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DIPLOMOVÁ PRÁCE

Petr Böhm

Volatility of Euro : Trends and modeling

Katedra pravděpodobnosti a matematické statistiky
Vedoucí diplomové práce: Prof. Ing. Evžen Kočenda, Ph.D.
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Poděkování

Děkuji vedoucímu diplomové práce Prof. Ing. Evženu Kočendovi, Ph.D, za poskytnutou literaturu, software a spoustu cenných rad.

Velký dík patří rodičům především za trpělivost.

Prohlašuji, že jsem svou diplomovou práci napsal samostatně a výhradně s použitím citovaných pramenů. Souhlasím se zapůjčováním práce.

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Autor: Petr Böhm
Katedra (ústav): Katedra pravděpodobnosti a matematické statistiky
Vedoucí diplomové práce: Prof. Ing. Evžen Kočenda, Ph.D.
e-mail vedoucího: evzen.kocenda@cerge-ei.cz
Abstrakt: Hlavním cílem této práce je modelovat volatilitu kurzu Eura a České Koruny mezi 1.1.1999 a 30.12.2005 a prozkoumat změny v jejím chování. Pro tyto účely vyhledáme okamžiky strukturálních změn v časové řadě směnného kurzu. Podmíněný rozptyl modelujeme pomocí ARCH modelu (model autoregresní podmíněné heteroskedasticity) mezi jednotlivými body zlomu. Docházíme k závěru, že přibližně od roku 2002 volatilita Eurokorunového kurzu klesá. Tento závěr nám potvrzuje i měření historické volatility, jak pomocí měsíčních průměrů tak denních pozorování. Tento pokles může být s největší pravděpodobností způsoben změnou měnové politiky, respektive přechodem na jiný režim udržování měnové stability - přímé inflační cílování.

Klíčová slova: Volatilita, Bod zlomu, ARCH model

Title: Volatility of Euro : Trends and modeling
Author: Petr Böhm
Department: Department of Probability and Matematical Statistic
Supervisor: Prof. Ing. Evžen Kočenda, Ph.D.
Supervisor's e-mail address: evzen.kocenda@cerge-ei.cz
Abstract: The main objective of this work is to model volatility of Euro to Czech Koruna exchange rate between 1.1.1999 and 30.12.2005 and investigate changes in its behaviour. In order to achieve this we search for structural breaks in exchange rate time series. We model the conditional variance with ARCH model (autoregressive conditional heteroscedasticity) between particular break points. Our findings are that since year 2002 volatility of Euro to Koruna exchange rate has been decreasing. This conclusion is confirmed by measuring historic volatility by using month average and daily observations. This may has been caused by changing monetary policy, more precisely by adopting new regime of maintaining monetary stability - implicit inflation targeting.

Keywords: Volatility, Breakpoint, ARCH model

Chapter 1

Motivation and Introduction

The main objective of this work is to estimate the size and trend of volatility of Euro to Czech Koruna exchange rate. This issue is very important now, because stability of exchange rates started playing a key part in financial analysis[1].

The next important goal is to find a connection between change in volatility behaviour and an institutional change in monetary policy. Here we focus on Convergence programs, accession of new members of the European Union etc. In order to show this connection we have to model exchange rate therefore we have to find important breakpoints[2]. So we divide the time series into time segments. On these segments we can measure volatility and so we obtain a sentence that can show us certain trend.

We estimate size and trend of volatility for exchange rates of some other countries namely Slovakia and Poland. We are interested in whether attributes of these exchange rates are similar to Euro to Czech Koruna exchange rate.

We are interested in behaviour of Euro to Koruna exchange rate with perspective to its volatility. As it is presented in Kočenda (2005)[25] we

[1]We only name few publications that are concerned with volatility of exchange rates :
Kočenda E. (1996) : Volatility of a Seemingly Fixed Exchange Rate,
Hasan S. & Wallace M. (1996) : Real Exchange Rate Volatility and Exchange Rate Regimes: Evidence from Long-term Data

[2]This matter was in detail described in: Kočenda[25] and Henry & McAdam[23]

assume that the monetary politics affects volatility of exchange rates. We try to show that decrease in volatility was influenced by certain institutional changes in monetary policy.

1.1 The Importance of Volatility

There are many reasons why volatility has been so important in last years. Central banks analyze financial stability from their primary objectives and functions.

Volatility is interesting and important issue because it has a huge influence on foreign trade. There is a lot of research on this issue. The major results show that increases in the volatility of the real effective exchange rate, approximating exchange-rate uncertainty, exert a significant negative effect on export demand in both the short-run and the long-run[3].

The other reason why we are concerned with volatility is that stability of exchange rates is one of the European Union convergence criteria[4] :

"the observance of the normal fluctuation margins provided for by the exchange-rate mechanism of the European Monetary System, for at least two years, without devaluing against the currency of any other Member State".

The fulfilment of the convergence criteria, better known as the Maastricht criteria, is not a precondition of European Union accession, but is a precondition for the adoption of Euro as a national currency. Only when a country becomes a member of the European Union (which in case of the Czech Republic has already happened) it can be authorized to adopt Euro. The countries have to fulfil the convergence criteria and successfully participate in ERM II (Exchange Rate Mechanism).

When writing about Euro, we should also describe its history.

[3] Arize A.C., Osang T. & Slottje D.J. :Exchange-Rate Volatility and Foreign Trade: Evidence from Thirteen LDC's[1]

[4] http://www.ecb.int/ecb/orga/escb/html/convergence-criteria.en.html

1.2 Brief history of Euro

Creating of the single European currency took decades of preparation.

As a beginning is usually indicated the 25th March 1957, when the Treaty of Rome was signed. In fact two treaties were signed in Rome that gave birth to the European Economic Community (EEC) and to the European Atomic Energy Community (Euratom). However, the treaty contains no mention of economic and monetary union and the single currency.

First mentions of monetary union appeared in 1970, with Werner Report. This report already contained all the elements of the future Economic and Monetary Union. It structured the establishment of the Monetary Union in three stages during a 10 year period.

In 1978, the intention of establishing a monetary stability zone in Europe recured, reducing the currency fluctuations between the various community countries. For this reason the European Monetary System was created. It entered into force on the 13th March 1979, based on an agreement between the central banks of the countries that formed part of the Community. The European Monetary System had these fundamental objectives:

- to stabilize the exchange rates in order to rectify the existing instability
- to reduce inflation
- to prepare European monetary unification through cooperation.

The project of a single European Market was adopted by the European Community in 1985. It was obvious that this will be supplemented by a single currency.

In 1989 a three stage plan was proposed in Delors Report. This plan assumed creation of a single currency and European central bank.

In 1992 the Maastricht Treaty transformed the European Community into a full Economic and Monetary Union. The treaty provided for the fixing of exchange rates between national currencies, leading eventually to the single currency, the Euro. The timetable had been set out in the Maastrich Treaty, with the EMU being established in three stages. The eleven participants were Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Portugal, and Spain.

A Stability and Growth Pact was adopted five years later in 1997. For the countries joining the Euro, it layed down certain common constraints relating to public finance, mainly a 3% ceiling on the budget deficit. These constraints were and are necessary in an asymmetrical system where the countries of the Euro area have a single monetary policy while retaining their national fiscal policy.

The Euro has been part of the financial landscape since the 1st January 1999. Until 2001 the Euro existed only in the form of cashless payments. Payments to tax and social security authorities could have been made in national currency or in Euro: there was no prohibition and no compulsion regarding the use of the single currency.

Stage 3 of Economic and Monetary Union began on the 1st January 2001. The exchange rates of the participating currencies were irrevocably fixed. The countries of the Euro area implemented a single monetary policy. The Euro was introduced as legal tender.

1.3 Changes in Volatility and their reasons

The size of volatility depends on many aspects. Changing these aspect should cause changes in volatility too.

We will only focus on aspects such as exchange rate regime changes, convergence programmes and other institutional changes. These aspects were described in Kočenda[25] and in Valachy & Kočenda[40] and we follow this line of research. Above mentioned aspects should have direct influence on volatility. We won't take into account such aspects as world instabilities, oil price dynamics or wars.

1.3.1 Exchange rate regimes

Changes in volatility behaviour is in detail described in Kočenda[25] and in Kočenda & Valachy[40]. In these publications the volatility changes are showed from perspective of monetary policy changes (exchange rate regime changes). It describes in detail changes in exchange rate volatility of certain European countries[5] after giving up currency peg and adopting implicit inflation targeting.

There is also a whole set of publications covering this area of research. For classic work see Mussa[28] (1986), who derived a clear conclusion that has

[5] Visegrad Four: Poland, Hungary, Czech Republic and Slovakia

since then become a stylized fact in international monetary economics: the variability of real exchange rate is higher under a flexible nominal exchange rate regime than under a fixed arrangement.

There are some state institutions, that can cause or influence volatility. Government and Central Bank are the most important ones. Following part shows us theirs objectives.

Governmental influences on volatility

The government created in August 2004 confirmed in its Programme Declaration[6] that it will follow up on the economic policy of previous governments, particulary focussed in on promoting economic growth, reducing the unemployment rate and improving the competitiveness of Czech economy, and will persist in the reform efforts that had been initiated. An updated medium-term economic strategy was to be prepared, relying on the following two basic pillars: the reduction of public finances deficit and effective and efficient promotion of economic growth. The question is whether this strategy keeps volatility low or increases it.

Mission and functions of the Czech National Bank

The CNB's monetary policy objective is set forth in Article 98 of the Constitution of the Czech Republic and in Article 2 of Act No. 6/1993 Coll., on the Czech National Bank. In particular, the CNB is required to maintain price stability. Without prejudice to its primary objective, the CNB shall support the general economic policies of the Government leading to sustainable economic growth.

The central banks of the most of democratic nations with market economies have a similar objective. The objective of maintaining price stability, i.e. of fostering a stable environment for the development of entrepreneurial activity, reflects the central bank's responsibility for sustainable economic growth.

Monetary stability has an internal dimension (price stability) and an external dimension (exchange rate stability). We are especially interested in latter stability, respectively volatility.

[6]Programme Declaration of the Czech Republic Government, Prague, 31. 8. 2004

In the pursuit of its primary monetary policy objective, the central bank can opt for any one of several monetary policy regimes. There are four basic types of regime.

A **regime with an implicit nominal anchor** involves targeting a particular nominal variable adopted only internally within the central bank without it being announced explicitly. A prerequisite for successful functioning of this regime is high credibility of the central bank, which enables the desired changes in inflation or inflation expectations to be achieved without explicit targets.

The **money targeting regime** focuses on the growth rate of a chosen monetary aggregate. It is based on the finding that in the long term, price growth is affected by money supply growth. A problem, however, lies in the choice of an appropriate monetary aggregate to target. In an environment of financial innovation, market computerization and globalization, the relationship between monetary aggregates and the price level is becoming ever weaker. The central bank may also fail to manage the selected monetary aggregate with sufficient precision.

Under the **exchange rate targeting regime**, the central bank tries to ensure nominal exchange rate stability vis-a-vis the currency of a so-called anchor country via interest rate changes and direct foreign exchange interventions, thereby "importing" price stability from the country. Maintaining the exchange rate requires an appropriate economic policy mix ensuring a low inflation differential vis-a-vis the anchor country, a sufficient level of international reserves, and the maintaining of the country's competitiveness and overall credibility, including its institutional and legislative framework and political stability. One of the major disadvantages of the regime is the loss of monetary policy autonomy.

Under **inflation targeting**, the central bank publicly pre-announces an inflation target (or a succession of targets) that it is determined to achieve. This involves active and direct shaping of inflation expectations. This regime's decision-making scheme involves the use of much more information than merely the exchange rate or monetary aggregates, covering the labour market, import prices, producer prices, the output gap, nominal and real interest rates, the nominal and real exchange rate, public budgets, etc.

In December 1997, the CNB Bank Board decided to change its monetary policy regime and at the start of 1998 it switched to inflation targeting. Targets for particular periods are showed in picture 6.1 - Inflation targeting. This did not involve any change in objective, only in the way of achieving this objective.

This is very important for us, because implementing of inflation targeting should have decisive influence on volatility of exchange rates. Also any changes within this regime can cause a breakpoint in behaviour of volatility. And this is exactly what we are looking for.

Chapter 2

Volatility Modeling

It is generally acknowledged that the volatility of many financial return series is not constant over time and that these series exhibit prolonged periods of high and low volatility, often referred to as volatility clustering.

Since 80's two main groups of model have been developed to capture this time-varying autocorrelated volatility process. These are Generalized autoregressive conditional heteroscedasticity (GARCH[1]) models and Stochastic Volatility (SV[2]) models. Also one measuring approach - A historic volatility - was introduced and improved in order to measure instability of economic time series.

GARCH models define the time-varying variance as a deterministic function of past squared innovations and lagged conditional variances. The variance in the SV model is modeled as an unobserved component that follows some stochastic process.

In our work we will use historic volatility, ARCH and GARCH models. Here we make a detail description of ARCH and GARCH models[3].

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[1]For GARCH literature we refer to Bollerslev, Chou & Kroner[5], Bera & Higgins[3], Bollerslev, Engle & Nelson[6] and Diebold & Lopez[8].

[2]SV models are reviewed in, for example, Taylor[39], Ghysels, Harvey & Renault[18] and Shephard[35].

[3]We will also briefly describe some modificated ARCH models

2.1 ARCH model - Autoregressive conditional heteroskedasticity model

The ARCH-model was first presented by Engle[10] in 1984 and has since then attracted a lot of attention[4]. First consider an ordinary AR(p) model of the stochastic process y_t.

$$y_t = c + \alpha_1 y_{t-1} + ... + \alpha_p y_{t-p} + u_t$$

where u_t is white noise.

The basic AR(p) - model is now extended so that the conditional variance of ut could change over time. One extension could be that u_t^2 itself follows an AR(m) - process.

$$u_t^2 = \theta_0 + \theta_1 u_{t-1}^2 + ... + \theta_m u_{t-m}^2 + w_t$$

where w_t is a new white noise process and u_t is the error in forecasting y_t. This is the general ARCH(m) - process. For easier calculations and for estimation, a stronger assumption about the process is added.

$$u_t = h_t^{\frac{1}{2}} v_t$$

where v_t is an i.i.d. Gaussian process with zero mean and a variance equal to one $v_t \sim$ N(0,1) and the whole model for the variance is now

$$\epsilon_t | \psi_{t-1} \sim N(0, ht)$$

$$h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \epsilon_{t-i}^2$$

where $\alpha_0 > 0, \alpha_i \geq 0$ for $i = 1...q$. ψ_{t-1} is the information available at time t-1. Now, when the process for the variance is defined, we add an additional equation for modeling y_t. The return price is modeled with a constant.

$$y_t = c + \epsilon_t$$

this means that ϵ_t is innovations from a linear regression.

[4] For example: Klaassen[26], Bollerslev, Chou & Kroner[5],Hamilton & Susmel [21] etc.

2.2 Generalized ARCH - GARCH

This section is describing a generalization of the ordinary ARCH-model. The model structure was introduced by Bollerslev[4]. The generalization is a similar to the extension of an AR(p) to an ARMA(p,q). Formally the process can be written as

$$\epsilon_t|\psi_{t-1} \sim N(0; ht)$$
$$h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \epsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i h_{t-i} \tag{2.1}$$

where p,q integer $\alpha_0 > 0$, $\alpha_i \geq 0$ for i in 1...p; $\beta_0 > 0$, $\beta_i \geq 0$ for i in 1...q thus the additional feature is that the process now also includes lagged h_{t-i} values. For $p = 0$ the process is an ARCH(q). For $p = q = 0$ (an extension allowing q = 0 if p = 0), ϵ_t is white noise.

In the above specification (2.1) ARCH term, say, $\alpha\epsilon_{t-1}^2$ reflects the impact of 'news' or 'surprises' from previous periods that affects volatility of a specific variable under research: significant and positive α depicts the extent of the shocks' effect on volatility which is not destabilizing. When α is greater than one then shocks materializing in the past are likely to be destabilizing. GARCH term, say, βh_{t-1} on the other hand, measures the impact of the forecast variance from previous periods on the current conditional variance, or volatility. Significant coefficient β (close to one) thus means a high degree of persistence in exchange rate volatility. The sum of both coefficients also tells us about the speed of convergence of the forecast of the conditional volatility to a steady state: the closer to one its value is, the slower the convergence.

2.3 Other ARCH modifications

Until now we have mentioned only the real basics of large ARCH family (ARCH & GARCH). In this part we try to briefly describe the important modifications. We will not use them in our work, but we present them here to show that there was intensive research in this area.

So-called integrated GARCH(p,q) or IGARCH(p,q) model was introduced by Engle and Bollerslev[11] in 1986 by restricting the sum of coefficients to equal one.

To capture the asymmetric effects exponential GARCH, or EGARCH, model was proposed by Nelson[30] in 1991.

Another popular way how to model the asymmetry of positive and negative innovations is the use of indicator functions as showed in GJG model by Glosten, Jagannathan & Runkle[17] in 1993.

A new way how to model asymmetric effects on the conditional standard deviation was introduced by Zakoian[42] (1990), and developed further in Rabemananjara and Zakoian[33] (1993), by defining the threshold GARCH, or TGARCH(p,q) model.

Taylor[38] (1986) and Schwert[36] (1989) assumed that the conditional standard deviation is a distributed lag of absolute innovations, and introduced the absolute GARCH, or AGARCH(p,q) model.

Geweke[16] (1986), Pantula[32] (1986) and Milhoj[27] (1987) suggested a specification in which the log of the conditional variance depends linearly on past logs of squared innovations. Their model was the multiplicative ARCH, or Log-GARCH(p,q) model.

Schwert[37] built the autoregressive standard deviation, or Stdev-ARCH(q) model in 1990.

Higgins & Bera[3] introduced the non-linear ARCH, or NARCH(p,q), model in 1992, which followed Engle and Bollerslev simpler non-linear ARCH model from year 1986.

In order to introduce asymmetric effects, Engle[12] proposed the asymmetric GARCH, or AGARCH(p,q) model in 1990.

Engle and Ng[13] (1993) presented two more ARCH models that incorporate asymmetry for good and bad news, the non-linear asymmetric GARCH, or NAGARCH(p,q) model and the VGARCH(p,q) model.

Ding[9] introduced in 1993 the asymmetric power ARCH, or APARCH(p,q) model, which included seven ARCH models as special cases (ARCH, GARCH, AGARCH, GJR, TARCH, NARCH and logARCH).

Sentana[34] introduced the quadratic GARCH, or GQARCH(p,q), model in 1995.

Gouriéroux and Monfort[19] proposed the qualitative threshold GARCH, or GQTARCH(p,q) model in 1992.

Fornari and Mele[14] introduced the volatility-switching ARCH model, or VSARCH(p,q) model in 1995 and mixed the GJR and the VSARCH models in 1996[15] and named it asymmetric volatility-switching ARCH, or AVSARCH(p,q) model.

In year 1996 Hagerud[20] inspired by the Smooth Transition Autoregressive (STAR) model proposed the smooth transition ARCH model. In the STAR model, the conditional mean is a non-linear function of lagged realizations of the series introduced via a transition function. Logistic smooth transition or LST-GARCH(p,q), and exponential smooth transition GARCH or EST-GARCH(p,q) models were introduced this way. Other model that originated by same approach but different transition function is asymmetric nonlinear smooth transition GARCH, or ANST-GARCH model by Nam[29] in 2002.

Engle and Lee[13] (1993) proposed the component GARCH model or CGARCH in order to investigate the long-run and the short-run movement of volatility and combined the component model with the GJR model to allow shocks to affect the volatility components asymmetrically resulting in asymmetric component GARCH, or the ACGARCH(1,1) model.

In year 1996 Baillie[2], motivated by the Fractionally Integrated Autoregressive Moving Average, or ARFIMA model, presented the Fractionally Integrated Generalized Autoregressive Conditional Heteroscedasticity, or FI-GARCH model.

Other approach was chosen in Regime-Switching models, described in Hamilton & Susmel[21]. This allows the system's dynamics to jump between different regimes. The jumps occur stochastically and are governed by a Markov process. In practice these are models in which we want to allow for periodic shifts in the parameters that describe the underlying dynamics, in order to account for structural shifts in the data generating process. The SWARCH model is a particular specification in which the parameters of the ARCH process can occasionally change.

Chapter 3

Data - Exchange rates

In previous chapters we described methods we are going to use without introducing the data. This will be fixed in this part by describing the exchange rates, we were using. We collected the data from Czech National Bank. The data starts on 1.1.1999 and ends on 30.12.2005 - which means 1768 observations. In this chapter we show basic statistics for each time series and brief description of breakpoints. These time series are Euro to Czech koruna, 100 Slovak Koruna to Czech Koruna, Polish Zloty and US Dollar to Czech Koruna exchange rate.

3.1 Basic Statistics

In this table we present basic statistics for all exchange rates we investigate.

Country	Mean	Std. Dev.	Minimum	Maximum	Variance
Euro	33.27620	2.37970	28.97000	38.60000	5.66295
Slovakia	79.02142	4.24764	65.12900	89.86800	18.04249
Poland	8.14177	0.89312	6.61500	10.12500	0.79766
United States	32.27106	5.43149	21.96800	42.12700	29.50111

3.2 Breakpoints

3.2.1 Exchange rate Euro to Czech Koruna

We found following breakpoints in exchange rate of Euro to Czech Koruna by using modified Vogelsang's test. Here we tried to connect some of them with certain economic or political event that should have had decisive influence or which had caused the break.

- 346 - 10.5.2000 - Possible connection with financial fall in Asia and slowdown in stock market in United States
- 553 - 6.3.2001 - Cycle Peak in US bussiness activity, the expansion that began in March 1991 ended in March 2001.
- 888 - 8.7.2002 - Rapid weakening of Dollar.
- 1317- 18.3.2004 - Disturbance on world stock markets caused by bomb attacks in Spain (11.3.2004).

3.2.2 Exchange rate Slovak Koruna to Czech Koruna

Following breakpoints were found in exchange rate of Slovak Koruna to Czech Koruna using modified Vogelsang's test.

- 369 - 12.6. 2000
- 888 - 8.7.2002 - Rapid weakening of Dollar, probably connected with war in Afghanistan. (The same breakpoint as Euro)
- 988 - 26.11.2002 - Public Budget committee indicate possibility of changes.
- 1317- 18.3.2004 - Disturbance on world stock markets caused by bomb attacks in Spain (11.3.2004).(The same breakpoint as Euro)

3.2.3 Exchange rate Polish Zloty to Czech Koruna

Following breakpoints were found in exchange rate of Polish Zloty to Czech Koruna using modified Vogelsang's test.

- 634 - 2.7.2001 - This breakpoint is common to United States and Poland
- 889 - 9.7.2002 - Rapid weakening of Dollar, probably connected with war in Afghanistan. (The same breakpoint as Euro)
- 1359 - 18.05.2004

3.2.4 Exchange rate American Dollar to Czech Koruna

Following breakpoints were found in exchange rate of US Dollar to Czech Koruna using modified Vogelsang's test.

- 293 - 22.2.2000 - US stock markets fell heavily, reacting to the warning by Federal Reserve Board Chairman Alan Greenspan that US monetary authorities were prepared to raise interest rates repeatedly in the coming months.
- 637 - 9.7.2001 - The slowdown in US economic activity was more sudden than expected and the unemployment rate rose to 4,5 percent.
- 798 - 26.2.2002 - Slow US recovery
- 1181 - 2.9. 2003 - The Budget committee of American congress takes an estimation of public finance deficit with result, that expenses will be higher than incomes by 480 billion dollars. This breakpoint can be caused by such important information.
- 1564 - 9.3.2005 - US central bank chief backs budget cuts and privatization.

3.3 Structural breaks in Exchange Rates

Structural breaks in Exchange Rates are very important for us in this work, because we need a model for exchange rates so we can fit residuals into ARCH or GARCH model. Therefore we need to model exchange rate appropriate, otherwise our results would be corrupted by possible changes (breaks) in trend of exchange rates.

This problematic is precisely described in Kočenda[25] from a different view.

Theory and traditional exchange rate models tell us that changes (breaks) in exchange rates are driven by expectations about present and future fundamentals and news in the fundamental variables. Standard theory also assumes the effect of monetary policy on exchange rates. We hypothesize that structural breaks in exchange rates are driven by exchange rate policies, mostly changes of exchange rate regime. This would mean that – if detected – a structural break should be indisputably paired with a policy step aimed at exchange rate developments. However, often regime choice is made under particular circumstances and a regime is maintained even when it can no longer be upheld, or even considered, the best choice in the long run – the costs of changing it may be perceived as just too large. Under such circumstances exchange rate development may experience a structural break, while the regime may be intact for a period of time. Thus, knowing the date of regime revision does not always automatically tell us about a structural break in exchange rate.

In the following part we describe the searching for single most decisive break, respectively the test we use for finding such break and modification for finding more breakpoints. Using this approach we want to divide the time series into segments. And by measuring or modeling volatility on these segments we obtain a sequence. And finally from this sequence we can show whether there is a trend in volatility behaviour or if there is a change in its behaviour.

3.3.1 Single break searching test

Since we are following the line of research by Kočenda, we use the same break-detecting test : the Wald-type test proposed and described by Vogelsang[41]. The part below is citation from Kočenda:Beware of Breaks in Exchange Rates: Evidence from European Transition Countries[25].

The test allows for a single break in each series. The procedure's advantage lies in its not imposing restrictions on the nature of the data. Further, since we want to detect a single decisive shift in the trend of exchange rate, the economically motivated restriction for a single break is in line with Vogelsang's technique.

The specifications of the test should be implemented so that they are robust to a unit-root dynamics of the data. Therefore, the first series of tests is related to a levels regression. We start with the following model :

$$\Delta y_t = \alpha + \beta t + \delta_1 DU_t + \delta_2 DT_t + \pi y_{t-1} + \sum_{j=1}^{k} c_j \Delta y_{t-j} + \epsilon_t \tag{3.1}$$

where y_t is a natural log of nominal exchange rate and Δy_t is its first logarithmic difference. The dummy variables for the structural break bear the following values: $DU_t = 1$ if $t > T_b$ and 0 otherwise, and $DT_t = (t - T_b)DU_t$. The break date, T_b, is treated as unknown. The null hypothesis of no structural change in the trend function is given by $\delta_1 = \delta_2 = 0$. The specification allows for a shift in the level and time trend at the break point. For this specification we use unit-root critical values since a conservative structural change test is meant to use the critical values appropriate for unit-root errors.

Writing the model in the form given by 3.1 is advantageous because the serial correlation in the errors is handled by including enough lags of Δy_t. The appropriate number of lagged differences (k) in equation 3.2 is determined using the parametric method proposed by Campbell and Perron[7] (1991) and Ng and Perron[31] (1995). The upper bound of the number of lagged differences k_{max} is initially set at an appropriate level (8 lags in our case). The regression is estimated and the significance (at 10%) of the coefficient c_j is determined. If the coefficient is not found to be significant, then k is reduced by one and the equation (1) 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 $k = 0$.

Vogelsang[41] shows that when the errors of the time series have a unit root, the power of the test can be improved by conducting a test in first differences. Since, by the virtue of pretesting, our raw data are not stationary, we adopt the specification in differences and estimate the following:

$$\Delta y_t = \beta + \delta_2 DU_t + \sum_{j=1}^{k} c_j \Delta y_{t-j} + \epsilon_t \tag{3.2}$$

where all variables are defined as for equation (5.2). To be robust to problems arising from over-differencing, the same k used for the results based on

(5.2) is used in (5.3). The null hypothesis of no structural change in the trend function is now given by $\delta_2 = 0$. This specification allows for an intercept shift at the break point, implying a change in the rate of depreciation or appreciation. For this specification we use stationary critical values.

Since Vogelsang's procedure represents a sequential F-test, both equations (5.2) and (5.3) are estimated sequentially for each break period with 1% trimming, i.e., for $0.01T < T_B < 0.99T$ where T is the number of observations; 1% trimming is chosen because we are not interested in breaks, that would indicate different trend before our observations started. For our model (5.2) the Sup$\{F_t\}$ is twice the maximum, over all possible trend breaks, of the standard F-statistics for testing $\delta_1 = \delta_2 = 0$. For our model (5.3) the Sup$\{F_t\}$ is the maximum, over all possible trend breaks, of the standard F-statistics for testing $\delta_2 = 0$.

3.3.2 Modification

Using the test described above we would get one breakpoint, but if we look on graphs of exchange rates we can see that it is not enough. All exchange rates that we take into account do have few visible breaks. Therefore we will use Vogelsang's test and instead of Sup$\{F_t\}$ we take few local maxima. Our partial goal is to find some common breakpoints. Then we create a partially linear model, where we allow shifts and trend breaks. And if all coefficients are statistically significant then we take all breaks we find into account. If in model neither shift coefficient nor trend break coefficient are significant, we set the the breakpoint aside.

Chapter 4

Calculations

4.1 Historic Volatility

Historic volatility is one of the measures of fluctuations. It is defined as standard deviation of a return on exchange rate over a period of time. Here we describe the process how to obtain a historic volatility of a time series. We start with the exchange rate itself.

Exchange rate F_i

When analyzing volatility, it is usual to use logarithmic normal distribution of rate differences, because the price decrease is limited by a simple fact, that it can't be negative. The standard deviation is not calculated directly from rate changes, but from their logarithms.

Logarithmic return $r_i = log(F_i/F_{i-1})$

Because standard deviation is square root of mean squared error, we need mean of returns and particular squared errors.

Mean of returns $r_e = \sum r_i/12$
Squared error $M_i = (r_i - r_e)^2$

And finally we get standard deviation.

Standard deviation $\sigma_M = \sqrt{\sum M_i/12}$

We have to make a final step to obtain year historic volatility, we need to multiply standard deviation by square root of number of observation (12 for month observations, 365 for daily).

Table 4.1: Historic Volatility : Years 1999-2005

Year	Euro	Polish Zloty	Slovak Koruna	American Dollar
1999	3.099 %	4.915 %	3.575 %	4.928 %
2000	1.922 %	5.512 %	2.606 %	5.379 %
2001	2.348 %	6.350 %	2.273 %	4.847 %
2002	3.333 %	5.283 %	3.423 %	4.670 %
2003	2.343 %	4.056 %	2.576 %	4.880 %
2004	2.171 %	3.291 %	2.221 %	4.812 %
2005	2.230 %	3.377 %	1.930 %	4.514 %

Year volatility estimate $\sigma_M * \sqrt{12}$

For first estimation we use month averages. Results can be found in tables 7.1, 7.2, 7.3, 7.4, 7.5, 7.6 and 7.7. In these tables we can see the returns on exchange rates, mean returns and standard deviation. This information presents us the image of volatility.

In these tables we can see, that historic volatility was highest in years 2002 and 1999 and lowest in 2003 and 2001. There is no visible trend.

Using original data instead of month averages we get following results, which should be more precise.

There are some interesting issues that should be mentioned in table 4.1. We can see absolutely different dynamics of Historic volatility of American Dollar and other countries. Historic volatility of American Dollar keeps its stable but relatively high level. Historic volatility of Euro has some minor fluctuations in 1999 and 2002 and since 2003 it keeps its stable level around 2,2%. Similar situation is in case of Slovak Koruna, same fluctuations in 1999 and 2002. But here the historic volatility keeps decreasing since 2002. We can see slightly different situation in case of Polish Zloty. The first difference is in size and the second is that there is only one extreme in year 2001 and since then historic volatility has decreased (increase in year 2005 was very small).

There are many aspects that could affect the volatility. In our work we focus on changes in exchange rate regime. The latter difference we described can be affected or caused by fact that Czech Republic and Slovakia adopted regime of inflation targeting later that Poland.

In the following parts we will try to prove this partial results by a different volatility measuring respectively modeling.

In previous calculations we didn't take into account possible structural breaks in exchange rates time series. And that is what we are going to do in following parts.

4.2 Removing trend factor

The method we are using is set up from these steps.

- Step 1. Finding important breakpoints
- Step 2. Modeling exchange rate time series as partially linear.
- Step 3. Removing these shifts and trends.
- Step 4. Calculating standard deviation of this trend-less series (and again there exist more ways, how to determine the volatility - one of them is simple calculation of standard deviation and another is the use of Garch method. This method determines unconditional variance)

As mentioned in section Single break searching (3.3.1) test we modified Vogelsang´s test to find more than one breakpoint in each time series. Actually we were looking for 3 to 5 most decisive breaks. Other problem occurred on both start and end of each time series. This problem was caused by fact that there is too few observations to talk about trend break. Therefore we found first and last important breakpoints and we worked only with observations between them.

4.2.1 Czech Koruna

We found following breakpoints using modification of Vogelsang's test 10.5.2000 (observation no.346), 6.3.2001 (no.553), 8.7.2002 (no.888), 18.3.2004 (no.1317). Following model covers data between 5.2.1999 (no.26) and 9.11.2005 (no.1734).

Coefficients:	Estimate	Std. Error	t value	Pr(> |t|)	
Intercept	37.9159246	0.0402726	941.481	$< 2 * 10^{-16}$	$***$
Shift - 346	0.6322332	0.0658213	9.605	$< 2 * 10^{-16}$	$***$
Shift - 553	0.8506583	0.0555479	15.314	$< 2 * 10^{-16}$	$***$
Shift - 888	0.1449856	0.0574505	2.524	0.0117	$*$
Shift - 1317	−0.5854514	0.0545890	−10.725	$< 2 * 10^{-16}$	$***$
Break - 26	−0.0076625	0.0002108	−36.345	$< 2 * 10^{-16}$	$***$
Break - 553	−0.0077822	0.0003067	−25.377	$< 2 * 10^{-16}$	$***$
Break - 888	0.0214662	0.0002706	79.338	$< 2 * 10^{-16}$	$***$
Break - 1317	−0.0137547	0.0002269	−60.626	$< 2 * 10^{-16}$	$***$

4.2.2 ARCH model

Here we divide the series of residuals into segments between breakpoints and we try to fit them into Arch(1) model.

5.2.1999 - 10.5.2000

Coefficients:	Estimate	Std. Error	t value	Pr(> |t|)	
$a0$	0.017612	0.002056	8.567	$< 2 * 10^{-16}$	$***$
$a1$	0.880051	0.218526	4.027	5.6410^{-5}	$***$

10.5.2000 - 6.3.2001

Coefficients:	Estimate	Std. Error	t value	Pr(> |t|)	
$a0$	0.008172	0.003092	2.643	0.008227	$**$
$a1$	0.909255	0.265102	3.430	$6.04 * 10^{-4}$	$***$

6.3.2001 - 8.7.2002

Coefficients:	Estimate	Std. Error	t value	Pr(> |t|)	
$a0$	0.020155	0.001772	11.377	$< 2 * 10^{-16}$	$***$
$a1$	0.902117	0.233523	3.863	0.000112	$***$

8.7.2002 - 18.3.2004

Coefficients:	Estimate	Std. Error	t value	Pr(> |t|)	
$a0$	0.015769	0.002616	6.029	$1.65 * 10^{-9}$	$***$
$a1$	0.869202	0.196191	4.430	$9.41 * 10^{-6}$	$***$

18.3.2004 - 9.11.2005

Coefficients:	Estimate	Std. Error	t value	Pr(> $\|t\|$)	
$a0$	0.011852	0.002289	5.179	$2.23 * 10^{-7}$	$***$
$a1$	0.914365	0.181128	5.048	$4.46 * 10^{-7}$	$***$

The whole series even fit into GARCH(1,1) model. Here is the estimation:

Coefficients:	Estimate	Std. Error	t value	Pr(> $\|t\|$)	
$a0$	0.011048	0.001073	10.296	$< 2 * 10^{-16}$	$***$
$a1$	0.809105	0.092247	8.771	$< 2 * 10^{-16}$	$***$
$b1$	0.119081	0.027700	4.299	$1.72 * 10^{-5}$	$***$

$$\text{Unconditional Variance} = \frac{a0}{1-a1-b1} = 0.1538419$$

As result we can say, that there is only one exception. The only segment with higher variance - volatility is between 6.3.2001 and 8.7.2002. And we can see that volatility in later segments is lower. If we compare this result with result obtained from historic volatility measuring, we can see certain similarities. In both cases is the highest volatility around 2002 and then volatility decreases and stabilizes.

Range	Volatility
5.2.1999 - 10.5.2000	0.1468
10.5.2000 - 6.3.2001	0.0934
6.3.2001 - 8.7.2002	0.2059
8.7.2002 - 18.3.2004	0.1205
18.3.2004 - 9.11.2005	0.1384

4.2.3 Slovak Koruna

We found following breakpoints using modification of Vogelsang's test 12.6.2000 (no.369), 8.7.2002 (no.888), 26.11.2002 (no.988), 18.3.2004 (no.1318) in Slovak to Czech Koruna exchange rate. Following model covers data between 17.5.1999 (no.96) and 9.11.2005 (no.1734).

Coefficients:	Estimate	Std. Error	t value	Pr(> $\|t\|$)	
Intercept	81.1059294	0.1368979	592.456	$< 2 * 10^{-16}$	$***$
Shift - 369	-2.3428153	0.1694645	-13.825	$< 2 * 10^{-16}$	$***$
Shift - 888	-4.7390611	0.2496678	-18.981	$< 2 * 10^{-16}$	$***$
Shift - 988	-0.8718403	0.2547683	-3.422	0.000639	$***$
Break - 96	0.0206556	0.0008678	23.803	$< 2 * 10^{-16}$	$***$
Break - 369	-0.0450287	0.0009294	-48.449	$< 2 * 10^{-16}$	$***$
Break - 888	0.1059832	0.0039499	26.832	$< 2 * 10^{-16}$	$***$
Break - 988	-0.0633982	0.0039730	-15.957	$< 2 * 10^{-16}$	$***$
Break - 1318	-0.0271375	0.0011671	-23.252	$< 2 * 10^{-16}$	$***$

After obtaining residuals of the model we divided the whole time series into segments and fitted into ARCH model.

Range	a0	a1	Unconditional variance
96-369	0.076374	0.96797	2.3843
369-888	0.116974	0.93944	1.9317
888-988	0.153471	0.80994	0.8075
988-1318	0.087559	0.93190	1.2858
1318-1734	0.046520	0.89032	0.4242

The evolving of variance respectively volatility is similar to situation in Euro to Czech Koruna exchange rate. There is a volatile segment followed by decrease in volatility. This is again similar to the results we obtained from historic volatility approach.

4.2.4 Polish Zloty

We found following breakpoints in Polish Zloty to Czech Koruna exchange rate 10.11.1999 (no.220),2.7.2001 (no.634), 9.7.2002 (no.889) and 18.05.2004 (no.1359). The model covers data between 5.2.1999 (no.26) and 19.10.2005 (no.1720).

Coefficients:	Estimate	Std. Error	t value	Pr(> |t|)	
(Intercept)	8.437	$2.1 * 10^{-2}$	404.514	$< 2 * 10^{-16}$	$***$
shift - 634	-0.2493	$3.4 * 10^{-2}$	-7.351	$3.4 * 10^{-13}$	$***$
shift - 889	-0.3187	$3.3 * 10^{-2}$	-9.640	$< 2 * 10^{-16}$	$***$
shift - 1359	0.1082	$3.6 * 10^{-2}$	3.008	0.00267	$**$
break - 220	$2.9 * 10^{-3}$	$8.7 * 10^{-5}$	33.394	$< 2 * 10^{-16}$	$***$
break - 634	$-8.2 * 10^{-3}$	$2.0 * 10^{-4}$	-40.730	$< 2 * 10^{-16}$	$***$
break - 889	$3.3 * 10^{-3}$	$2.0 * 10^{-4}$	16.669	$< 2 * 10^{-16}$	$***$
break - 1359	$5.6 * 10^{-3}$	$2.7 * 10^{-4}$	20.662	$< 2 * 10^{-16}$	$***$

In following table we can see that the highest volatility is in the third segment (2.7.2001-20.7.2002), which is the only exception from lower volatility level.

Range	a0	a1	Uncond.var
26-1720	0.00228	0.97768	0.1021
26-220	0.00420	0.90976	0.0465
220-634	0.00515	0.90389	0.0536
634-889	0.00577	0.98686	0.4392
889-1359	0.00179	0.93117	0.0260
1359-1556	0.00080	0.82459	0.0045
1556-1720	0.00258	0.84116	0.0163

Chapter 5

Results

Our goal in this work was to model volatility and connect some changes in exchange rates with some events, which should cause or influent volatility. And on the basis of this minor results we can formulate a major conclusion.

From the perspective of historic volatility there was one extreme in 2002 in Euro and Slovak Koruna exchange rates time series and in 2001 in Polish Zloty exchange rate.

From the ARCH results we can see, that after 8.7.2002 in Euro, Slovak Koruna and Polish Zloty exchange rates there came an era with lower volatility. The breakpoints we found, were only the helping instrument, that showed us the evolution of volatility, they were not supposed to set up exact time. In all these countries we can see a very volatile time segment

- 6.3.2001 - 8.7.2002 in the Czech Republic
- 2.7.2001 - 9.7.2002 in Poland
- 17.5.1999 - 8.7.2002 in Slovakia

But why was volatility so high then? From previous research[1] we can see that after a major switch in exchange regime, volatility tends to increase. This finding corresponds with a fact that exchange volatility is greater under a flexible regime than under a tight one[2].

[1] See Valachy & Kočenda [40]

[2] See Mussa[28]

This explains only the first common attribute of our two approaches. The extreme value of volatility between years 2001 and 2002. This increase was mostly influenced by changing monetary policy.

But there is one more common attribute that deserves to be described or explained. This is the decrease in volatility after previous era with high volatility.

These three states adopted a new monetary regime - inflation targeting.

In the Czech Republic it was adopted in 1999 and it had three stages. There were point targets for inflation in 1998, 1999, 2000 and 2001. In January 2002 a target band for headline inflation was defined. And since 2005 there has been a target for headline inflation of 3%. Our data cover only one of these changes within inflation targeting and we can see that after adopting target band for headline inflation the volatility decreased.

In Poland the National Bank has had a "direct inflation targeting strategy" since 1999. As the first step, the National Bank announced the intent of reaching a medium-term target of below 4% by 2003. More precisely in range 2-4%. Since the beginning of 2004, the National Bank of Poland has pursued a continuous inflation target at the level of 2.5% with a permissible fluctuation band of ±1 percentage point. This phase began sooner than in the Czech Republic which could influence a fact that there was sooner decrease in historic volatility[3].

And in Slovakia the inflation targeting was adopted in 1998 with short-term targets. In addition in 2001 the Nation Bank of Slovakia defined medium-term targets. The most eminent step has been done in 2004 when the national Bank of Slovakia set up its goal to decrease inflation below 2.5% on the end of year 2006. We can see that before 2004 volatility had slightly increased and after there was a big decrease in volatility.

We succeeded to show a connection between implementing inflation targeting increase and following decrease in volatility of exchange rates in investigated countries. Although there exist a whole series of aspects that do influence volatility, this one is the most important from economic perspective.

[3]See table 4.1

Chapter 6

Apendix 1 - Graphs

List of Graphs

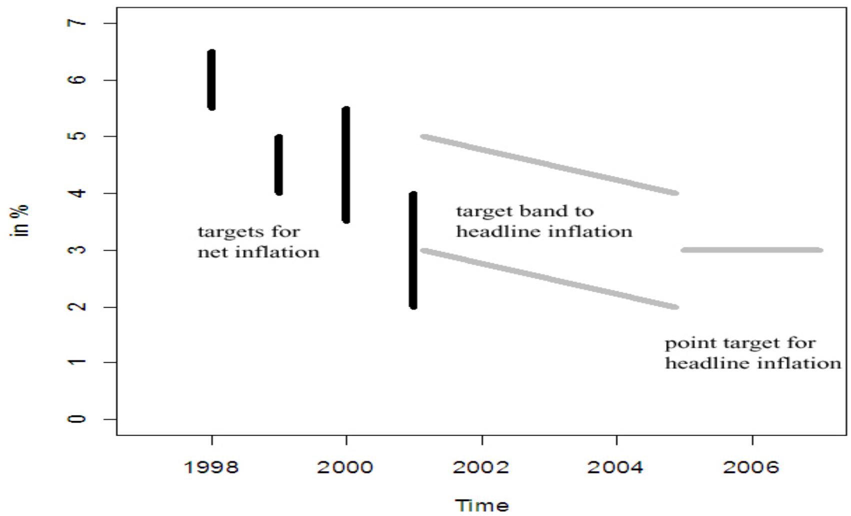

Figure 6.1: The Czech National Bank inflation targets

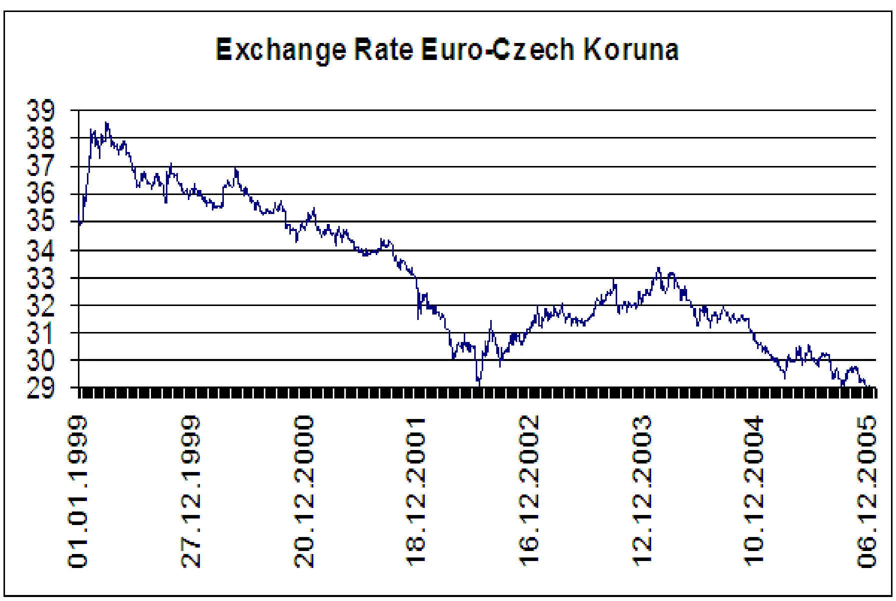

Figure 6.2: Dynamics of Exchange Rate : Euro - Czech koruna

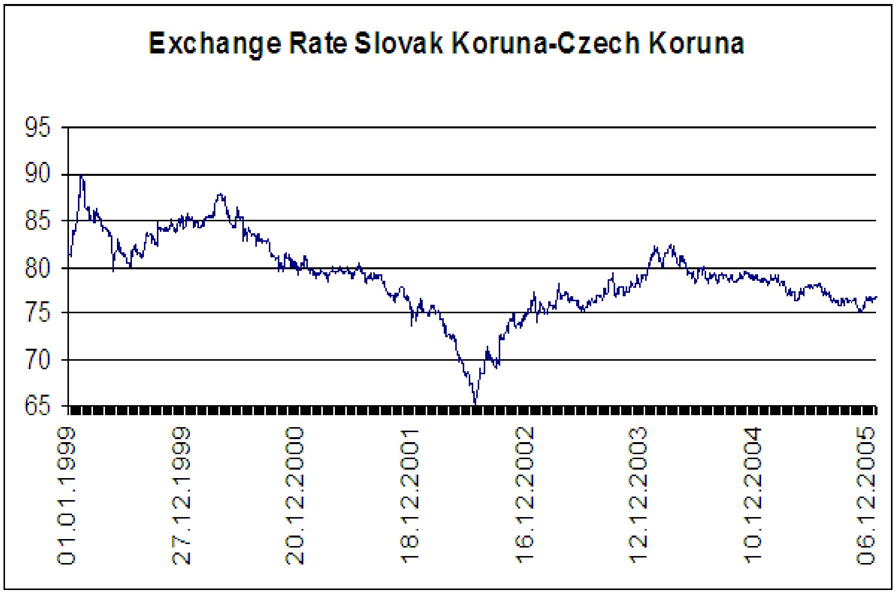

Figure 6.3: Dynamics of Exchange Rate : Slovak Koruna - Czech koruna

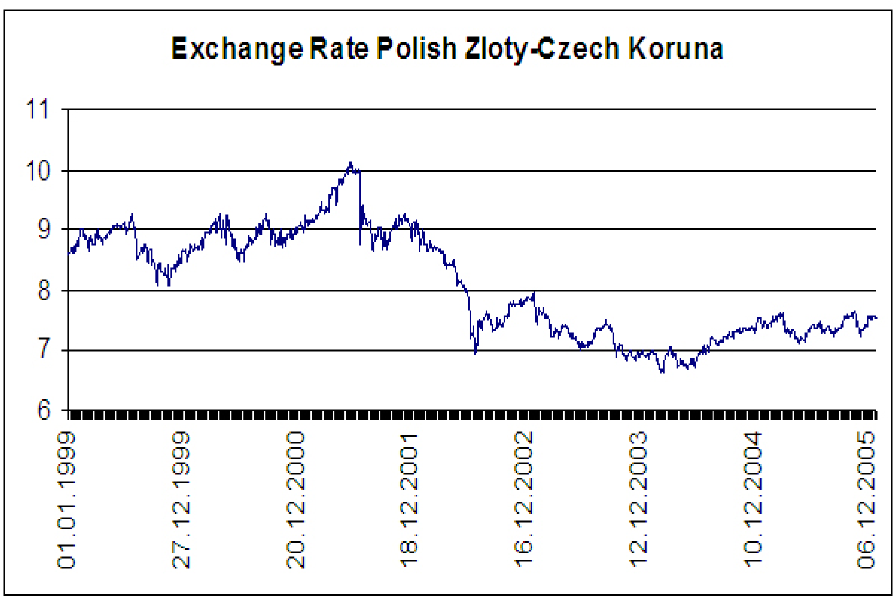

Figure 6.4: Dynamics of Exchange Rate : Polish Zloty - Czech koruna

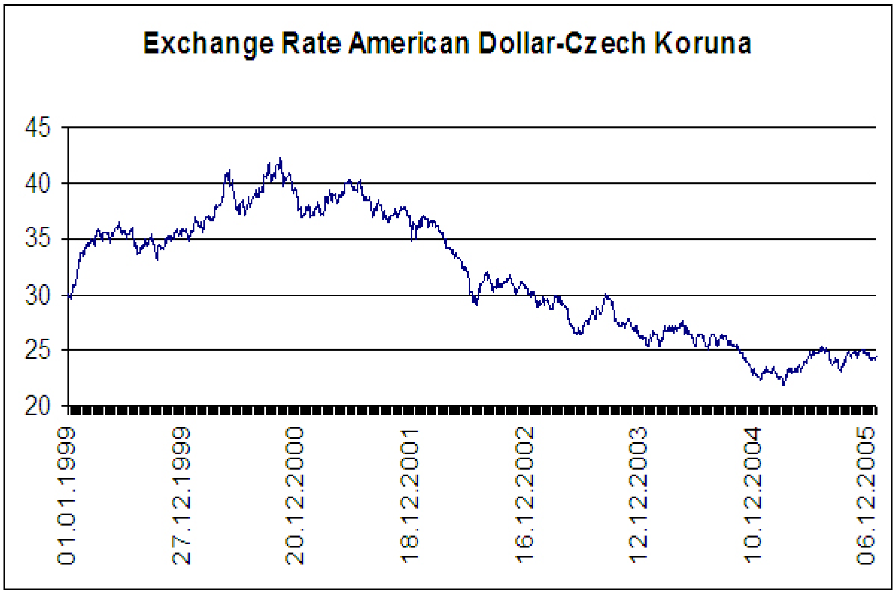

Figure 6.5: Dynamics of Exchange Rate : US Dollar - Czech koruna

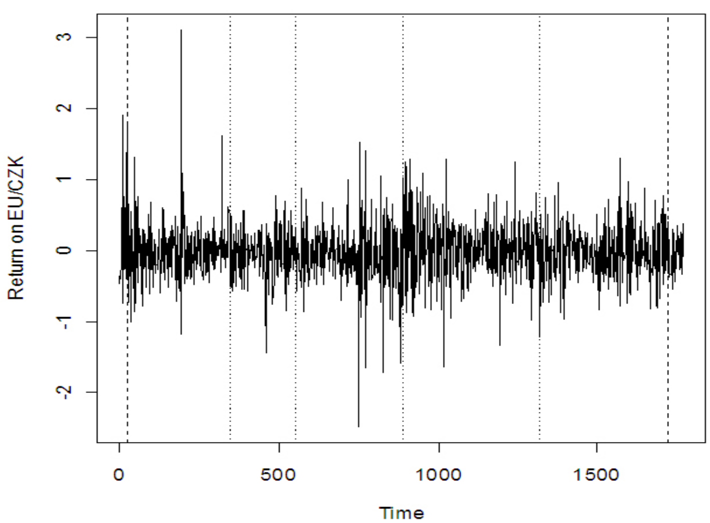

Figure 6.6: Return on Euro-CZK Exchange Rate

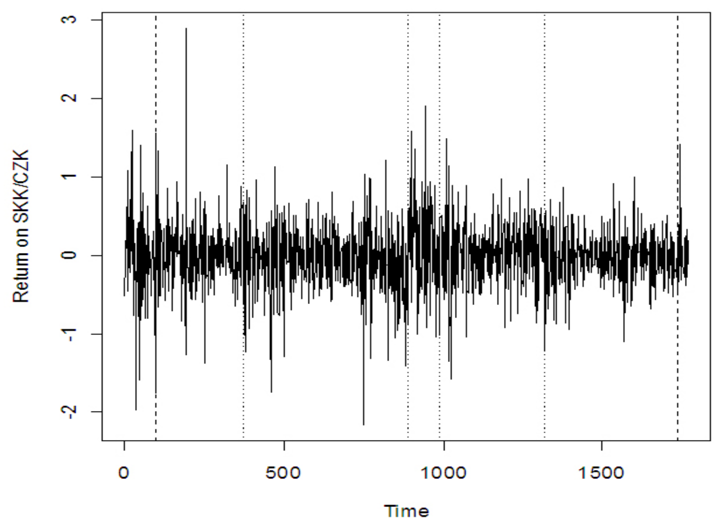

Figure 6.7: Return on Slovak Koruna-CZK Exchange Rate

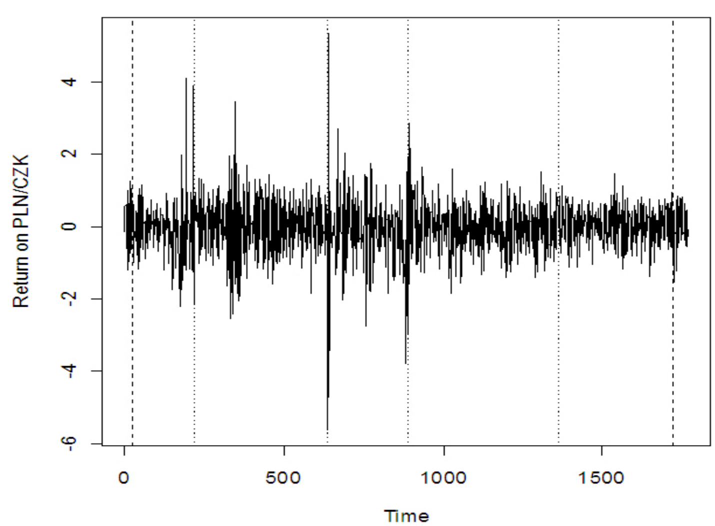

Figure 6.8: Return on Polish Zloty-CZK Exchange Rate

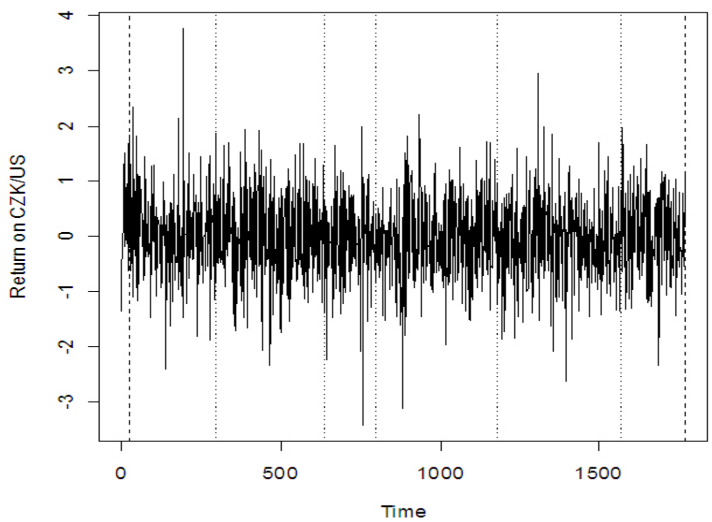

Figure 6.9: Return on American Dollar-CZK Exchange Rate

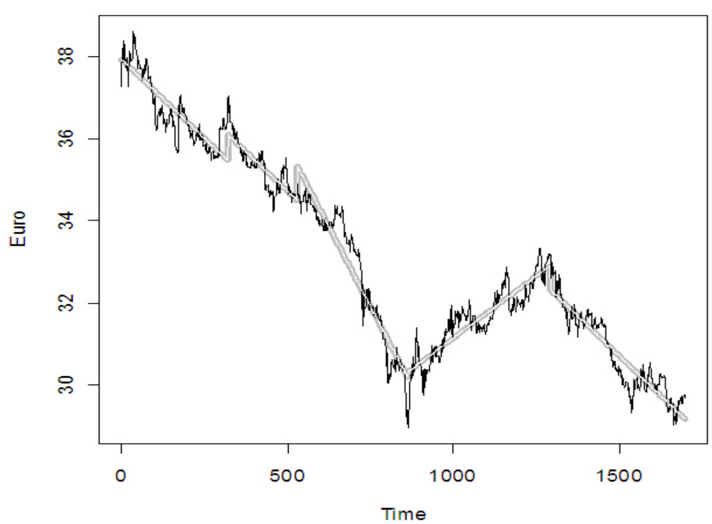

Figure 6.10: Model of Euro

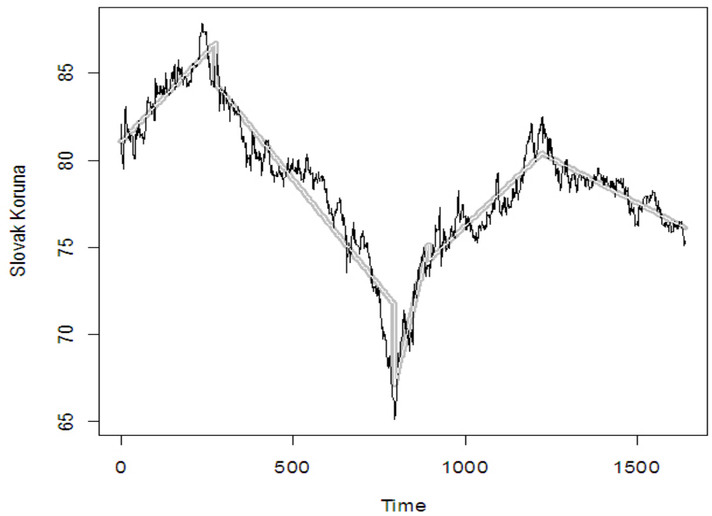

Figure 6.11: Model of Slovak Koruna

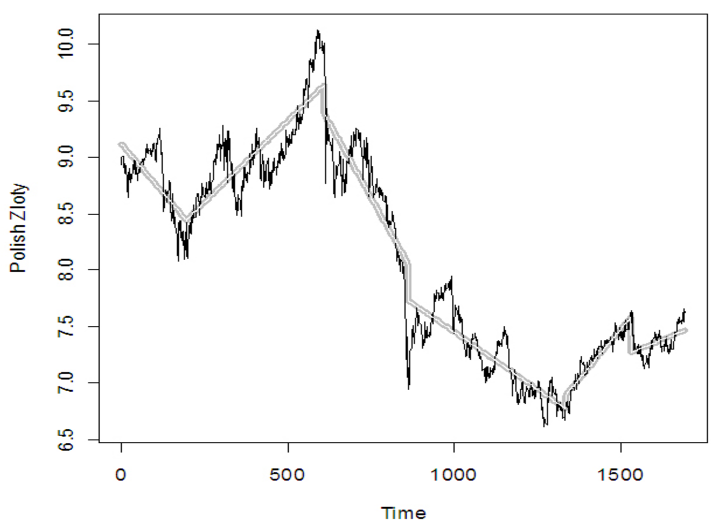

Figure 6.12: Model of one Polish Zloty

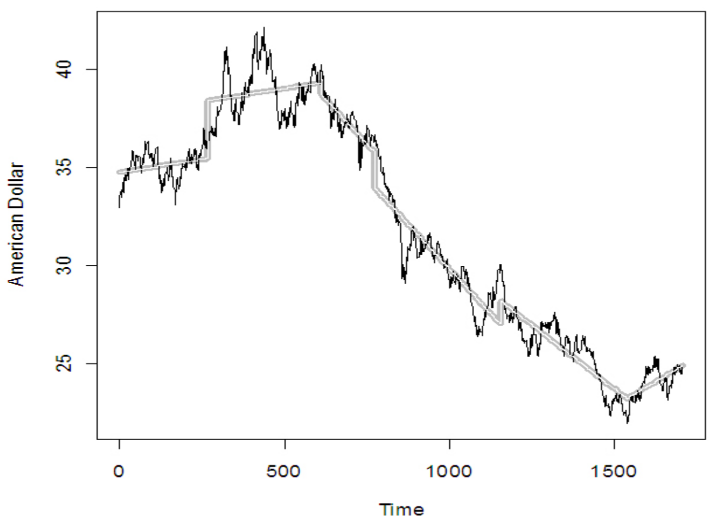

Figure 6.13: Model of American Dollar

Chapter 7

Appendix 2 - Tables

List of Tables

Table 7.1: Year 1999 - Historic Volatility using month averages

Month(i)	Rate(F_i)	r_i	$r_i - r_e$	M_i
January	35.638			
February	37.715	0.024601	0.024210	0.0005861
March	37.989	0.003144	0.002753	0.0000076
April	37.997	0.000091	-0.000299	0.0000001
May	37.692	-0.003500	-0.003891	0.0000151
June	37.152	-0.006267	-0.006658	0.0000443
July	36.521	-0.007440	-0.007830	0.0000613
August	36.415	-0.001262	-0.001653	0.0000027
September	36.356	-0.000704	-0.001095	0.0000012
October	36.587	0.002751	0.002360	0.0000056
November	36.403	-0.002190	-0.002581	0.0000067
December	36.054	-0.004184	-0.004575	0.0000209
January	36.025	-0.000349	-0.000740	0.0000005
Annual	0.027426	= 2.74%		

Table 7.2: Year 2000 - Historic Volatility using month averages

Month(i)	Rate(F_i)	r_i	$r_i - r_e$	M_i
December	36.054			
January	36.025	-0.000349	0.000914	0.00000084
February	35.709	-0.003826	-0.002563	0.00000657
March	35.595	-0.001389	-0.000125	0.00000002
April	36.310	0.008637	0.009901	0.00009803
May	36.555	0.002921	0.004184	0.00001751
June	36.017	-0.006439	-0.005176	0.00002679
July	35.619	-0.004826	-0.003562	0.00001269
August	35.356	-0.003219	-0.001955	0.00000382
September	35.425	0.000847	0.002110	0.00000445
October	35.275	-0.001843	-0.000579	0.00000034
November	34.617	-0.008178	-0.006914	0.00004780
December	34.817	0.002502	0.003765	0.00001418
Annual	0.0153	= 1.53 %		

Table 7.3: Year 2001 - Historic Volatility using month averages

Month(i)	Rate(F_i)	r_i	$r_i - r_e$	M_i
December	34.817			
January	35.139	0.003998	0.006388	0.00004081
February	34.640	-0.006212	-0.003821	0.00001460
March	34.601	-0.000489	0.001901	0.00000361
April	34.550	-0.000641	0.001749	0.00000306
May	34.382	-0.002117	0.000273	0.00000007
June	33.975	-0.005172	-0.002782	0.00000774
July	33.855	-0.001537	0.000853	0.00000073
August	34.034	0.002290	0.004680	0.00002190
September	34.188	0.001961	0.004351	0.00001893
October	33.562	-0.008026	-0.005636	0.00003176
November	33.325	-0.003078	-0.000688	0.00000047
December	32.592	-0.009659	-0.007269	0.00005284
Annual	0.0140	= 1.4%		

Table 7.4: Year 2002 - Historic Volatility using month averages

Month(i)	Rate(F_i)	r_i	$r_i - r_e$	M_i
December	32.592			
January	32.078	-0.006904	-0.005315	0.00002825
February	31.789	-0.003930	-0.002341	0.00000548
March	30.356	-0.020032	-0.018443	0.00034016
April	31.388	0.014519	0.016108	0.00025947
May	30.558	-0.011639	-0.010050	0.00010100
June	30.295	-0.003754	-0.002165	0.00000469
July	29.749	-0.007899	-0.00631	0.00003981
August	30.796	0.015022	0.016611	0.00027592
September	30.193	-0.008588	-0.006999	0.00004899
October	30.653	0.006567	0.008156	0.00006652
November	30.756	0.001457	0.003046	0.00000928
December	31.192	0.006113	0.007702	0.00005933
Annual	0.0352	= 3.52%		

Table 7.5: Year 2003 - Historic Volatility using month averages

Month(i)	Rate(F_i)	r_i	$r_i - r_e$	M_i
December	31.192			
January	31.490	0.004129	0.002852	0.00000813
February	31.645	0.002132	0.000855	0.00000073
March	31.758	0.001548	0.000270	0.00000007
April	31.625	-0.001823	-0.003100	0.00000961
May	31.391	-0.003225	-0.004503	0.00002028
June	31.410	0.000263	-0.001015	0.00000103
July	31.877	0.006410	0.005132	0.00002633
August	32.289	0.005577	0.004299	0.00001848
September	32.354	0.000873	-0.000404	0.00000016
October	31.985	-0.004982	-0.006259	0.00003918
November	31.974	-0.000149	-0.001427	0.00000204
December	32.313	0.004580	0.003302	0.00001091
Annual	0.0117	= 1.17%		

Table 7.6: Year 2004 - Historic Volatility using month averages

Month(i)	Rate(F_i)	r_i	$r_i - r_e$	M_i
December	32.313			
January	32.723	0.005476	0.007792	0.00006071
February	32.857	0.001775	0.004091	0.00001673
March	32.984	0.001675	0.003991	0.00001593
April	31.974	-0.013506	-0.011190	0.00012523
May	32.514	0.007273	0.009589	0.00009196
June	31.614	-0.012191	-0.009875	0.00009752
July	31.521	-0.001279	0.001036	0.00000107
August	31.634	0.001554	0.003870	0.00001498
September	31.634	0	0.002316	0.00000536
October	31.484	-0.002064	0.000252	0.00000006
November	30.647	-0.011702	-0.009386	0.00008810
December	30.310	-0.004802	-0.002486	0.00000618
Annual	0.0229	= 2.29%		

Table 7.7: Year 2005 - Historic Volatility using month averages

Month(i)	Rate(F_i)	r_i	$r_i - r_e$	M_i
December	30.647			
January	30.310	-0.00481	-0.002776	0.0000077
February	29.961	-0.00503	-0.002999	0.0000090
March	29.782	-0.00260	-0.000567	0.0000003
April	30.130	0.00504	0.007075	0.0000501
May	30.216	0.00124	0.003271	0.0000107
June	30.032	-0.00265	-0.00062	0.0000004
July	30.185	0.00221	0.004237	0.0000180
August	29.592	-0.00861	-0.006584	0.0000433
September	29.305	-0.00423	-0.002201	0.0000048
October	29.677	0.00548	0.007509	0.0000564
November	29.261	-0.00613	-0.004101	0.0000168
December	28.975	-0.00428	-0.002245	0.0000050
Annual	0.0149	= 1.49%		

Table 7.8: Historic Volatility using month averages

Year	Historic Volatility of Euro
1999	2.74 %
2000	1.53 %
2001	1.40 %
2002	3.52 %
2003	1.17 %
2004	2.29 %
2005	1.49 %

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