0.0517
	(0.0326)	(0.0330)	(0.0326)	(0.0325)	(0.0328)	(0.0325)
a_5	-0.0400	0.0214	0.0283	0.0151	0.0018	0.0214
	(0.0327)	(0.0330)	(0.0327)	(0.0326)	(0.0328)	(0.0325)
a_6	-0.0165	-0.0533	-0.0551	-0.0421	-0.0130	-0.0233
	(0.0326)	(0.0330)	(0.0327)	(0.0326)	(0.0328)	(0.0325)
a_7	-0.0536	-0.0183	-0.0188	-0.0001	0.0232	-0.0661[a]
	(0.0325)	(0.0329)	(0.0325)	(0.0323)	(0.0328)	(0.0324)
a_8	0.0383	-0.0268	-0.0403	-0.0115	-0.0014	-0.0793[a]
	(0.0326)	(0.0329)	(0.0325)	(0.0324)	(0.0328)	(0.0325)
a_9	0.0428	0.0088	0.0076	-0.0124	0.0259	-0.0233
	(0.0326)	(0.0329)	(0.0325)	(0.0323)	(0.0328)	(0.0326)
a_{10}	0.1202[a]	0.0499	0.0696[b]	0.0747[b]	0.0170	0.0650[a]
	(0.0325)	(0.0327)	(0.0325)	(0.0322)	(0.0326)	(0.0326)
γ_1	$5.27\cdot10^{-4}$	$-0.61\cdot10^{-4}$	$-2.13\cdot10^{-4}$	$2.83\cdot10^{-4}$	$5.24\cdot10^{-4}$	$0.24\cdot10^{-4}$
	$(5.02\cdot10^{-4})$	$(3.70\cdot10^{-4})$	$(3.51\cdot10^{-4})$	$(4.85\cdot10^{-4})$	$(4.68\cdot10^{-4})$	$(3.57\cdot10^{-4})$
γ_2	$0.42\cdot10^{-4}$	$0.21\cdot10^{-4}$	$2.30\cdot10^{-4}$	$-2.37\cdot10^{-4}$	$7.80\cdot10^{-4}$	$1.46\cdot10^{-4}$
	$(4.99\cdot10^{-4})$	$(3.68\cdot10^{-4})$	$(3.50\cdot10^{-4})$	$(4.83\cdot10^{-4})$	$(4.67\cdot10^{-4})$	$(3.56\cdot10^{-4})$
γ_3	$8.51\cdot10^{-4}$[c]	$3.62\cdot10^{-4}$	$4.92\cdot10^{-4}$	$-6.55\cdot10^{-4}$	$7.04\cdot10^{-4}$	$5.25\cdot10^{-4}$
	$(5.01\cdot10^{-4})$	$(3.69\cdot10^{-4})$	$(3.51\cdot10^{-4})$	$(4.84\cdot10^{-4})$	$(4.69\cdot10^{-4})$	$(3.57\cdot10^{-4})$
γ_4	$3.78\cdot10^{-4}$	$1.93\cdot10^{-4}$	$3.12\cdot10^{-4}$	$2.82\cdot10^{-4}$	$7.26\cdot10^{-4}$	$5.04\cdot10^{-4}$
	$(4.99\cdot10^{-4})$	$(3.68\cdot10^{-4})$	$(3.49\cdot10^{-4})$	$(4.83\cdot10^{-4})$	$(4.65\cdot10^{-4})$	$(3.55\cdot10^{-4})$
γ_5	$6.00\cdot10^{-4}$	$8.23\cdot10^{-4}$	$13.02\cdot10^{-4}$[b]	$-24.76\cdot10^{-4}$[a]	$11.32\cdot10^{-4}$	$10.71\cdot10^{-4}$[c]
	$(8.06\cdot10^{-4})$	$(5.93\cdot10^{-4})$	$(5.63\cdot10^{-4})$	$(7.78\cdot10^{-4})$	$(7.52\cdot10^{-4})$	$(5.72\cdot10^{-4})$

Standard errors are in parentheses. Significantly different from zero at 1% ([a]) , 5% ([b]) and, 10%([c]) level.

The results from the estimation are divided into two separate tables for better accessibility. Table 2.4 contains estimated parameters from the mean equation. There are only a few parameters within the lag range from 1 to 9 that are statistically different from zero. However, in four cases coefficients of lag 10 are highly significant. This confirms the original tests suggesting an AR(10) structure in the data. Lag 10 means exactly two business weeks' memory of the market.

Table 2.5 Estimating conditional variance for GARCH(1,1):

$$h_t = \omega + \alpha\varepsilon_{t-1}^2 + \beta h_{t-1} + \phi_1 d_{MO,t} + \phi_2 d_{TU,t} + \phi_3 d_{WE,t} + \phi_4 d_{TH,t} + \phi_5 d_{HO,t}$$

Estimates and statistics	GBP	ATS	DEM	USD	CHF	FRF
ω	$0.036\cdot10^{-6}$	$1.68\cdot10^{-6}$	$1.75\cdot10^{-6b}$	$5.89\cdot10^{-6a}$	$0.98\cdot10^{-6}$	$0.90\cdot10^{-6}$
	$(1.07\cdot10^{-6})$	$(0.95\cdot10^{-6})$	$(0.69\cdot10^{-6})$	$(1.48\cdot10^{-6})$	$(1.70\cdot10^{-6})$	$(0.77\cdot10^{-6})$
α	0.164^a	0.048^a	0.056^a	0.056^a	0.053^a	0.124^a
	(0.013)	(0.013)	(0.010)	(0.015)	(0.011)	(0.016)
β	0.824^a	0.913^a	0.922^a	0.906^a	0.934^a	0.837^a
	(0.016)	(0.019)	(0.013)	(0.021)	(0.013)	(0.023)
ϕ_1	$1.35\cdot10^{-6}$	$-0.12\cdot10^{-6}$	$-1.73\cdot10^{-6}$	$-5.95\cdot10^{-6b}$	$-2.32\cdot10^{-6}$	$0.26\cdot10^{-6}$
	$(1.69\cdot10^{-6})$	$(1.54\cdot10^{-6})$	$(1.16\cdot10^{-6})$	$(2.63\cdot10^{-6})$	$(2.89\cdot10^{-6})$	$(1.38\cdot10^{-6})$
ϕ_2	$1.91\cdot10^{-6}$	$3.38\cdot10^{-6}$	$5.81\cdot10^{-6a}$	$5.31\cdot10^{-6c}$	$5.88\cdot10^{-6b}$	$2.77\cdot10^{-6b}$
	$(1.56\cdot10^{-6})$	$(1.81\cdot10^{-6})$	$(1.33\cdot10^{-6})$	$(3.12\cdot10^{-6})$	$(2.82\cdot10^{-6})$	$(1.43\cdot10^{-6})$
ϕ_3	$-0.94\cdot10^{-6}$	$-7.98\cdot10^{-6a}$	$-10.38\cdot10^{-6a}$	$-19.03\cdot10^{-6a}$	$-8.33\cdot10^{-6a}$	$-5.90\cdot10^{-6a}$
	$(1.60\cdot10^{-6})$	$(1.47\cdot10^{-6})$	$(1.25\cdot10^{-6})$	$(2.86\cdot10^{-6})$	$(2.72\cdot10^{-6})$	$(1.24\cdot10^{-6})$
ϕ_4	$-0.02\cdot10^{-6}$	$-1.65\cdot10^{-6}$	$-1.19\cdot10^{-6}$	$-5.87\cdot10^{-6a}$	$0.75\cdot10^{-6}$	$0.44\cdot10^{-6}$
	$(2.04\cdot10^{-6})$	$(1.82\cdot10^{-6})$	$(1.14\cdot10^{-6})$	$(2.26\cdot10^{-6})$	$(2.62\cdot10^{-6})$	$(1.19\cdot10^{-6})$
ϕ_5	$3.45\cdot10^{-6}$	$2.75\cdot10^{-6}$	$0.47\cdot10^{-6}$	$2.64\cdot10^{-6}$	$3.71\cdot10^{-6b}$	$2.76\cdot10^{-6}$
	$(2.14\cdot10^{-6})$	$(1.31\cdot10^{-6})$	$(0.68\cdot10^{-6})$	$(2.02\cdot10^{-6})$	$(1.79\cdot10^{-6})$	$(1.70\cdot10^{-6})$

Standart errors are in parentheses. Significantly different from zero at 1% ([a]) , 5% ([b]) and, 10%([c]) level.

Table 2.5 contains results from the iterative estimation of the variance equation, which is of prime interest for the following reason. If a conditional variance changes through time in a predictable way, then the correct modeling of such a variance would yield better estimates of the parameters in the mean equation. It would improve estimates of confidence intervals around the mean forecasts as well. Restrictions put on the coefficients ω, α, and β are satisfied, as well as finite conditional variance condition of $\alpha + \beta < 1$. However, Nelson (1991) has shown that even for a region of parameter value beyond this boundary (e.g. $\alpha + \beta > 1$) the conditional variance process will be strictly stationary and ergodic.

Coefficients of constant ω are small and mostly insignificant. Estimates of lagged squared residuals α and lagged variance β are large and comparable with those found in literature. All of them are significantly different from zero at 1% level. The magnitude of the lagged variance in all six currencies produce unrefutable evidence of the importance that this lagged term must be included in the equation of the conditional variance.

The sum of the estimated values of α and β amounts on average to 0.937 for all six currencies. This fact might suggest employment of an Integrated GARCH(1,1) model. IGARCH model imposes the restriction $\alpha + \beta = 1$ on the coefficients and provides a simpler characterization of exchange rates in question. However, the IGARCH model imposes complete persistence of a shock for infinite time horizon. The covariance stationary GARCH model, on the contrary, implies relatively rapid exponential decay of the shock. Due to the fact that the currency basket peg dilutes external shocks in free rates and other influences proportionately according to the weights, their full impact is eventually damped within a relatively short period of time. This is fully in accordance with the character of the data, and therefore, justifies the use of the GARCH model vs. IGARCH. Further discussion on this subject can be found in Bollerslev and Engle (1993).

Estimates of the day-of-the-week dummy coefficients are fairly small. Despite this, all six currencies show evidence of systematic daily patterns in conditional variance. Similar daily effects were reported by Baillie and Bollerslev (1989) and Hsieh (1988). They are clearly divided into positive and negative effects across days of the week with corresponding daily magnitude levels. Monday, Wednesday, and Thursday show a negative effect while Tuesday, and Holiday show a positive effect. Tuesday’s effect is evident for four currencies and Wednesday’s effect is clearly visible for five of them.

The basket peg causes the exchange rates of koruna to lag one day behind the changes in currencies to which the basket is pegged. This is because free exchange rates at the market in Frankfurt at time (t) are used to set the currency basket and exchange rates of koruna at time (t+1). Due to the one-day-lag, it is a Tuesday’s effect that captures reaction on the accumulation of information in the financial markets over the weekend.

When modeling free exchange rates, it would be Monday's effect that should capture this phenomenon because of the lack of a time lag. The Wednesday's effect may be understood as a natural correction of the financial markets after a possible over-reacting on accumulated information a day before, as seen on Tuesday in free exchange rate countries.

2.5 Testing the fit of the model

2.5.1 Standard method (Ljung-Box)

The overall fit of the model is assessed by diagnostic tests on standardized residuals z_t that are constructed as

$$z_t = \varepsilon_t / \sigma_t \tag{2.8}$$

where ε_t is the residual of the mean equation (2.5), and σ_t is a standard deviation derived from the estimated conditional variance from (2.6). The tests and statistics are shown in Table 2.6.

Means are close to zero and variances tend to unity for the exchange rates residuals. Under these conditions it shows that equations (2.5) and (2.6) are correctly specified. Ljung-Box tests document that first order serial dependency is not present at all. Second order dependence is generally missing as well, however, it is detected at 5% level in standardized residuals for ATS and FRF. Kurtosis dropped for all currencies except USD, though, its decrease in case of GBP and DEM was not large enough to fit into a normal distribution. Kurtosis of ATS, CHF, and FRF decreased sufficiently to fit into normal distribution.

Table 2.6 Tests on standartized residuals

Statistics	GBP	ATS	DEM	USD	CHF	FRF
Mean	0.006	0.008	0.016	0.003	0.009	0.006
Variance	1.117	1.012	1.056	1.129	1.004	1.004
Skewness	-1.284	-0.212	0.017	1.370	0.031	-0.547
Kurtosis	12.795	1.028	3.200	12.436	0.885	1.772
nQ(10)	8.427	2.443	2.522	2.918	1.572	4.411
$nQ^2(10)$	1.637	20.826	4.246	6.152	11.850	19.144

Ljung-Box: critical value of 23.21 from χ^2 distribution with 10 d.f. at 1% level is used.

2.5.2 BDS test of the fit

The standardized residuals were also examined with a BDS test of Brock, Dechert, Scheinkman, and LeBaron (1996). We refer to this test as the BDS test since this methodology was originally published by Brock, Dechert, and Scheinkman (1987). The BDS test is a nonparametric test of null hypothesis that the data is independently and identically distributed (iid). The technique enables to test for nonlinear dependence and uses the concept of correlation integral employed by Grassberger and Procaccia (1983) to distinguish between chaotic deterministic systems and stochastic systems.

In order to define the correlation integral $C_{m,T}(\varepsilon)$, let $\{x_t\}$be a scalar time series of lenght *T*. Then, we form *m*-dimensional vectors, called *m*-histories, $x_t^m = (x_t, x_{t+1}, \ldots, x_{t+m-1})$. Such *m*-dimensional vectors are used to calculate the correlation integral at embedding dimension *m*, which is given by

$$C_{m,T}(\varepsilon) = \sum_{t=1}^{T_{m-1}} \sum_{s=t+1}^{T_m} I_\varepsilon(x_t^m, x_s^m) \cdot 2/(T_m(T_m - 1)) \qquad (2.9)$$

where $T_m = T - m + 1$, and $I_\varepsilon(x_t^m, x_s^m)$ is an indicator function of event

$$\left\| x_i^m - x_j^m \right\| = \sup_{i=0,\ldots,m-1} \left| x_{t+i} - x_{s+i} \right| < \varepsilon .$$

Thus, the correlation integral measures the fraction of pairs that lie within the tolerance distance *e* for the particular spatial dimension *m.*

The correlation integral is used to define the BDS statistics

$$BDS_{m,T}(\varepsilon) = T^{\frac{1}{2}} \left[C_{m,T}(\varepsilon) - C_{1,T}(\varepsilon)^m \right] / \sigma_{m,T}(\varepsilon) \qquad (2.10)$$

where *T* is the sample size, $C_{m,T}(\varepsilon)$is the value of a correlation integral or a number of clustered pairs lying within a particular tolerance distance *e* at spatial dimension *m*, and $\sigma_{m,T}(\varepsilon)$is a standard deviation of the statistic that varies with dimension *m*. The proximity parameter ε is chosen arbitrarily and is chiefly enumerated as a ratio of the sample's standard deviation.

The BDS test is a nonparametric test of the null hypothesis that the data is independently and identically distributed (iid) against an unspecified alternative. The test enables one to test for nonlinear dependence because it is no affected by linear dependencies in the data. The procedure has power against both deterministic and stochastic systems. The ability of this test to deal with stochastic time series makes its application in modern macroeconomics and financial economics very appealing.

By detecting pairs of histories that cluster together within a specific range ε too often, the BDS test is able to reveal hidden patterns which should not occur in a truly randomly distributed data. A "pattern", in this case, is defined as an occurrence of two histories that lie within a certain distance ε of each other for different spatial dimensions m. Further detailed explanation and application of the BDS test can be found in the original paper as well as in numerous studies by Brock and Dechert (1988), Hsieh and LeBaron (1988), Hsieh (1989), Kugler and Lenz (1990), Hsieh (1991), Brock, Hsieh and LeBaron (1993), Kugler and Lenz (1993), Olmeda and Perez (1995), and Kocenda (1996). The software program of Dechert (1987) was used to compute the BDS statistic.

The BDS test is able to reveal hidden patterns in seemingly random numbers. This can be illustrated by results from the BDS test performed on stationary first logarithmic differences to test for the nonlinearity in the data. Results in Table 2.7 support decisive rejection of the hypothesis that logarithmic first differences of the exchange rates are iid for all currencies.

The subsequent application of the BDS test on the standardized residuals has a strong implication. If the standardized residuals originate from a correctly specified model of the mean with a correctly specified model of the conditional variance, then they should not contain any other useful forecastable structure. In other words standardized residuals derived from such a model should become white noise.

Table 2.7 BDS Test: First Logarithmic Differences

m	ε	ATS	GBP	DEM	USD	CHF	FRF
2	1	8.72*	7.86*	3.70*	1.19	3.64*	4.72*
3	1	10.3*	10.2*	4.11*	1.09	4.18*	5.68*
4	1	11.7*	12.0*	4.90*	1.62	4.88*	6.93*
5	1	12.7*	13.27*	5.62*	2.34*	5.74*	8.12*
6	1	14.21*	14.39*	6.43*	3.19*	6.46*	9.57*
7	1	16.25*	15.28*	7.30*	3.89*	6.92*	11.36*
8	1	18.50*	16.23*	8.06*	4.46*	7.28*	12.76*
9	1	21.13*	17.26*	9.10*	5.06*	7.48*	14.36*
10	1	24.01*	18.40*	10.32*	5.56*	7.45*	15.87*
2	1/2	2.87*	6.27*	3.69*	1.91	3.35*	7.18*
3	1/2	2.68*	7.80*	3.83*	1.74	4.06*	8.59*
4	1/2	2.39*	9.31*	4.48*	2.19	4.56*	10.45*
5	1/2	1.96	10.20*	5.03*	2.61*	4.84*	12.35*
6	1/2	2.18	10.88*	5.36*	3.31*	4.92*	15.89*
7	1/2	3.10*	11.28*	6.24*	2.65*	6.03*	21.01*
8	1/2	3.34*	11.73*	5.27*	3.81*	6.06*	26.91*
9	1/2	5.16*	12.67*	2.99*	3.19*	4.37*	35.85*
10	1/2	6.82*	13.43*	1.60	8.44*	-2.66	50.24*

BDS follows t-distribution. * indicates 1% significance level (> 2.33).

Table 2.8 BDS tests of nonlinearity: Standardized Residuals GARCH(1,1)

M	ε	GBP	ATS	DEM	USD	CHF	FRF
2	1	-1.92	-0.51	-1.10	-0.84	0.79	-0.53
3	1	-2.02*	-0.68	-1.37	-1.27	0.75	-1.09
4	1	-1.61*	-0.47	-1.37	-1.43*	0.79	-1.23
5	1	-1.78*	-0.66	-1.35	-1.50*	0.98	-1.20
10	1	-2.63*	-0.64	-1.46	-1.15	0.23	-0.94
2	0.5	-1.95	0.20	-0.51	-1.26	1.01	-0.87
3	0.5	-2.09*	0.21	-1.02	-1.73	0.84	-1.37
4	0.5	-1.71	-0.01	-0.97	-1.80	0.92	-1.38
5	0.5	-2.11	-0.37	-0.93	-1.86	0.27	-1.72
10	0.5	-1.14	4.99	-0.60	-1.72	-4.48	-2.21

BDS: critical values in a form of Qantiles of BDS Statistic
are provided in a separate Table 9

Table 2.9 Quantiles of BDS Statistic GARCH(1,1) Standardized Residuals 1000 observations

Quantile	m					
	2	3	4	5	10	N(0,1)
ε=1.0σ						
1.0%	-1.97	-1.64	-1.42	-1.45	-1.66	-2.33
2.5%	-1.69	-1.41	-1.26	-1.20	-1.46	-1.96
97.5%	1.63	1.42	1.32	1.23	1.75	1.96
99.0%	2.01	1.78	1.61	1.51	2.23	2.33
ε=0.5σ						
1.0%	-2.11	-1.96	-2.09	-2.45	-7.31	-2.33
2.5%	-1.84	-1.72	-1.80	-2.05	-6.93	-1.96
97.5%	1.80	1.79	1.92	2.19	16.83	1.96
99.0%	2.29	2.18	2.25	2.69	23.48	2.33

Based on 2000 replications

Source: Brock, Hsieh, and LeBaron (1993), p. 278

Table 2.8 shows the results of the BDS test on standardized residuals. The results can be interpreted with the help of Table 2.9 which contains quantiles of the BDS statistic of standardized residuals from GARCH(1,1) model of exchange rates. The asymmetric distribution was derived by Brock, Hsieh, and LeBaron (1993), p.278, after 2000 replications (the table, however, states values for ε=1 and 0.5 only). For tolerance distance ε=1 the test reveals no evidence of nonlinear dependence for four currencies: ATS, DEM, CHF, and FRF. However, the critical values are exceeded for spatial dimensions *m*=3,4,5, and 10 in case of GBP which shows rather high values for all dimensions in any event, and for *m*=4, and 5 in case of USD. This indicates the existence of a more complex dimensional structure governing the behavior of these particular rates. In case of USD it is a marginal decision though. A missing nonlinear term is to be added to better the model. At tolerance distance ε=0.5 a nonlinear dependence is not detected in general. The critical value is exceeded at the dimensional level of *m*=3 in rate of GBP. In no case is the critical value exceeded at the highest dimensional level. If it were, it would have been for a different reason. As spatial dimension *m* increases, the number of pairs of histories that lie within the distance ε decreases rapidly. The lack of available data, therefore, causes the test to go beyond the statistical range and distortions are likely to occur.

It can be concluded that the model fits all six currencies very well, but GBP requires some nonlinear improvement. Diagnostic tests show that GARCH(1,1) model is capable of accounting for most of the nonlinearity in the particular set of exchange rates.

2.6 Empirical summary

Exchange rates of the Czech koruna to six major currencies evolved relatively stable through the researched period. Due to their dependency on the currency basket, they are of a semi-fixed character. They showed remarkable similarities in behavior and statistical characteristics with those exchange rates that are free to float. This is to be attributed to the consistent policy of the central bank that kept the basket index relatively unchanged within the ± 0.5% band. The exchange rates achieved stationarity after the first logarithmic differencing and were shown not to be identically and independently distributed. Their conditional first moments are linearly independent. However, non-linear dependency was detected in conditional second moments. These facts along with a Lagrange-multiplier test confirmed the presence of an ARCH process in the data.

GARCH(1,1) model was employed to capture the properties of the exchange rates and to model their conditional variance along with the day-of-the-week effects. Mean equation of the model exhibits a strong statistical significance at the tenth lag level which indicates a two business week memory of the market. Variance equation shows highly significant coefficients of lagged residuals and own variance. Altogether it is shown that change in a rate is very closely related to its conditional variance. Strong Wednesday and Tuesday effects uncover a significant sequential responsiveness to the information flow within financial markets.

Tests performed on the standardized residuals from the GARCH(1,1) model revealed nonexistence of both first and second order serial dependency. However, the latter was detected at 5% level for two currencies. The model accounted for decrease in kurtosis for five currencies, although marginally in two cases.

An advanced nonparametric BDS test revealed existence of nonlinear dependency in exchange rates. Standardized residuals, on the contrary, revealed a lack of such a dependency and become white noise. The only exception is GBP (and marginally USD), where a nonlinear component should be added to improve the model. The particular model accounted for most of the nonlinearity in the data and other nonlinear model is not likely to be able to pick up more of the forecastable structure from a time series.

The application of conditional heteroskedasticity proved to be an efficient tool to analyze semi-fixed exchange rates managed under strict discipline. Combined results of the analysis showed that the Czech National Bank managed to mantain exchange rate of the Czech koruna without subjective tampering. Doing so, the rates were able to fully reflect influences of the currencies in the currency basket. A similar approach could be used in examining other (transition) economies that choose to impose such a strict discipline and peg their currencies using a fixed exchange rate arrangement of a similar fashion.

3 Volatility of exchange rate with change in fluctuation band

3.1 Altered band

This part extends the analysis of exchange rate and examines the behavior of the Czech koruna when it was pegged to a currency basket under different fluctuation bands. The period of our interest starts after the monetary separation of the Czech and Slovak republics in the beginning of 1993 until the end of 1996. It offers a different angle of application of generalized autoregressive conditional heteroskedasticity to analyze a currency movement. In chapter 2 we outlined monetary environment in which the exchange rate of the koruna evolved since 1991.

Most importantly we stated that the koruna could not be openly traded for several years and its full was instituted convertibility on October 1, 1995. This measure meant that the koruna could be traded for foreign exchange without restrictions by both companies and citizens. However, this step was not paired with any kind of change in the exchange rate regime itself.

Such a change happened in 1996 and concerns the fluctuation band. The fluctuation band imposed on the currency basket was originally set at ± 0.5% (narrow band period). It was widened on February 28, 1996 to allow the index to fluctuate by ± 7.5% (wide band period). By allowing for a wider fluctuation band, the CNB let the exchange rate fluctuate more freely, thus reducing its potential nominal stability. Because of the fact that the currency basket was introduced to keep a relatively stable nominal exchange rate, a further implication is that allowing for a wider fluctuation band should lead to more pronounced movements and increased volatility of the koruna. Whether this is true is addressed in the following analysis that starts with data description.

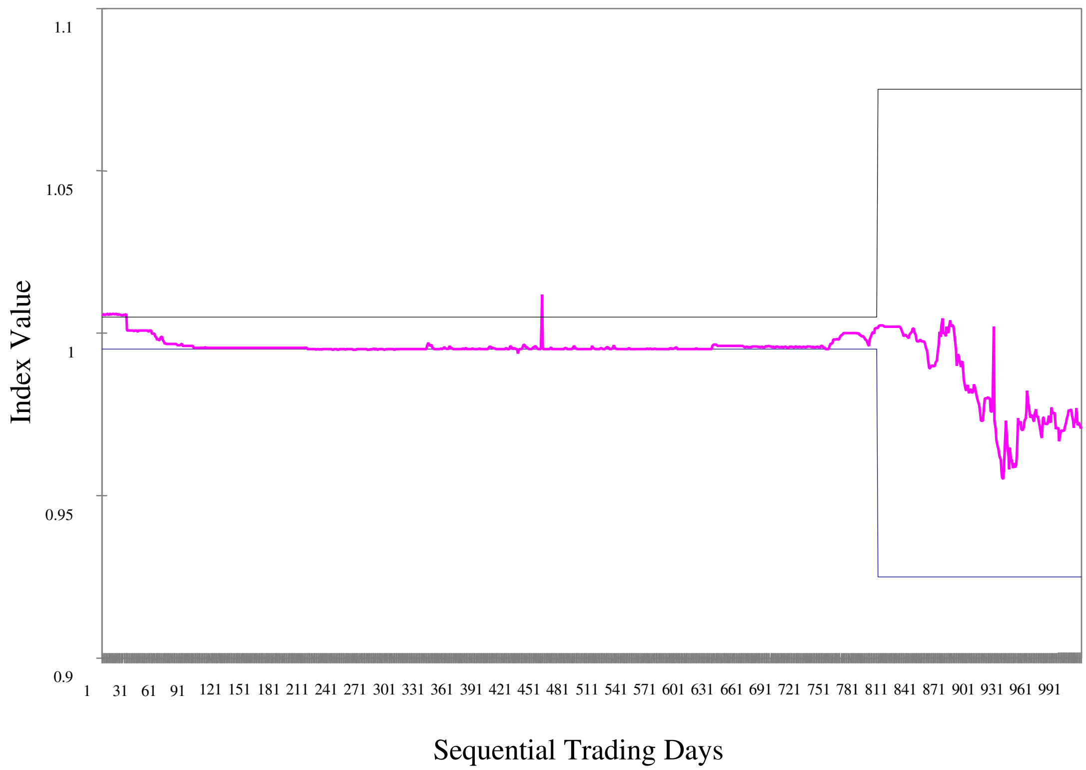
3.2 Data

The data consists of daily midpoint exchange rates of the Czech koruna (CZK) to six major currencies from January 4, 1993 to December 31, 1996. The data was supplied by the Czech National Bank (CNB), Prague. The rates of foreign currencies in terms of the Czech koruna are: Deutsche Mark (DEM), U.S. Dollar (USD), British pound (GBP), Canadian dollar (CAD), Japanese yen (JPY), and Swedish kron (SEK). The six major currencies were selected for this study because the majority of them are quite important in international trade (USD, GBP, JPY), and some of them are included in the currency basket to which the Czech koruna was pegged (USD, DEM). Another reason is that they represent a set of currencies that are governed by different exchange rate regimes: from a real free float (USD, CAD, JPY) to a more limited float or interlinked peg (DEM, SEK, GBP). A significant reason for analyzing CAD, JPY, GBP, and SEK is the fact that these currencies were not in any formal way associated with the composition of the basket during the researched period.

There are a total of 1016 daily observations for each currency. The data are not stationary but represent a first order integrated process. A further analysis is performed on the rate of change of respective exchange rates calculated as a percentual change between two consecutive business days. Such a transformed time series exhibits the usual mean close to zero and skewness and kurtosis far from normality, as one would expect in the case of high frequency financial data.

The change in the fluctuation band allows us to divide the whole span of data into two periods. The first one covers the period from January 4, 1993 to February 27, 1996, and has 804 observations. The latter one, with 212 observations, covers the rest of the data until the end of 1996. From the data we reconstructed evolution of the currency basket index exactly the same way as in section 2.2. The CNB managed to keep the index of the basket within the band during both periods. However, minor incidents of mismanagement occurred, as can be seen in Figure 3.1. Again, it should be stressed that the index, calculated from daily midpoint exchange rates, serves only as an illustration of how it evolved over time.

Figure 3.1
Evolution of the Currency Basket Index



3.3 Leverage effect

As before we use the autoregressive conditional heteroskedasticity (ARCH) model specified by Engle (1982) as an effective approach to modeling volatility. Particularly we use the extension of Bollerslev (1986) who put the original framework forth to a generalized autoregressive conditional heteroskedasticity model (GARCH) where current volatility depends not only on past squared residuals but also on a lagged autoregressive component, e.g. lagged own variances. By deriving residuals ε_t from an underlying process, which are conditioned by the information set Ω_t, a GARCH(p,q) process is given by $\varepsilon_t \mid \Omega_{t-1} \sim N(0,\sigma_t^2)$ with conditional autoregressive variance specified as

$$\sigma_t^2 = \omega + \sum_{j=1}^{p} \alpha_j \varepsilon_{t-j}^2 + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2 \quad . \tag{3.1}$$

Research done with exchange rates and security prices uses random walk as well as different univariate processes to model underlying movement in the data. When taking into account the basket pegged character of the exchange rates in the data set and having performed several tests, we opted for an autoregressive process to model the underlying movement in the data. The number of lags was determined to be 1, 1, 3, 1, 1, and 2 for DEM, USD, GBP, CAD, JPY and SEK, respectively. The mean equation was specified as

$$\mathrm{r_t} = \mathrm{a_0} + \sum_{\mathrm{i=1}}^{\mathrm{k}} \mathrm{a_i} r_{t-i} + \varepsilon_t \tag{3.2}$$

where, $\varepsilon_t \mid \Omega_{t-1} \sim D(0,\sigma_t^2)$.

In order to analyze volatility of the koruna the following concept was introduced. A change in volatility is analyzed with the use of a phenomenon known as a "leverage effect," which is the negative correlation between volatility and past returns. Following the parametrization of Glosten, Jagannathan, and Runkle (1993) and its application by Engle and Ng (1993) and Hamilton and Susmel (1994), the variance equation was specified as

$$\sigma_t^2 = \omega + \alpha \cdot \varepsilon_{t-1}^2 + \beta \cdot \sigma_{t-1}^2 + \xi \cdot d_{t-1} \cdot \varepsilon_{\mathrm{t\text{-}1}}^2 \tag{3.3}$$

where d_{t-1} is a dummy variable that is equal to zero if $\varepsilon_{t-1} > 0$, and equal to unity if $\varepsilon_{t-1} \le 0$. The leverage effect predicts that $\xi > 0$. The restrictions on the parameters in the variance equation require that $\omega > 0$, $\alpha \ge 0$, and $\beta \ge 0$. Further, when $\alpha + \beta < 1$, then the unconditional variance is finite and stationarity is ensured by not having unit root, as shown by Bollerslev (1986). The above specification yields the GARCH-L(1,1) model that is estimated later.

The leverage effect was analyzed in stock price movements. For example, in the case of equities, Black (1976) and Nelson (1991), among others, argued that a stock price decrease tends to increase subsequent volatility by more than would a stock price increase of the same magnitude. 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 the koruna, or the koruna's appreciation, would tend to increase the subsequent volatility of the koruna more than would a depreciation of an equal magnitude. Despite the fact that holding foreign exchange is, in terms of risk, similar to holding equities, literature dealing with the "leverage effect" in the context of exchange rate fluctuation is still lacking.

While the value of the statistically significant leverage coefficient ξ indicates the magnitude of the leverage effect, the sign implies its direction. A positive value of the coefficient ξ indicates an increase, and a negative coefficient indicates a decrease in subsequent volatility of the exchange rate. By comparing values and signs of statistically significant leverage coefficients for a particular exchange rate in the two separate periods of narrow and wide fluctuation bands, it is possible to comment on the effect of the fluctuation band change on the koruna's volatility.

3.4 Leverage effect empirics in exchange rate

An estimation of the model was performed by using a log-likelihood function of the form $L = \left(-\frac{1}{2}\ln\sigma_t^2 - \frac{1}{2}\left(\varepsilon_t^2 / \sigma_t^2\right)\right)$. The maximum likelihood estimates were obtained by using a numerical optimization algorithm described by Berndt, Hall, Hall, and Hausman (1974). The results from the estimation are presented in Table 3.1 and Table 3.2 for narrow and wide fluctuation band periods respectively.

Coefficients of the mean equation reveal a small and mostly insignificant intercept for both periods. Lagged rates are mostly insignificant in the first period but highly significant in the later one. The second period dominates the whole process and the number of lags in the AR model is kept the same in both periods for the sake of consistency.

Table 3.1
Estimating GARCH-L (1,1): First (Narrow Band) Period

Estimates and statistics	DEM	USD	GBP	CAD	JPY	SEK
a_0	0.00006	-0.00009	0.00059	-0.00018	0.00014	0.00001
	(0.00009)	(0.00015)	(0.00091)	(0.00020)	(0.00021)	(0.0021)
a_1	-0.135^a	-0.039	-0.553^a	-0.018	0.028	0.004
	(0.035)	(0.035)	(0.035)	(0.035)	(0.035)	(0.035)
a_2	-	-	-0.292^a	-	-	-0.113^a
			(0.039)			(0.035)
a_3	-	-	-0.122^a	-	-	-
			(0.035)			
ω	$2.01 \cdot 10^{-6a}$	$7.29 \cdot 10^{-7a}$	0.00059	0.00011^a	0.00001^a	0.00012^a
	$(0.51 \cdot 10^{-6})$	$(1.50 \cdot 10^{-7})$	(0.00052)	(0.00003)	(0.000003)	(0.000017)
α	0.059^a	0.004	0.165	0.005	0.103^a	0.024
	(0.019)	(0.009)	(0.174)	(0.012)	(0.018)	(0.033)
β	0.886^a	0.922^a	0.822^a	0.933^a	0.893^a	0.554^a
	(0.030)	(0.016)	(0.159)	(0.017)	(0.017)	(0.061)
ξ	-0.167^a	0.079^a	-0.567	0.062^a	-0.054^a	0.217^a
	(0.023)	(0.017)	(0.503)	(0.018)	(0.021)	(0.055)

Standard errors are in parentheses. Significantly different from zero at 1% (a) , 5% (b) and, 10%(c) level.

In the case of the variance equation, coefficients of constant ω are small and mostly insignificant. Estimates of lagged squared residuals α and lagged variance β are generally large and comparable with those found in the literature. Nearly all of them are significantly different from zero at 5 or 10% level; however, 1% level significance predominates. The magnitude of the lagged variance in most of the currencies provides irrefutable evidence of the importance of including this lagged term in the equation of the conditional variance.

The focal results of this paper are provided by comparing the leverage effect coefficients. The focus is naturally on the DEM and USD. In both periods the Deutsche mark shows quite a large negative coefficient which increased roughly by one third from one period to another. The volatility of this exchange rate tends to decrease during the wide band period. The dollar starts with a relatively small positive coefficient for the first period and ends up with an almost equal coefficient of the negative sign in the second one. This represents a significant change in the behavior of this exchange rate as well as the tendency for the volatility to decrease during the wide band period as in the case of the Deutsche mark.

Table 3.2
Estimating GARCH-L (1,1): Second (Wide Band) Period

Estimates and statistics	DEM	USD	GBP	CAD	JPY	SEK
a_0	-0.00030	-0.00009	0.00052	0.00013	-0.00047	-0.00006
	(0.00026)	(0.00029)	(0.00034)	(0.00037)	(0.00041)	(0.00031)
a_1	-0.199[a]	-0.148[a]	-0.041	-0.218[a]	-0.118[c]	-0.054
	(0.067)	(0.068)	(0.070)	(0.067)	(0.069)	(0.069)
a_2	-	-	0.042	-	-	0.041[a]
			(0.071)			(0.069)
a_3	-	-	-0.012	-	-	-
			(0.070)			
ω	$0.87 \cdot 10^{-6}$[a]	$2.66 \cdot 10^{-5}$[a]	$0.41 \cdot 10^{-6}$[a]	0.00042[a]	0.00001[a]	0.00001[c]
	($0.27 \cdot 10^{-6}$)	($1.69 \cdot 10^{-6}$)	($0.04 \cdot 10^{-6}$)	(0.00002)	(0.000003)	(0.000078)
α	0.140[a]	0.182[a]	0.023[a]	0.148[a]	0.031[b]	0.217[b]
	(0.045)	(0.044)	(0.007)	(0.073)	(0.016)	(0.101)
β	0.807[a]	0.750[a]	0.940[a]	0.812[a]	0.941[a]	0.756[a]
	(0.022)	(0.102)	(0.004)	(0.073)	(0.061)	(0.061)
ξ	-0.221[a]	-0.082[c]	-0.059[a]	-0.054	-0.430[a]	-0.242[b]
	(0.066)	(0.049)	(0.015)	(0.624)	(0.244)	(0.125)

Standard errors are in parentheses. Significantly different from zero at 1% ([a]) , 5% ([b]) and, 10%([c]) level.

What happened in the case of the other currencies? The exchange rate of the Japanese yen records an increase of the negative leverage coefficient. The British pound, on the other hand, exhibits a decrease of the negative leverage coefficient. The coefficient is however, statistically insignificant in the first period, so any strong statement concerning intertemporal comparison is precluded. A similar situation regards the Canadian dollar, which starts with a positive coefficient and ends with a negative one in the wide band period. The latter one is statistically insignificant, though. The Swedish koruna shows a change in the behavior of the exchange rate since it starts with a positive leverage coefficient but records a negative one later. This indicates a considerable decrease in volatility for this exchange rate.

The results of the analysis clearly indicate that allowing for the wider fluctuation band resulted in a decrease in volatility of the key currencies (DEM and USD), as well as of two other ones (JPY and SEK). An analysis of the other two currencies (GBP and CAD) is unfortunately precluded by the lack of statistical significance associated with the leverage effect coefficient in the broad or wide band periods respectively. One possible explanation might be the fact that the key currencies (DEM and USD), being a part of the currency basket, affect themselves directly. Their movements actually counteract each other because their influences represented by weights in the basket must be strictly balanced in order to keep the basket index constant. However, the wide fluctuation band allows relatively far deviations from this target. This is empirically documented by the evolution of the index that stayed almost entirely within the appreciation part of the fluctuation band during the wide band period (see Figure 3.1).

The currencies that are not part of the basket are affected indirectly by a simple mechanical calculation of their exchange rate for each respective day. Their diminished volatility associated with a wider fluctuation band then goes against conventional wisdom, which is documented in some previously published work. Flood and Rose (1995) claim that "fixed exchange rates are less volatile than floating rates, but the volatility of macroeconomic variables such as money and output does not change very much across exchange rate regimes." Hasan and Wallace (1996) argue that using long-term data "real exchange rate volatility is greater for flexible exchange rate periods than for fixed-rate periods."

3.5 Brief summary

The exchange rate of the Czech koruna pegged to a currency basket was analyzed. The change of the value of the basket is measured by its index.

The central point of the analysis is how the change in the fluctuation band of the index affected volatility of the exchange rate.

By allowing for a wider fluctuation band, the CNB let the exchange rate fluctuate more freely, thus reducing its potential nominal stability. Because of the fact that the currency basket was introduced to keep a relatively stable nominal exchange rate and limit its volatility, a further implication is that allowing for a wider fluctuation band should lead to more pronounced movements and increased volatility of the koruna.

The analysis showed that, against conventional wisdom, the volatility of the exchange rate diminished after a much wider fluctuation band was introduced. Particularly, the results of the analysis clearly indicate that allowing for a wider fluctuation band resulted in a decrease in volatility of the key currencies (DEM and USD). Two other currencies (JPY and SEK) exhibited decreased volatility, after the narrow fluctuation band was abolished, as well.

4 Intratemporal links among interest and exchange rates*

4.1 Basic facts

Chapters 2 and 3 presented some economic and institutional background of the exchange rate regime that governed the behavior of the Czech koruna from the early 90's. Since exchange rate regime is an important element in the overall monetary policy of each country, it transfers a great deal of influence into the financial market. Such an influence is often likely to be indirect *via* interest rates. Our goal in this part is to assess the money market in the Czech Republic and to study the interactions between short and long interest rates, and specifically a lead-lag relationship. In particular, we will study linkages between interest rates, as well as exchange rates, and compare the results of the periods before 1997 with those in the year when the country experienced financial crisis. Despite the fact that the turbulence in the mid of 1997 was officially labeled as a financial crisis, in the view of what happened on a global scale in 1998 such term should be understood with caution.

As we said before, former Czechoslovakia officially started its economic transformation in 1991. The temporary anchor of an exchange rate regime based on a currency basket peg with a new level of base rates was introduced in 1991 as a part of overall transformation strategy. Czech koruna emerged after the split of the country into two independent nations followed shortly by the formal monetary separation. Over the years several important changes took place. First, the Czech National Bank (CNB) changed the composition of the basket on January 2, 1992, and then on May 2, 1993. From the latter date on, the basket was composed of the US dollar and the Deutsche mark at a ratio of 35:65. Second, there was a

* This chapter was written with Jan Hanousek.

change of the fluctuation band. The band imposed on the basket was originally set at ± 0.5%. It was widened on February 28, 1996, to allow the index to fluctuate by ± 7.5%, while the exchange rate was still kept within the fixed regime. Previous chapters dealt with this subject in detail.

During the period from 1991 to 1996 the koruna evolved in a relatively stable manner. The stability was interrupted in 1997.

From the very beginning of 1997 the exchange rate started to appreciate significantly. In the middle of February it reached a local maximum of 5.5% above a central parity, and from then on it steadily depreciated. At first the fall was not very sharp and the rate even became steady in the beginning of May. A strong speculative pressure had emerged by the middle of May. CNB fought the speculative attacks for roughly two weeks with the help of foreign exchange interventions and with a sharp increase in interest rates. Then on May 26, 1997, the CNB abandoned the fixed exchange rate regime and let the koruna float freely with some unspecified tie to the Deutsche mark. The koruna immediately devalued by 12-13%. This dive stopped quite quickly, and subsequently the koruna strengthened and moved into the lower range of the original parity.

The devaluation of the koruna acted as a natural pro-export feature and hurt the economy only mildly. The sharp increase in interest rates was the damaging factor, instead. The CNB ceased performing repo operations on May 15, 1997, and set a floating repo rate, which was dependent on the current market situation. The rates rose slightly. On May 16, 1997, the CNB increased the lombard rate from 14 to 50%, and during the next week it started to lower market liquidity with a 45 and later 75% repo rate. As a result of such strict monetary policy, short-term interest rates on the inter-bank market reached an unbelievable 200% and even peaked above 400%. Commercial banks were cut off from liquidity and acted accordingly. Tied to the subsequent appreciation of the currency, interest rates decreased but did not reach original levels.

The relatively stable environment of the fixed exchange rate regime and semi-regulated interest rates in the early 90’s provided a soft environment for the evolution of links among key interest rates. The bonds among interest rates tended to evolve in a weak economic sense. They naturally changed from 1993, when a modern banking sector emerged in the country. In 1996 these links were found to be quite independent. The peaceful evolution lasted till the beginning of 1997. Then turbulence started to sweep the entire industry and to erode the original arrangements.

It is not our purpose to discuss whether the interest rates were correctly or incorrectly set during the crisis. Rather we would like to take the interest rate settings as exogenous shocks and analyze what their impact was. The great exogenous shocks might have great effect on links among interest rates at the inter-bank market and the position of its leading rate. Similar links are expected to exist between the exchange rate and interest rates.

4.2 Vector autoregresive analysis of lead-lag relationship

A usual vector autoregressive process (VAR) specification is

$$Y_t = A_0 + A_1 \cdot Y_{t-1} + ... + A_m Y_{t-m} + \mathrm{E}_t , \qquad (4.1)$$

where Y is a list of macroeconomic variables. A VAR is a non-structural model which simply estimates how variables are related to their lagged values over time. VAR models have been used extensively, in particular in macroeconomic forecasting. Several authors give a strong critique of structural models, arguing that VAR works better for forecasting and for policy evaluation (see Litterman (1979) and Sims (1980) among others). On the other hand, VAR specification represents a reduced form of a structural model.

Since Granger (1969) introduced his definition of "causality," (see also Sims (1980)) the test of Granger-type causality has been applied quite frequently in a variety of empirical papers, including studies on market links. The methodology for testing linkages between markets is quite standard and was extensively used by Agmon (1972), Hiemstra and Jones (1994), Hsiao (1981), Joy et al. (1976), Kwan et al. (1995), and Smith et al. (1993) among others. A similar approach has been used to test interrelations between the cash market and stock index futures by Chan (1992) and Kawaller et al. (1987), to mention a few.

The described model fits our goal of studying the efficiency of the newly established inter-bank market in the Czech Republic. The interactions between short and long interest rates, and specifically a lead-lag relationship, are our general interest. In particular, we intend to study linkages between interest rates, and later between exchange rates and interest rates.

If the inter-bank market is efficient, then arbitrage and base trading will maintain the correct pricing relationship. This lead-lag relationship can be attributed to several specific factors of the Czech inter-bank market: the unsettled character of the new market, the low volume of trade for some maturities, and institutional design. While strong bilateral links support the hypothesis of market integration, a unilateral link leads to market segmentation and arbitrage opportunities.

To test such a hypothesis we use the tool of Granger causality. We say that "$\{x_t\}$ Granger causes $\{y_t\}$," when the lagged values of x_t have an explanatory power in regression of y_t on lagged values of y_t and x_t. The Granger causality is then tested *via* an autoregressive representation:

$$\begin{pmatrix} x_t \\ y_t \end{pmatrix} = \begin{bmatrix} a(L) & b(L) \\ c(L) & d(L) \end{bmatrix} \begin{pmatrix} x_t \\ y_t \end{pmatrix} + \begin{pmatrix} \varepsilon_t \\ \delta_t \end{pmatrix}. \tag{4.2}$$

For a review of alternative tests see Geweke et al. (1983).

Because disturbances are serially uncorrelated, the direction of causality between $\{x_t\}$ and $\{y_t\}$ can be turned into a standard test of whether *b(L)*=0 and/or *c(L)*=0. The test of the hypothesis "$\{x_t\}$ Granger causes $\{y_t\}$" is equivalent to the test of the restriction *b(L)*=0. Similarly, the opposite direction of causality can be tested *via* the restriction *c(L)*=0.

The testing can proceed only if some restrictions on the autoregressive form (4.2) are specified before the actual estimation is done. For instance, we should identify the length of autoregression prior to estimation of (4.2).

We applied Hsiao's (1981) two-step approach to determine the length of the lag structure. The linkages between inter-bank interest rates were examined in the context of the following models:

$$\Delta X_t = \alpha_0 + \sum_{i=1}^{k_1} \alpha_i \Delta X_{t-i} + \sum_{i=1}^{k_2} \beta_i \Delta Y_{t-i} + \varepsilon_t \qquad (4.3)$$

$$\Delta Y_t = \chi_0 + \sum_{i=1}^{k_3} \chi_i \Delta Y_{t-i} + \sum_{i=1}^{k_4} \delta_i \Delta X_{t-i} + \nu_t, \qquad (4.4)$$

where X_t and Y_t denote interest rates associated with different maturity.

For each maturity the proper pair of lag lengths (k_1, k_2) and (k_3, k_4) were specified using a search method over a range of lag lengths from 1 to 10. The choice of the optimal lengths was based on standard information criteria of Akaike (1969), Hannan-Quinn (1979), and Schwarz (1978). Thorton and Batetten (1985) show the sensitivity of the causal relationships (links) to the chosen number of lags. In particular, it is necessary to test whether both series are cointegrated. Such testing is extensively illustrated by the standard methodology developed by Engle and Granger (1987).

Therefore, we did several robust checks, using the number of lags recommended by different information criteria. Moreover, we used six and seven lags of both the dependent and independent variables to test for market linkages. In all cases, we obtained the same results. Because the error terms were not autocorrelated and cointegration was not rejected for any equation, we tested the lead-lag relationship between the interest rates by stating the following hypothesizes:

H_0 : $\beta_i = 0$ for all i, which means that there is no link from maturity Y to X

and

H_0 : $\delta_i = 0$ for all i, which means that there is no link from maturity X to Y.

4.3 Data

All the data we used were provided by the CNB. We used daily exchange rates of the koruna in terms of the US dollar and the Deutsche mark. Further we used daily interest rates for different maturities. One is the **Pr**ague **I**nter**b**ank **O**ffe**r** Rate (PRIBOR); the other is the **Pr**ague **I**nter**b**ank B**id** Rate (PRIBID). Both rates were used in price quotations for: one day, one week, two weeks, one month, two months, three months, six months, nine months, and one year. We are aware of the fact that a one day rate is known to behave rather strangely sometime. However, we included this rate to cover the entire range of interest rates on the interbank market.

There was a total of 1131 observations, which were divided according to years in the following manner: 1993 with 229 observations, 1994 with 247 observations, 1995 with 245 observations, 1996 with 245 observations, and 1997 with 165 observations. The years from 1993 to 1996 cover 12 months each. The data for 1997 covers a period of nine months.

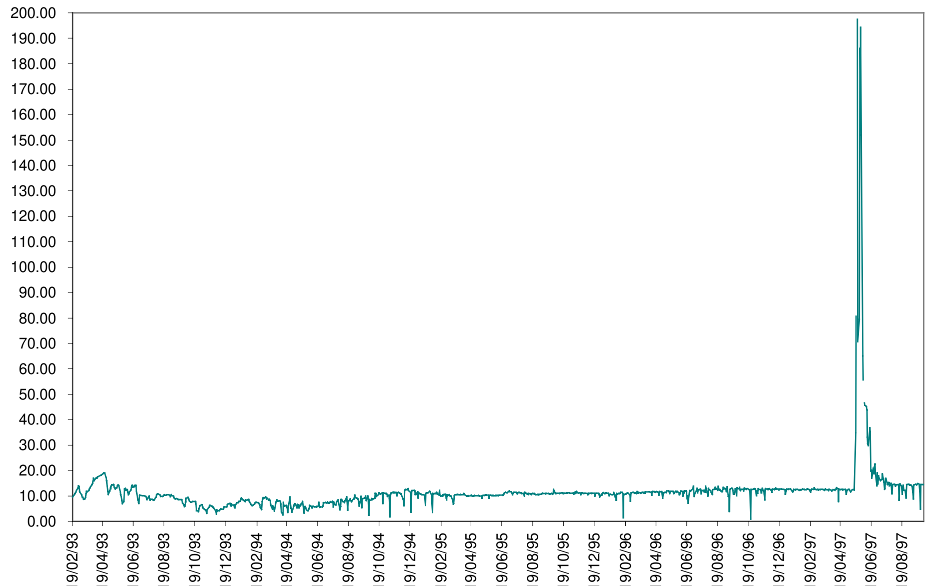
As one might expect, the data are the first order integrated process. The analysis is therefore performed on the changes in exchange and interest rates between two consecutive business days.

4.4 Intratemporal linkages

4.4.1 Overall inter-bank performance

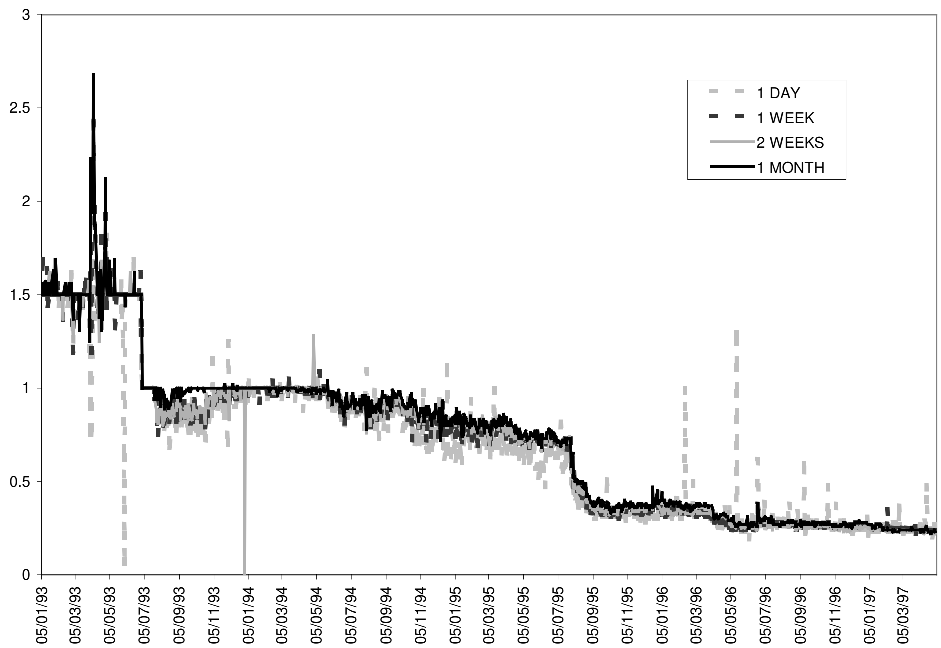
The overall performance of the inter-bank rates from 1993 to the end of September 1997 is illustrated in Figure 4.1. For the sake of simplicity, the magnitudes of the inter-bank rates are presented only for the overnight rate. The picture shows a large peak during the financial crisis. A more important observation is that despite significant differences in the inflation rate during the period prior to the financial crisis, the interest rate was quite stable. In real terms, the rate was significantly negative and significantly below prime rates for the majority of Czech banks. The main point is that during the time of notably different inflation rates, the interest rate was kept more or less constant.

Figure 4.1 One Day Offer Rate on the Prague Inter-bank Market: January 3, 1993 to September 30, 1997



It is very useful to look at the spread, which is defined as the difference between offer and bid rate. The spread is often used as a proxy to measure the degree of stability on the market. Figure 4.2 shows the evolution of short-term interest rate spreads on the inter-bank market from January 3, 1993, to May 16, 1997, just immediately prior to the crisis. It can be concluded that the period before the crisis was characterized by a notable decline in spreads. This can be translated into low uncertainty in and low volatility of the money market.

Figure 4.2 Short Term Interest Rate Spreads on the Prague Inter-bank Market: January 3, 1993 to May 16, 1997



4.4.2 Links among interest rates

The following part of the paper points out the major elements of the monetary policy during the transformation. Further it brings the results of the quantitative analysis of the links among interest rates at the inter-bank market together with the comments.

In the beginning of 1993 the CNB stressed free reserve regulation in the banking system. Interest rates on the inter-bank deposit market rose until the middle of April. Relaxation of monetary policy starting in April led to a gradual decline in interest rates which continued until the end of the year. Tables 4.1 and 4.2 show that the leading rate for bids was one week, while the leading rate for offers ranged from one month to six months. This might imply that interest was primarily in long money. The one-day rate had no meaning in this year, while the nine-month and one-year rates had not yet been introduced.

In 1994 developments on the money market were affected mainly by continuing foreign capital inflows and the CNB employed free market operations. Beginning in the second half of the year, interest rates increased.

Table 4.3 and Table 4.4 show that leading rates for both bids and offers were one-week rates. Similarly, in the case of both rates, the nine-month rate showed a tendency to affect market links as well. As for offers, the two-week rate had some impact too. As before, the one-day rate had no impact.

Table 4.1 1993: Bid

	1D	1W	2W	1M	2M	3M	6M	9M	1Y
1D									
1W	$\rightarrow^{A}$		$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$		
2W	$\rightarrow^{A}$	$\rightarrow^{B}$			$\rightarrow^{A}$	$\rightarrow^{B}$	$\rightarrow^{B}$		
1M	$\rightarrow^{A}$	$\rightarrow^{B}$				$\rightarrow^{B}$	$\rightarrow^{B}$		
2M	$\rightarrow^{A}$		$\rightarrow^{B}$			$\rightarrow^{A}$	$\rightarrow^{A}$		
3M	$\rightarrow^{B}$								
6M	$\rightarrow^{A}$								

Table 4.2 1993: Offer

	1D	1W	2W	1M	2M	3M	6M	9M	1Y
1D									
1W	$\rightarrow^{A}$		$\rightarrow^{A}$	$\rightarrow^{B}$	$\rightarrow^{A}$	$\rightarrow^{B}$			
2W	$\rightarrow^{A}$	$\rightarrow^{A}$			$\rightarrow^{B}$	$\rightarrow^{B}$			
1M	$\rightarrow^{A}$	$\rightarrow^{B}$	$\rightarrow^{B}$		$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$		
2M	$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{B}$	$\rightarrow^{A}$		$\rightarrow^{A}$	$\rightarrow^{A}$		
3M	$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{B}$	$\rightarrow^{A}$	$\rightarrow^{A}$		$\rightarrow^{A}$		
6M	$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$			

Table 4.3 1994: Bid

	1D	1W	2W	1M	2M	3M	6M	9M	1Y
1D							$\rightarrow^{B}$		
1W	$\rightarrow^{A}$		$\rightarrow^{B}$	$\rightarrow^{A}$	$\rightarrow^{B}$	$\rightarrow^{A}$	$\rightarrow^{B}$		$\rightarrow^{A}$
2W	$\rightarrow^{A}$					$\rightarrow^{A}$			$\rightarrow^{A}$
1M	$\rightarrow^{A}$				$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{B}$		$\rightarrow^{A}$
2M	$\rightarrow^{A}$					$\rightarrow^{A}$			$\rightarrow^{A}$
3M	$\rightarrow^{A}$								$\rightarrow^{A}$
6M	$\rightarrow^{A}$				$\rightarrow^{B}$	$\rightarrow^{A}$			$\rightarrow^{B}$
9M	$\rightarrow^{A}$				$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$		$\rightarrow^{A}$
1Y					$\rightarrow^{A}$	$\rightarrow^{A}$			

Table 4.4 1994: Offer

	1D	1W	2W	1M	2M	3M	6M	9M	1Y
1D									
1W	$\rightarrow^{A}$		$\rightarrow^{B}$	$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$			$\rightarrow^{A}$
2W	$\rightarrow^{A}$			$\rightarrow^{B}$	$\rightarrow^{A}$	$\rightarrow^{A}$			$\rightarrow^{A}$
1M	$\rightarrow^{A}$				$\rightarrow^{A}$	$\rightarrow^{A}$			$\rightarrow^{A}$
2M									
3M	$\rightarrow^{A}$				$\rightarrow^{A}$				$\rightarrow^{A}$
6M	$\rightarrow^{A}$				$\rightarrow^{A}$	$\rightarrow^{A}$			$\rightarrow^{A}$
9M	$\rightarrow^{A}$				$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{B}$		$\rightarrow^{A}$
1Y									

$\rightarrow^{A}$ means the direction of a causality link at 1% significance level

$\rightarrow^{B}$ means the direction of a causality link at 5% significance level

In 1995 foreign capital inflow affected the decline in money market interest rates. The CNB used a range of operations to sterilize the impact of this inflow on money market interest rates. Interest rates on total credits and deposits changed little throughout the year. Real interest rates on new credits and time deposits increased. An analysis of this year provides a disquieting view, which is illustrated by Tables 4.5 and 4.6. The market links weakened instead of strengthening. Weekly rates were no longer linked and one-day rates began to tie themselves to one and two-week rates. Other linkages show that short-term weekly rates were becoming leading rates. This might reflect an already emerging uncertainty in the economy. Long money definitely started to lose its position.

Table 4.5 1995: Bid

	1D	1W	2W	1M	2M	3M	6M	9M	1Y
1D		$\rightarrow^{A}$	$\rightarrow^{A}$				$\rightarrow^{B}$		
1W	$\rightarrow^{A}$			$\rightarrow^{A}$	$\rightarrow^{A}$		$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$
2W	$\rightarrow^{A}$			$\rightarrow^{A}$	$\rightarrow^{A}$		$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$
1M	$\rightarrow^{A}$	$\rightarrow^{B}$	$\rightarrow^{B}$					$\rightarrow^{A}$	
2M	$\rightarrow^{A}$							$\rightarrow^{A}$	
3M	$\rightarrow^{A}$	$\rightarrow^{B}$	$\rightarrow^{B}$					$\rightarrow^{A}$	
6M	$\rightarrow^{A}$							$\rightarrow^{A}$	
9M	$\rightarrow^{A}$								
1Y	$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$					$\rightarrow^{A}$	

Table 4.6 1995: Offer

	1D	1W	2W	1M	2M	3M	6M	9M	1Y
1D		$\rightarrow^{B}$	$\rightarrow^{B}$						
1W	$\rightarrow^{A}$			$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{B}$	$\rightarrow^{A}$
2W	$\rightarrow^{A}$	$\rightarrow^{A}$		$\rightarrow^{A}$	$\rightarrow^{B}$		$\rightarrow^{A}$	$\rightarrow^{A}$	$\rightarrow^{A}$
1M	$\rightarrow^{A}$	$\rightarrow^{A}$						$\rightarrow^{B}$	$\rightarrow^{B}$
2M	$\rightarrow^{A}$	$\rightarrow^{A}$							
3M	$\rightarrow^{A}$	$\rightarrow^{A}$						$\rightarrow^{B}$	$\rightarrow^{B}$
6M	$\rightarrow^{A}$	$\rightarrow^{A}$							$\rightarrow^{B}$
9M	$\rightarrow^{A}$	$\rightarrow^{A}$							
1Y	$\rightarrow^{A}$	$\rightarrow^{A}$							

Table 4.7 1996: Bid

	1D	1W	2W	1M	2M	3M	6M	9M	1Y
1D									
1W	$\rightarrow^{A}$								
2W	$\rightarrow^{A}$								
1M	$\rightarrow^{A}$								
2M	$\rightarrow^{A}$								
3M	$\rightarrow^{A}$								
6M	$\rightarrow^{A}$								
9M									
1Y	$\rightarrow^{A}$								

Table 4.8 1996: Offer

	1D	1W	2W	1M	2M	3M	6M	9M	1Y
1D									
1W	$\rightarrow^{A}$								
2W	$\rightarrow^{A}$								
1M	$\rightarrow^{A}$	$\rightarrow^{A}$							
2M	$\rightarrow^{A}$	$\rightarrow^{A}$							
3M	$\rightarrow^{A}$	$\rightarrow^{A}$							
6M	$\rightarrow^{A}$	$\rightarrow^{A}$							
9M	$\rightarrow^{A}$	$\rightarrow^{A+}$							
1Y	$\rightarrow^{A}$	$\rightarrow^{A}$							

$\rightarrow^{A}$ means the direction of a causality link at 1% significance level
$\rightarrow^{B}$ means the direction of a causality link at 5% significance level

In 1996 foreign capital inflow had a smaller effect on money market interest rates. Turnover on the inter-bank deposit market grew substantially. The issue of the year, tighter monetary policy, resulted in an increase in interest rates. Tables 4.7 and 4.8 reveal surprising outcome. The interest rates lack any substantial link and, in plain fact, are not linked among themselves at all. This fact cannot be changed by a slightly better result in the case of offer rates. The outcome might very well have been caused by the small bank crisis that erupted in 1995. The deviant structure on the money market had possibly led to the bizarre situation in which the question of “to whom a bank would lend” was more important than the question of what the price of the loan should be. This is exactly when interest rates failed to give information essential to correct functioning of the money market. They stopped being the price of money.

Table 4.9 1997: Bid

	1D	1W	2W	1M	2M	3M	6M	9M	1Y
1D		$\rightarrow^A$	$\rightarrow^A$		$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$
1W	$\rightarrow^A$			$\rightarrow^A$	$\rightarrow^B$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^B$	$\rightarrow^A$
2W	$\rightarrow^A$	$\rightarrow^A$		$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$
1M	$\rightarrow^A$	$\rightarrow^A$			$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$
2M	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^B$	$\rightarrow^A$		$\rightarrow^A$		$\rightarrow^A$	$\rightarrow^A$
3M	$\rightarrow^A$	$\rightarrow^A$		$\rightarrow^A$	$\rightarrow^A$		$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$
6M	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$		$\rightarrow^A$	
9M				$\rightarrow^A$	$\rightarrow^B$		$\rightarrow^B$		$\rightarrow^A$
1Y	$\rightarrow^A$		$\rightarrow^B$	$\rightarrow^A$	$\rightarrow^B$		$\rightarrow^A$	$\rightarrow^A$	

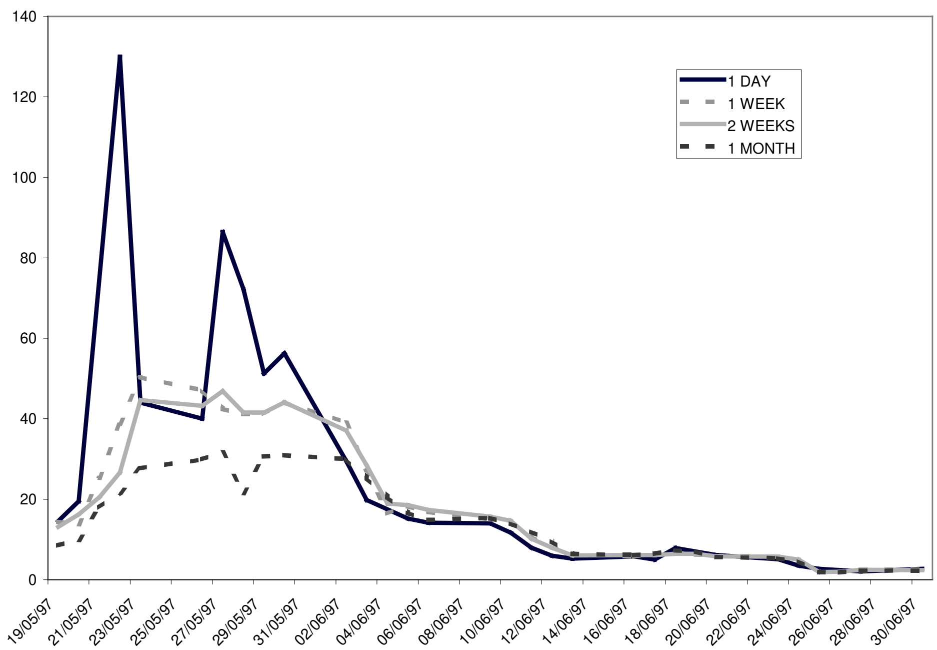
Table 4.10 1997: Offer

	1D	1W	2W	1M	2M	3M	6M	9M	1Y
1D		$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^B$		
1W	$\rightarrow^A$		$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$		
2W	$\rightarrow^A$	$\rightarrow^A$		$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$			
1M	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$		$\rightarrow^B$	$\rightarrow^B$			
2M	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$		$\rightarrow^A$	$\rightarrow^B$		
3M	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$		$\rightarrow^A$	$\rightarrow^B$	$\rightarrow^B$
6M	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^B$	$\rightarrow^A$			
9M	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$		
1Y	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$	$\rightarrow^A$		

$\rightarrow^A$ means the direction of a causality link at 1% significance level
$\rightarrow^B$ means the direction of a causality link at 5% significance level

So far, 1997 has been the most dramatic year on the money market since the beginning of the transformation. The koruna has become the most traded currency of all transition countries. Interest rates were relatively stable at the beginning of the year. A financial crisis prompted their rise and stirred the foreign exchange market considerably. The fixed exchange rate regime was abandoned, but mild foreign exchange interventions remained on the agenda almost daily. Interest rates declined only slowly because of the reluctance of the CNB. The unprecedented uncertainty that started to peak during the financial crisis in the middle of the year is implicitly portrayed in Tables 4.9 and 4.10. The mutual links among interest rates are visibly abundant among almost all interest rates. Two-way links show that one-week and two-week interest rates lost their exclusive position on the market.

Figure 4.3 Short Term Interest Rate Spreads on the Prague Inter-bank Market: May 17, 1997 to June 30, 1997



Again we examine the interest rate spread. Figure 4.3 presents the evolution of short-term interest rate spreads on the inter-bank market from May 17, 1997, to June 30, 1997. Naturally the magnitudes are very different than those before the crisis. The uncertainty in the market increased dramatically. The period after the crisis, from July 1, 1997, to September 30, 1997, is illustrated in Figure 4.4. This period showed a decrease in the interest rate spreads. However, the sudden gaps in spreads suggest that the market was still very sensitive to external shocks and the stability of the market was not comparable to the stability before the crisis.

Figure 4.4 Short Term Interest Rate Spreads on the Prague Inter-bank Market: July 1, 1997 to September 30, 1997

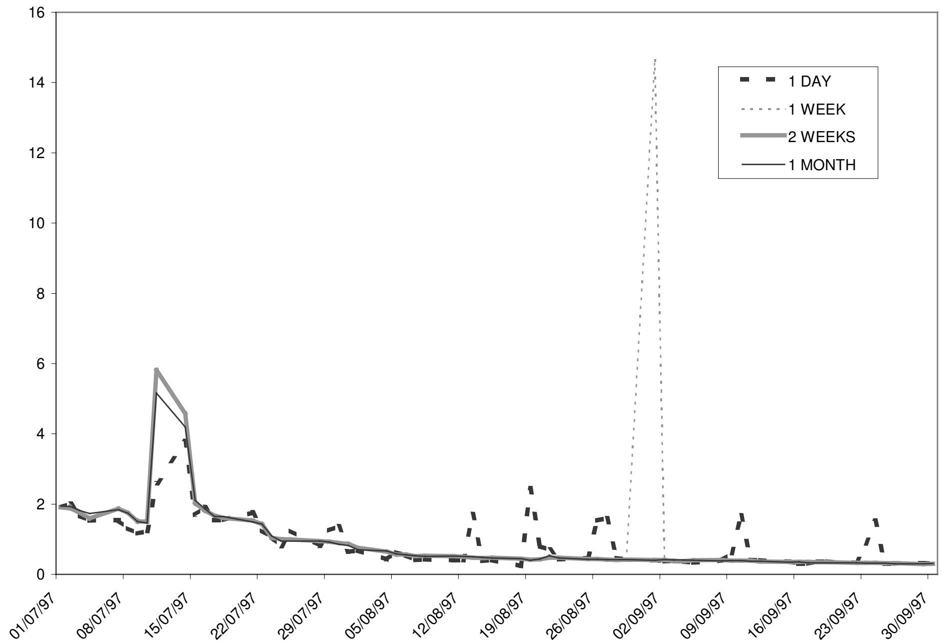


Table 4.11 Links among Exchange and Interest Rates: 1997

Rate	Causality, F-value	Currency		Causality, F-value	Rate
1 Day					1 Day
	7.64 ➜			← 11.5	
1 Week	← 3.69			3.24 ➜	1 Week
	9.76 ➜			← 15.3	
2 Week	← 3.29			3.79 ➜	2 Week
	8.89 ➜			← 12.5	
1 Month	← 4.25			4.81 ➜	1 Month
	7.69 ➜			← 9.51	
2 Month	⇦ 2.14			2.09 ⇨	2 Month
	8.97 ➜	USD	DEM	← 13.8	
3 Month					3 Month
	9.54 ➜			← 13.9	
6 Month					6 Month
	12.3 ➜			← 21.3	
9 Month					9 Month
	11.2 ➜			← 20.7	
1 Year					1 Year
	10.9 ➜			← 19.6	

Arrow marks the direction of link/causality. ➜ means significance at 1% level, and ⇨ means significance at 5% level.

4.4.3 Links between interest and exchange rates

We also researched links between the exchange rate and interest rate. Table 4.11 presents a comprehensive picture of the situation on the market in 1997. For both currencies (US dollar and Deutsche mark) there exists a strong link between short and long-term interest rates that have an influence on exchange rate. However, the opposite link—the exchange rate influencing the interest rate—was detected only for short-term interest rates.

4.5 Comments and implications

The goal of this paper was to assess the interactions between short and long interest rates and between exchange and interest rates. In particular, we have studied linkages between interest rates, as well as exchange rates and interest rates, and compared the results of pre-crisis periods with those in a year of turbulence. While strong bilateral links support the hypothesis of market integration, a unilateral link leads to market segmentation and arbitrage opportunities.

The relatively stable environment of the fixed exchange rate regime and semi-regulated interest rates provided a soft environment for the evolution of links among key interest rates. The bonds among interest rates tended to evolve in a weak economic sense. They naturally changed from 1993, when a modern banking sector emerged in the country. In 1996 these links were found to be quite independent. The peaceful evolution lasted till the beginning of 1997, when turbulence started to sweep the entire industry and to erode the original arrangements. Even the financial crisis was damaging economy, at least it helped to reestablish links on the money market.

It was not our purpose to discuss whether the interest rates were correctly or incorrectly set during the crisis. Rather we took the interest rate settings as exogenous shocks and analyzed what their impact has been. During the turbulent times of a financial crisis, the prevailing links among interest rates tended to gain strength. The mutual links among interest rates are visibly abundant among almost all interest rates. Two-way links show that one-week and two-week interest rates lost their exclusive position on the market. The evolution of linkages show that interest rates influenced the exchange rate during the year of crisis. The exchange rate was found to influence only the short-term interest rates.

As a policy implication we feel that despite the fact that the financial crisis started due to the unreal exchange rate, the rise in interest rates was the most damaging factor. The CNB kept the exchange rate pegged to the currency basket far too long and the koruna eventually moved too far from its market equilibrium level. The CNB should abandon such an exchange rate regime much earlier, at the mid of 1996 at latest. During the financial crisis the CNB cut the commercial banks almost entirely out of liquidity what should not happen. Its reluctance to lower the interest rates for the sake of slower adjustment of the exchange rate caused even stronger pressure on manufacturers and services providers. Thus, the artificial nominal stability of exchange rate proved to be quite expensive.

5 Convergence of exchange rates

5.1 Exchange rate and its regime in transition countries

5.1.1 Institutional environment

From the very beginning of the transition process in Central and Eastern European economies, exchange rate behavior and associated exchange rate regimes were closely monitored. The choice of a particular exchange rate regime is one of the major policy decisions countries in transition had to make. This topic was extensively discussed by Edison and Melvin (1990), Edwards (1993), Quirk (1994), Begg (1996), and Sachs (1996), among others.

Exchange regimes and the evolution of nominal exchange rates relative to major currencies differ widely across the transition countries. The Czech Republic and Slovakia favored the semi-fixed regime of a basket peg, while Hungary moved from an adjustable peg to a pre-announced crawling band in 1995, and Poland moved from a fixed basket peg to a crawling basket peg. Many other countries in the region favored a managed float or currency board. Table 5.1 summarizes the types of exchange rate regimes that the CEE countries have adopted since their economic transition.

A fundamental issue is how the exchange rates themselves evolved during the transition process. Koch (1997) reviews and analyzes monetary and exchange rate policy issues in selected European transition countries and provides a timely and thorough survey of the monetary practices in the Czech Republic, Poland, and Hungary with cross references to other transition countries. Graphs that illustrate both nominal and real evolution of exchange rates are also presented later in this analysis.

A strength of a currency normally corresponds to the strength of an entire economy. Thus an exchange rate can be considered as a monetary mirror of a real side of an economy as a whole. When we take into the account a high degree of openness of the CEE economies we have to admit that exchange rate is an important variable within the scope of how these economies are becoming interconnected. This is, beside other facts, a reason why it is important to study exchange rate convergence. An innovative way of analyzing this process is to examine whether the differentials of exchange rate changes converge or diverge over time. We provide a complete formal definition of exchange rate convergence in section 5.3.

Table 5.1 Exchange Rate Regimes

Country	Regime
Czech Republic	Fixed (basket peg) since January 1991 to May 1997 Float from May 1997
Slovakia	Fixed (basket peg) since January 1991
Hungary	Adjustable peg (basket peg) since before 1989 Pre-announced crawling band (peg) since March 1995
Poland	Fixed (basket peg) from January 1990 to October 1991 Pre-announced crawling peg from October 1991 to May 1995 Float within crawling band from May 1995 to January 1996 Pre-announced crawling peg from January 1996
Slovenia	Managed float from October 1991
Bulgaria	Managed float from February 1991 Currency board from July 1997
Romania	Managed float from August 1992
Albania	Managed float from July 1992
Estonia	Currency board from june 1992
Latvia	Managed float from July 1992 (in reality peg to SDR basket)
Lithuania	Float from October 1992 to April 1994 Currency board from April 1994

From the historical context the issue of the exchange rate convergence starts with a launch of transition reforms. At the beginning of the transition process most of the CEE countries devalued their national currencies. Halpern and Wyplosz (1995) suggest four main factors for the initially large undervaluation of transition currencies: (i) the existence of monetary overhang, (ii) pent-up demand for foreign assets, (iii) the lack of credibility on the part of the new authorities, and (iv) total uncertainty about the appropriate equilibrium exchange rate and, therefore, the tendency for risk-averse authorities to err on the side of undervaluation rather than overvaluation. The crucial reason for undervaluation seems to be more simple: the rates were undervalued in order to be long lasting and able to promote exports of local companies while discouraging mainly imports of consumer goods.

Massive devaluation was also meant to partially offset substantial inflation that the CEE countries were expected to experience. Indeed they did and the Transition Report (1997) of the EBRD serves as a compact reference for this subject. Thus, evolution of nominal exchange rates in the CEE countries might alone provide a misleading picture. Nevertheless, Figures 5.1 and 5.2 comprehensively document the evolution of nominal exchange rates in all the countries under consideration from 1991 to 1997. The Czech koruna remained quite stable and depreciated in connection with the financial crisis in summer of 1997. The nominal exchange rates of Poland and Hungary depreciated over time. The Slovak koruna was devalued by 10% in July 1993, but remained more or less stable during the period. The nominal exchange rates of Slovenia and other Balkan countries also depreciated to a greater or lesser extent over the researched period. The Baltic countries offer interesting picture of evolution, as its countries were severing monetary ties with the former Soviet Union while gradually establishing different exchange rate regimes.

Figure 5.1 US Dollar Nominal Exchange Rates

Figure 5.1 US Dollar Nominal Exchange Rates: Continuation

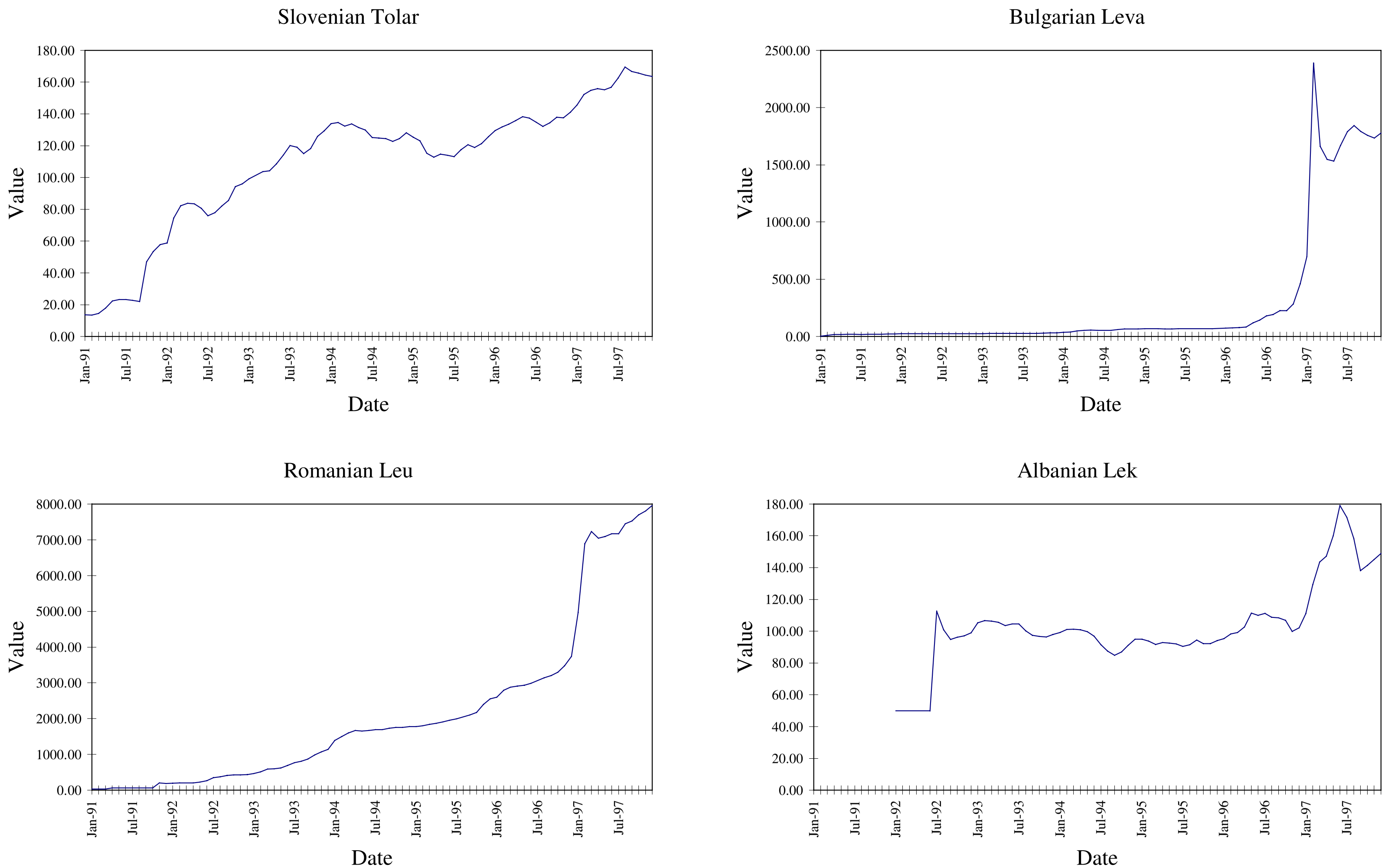
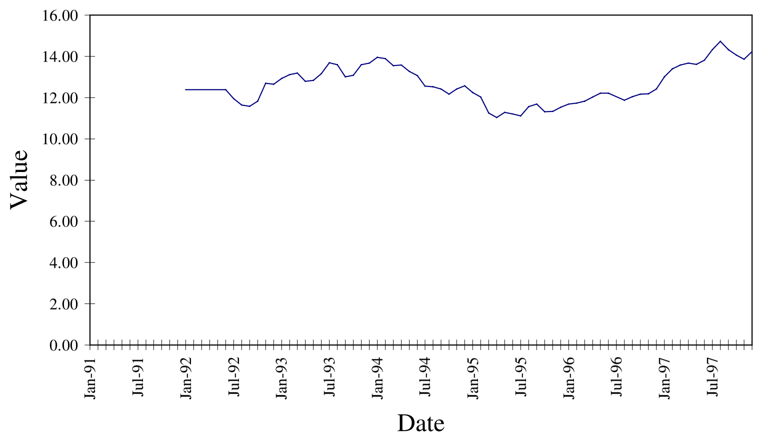
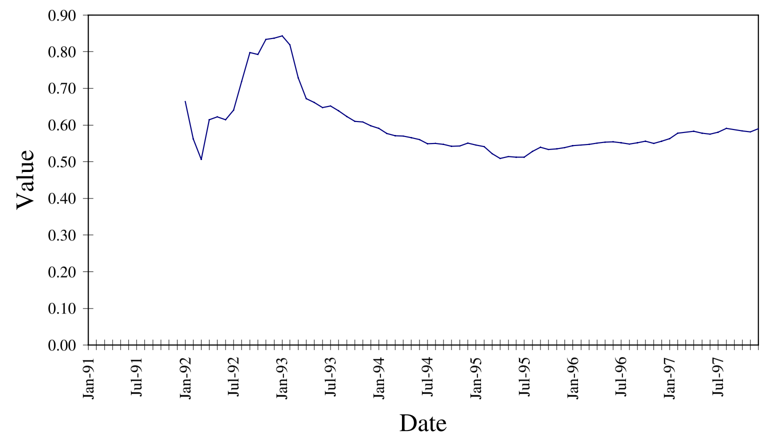


Figure 5.1 US Dollar Nominal Exchange Rates: Continuation 2

Estonian Kroon



Latvian Lats



Lithuanian Litas

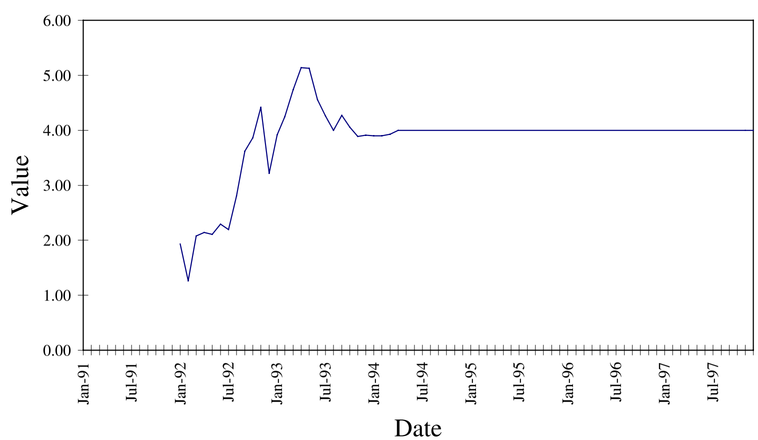


Figure 5.2 Deutsche Mark Nominal Exchange Rates

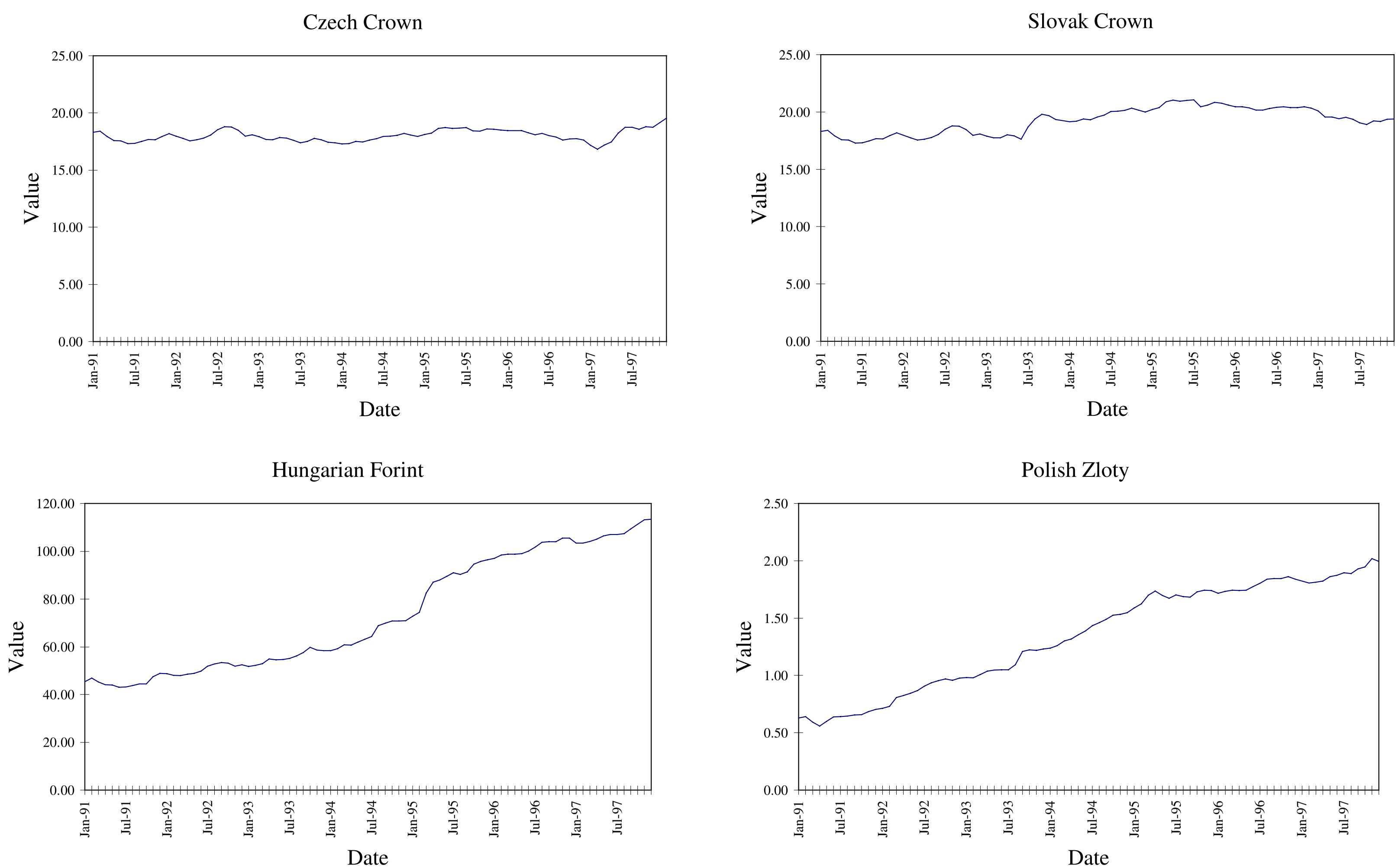
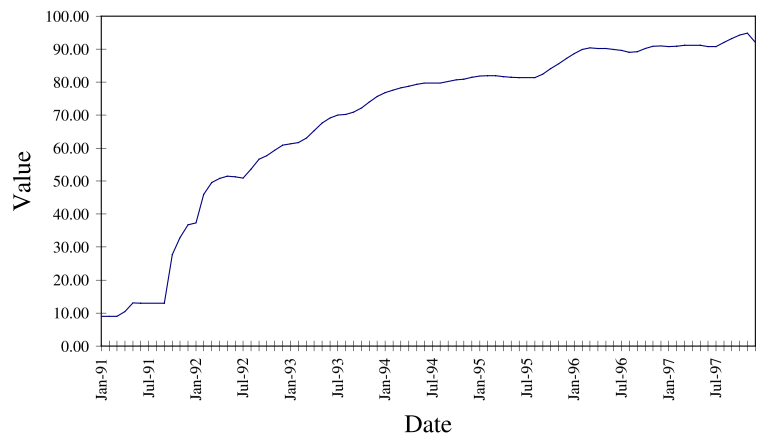
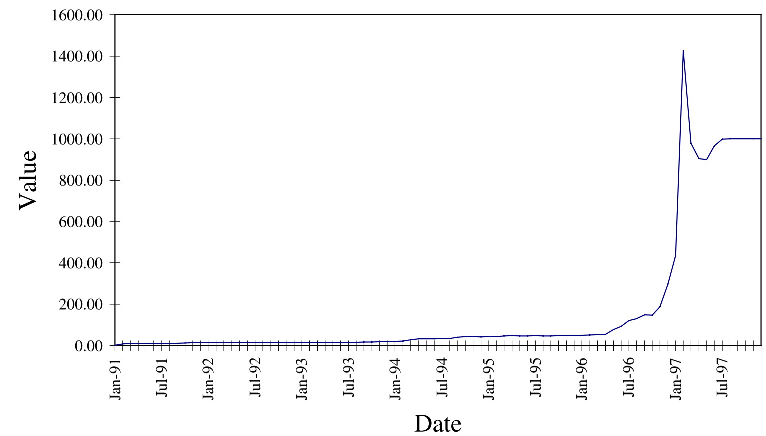


Figure 5.2 Deutsche Mark Nominal Exchange Rates: Continuation

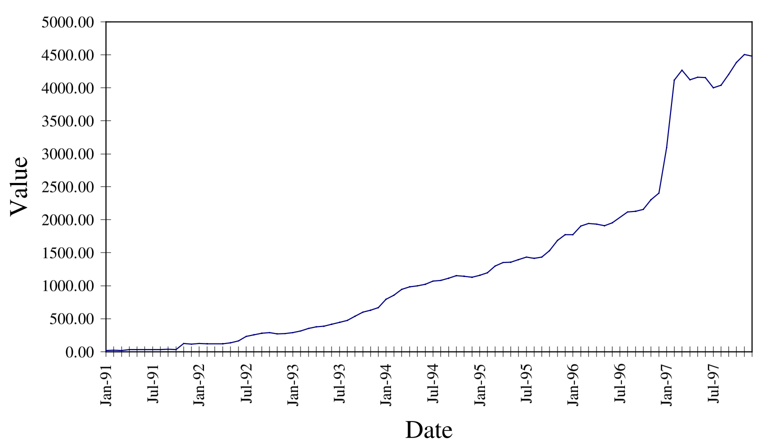
Slovenian Tolar



Bulgarian Leva



Romanian Leu



Albanian Lek

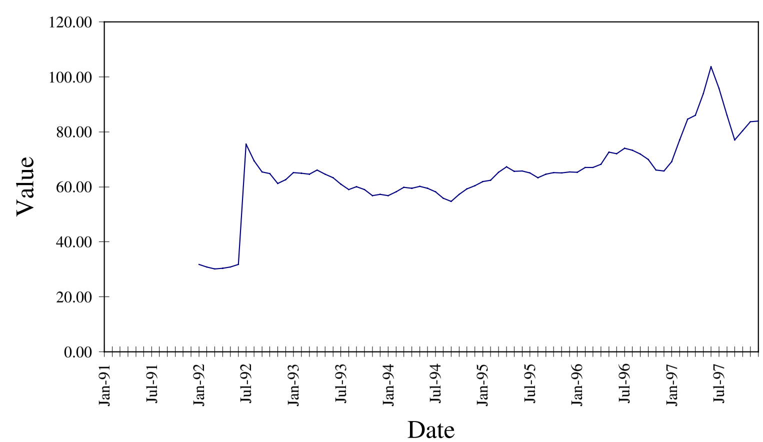
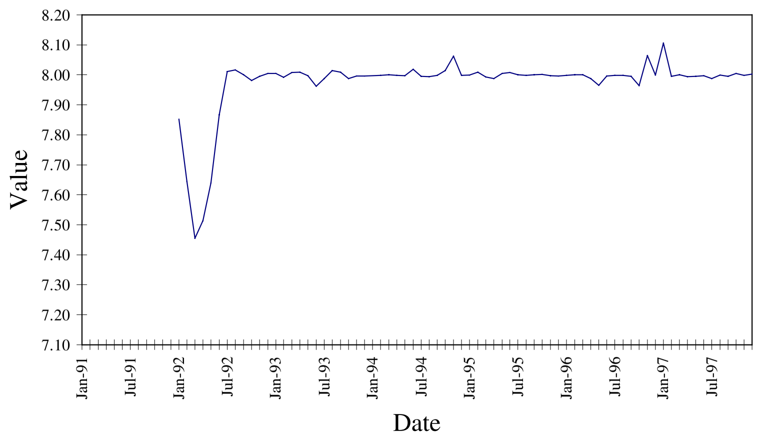
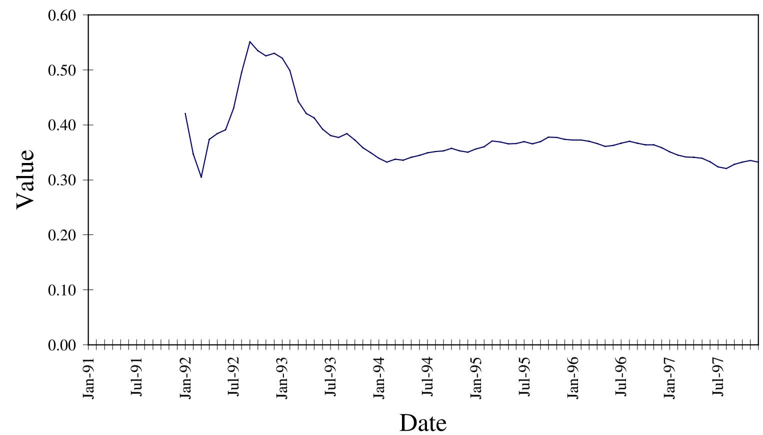


Figure 5.2 Deutsche Mark Nominal Exchange Rates: Continuation 2

Estonian Kroon



Latvian Lats



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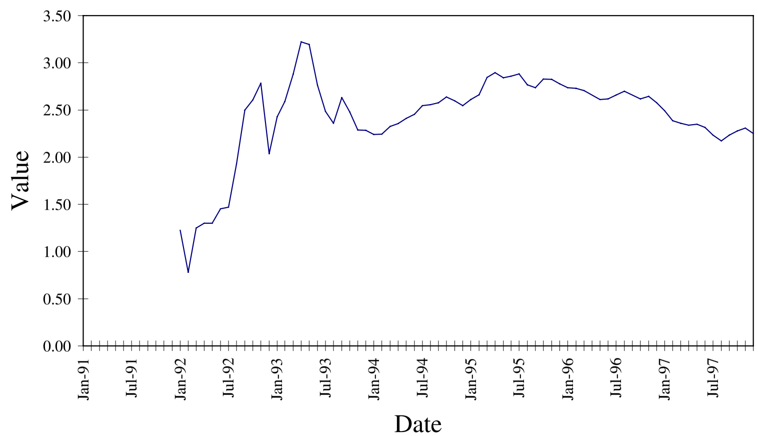
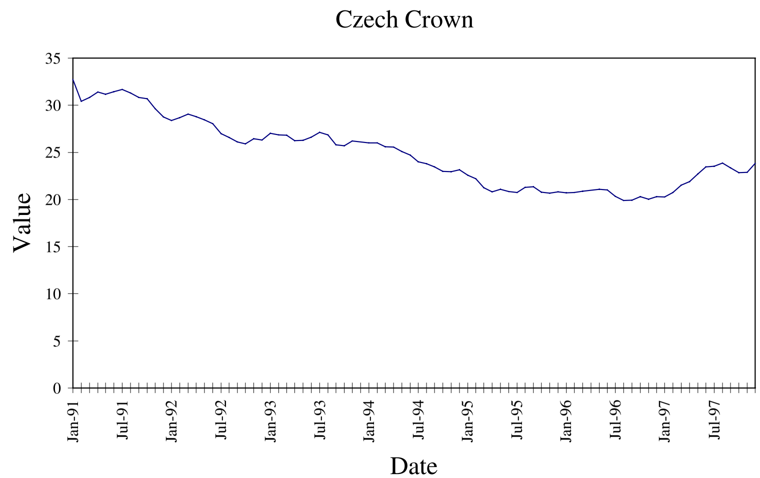
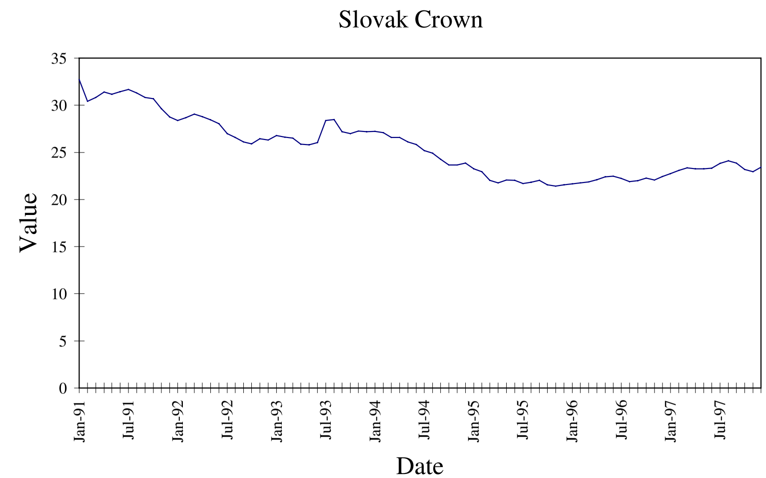
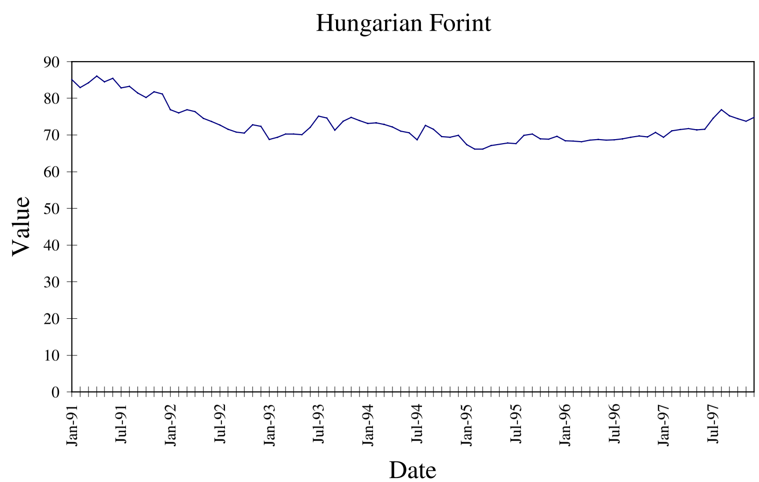


Figure 5.3 US Dollar Real Exchange Rates







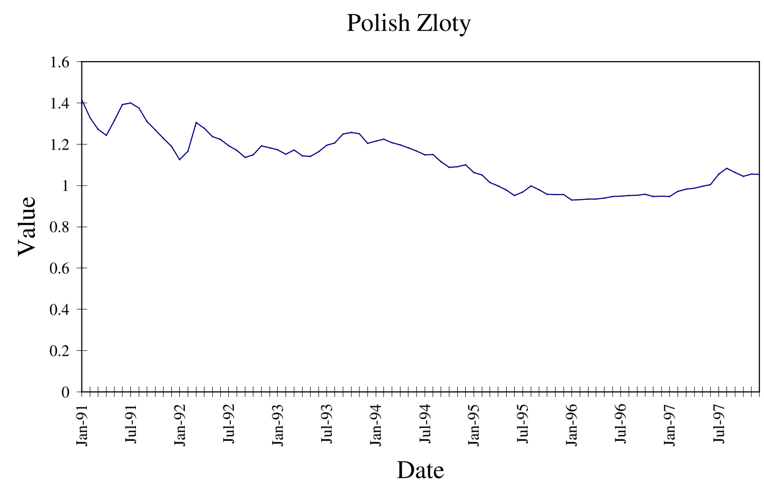
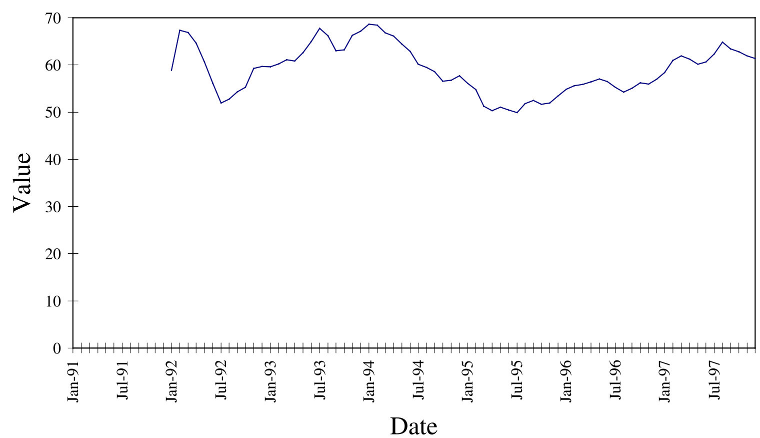
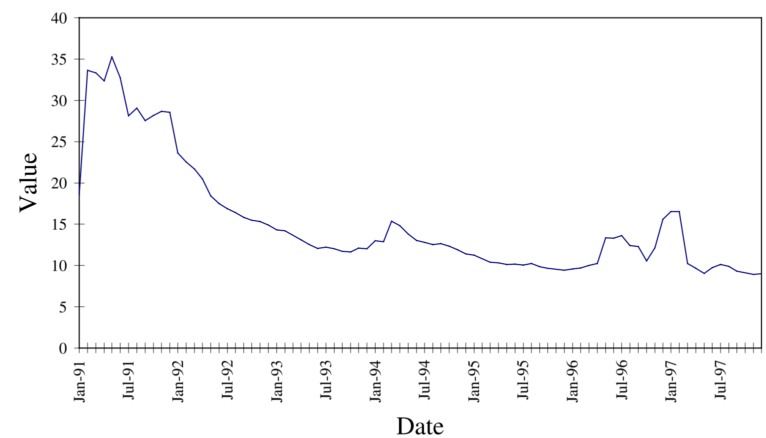


Figure 5.3 US Dollar Real Exchange Rate: Continuation

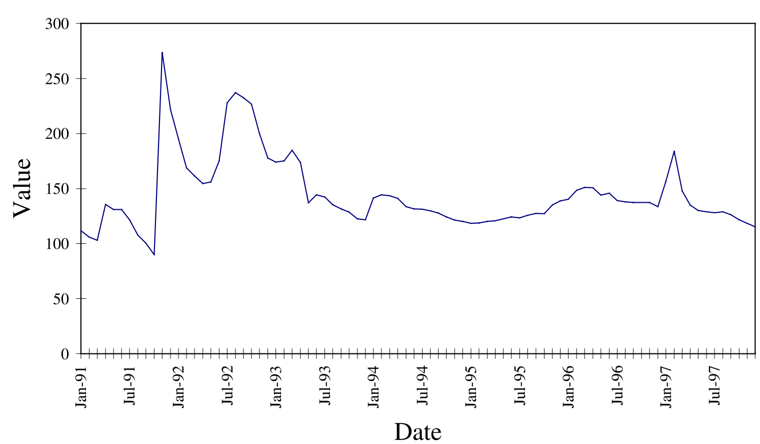
Slovenian Tolar



Bulgarian Leva



Romanian Leu



Albanian Lek

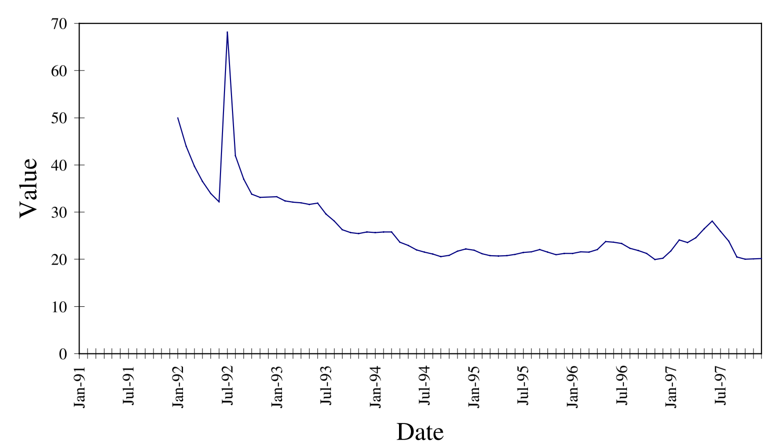
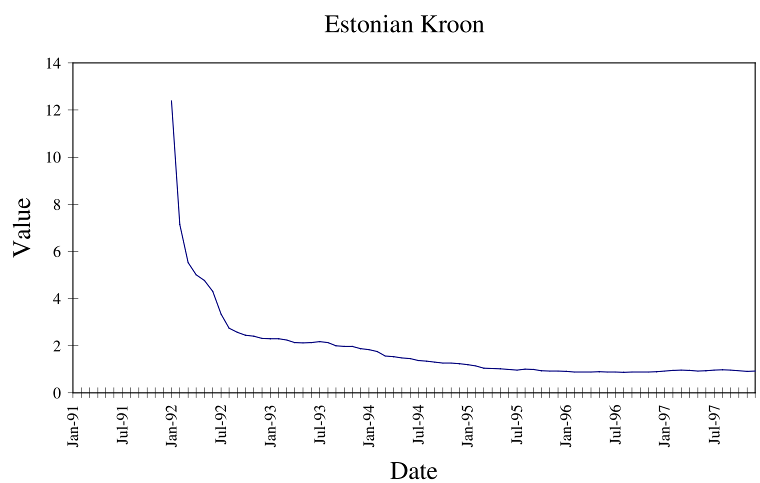
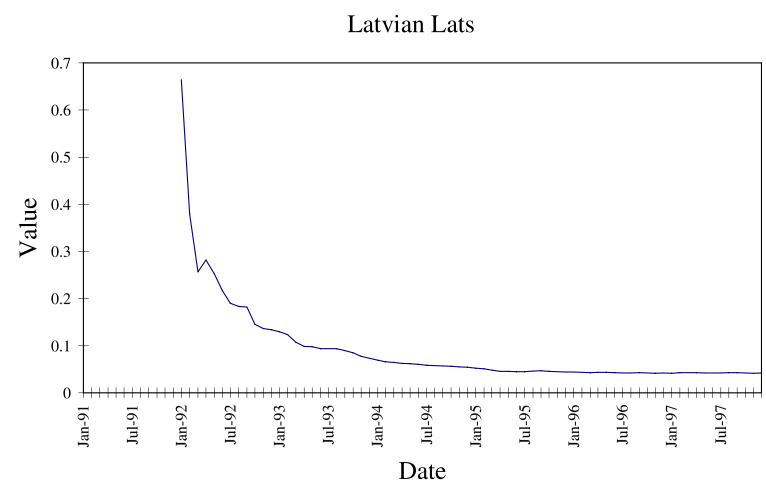


Figure 5.3 US Dollar Real Exchange Rate: Continuation 2





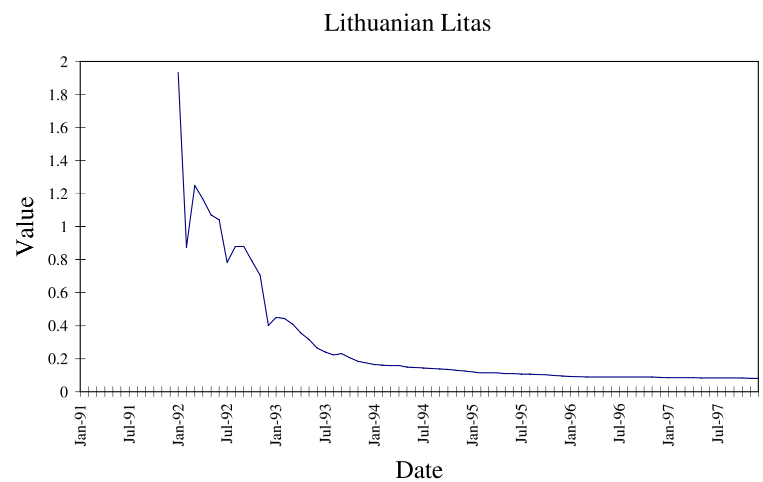


Figure 5.4 Deutsche Mark Real Exchange Rates

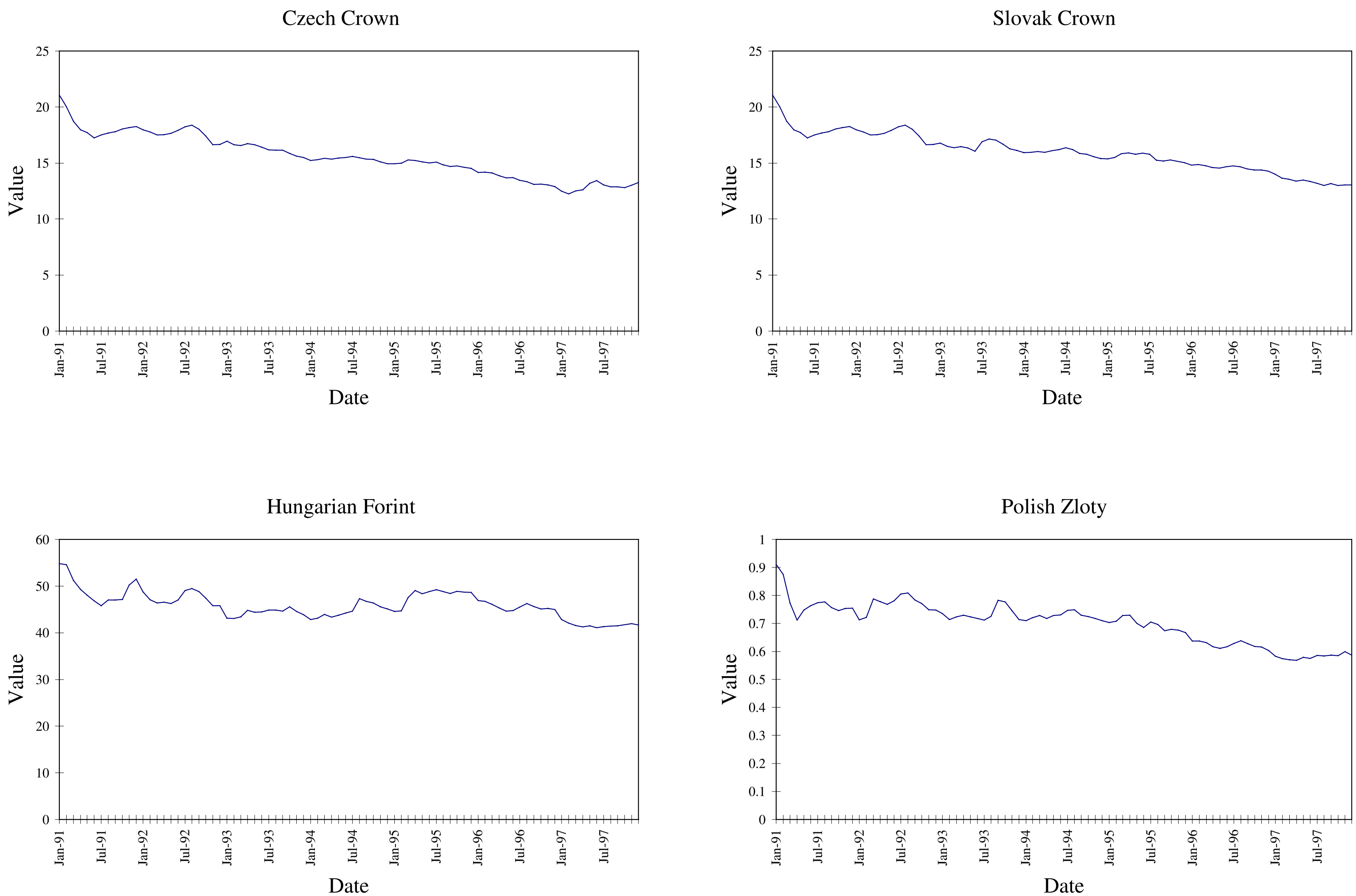


Figure 5.4 Deutsche Mark Real Exchange Rates: Continuation

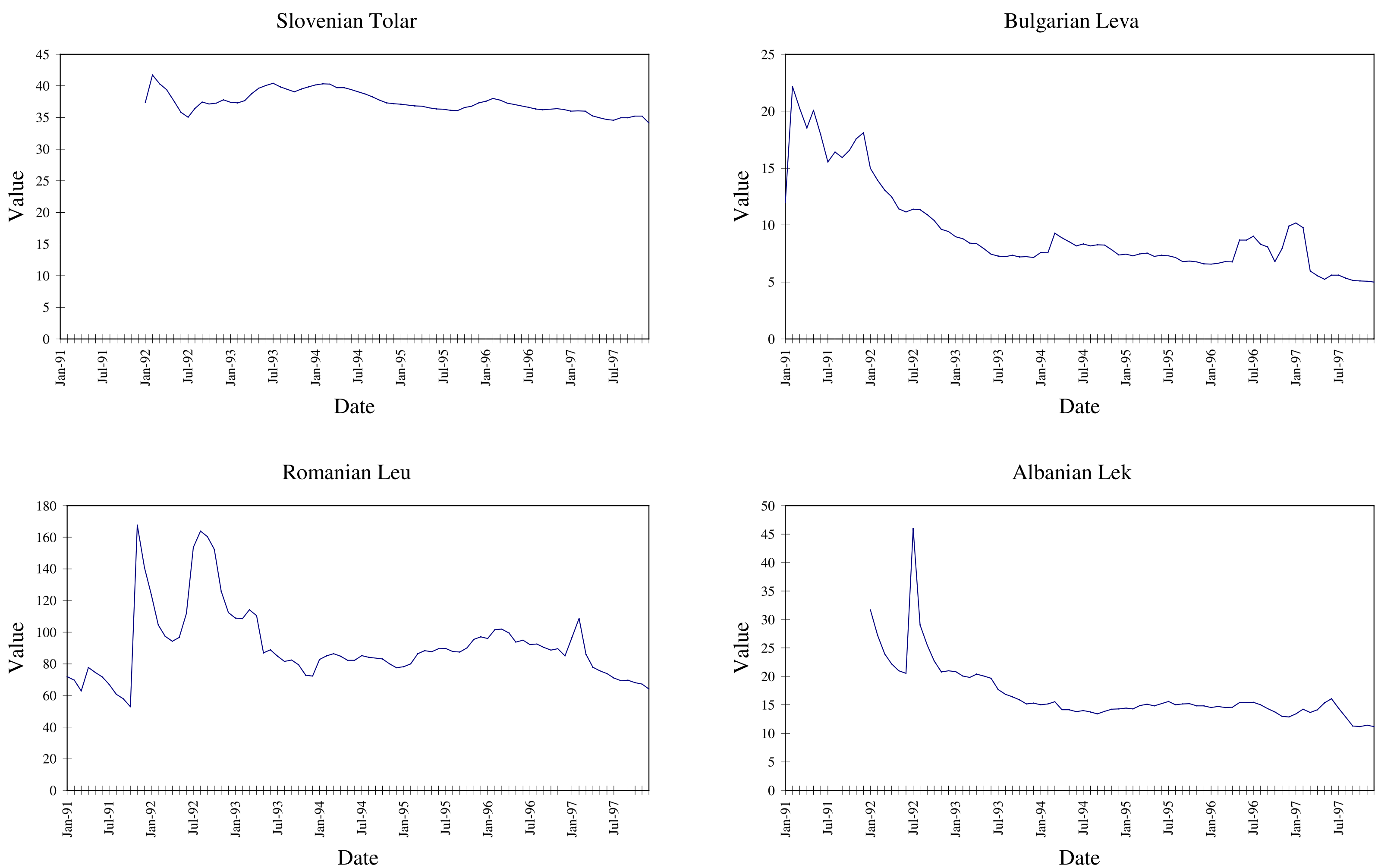
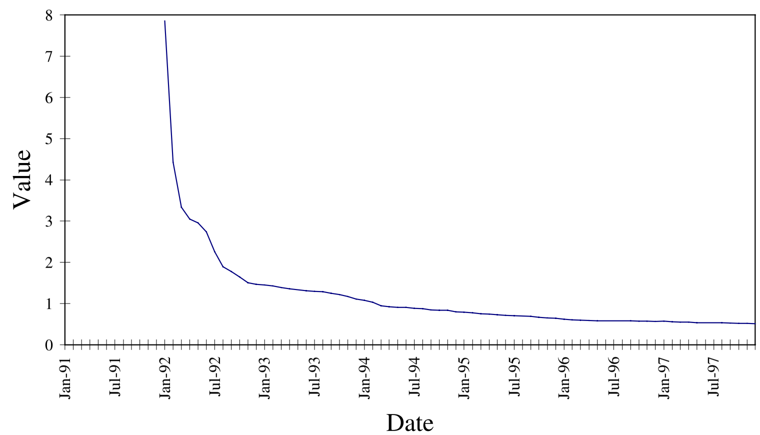
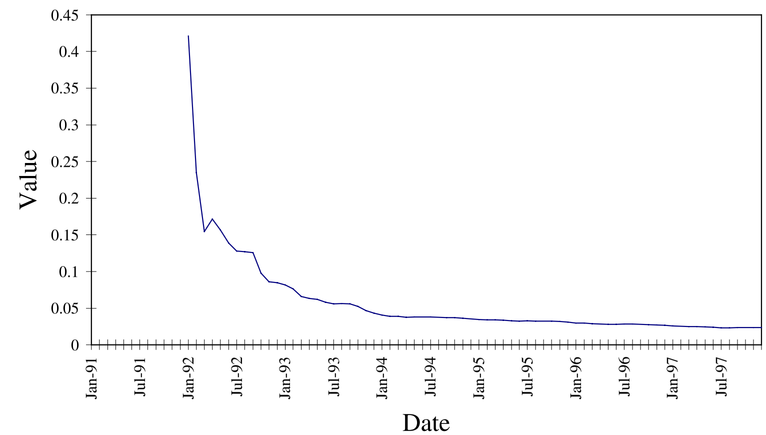


Figure 5.4 Deutsche Mark Real Exchange Rates: Continuation 2

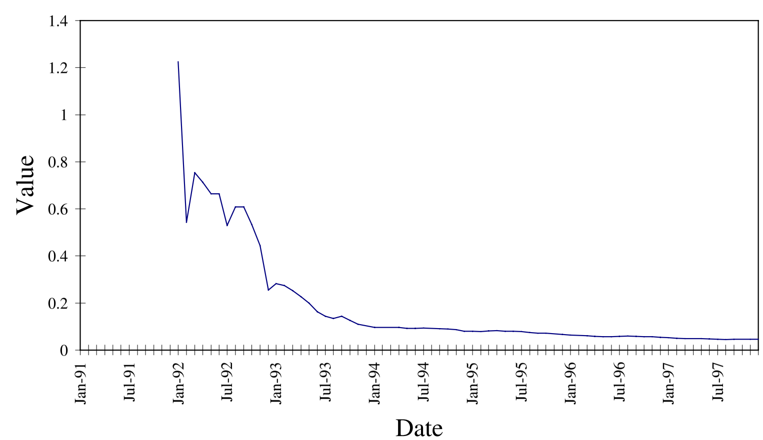
Estonian Kroon



Latvian Lats



Lithuanian Litas



5.1.2 Real exchange rate

It is inflation that in case of transition economies is likely to substantially differentiate nominal and real sides of the story. In order to see the real evolution of the national currencies we explore the real exchange rates. For the purpose of econometric analysis the real exchange rates (Q_t) of national currencies in relation to the US Dollar and the Deutsche Mark were constructed in the usual manner as

$$Q_t = \left(E_t \cdot CPI_t^*\right) / CPI_t \tag{5.1}$$

where Q_t is the defined real exchange rate, E_t is a nominal exchange rate, CPI_t is a domestic consumer price index (CPI), and CPI_t^* is a foreign CPI.

Figure 5.3 and 5.4 illustrate the evolution of currencies in real terms. The real exchange rates are plotted in levels. The currencies of the countries belonging to the Visegrad Four continuously appreciated in real terms over time, but the extent of appreciation varied. Koch (1997) claims that the empirical evidence indicates that the current level of the real effective exchange rates does not appear to be seriously out of line with the underlying fundamentals of the Czech Republic, Poland, and Hungary. The Baltic countries uniformly experienced a massive real appreciation during 1992. This movement, over next two years, transformed into an almost stable real exchange rate. The Balkan countries together with Slovenia offer the most varied picture of currencies which appreciated and depreciated in real terms over time.

Koch (1997) argues that in general terms, in most of the CEE countries occurred a period when real appreciation has been stronger when measured in consumer rather than producer prices. The two most important factors that may explain such difference are phasing-out of consumer subsidies (affecting CPI) and an increased demand for services (affecting both CPI and PPI) combined with an initially small services sector. In any event it is a real exchange rate that in fact matters to deliver an information about a real strength of a national currency. This is the reason why it is only the real exchange rate that matters for analysis of exchange rate convergence.

Real exchange convergence is especially important with respect to eventual accession of the CEE countries to the EU. As for the EU itself convergence has taken place within the framework of the European Monetary System (EMS) and has accelerated with the announcement of the Euro. Such process is expected to continue with the following schedule in mind. On January 1, 1999 the European Commission will settle irrevocable exchange rates between individual national currencies of the member states of the EMU and Euro. The European Central Bank (ECB), that will start to function, will be handed mandate to conduct common policy on behalf of central banks of individual member countries. Member states will convert their debts into Euro. Transition period will start to introduce new measures associated with a single currency and will last to 2002. During 2000 the ECB will supervise and monitor exchange of banknotes according to fixed exchange rates. National currencies and Euro banknotes will be allowed to circulate together during 2001. The transition period ends in 2002 and by January 1, member countries will convert their public expenditures into Euro. From July 1 on, the Euro (and its fraction cent) will become a sole and legal mean of payment within the member states of the EMU.

As it was hinted earlier an exchange rate convergence cannot be discussed as a phenomenon isolated from other variables, specifically inflation that disguise the real picture. The EU countries participating in the European Monetary System (EMS) have already a record of their exchange rates convergence. Sarno (1997) found evidence of long-run convergence for both nominal and real exchange rates that was more frequent in cases of countries that adhered to the Exchange Rate Mechanism (ERM) than for the non-ERM countries. This suggests that the ERM of the EMS has been effective in reducing the tendency towards exchange rate misalignment, at least among its own members. Kocenda and Papell (1997) found evidence of dramatic convergence in inflation rates among the countries that adhered to the ERM. The results therefore suggest that a significant increase in policy convergence has been achieved within the EMS.

5.1.3 Convergence and exchange rate regime

Starting massive devaluation at the beginning of transition reforms was tied with new exchange regimes in respective countries. The choice of an exchange rate regime was an institutional decision of each country that often depended to various extent on the advice of an international institution (the IMF for example). Any form of non-free-float exchange regime (i.e. fixed, pegged, crawling-peg, managed float etc.) requires a certain degree of commitment from the monetary authorities. Such a commitment is a way of creating a consistent policy and establishing confidence in the policy actions of monetary authorities. For example the peg to a single currency may be the exchange regime with the greatest potential to gain credibility because it represent the simplest rule that is clear and understood by both the policy makers and the public.

Although the problem of exchange regime choice is of major concern for transition countries, the optimality of any such choice is subject to debate. The reason stems from two stylized facts: (i) no exchange regime has proven to be everlasting, and (ii) countries have tended to shift back and forth between exchange rate regimes. Despite the fact that the suitability of any adopted exchange rate regime remains an important topic in transition economies, its choice resulted from economic and/or political forces dominating each country at a time.

Currently ten countries in Central and Eastern Europe have formally applied for full membership in the European Union. In the future a crucial issue will be to harmonize exchange rate policies of the CEE countries with those prevailing in the European Union and especially with the forthcoming European Monetary Union (EMU). In case of the CEE countries a relevant and related question arises. With so many varieties of exchange rate regimes does the degree of convergence depend on a particular exchange rate regime? Or in other words, is convergence faster in countries that favored some kind of tight exchange regime opposite to a rather free one?

According to the recommendations of the IMF many transition economies adopted exchange rate regimes characterized by different degrees of flexibility and management. Several countries, including the Czech Republic, adopted an exchange regime based on a currency basket peg. Such a regime is, according to the IMF, characterized as a fixed exchange rate regime. However, a critical difference is that such an exchange rate is actually pegged to a currency basket rather than fixed to one foreign currency. The essence of the argument comes from a possible dichotomy between exchange rate regime and monetary policy. For further details see Kocenda (1998).

In the case of the fixed regime, a country has by definition an exchange regime policy, gives up its own monetary policy, and the origin of a monetary base is purely a foreign one. The exact opposite is true for a floating exchange regime. A crucial difference arises in the case of a pegged regime whereby a country maintains both exchange rate and monetary policies. Under such an arrangement, eventual conflict between these two policies is likely to materialize due to the both domestic and foreign origin of the monetary base. Such a conflict may eventually evolve into a balance of payments crisis. The kind of exchange regime is thus likely to affect degree of exchange convergence as well.

The transition process in Central and Eastern Europe provides a unique opportunity to carry out quantitative analysis of exchange rate convergence within distinctive groups of the CEE countries based on different exchange rate regimes. This project addresses the question as to whether the transition countries have achieved exchange rate convergence and what are the implications for their eventual accession to the European Union.

5.2 Data and definitions

We use the data from the following eleven countries: the Czech Republic, Slovakia, Hungary, Poland, Slovenia, Romania, Bulgaria, Albania, Estonia, Latvia, and Lithuania. The time span of the data is from January 1991 to December 1997. The monthly averages of exchange rates of respective national currencies were obtained from the Bank for International Settlements, Basel, the International Monetary Fund's International Financial Statistics, and the EBRD. The monthly consumer price indices were obtained from the latter two sources. The bulletins of the national banks of each country in question were consulted as well.

The prevalent view in the literature is that floating exchange rates follow a random walk. No strong statistical evidence has emerged to confirm or refute this view so far (see Brock, Hsieh, and LeBaron (1993), p.130). Such behavior was not found in case of exchange rates of transition economies. This is apparently due to the nature of their exchange rate regimes and the fact that these economies are still undergoing huge structural shifts. The data (exchange rates) are not stationary but are integrated of degree one. The analysis is therefore performed on the changes in exchange rates between two consecutive periods. These changes are analogous to the first logarithmic differences. Such a method of how to achieve stationarity is preferred to that of detrending the data. By their nature the exchange rates contain polynomial trends of different degrees and thus a formerly described method is preferred to the latter one.

For the purpose of further analysis the countries were pooled in several logically differentiated groups. There are 84 observations per country and the dimension of each panel data structure changes accordingly. Table 5.2 shows all the countries that were included in our analysis and describes the composition of the various groups for which we tested the convergence hypothesis.

The institutional groups are defined with respect to eventual accession. Three groups were formed with respect to the analyses of progress in economic and political transition made by the EBRD about ten countries that have applied for the membership in the European Union. According to the European Commission five of the countries were identified as leading candidates in terms of the progress they have made so far. These are the Czech Republic, Hungary, Poland, Slovenia, and Estonia and form the First Round group. Removing Estonia makes a control group because this country maintained currency board exchange regime throughout the researched period. Thus, elimination of Estonia from The First Round group should be understood as a purely institutional step. The Second Round group was formed from Bulgaria, Latvia, Lithuania, Romania, and Slovakia.

Table 5.2 Groups of Countries in Each Panel Data Set

Group	No.	Countries
		Accession Rounds Groups
First Round	5	Czech Republic, Hungary, Poland, Slovenia, Estonia
First Round w/o Estonia	4	Czech Republic, Hungary, Poland, Slovenia
Second Round	5	Bulgaria, Latvia, Lithuania, Romania, Slovakia
		Exchange Rate Regime Groups
Peg (A)	4	Slovakia, Hungary, Poland, Latvia
Peg (B)	5	Slovakia, Hungary, Poland, Latvia, Czech Republic
Fix	2	Estonia, Lithuania
Float (A)	4	Albania, Romania, Slovenia, Bulgaria
Float (B)	5	Albania, Romania, Slovenia, Bulgaria, Czech republic

No. denotes number of countries in a particular group.

Other groups were formed on the basis of the exchange rate regime prevailing in each country for the time span of our analysis. There are two groups with a peg regime. One group, Peg A, contains Slovakia, Hungary, Poland, and Latvia. The other group, Peg B, includes also the Czech Republic. This country abandoned currency basket peg regime in May 1997 and therefore two peg groups were created. There is one group of countries that maintains fixed regime. The group is called Fix and contains Estonia and Lithuania. At last, we formed two groups of countries with float regimes. The Float A group contains Albania, Romania, Slovenia, and Bulgaria. The control Float B group in addition includes also the Czech Republic. Bulgaria is included in both groups because this country changed its regime from the managed float to a currency board only recently in July 1997. Pooling countries in certain groups is meant to show not only the consistency, but also the sensitivity of our results.

A detailed description of the method to test for convergence follows in the next section. That section concentrates on investigating logically structured groups of countries to see how the differences in exchange rate differentials evolved over time, i.e. whether they increased or diminished.

5.3 Methodology of convergence

5.3.1 Definitions

The usual notion of convergence is that the difference between two or more variables should become negligible over time. The formal way of describing this event is to employ a useful concept from large-sample distribution theory (for details and proofs regarding following subject see Greene (1993), pp. 99-102). We can say that the random variable x_n converges in probability to a constant *c* if $\lim_{n\to\infty} \text{Prob}(|x_n - c| > \varepsilon) = 0$ for any positive ε. Simply put, convergence in probability implies that the values that the variable may take that are not close to *c* become increasingly unlikely. Thus, if x_n converges in probability to *c* we can write $p\lim x_n = c$.

A special case of convergence in probability is convergence in mean square or convergence in quadratic mean that can be characterize the following way. If x_n has mean μ_n and variance σ_n^2 such that the ordinary limits of μ_n and σ_n^2 are *c* and 0 respectively, then x_n converges in mean square to *c*, and $p\lim x_n = c$. It can be shown that convergence in probability does not imply convergence in mean square, however, convergence in mean square implies convergence in probability. The conditions for convergence in mean square are usually easier to verify than those for more general form. We will use the outlined ideas in testing for convergence in macroeconomic fundamentals using the method of the panel unit-root test.

The following econometric methodology, which was exploited in several published empirical analyses, utilizes a combination of cross-sections of individual time-series. Ben-David (1995, 1996) performed an analysis of real per-capita income growth on numerous countries. Kocenda and Papell (1997) recently applied this methodology to study inflation convergence in the European Union. Papell (1997) tested purchasing power parity for the real exchange rates of 20 developed countries. Kocenda and Hanousek (1998) tested for convergence and integration of Asian capital markets.

A panel data analysis of the convergence of exchange rate differentials is conducted in order to fully exploit the effect of cross-variances in a pooled time series of moderate length. Previous econometric research has demonstrated the specific advantages of utilizing panel data in studying a wide range of economic issues. As shown by Levin and Lin (1992), the statistical power of a unit root test for a relatively small panel may be an order of magnitude higher than the power of the test for a single time series.

The analysis is performed for two types of exchange rates (X_t) which are measured as a change in the respective exchange rate over two successive periods. The individual nominal change in the exchange rate between two consecutive months is defined as

$$EX_{\mathrm{t}} = \left(E_{\mathrm{t}} / E_{\mathrm{t-1}}\right) - 1 \qquad (5.2)$$

where E_t denotes the nominal exchange rate at time t. In a consistent manner we define the change in the real exchange rate as

$$QX_{\mathrm{t}} = \left(Q_t / Q_{t-1}\right) - 1 \qquad (5.3)$$

where Q_t is a real exchange rate at a time t as defined earlier in equation (5.1).

We model the evolution of exchange rates (X_t) for a group of i individual countries with observations spanning over t time periods in the following way:

$$X_{i,t} = \alpha + \phi X_{i,t-1} + \varepsilon_{i,t} \tag{5.4}$$

The fact that the exchange rate is modeled as an autoregressive process is based on the common practice in the literature and does not represent any theory of how this variable is determined. It also constitutes a suitable form for the convergence test introduced later in this section.

The convergence measure adopted here is based on a relationship that describes the dynamics of exchange rate differentials in a panel setting. Formally, we can transcribe this as follows:

$$X_{i,t} - \overline{X_t} = \phi\left(X_{i,t-1} - \overline{X_{t-1}}\right) + u_{i,t} \tag{5.5}$$

where $\overline{X_t} = \frac{1}{n}\sum_{i=1}^{n} X_{i,t}$. In the presence of pooling, the intercept α vanishes since, by construction, the exchange rate differentials have a zero mean over all the countries and time periods. How the countries are pooled into different groups was described in detail in the previous section.

Convergence in this context requires that the differentials of the respective variables become smaller and smaller over time. For this to be true ϕ must be less than one. On other hand, ϕ greater than one indicates a divergence of these differentials. The value of ϕ itself then tells us about the degree of convergence. Further, one of the sufficient conditions for convergence in our context is that the sample average of squared differentials must decrease over time, as we outlined in the beginning of this section.

5.3.2 Panel unit-root test

The convergence coefficient ϕ for a particular group of countries can be obtained using the Dickey and Fuller (1979) test on equation (5.5). The augmented version of this test (ADF) is used in order to remove possible serial correlation from the data. It was found that, in cases of both nominal and real exchange rates, the correlation sensitivity threshold was about 0.50. Employing the ridge regression of Hoerl and Kennard (1970) compensated for the encountered multicollinearity.

Since the analysis is performed on panel data of exchange rate changes, there will be no intercept by construction. Denoting the exchange rate differential as $d_{i,t} = X_{i,t} - \overline{X_t}$, and its difference as $\Delta d_{i,t} = d_{i,t} - d_{i,t-1}$, the equation for the ADF test is written as

$$\Delta d_{i,t} = (\phi - 1)d_{i,t-1} - \sum_{j=1}^{k} \gamma_j \Delta d_{i,t-j} + z_{i,t} \tag{5.6}$$

where the subscript i = 1,...,k indexes the countries in a particular group. Equation (5.6) tests for a unit root in the panel of exchange rate differentials. The null hypothesis of a unit root is rejected in favor of the alternative of level stationarity if $(\phi - 1)$ is significantly different from zero or, implicitly, if ϕ is significantly different from one.

The number of lagged differences k is determined using the parametric method proposed by Campbell and Perron (1991) and Ng and Perron (1995). An upper bound of the number of lagged differences k_{max} is initially set at an appropriate level. $k_{max} = 7$ since monthly data are used. We also wanted to incorporate up to half-year lags between monetary and real sides of economy.

The regression is estimated and the significance of the coefficient γ_j is determined. If the coefficient is not found to be significant, then k is reduced by one and the equation (6) is re-estimated. This procedure is repeated with a diminishing number of lagged differences until the coefficient is found to be significant. If no coefficient is found to be significant in conjunction with the respective k, then k = 0 and a standard form of the Dickey-Fuller test is used in the analysis. A ten- percent value of the asymptotic normal distribution (1.64) is used to assess the significance of the last lag. The advantage of this recursive t-statistic method over alternative procedures where k is either fixed or selected in order to minimize the Akaike Information Criterion is discussed in detail by Ng and Perron (1995).

Recent work has established that a sub-unity convergence coefficient ϕ is indeed a robust indication of convergence which is respectively true for divergence (when $\phi > 1$). Ben-David (1995) performed 10,000 simulations for each of three possible cases where data should portray the processes of convergence, divergence, and neutrality. His numerous simulations provide ample evidence of convergence or divergence when these features truly reflect the situation. When neutral data with no strong inclination in either direction are used, the convergence coefficient tends towards unity.

To evaluate the statistical significance of the convergence coefficient ϕ we cannot use the standard critical values which are used when such an analysis is conducted on panel data. The common critical values for panel unit root tests tabulated by Levin and Lin (1992) do not incorporate serial correlation in disturbances and are, therefore, incorrect for small samples of data. Using the Monte Carlo technique, Papell (1997) tabulated critical values taking serial correlation into account and found that, for both quarterly and monthly data in his data sets, the critical values were higher than those reported in Levin and Lin (1992). A similar result was found in Kocenda and Papell (1997).

Because of these findings, the exact finite sample critical values for the resulting test statistics were computed using the Monte Carlo method in the following way. Autoregressive (AR) models were first fit to the first differences of each panel group of exchange rate differentials using the Schwarz (1978) criterion to choose the optimal AR models. These optimal estimated AR models were then considered to be the true data generating process for errors of each of the panel group of data. Finally, for each panel, pseudo samples of corresponding size were constructed employing the optimal AR models described earlier with iid $N(0,\sigma^2)$ innovations. The variance σ^2 is the estimated innovation variance of a particular optimal AR model. The resulting test statistic is the t-statistic on the coefficient (1-ϕ) in equation (5.6), with lag length k for each panel group chosen as described above.

This process was replicated 10,000 times and the critical values for the finite sample distributions were obtained from the sorted vector of such replicated statistics. The derived finite sample critical values are reported for significance levels of 1%, 5%, and 10% in the tables, along with the results of the ADF test conducted on different panel groups in the respective time periods.

5.4 Empirical results of convergence analysis

5.4.1 Nominal convergence

Earlier in section 5.1.2 we argued that in the framework of transition economies it is the real exchange rate convergence that matters. Despite this fact we report results of nominal convergence as well in order to provide reader with an institutional overview as well as with the data. We justify this by two reasons.

One reason why it is legitimate to analyze the nominal convergence is that in theory real exchange rate should behave the same way no matter whether the nominal rate is pegged or not because the price level should move as well. In practice, however, price level movements are much slower than nominal exchange rate movements and the convergence should be different as well. The second reason is that by fixing or pegging nominal exchange rate the authorities aim to lower inflation. By definition the fixed or pegged regimes should affect real exchange rate changes in a different manner than the floating regime.

Table 5.3 US Dollar Nominal Exchange Rates: Period 1991:1 - 1997:12

Group	No.	ϕ	t-stat(ϕ)	*k*	Critical Values		
					1%	5%	10%
Accession Rounds Groups							
First Round	5	0.5152[a]	-5.16	5	-3.19	-2.41	-1.93
First Round w/o Estonia	4	0.5109[a]	-4.70	5	-2.81	-2.07	-1.69
Second Round	5	0.4188[a]	-5.35	6	-3.34	-2.28	-1.80
Exchange Rate Regime Groups							
Peg (A)	4	0.5216[a]	-6.71	5	-2.80	-2.05	-1.66
Peg (B)	5	0.5716[a]	-6.53	6	-2.98	-2.22	-1.80
Fix	2	0.4988[a]	-4.12	5	-3.77	-2.40	-1.93
Float (A)	4	0.2861[a]	-5.26	6	-2.98	-2.16	-1.74
Float (B)	5	0.3296[a]	-5.86	6	-3.40	-2.23	-1.82

No. means number of countries in a particular group, *k* denotes number of lags.
a denotes significance at 1% level.

Table 5.4 Deutsche Mark Nominal Exchange Rates: Period 1991:1 - 1997:12

Group	No.	ϕ	t-stat(ϕ)	*k*	Critical Values		
					1%	5%	10%
Accession Rounds Groups							
First Round	5	0.5107[a]	-5.20	5	-3.20	-2.41	-1.95
First Round w/o Estonia	4	0.5061[a]	-4.74	5	-2.94	-2.19	-1.75
Second Round	5	0.4122[a]	-5.37	6	-3.37	-2.29	-1.80
Exchange Rate Regime Groups							
Peg (A)	4	0.5234[a]	-6.71	5	-2.79	-2.06	-1.66
Peg (B)	5	0.5413[a]	-7.47	5	-2.88	-2.15	-1.70
Fix	2	0.4996[a]	-4.12	5	-3.81	-2.42	-1.95
Float (A)	4	0.2717[a]	-5.32	6	-2.84	-2.14	-1.72
Float (B)	5	0.3181[a]	-5.92	6	-3.33	-2.24	-1.82

No. means number of countries in a particular group, *k* denotes number of lags.
a denotes significance at 1% level.

The results of convergence tests for all constructed groups of countries are presented in four tables. Tables 5.3 and 5.4 show results for the nominal exchange rate differentials as an introduction to the principal part of real exchange rates. The results of the test performed on exchange rate differentials expressed in US Dollars and Deutsche Marks show that the values of coefficient ϕ are very similar, but not completely identical. The coefficients are lower than and significantly different from one. Thus, the differences in the differentials of all groups clearly diminish over time. From the construction of the test it follows that, as the value of the statistically significant coefficient ϕ approaches unity in absolute value, the convergence effect decreases and vanishes. Implicitly, as the value of the statistically significant coefficient ϕ approaches zero, the convergence effect becomes greater. Although it is coefficient ϕ that we are interested in because its value provides us with an information about the degree of convergence, it was mentioned in the previous section that ($\phi<1$) *per se* does not necessarily imply convergence. The sufficient condition must be satisfied and therefore, the sample average of squared return differentials (i.e. sample dispersion) was computed as well. We did not reject hypothesis that sample dispersion was decreasing over time for all groups of countries listed in Table 5.2.

When we compare the two groups seeking accession, we can see that both of them show comparable speed of convergence. However, the Second Round group fares somehow better. Performance of the groups divided on the base of the exchange rate regime is shown in the second part of both tables. Countries with a float regime converge at the fastest pace, followed by those with a fixed regime. The countries favoring peg regime stand at the last place.

The primary results of the convergence test on differentials of real exchange rates are presented in Tables 5.5 and 5.6. The countries of the First Round converge at slower pace than those from the Second Round. However, when Estonia is removed from the First Round group, than this group surpasses the Second Round group. These results may be caused by two reasons. First one is an extent of economic integration of the CEE countries with the EU. Such an extent should be greater for the countries of the First Group. This effect mirroring the real side of the economy should be even more pronounced in the later years of transition. The second reason stems from the monetary side and reflects the beginning situation when exchange rate and inflation in particular countries started to evolve from very different conditions. Unfortunately, both two effects tend to cancel each other with respect to the speed of convergence.

In order to investigate the extent of both effects, the test was performed on First and Second Round groups again but this time the time span was divided to two periods of equal length of three and half years (1991:1 – 1993:6 and 1993:7 – 1997:12).

Table 5.5 US Dollar Real Exchange Rates: Period 1991:1 - 1997:12

Group	No.	ϕ	t-stat(ϕ)	*k*	Critical Values 1%	5%	10%
Accession Rounds Groups							
First Round	5	0.5575[a]	-8.04	6	-2.74	-2.07	-1.70
First Round w/o Estonia	4	0.1959[a]	-10.80	4	-2.76	-2.05	-1.68
Second Round	5	0.2163[a]	-4.98	7	-2.95	-2.20	-1.77
Exchange Rate Regime Groups							
Peg (A)	4	0.6958[a]	-4.38	6	-2.91	-2.15	-1.71
Peg (B)	5	0.6806[a]	-5.13	6	-2.88	-2.10	-1.74
Fix	2	0.4440[b]	-4.11	4	-4.46	-2.39	-1.90
Float (A)	4	0.1028[a]	-4.82	7	-2.87	-2.07	-1.65
Float (B)	5	0.1758[a]	-7.22	6	-2.79	-2.05	-1.69

No. means number of countries in a particular group, *k* denotes number of lags.
a and b denote significance at 1% and 5% levels, respectively.

Table 5.6 Deutsche Mark Real Exchange Rates: Period 1991:1 - 1997:12

Group	No.	ϕ	t-stat(ϕ)	*k*	Critical Values 1%	5%	10%
Accession Rounds Groups							
First Round	5	0.5552[a]	-8.14	6	-2.86	-2.06	-1.64
First Round w/o Estonia	4	0.2008[a]	-10.88	4	-2.79	-2.05	-1.69
Second Round	5	0.2061[a]	-5.01	7	-2.90	-2.15	-1.70
Exchange Rate Regime Groups							
Peg (A)	4	0.6398[a]	-5.13	5	-2.87	-2.11	-1.73
Peg (B)	5	0.6239[a]	-5.96	5	-2.83	-2.11	-1.72
Fix	2	0.4395[b]	-4.10	4	-4.47	-2.43	-1.91
Float (A)	4	0.0978[a]	-4.86	7	-2.90	-2.15	-1.70
Float (B)	5	0.1807[a]	-7.28	6	-2.85	-2.09	-1.74

No. means number of countries in a particular group, *k* denotes number of lags.
a and b denote significance at 1% and 5% levels, respectively.

We opted for such division because of the necessary requirements for panel data format. The panel has to have a certain dimension given by the number of countries and time periods to yield reliable results. Investigation that would account for time periods which are determined by regime switches in individual countries would lead to identification problems and/or unreliable parameter estimates. Such panels would then simply yield incorrect results.

Table 5.7 US Dollar Real Exchange Rates: Two Period Division

Group	No.	ϕ	t-stat(ϕ)	k	Critical Values 1%	5%	10%
Period 1991:1 – 1993:6							
First Round w/o Estonia	4	0.4145	-8.23[a]	4	-3.55	-2.46	-2.01
Second Round	5	0.2498	-2.98[b]	7	-3.22	-2.39	-1.94
Second Round w/o Lithuania	4	0.1680	-2.92[b]	7	-2.99	-2.21	-1.76
Period 1993:7 – 1997:12							
First Round w/o Estonia	4	0.1205	-6.08[a]	4	-3.04	-2.28	-1.89
Second Round	5	0.1616	-4.26[a]	6	-3.63	-2.52	-2.00
Second Round w/o Lithuania	4	0.2001	-4.29[a]	7	-3.45	-2.41	-1.91

No. means number of countries in a particular group, k denotes number of lags.
a and b denote significance at 1% and 5% levels, respectively.

Table 5.8 Deutsche Mark Real Exchange Rates: Two Period Division

Group	No.	ϕ	t-stat(ϕ)	k	Critical Values 1%	5%	10%
Period 1991:1 – 1993:6							
First Round w/o Estonia	4	0.4284	-8.34[a]	4	-3.50	-2.47	-2.01
Second Round	5	0.2346	-3.02[b]	7	-3.20	-2.37	-1.92
Second Round w/o Lithuania	4	0.1556	-2.95[b]	7	-2.99	-2.21	-1.77
Period 1993:7 – 1997:12							
First Round w/o Estonia	4	0.1253	-6.07[a]	4	-3.12	-2.32	-1.93
Second Round	5	0.1735	-4.24[a]	6	-3.62	-2.52	-2.00
Second Round w/o Lithuania	4	0.1816	-4.26[a]	7	-3.46	-2.40	-1.90

No. means number of countries in a particular group, k denotes number of lags.
a and b denote significance at 1% and 5% levels, respectively.

The results for periods 1991:1 – 1993:6 and 1993:7 – 1997:12 are reported in Tables 5.7 and 5.8. For both currencies we can see that the Second Round group converges during the earlier period of transition at the faster pace than the First Round group. The monetary effect representing the beginning conditions thus prevails since the degree of real integration was quite limited in that time. However, during the later period of transition the First Round group converges faster then the Second Round group. This is presumably due to the higher degree of real economic integration of the CEE countries with the EU that was achieved at the advanced stage of the transition period. Thus we can conclude that the countries of the First Round are, from the point of their exchange rate conversion, better equipped for accession to the EU.

Additional information about real convergence is contained in the second part of Table 5.5 and 5.6. When we compare countries according to their exchange rate regimes, then countries with the float regime show greater degree of convergence than those with fixed regimes. The groups of countries with peg regimes converge at the slowest pace.

We conclude that the peg regime is the least effective regime to promote convergence in both nominal and real terms. On other hand, the float regime seems to be one that is most effective in this sense. Fixed regime lies between. The policy implication of these facts is that the countries with a float or fixed exchange rate regimes are cutting disparities among the exchange rates of their currencies faster than those with a peg regime. It comes as a no surprise that the First Round countries also favor the regimes that allow for faster convergence.

Quite interesting conclusion stems from comparison of results that come from two different currencies in which exchange rates are expressed. The exchange rates in Deutsche Mark show higher degree of convergence than those expressed in US Dollars. The difference is not large but consistent across all the groups. This fact hints on the stabilizing effect of Deutsche Mark for the exchange rates of the CEE countries.

Convergence of nominal exchange rates is an indicator of increasing stability of the currencies. It is not an incidental event that majority of the CEE countries included Deutsche Mark in their exchange rate regimes in a form of direct peg or heavily weighted currency in a currency basket. This can be viewed from the perspective of eventual accession to EU and further joining the EMU. The policy implication is that convergence of exchange rates to some long-run equilibrium is likely to be faster in case of real exchange rates rather than nominal ones. The reason is a higher rate of inflation in the CEE countries than that in Germany or the USA. This is connected with the process of decreasing disparities of the inflation rates among the CEE countries and Germany. Only after the inflation rates in transition economies come near to that of Germany, there will be more pronounced convergence of the nominal exchange rates.

There is certain portion of institutional noise that has to be taken into account when presenting results of our analysis. Changes in exchange regimes are the most important ones. In addition, at the beginning of transition reforms exchange rates in some transition economies were official rates for currencies that were not fully convertible yet and thus were not really free market exchange rates. The potential impact of non-convertibility on exchange rate convergence in this analysis is not likely to be large. The CEE countries early during the transition reforms realized that convertibility of currency benefits its real strength. Non-negligible effects certainly also played wild Ponzi games in Albania and Bulgaria. Such pyramid schemes considerably disturbed the financial sector and, naturally, the exchange rates as well. To analyze the hypotheses outlined above is a task for further research.

5.5 Concluding observations

The results of this paper show that there exists an exchange rate convergence among the CEE countries in general. The degree of convergence varies substantially among the groups of countries though. The primary division of countries is done based on criteria of prospective accession to the EU and exchange rate regime prevailing in specific countries during transition.

When we compare two groups of countries seeking accession, we can see that both of them show comparable speed of convergence. When time span of the data is divided to two equal periods then the Second Round group converges during the earlier period of transition at the faster pace than the First Round group. The monetary effect representing the beginning conditions thus prevails since the degree of real integration was quite limited in that time. However, during the later period of transition the First Round group converges faster then the Second Round group. This is presumably due to the higher degree of real economic integration of the CEE countries with the EU that was achieved at the advanced stage of the transition period. We can conclude that the countries of the First Round are, from the point of their exchange rate conversion, better prepared for accession to the EU.

Performance of the groups divided on the base of the exchange rate regime significantly differs. Countries with a float regime converge at the fastest pace, followed by those with a fixed regime. The countries favoring peg regime are the slowest ones. The policy implication of these facts is that the countries with a float or fixed exchange rate regimes are cutting disparities among the exchange rates of their currencies faster than those with a peg regime. The First Round countries belong among those that favor the regimes showing faster convergence.

Further, the exchange rates in Deutsche Mark show higher degree of convergence than those expressed in US Dollars. This fact hints on the stabilizing effect of Deutsche Mark for the exchange rates of the CEE countries.

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