ACTA UNIVERSITATIS LODZIENSIS
FOLIA OECONOMICA 192, 2005

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# THE CO-MOVEMENT BETWEEN RETURNS OF FOREIGN EXCHANGE RATES IN THE CENTRAL EUROPEAN COUNTRIES

**Abstract**. The analysis of conditional correlations between returns of foreign exchange rates gives us significant information about co-movement between different currency markets. In the paper, we model this kind of dependency in the case of currency markets in Central European countries using Engle's DCC models. We investigate the changes in the level of conditional correlations during stability and crisis periods. In this context we try to find the evidence of the contagion effect in the considered region.

**Keywords**: currency market, co-movement, dynamic correlations, exchange rates, contagion.
**JEL Classification**: F31, C32.

## 1. INTRODUCTION

The question about co-movement of security prices is one of the most important problems in finance theory and applications. An answer to this question affects such fields as portfolio selection, risk management or security pricing. The analysis of conditional correlations between financial returns gives a possibility to describe dependencies changing in time and to get a deeper insight into the financial markets dynamics.

The currencies are an important class of assets. The mechanism of currency co-movement is essential for diversifiability of currency exchange risk, which occurs during cross-border investments and trade. However, the analysis of co-movement in the case of currency markets is more complicated than it is, for example, in the case of capital market. The specifics of this problem are connected with the fact that examining the linkages between currency markets, we use exchange rates which are always against some

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third currency (usually US dollar or euro). The results of analysis essentially depend on the choice of this third currency.

In this paper we use Engle's dynamic conditional correlation (DCC) model to investigate the dynamic conditional correlation between currencies of Central European countries (Czech Republic, Hungary, Poland, Slovakia) and Russian ruble. Our analysis is based on the returns of exchange rates against the US dollar and the euro. As byproduct, we get some results concerning the contagion effect in this region.

## 2. CO-MOVEMENT OF CURRENCY MARKETS

In view of financial market globalization, the currency market co-movement is worth the careful analysis because of its importance for risk management. The currency co-movement is essential for the diversification of currency exchange risk. Though the exchange rates fluctuations are subject to different shocks, it is possible to find some pattern of dependencies suggesting that some currencies can co-move in a predictable manner (cf. Figure 2).

The cross-market linkages can be measured by a number of different statistics such as the correlation in asset returns, the probability of a speculative attack, or the transmission of shocks or volatility. However the analysis of conditional correlations between the returns of interest seems to be the most popular method. Such approach is very common in literature concerning the capital market co-movement. The suggestion that one should measure contagion as a significant increase in the correlation between asset returns, comes from King and Wadhwani (1990).

The investigation of currency markets linkages is more complicated than it is in the capital market case. The reason for this is that the analysis of co-movement between two currencies requires the consideration of exchange rates which are always calculated against a third currency. The choice of this third currency significantly influences the results of comparison. The plots of exchange rates presented in Figures 1 and 2 show different behavior of the returns against the US dollar and euro. The diverse dependencies between the returns of exchange rates calculated against different currencies make the inference rather sophisticated. As mentioned above, the examination of cross-market correlations is usually based on some correlation tests. In this paper, we propose to analyze the dependencies between some currency markets by directly modeling the dynamic conditional correlation between exchange rate returns. The tool is Engle's DCC model presented in the next section.

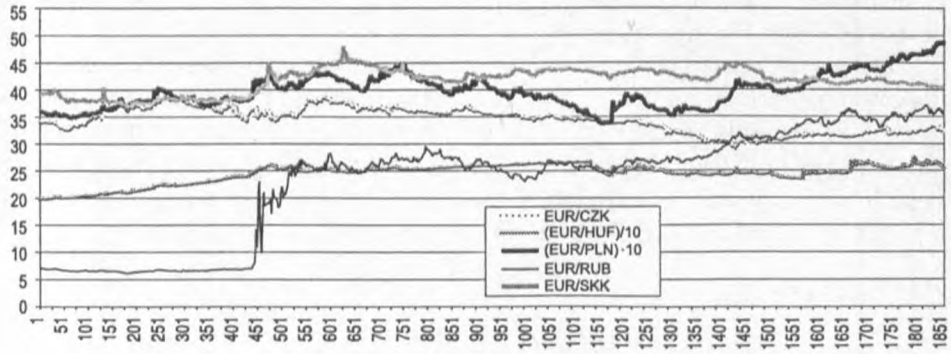


Fig. 1. The plots of EUR/CZK, (EUR/HUF)/10, (EUR/PLN)·10, EUR/RUB and EUR/SKK


Fig. 2. The plots of USD/CZK, (USD/HUF)/10, (USD/PLN)·10, USD/RUB and USD/SKK

The subject of special interest of researchers and practitioners is the effect of contagion occurring when a financial crisis starts as country-specific event but quickly spreads into other countries. There is no agreement on the definition of contagion between the financial markets. In this paper we apply Forbes' and Rigobon's (2001) definition of contagion. It means that we characterize the contagion as a significant increase in cross-market linkages after a crisis occurring in one country. The term interdependence is used in the situation where the strong linkages between the two markets are permanent.

As concerns the question about the evidence of contagion, the analysis of direct modeling of correlations seems to have some advantages over the correlation tests. There is no need to divide the sample according to the crisis and non-crisis periods. The crisis period is easy to identify as a period

of increased volatility. The breakpoints are detected by means of an estimated volatility level. The model we used takes into account the conditional heteroscedasticity of return series. It is very important because of the fact that the majority of correlation tests occur to be inaccurate due to heteroscedasticity. Forbes and Rigobon (2001, 2002) claim that cross-market correlation coefficients are conditional on market volatility. During crises, markets are more volatile and estimates of correlation coefficients tend to increase and be biased upward which results in finding spurious evidence of contagion.

## 3. THE DCC MODEL

Let $y_1$ and $y_2$ be two random variables with the conditional means equal to zero. The conditional correlation between $y_1$ and $y_2$ is defined by

$$\rho_{12,t} = \frac{E(y_1 y_2 | \Omega_{t-1})}{\sqrt{E(y_1^2 | \Omega_{t-1}) E(y_2^2 | \Omega_{t-1})}},$$

where $\Omega_{t-1}$ is the set of information available on the daily return process $r_t$ up to time $t-1$.

It is reasonable to assume that conditional correlations change over time. The problem of estimation of the conditional correlation between financial variables is still widely discussed in the econometric literature. In this paper, we propose to use Engle's (2000) DCC model to describe the conditional correlations between returns and volume.

Let $\mathbf{r}_t = (r_{1t}, \ldots, r_{kt})'$ be a multidimensional series of returns. The $\mathbf{r}_t$ can be written as the sum $\mathbf{r}_t = \boldsymbol{\mu}_t + \mathbf{y}_t$, where $\mathbf{y}_t = (y_{1t}, \ldots, y_{kt})'$ and $\boldsymbol{\mu}_t = \mathbf{E}(\mathbf{r}_t | \Omega_{t-1})$ is the conditional mean of the vector $r_t$ upon the information set $\Omega_{t-1}$.

In the DCC model, as in multivariate GARCH models, we assume that $y_t$ satisfies the equation

$$\mathbf{y}_t = \mathbf{H}_t^{1/2} \boldsymbol{\varepsilon}_t,$$

where $\boldsymbol{\varepsilon}_t$ is a $k$-dimensional process of normally distributed independent random variables with unit mean and the covariance matrix $\mathbf{I}_k(\boldsymbol{\varepsilon}_t \sim \text{iid}(\mathbf{0}, \mathbf{I}_k))$. Then $\mathbf{y}_t | \Omega_{t-1} \sim N(\mathbf{0}, \mathbf{H}_t)$. The matrix $\mathbf{H}_t$ is specified as

$$\mathbf{H}_t = \mathbf{D}_t \mathbf{R}_t \mathbf{D}_t,$$

where $\mathbf{D}_t = \text{diag}(\sqrt{h_{11t}}, \ldots, \sqrt{h_{kkt}})$ and the conditional variances $h_{iit}$ can be modeled by any univariate GARCH model, for example,

$$h_{iit} = \omega_i + \sum_{j=1}^{q} \alpha_{ij} y_{i,t-j}^2 + \sum_{j=1}^{p} \beta_{ij} h_{ii,t-j}, \quad i = 1, \ldots, k$$

The matrix $\mathbf{R}_t$ is defined by

$$\mathbf{R}_t = (\mathrm{diag}(\mathbf{Q}_t))^{=-1/2}\, \mathbf{Q}_t (\mathrm{diag}(\mathbf{Q}_t))^{-1/2}.$$

The positive definite symmetric $(k \times k)$ matrices $\mathbf{Q}_t$ are assumed to satisfy the equation

$$\mathbf{Q}_t = \left(1 - \sum_{m=1}^{M} \alpha_m - \sum_{n=1}^{N} \beta_n\right)\mathbf{Q} + \sum_{m=1}^{M} \alpha_m \mathbf{u}_{t-m}\mathbf{u}'_{t-m} + \sum_{n=1}^{N} \beta_n \mathbf{Q}_{t-n}.$$

The coefficients of $k$-dimensional vectors $\mathbf{u}_t$ are of the form $u_{it} = y_{it}/\sqrt{h_{iit}}$. The $(k \times k)$ matrix $\mathbf{Q}$ is the unconditional covariance matrix of the variables $\mathbf{u}_t$. The assumptions about the parameters $\alpha_m$, $\beta_n$ are as follows: $\alpha_m$, $\beta_n > 0$ and $\sum_{m=1}^{M} \alpha_m + \sum_{n=1}^{N} \beta_n < 1$.

The special case of the above model (constant matrix $\mathbf{R}_t = \mathbf{R}$) is the constant conditional correlation model introduced by Bollerslev (1990).

An estimation procedure for DCC model proceeds in two steps where in the first one the univariate GARCH models are estimated for each residuals series $y_{it}$, and in the second one, the residuals divided by their conditional standard deviation estimated in the first step, are used to estimate the parameters of the dynamic correlation. The likelihood function used in the first step is the sum of the likelihoods of the considered univariate GARCH models and so it is given by

$$QL_1(\boldsymbol{\varphi}|\mathbf{y}_t) = -\frac{1}{2}\sum_{t=1}^{T} k\ln(2\pi) + 2\ln(|\mathbf{D}_t|) + \mathbf{y}'_t \mathbf{D}_t^{-1} \mathbf{I}_k \mathbf{D}_t^{-1} \mathbf{y}_t) =$$

$$= -\frac{1}{2}\sum_{i=1}^{k}\left(T\ln(2\pi) + \sum_{t=1}^{T}\left(\ln(h_{it}) + \frac{y_{it}^2}{h_{it}}\right)\right).$$

Given the parameter vector $\boldsymbol{\varphi}$, the consistent estimator of correlation parameters vector $\boldsymbol{\psi}$ can be determined by means of the likelihood function

$$QL_2(\psi|\varphi, y_t) = -\frac{1}{2}\sum_{t=1}^{T} (\ln|\mathbf{R}_t| + \mathbf{u}'_t \mathbf{R}_t^{-1} \mathbf{u}_t),$$

where $\mathbf{u}_t = \mathbf{D}_t^{-1}\mathbf{y}_t$.

The software we used for the calculations presented in this paper is the UCSD_GARCH Toolbox v. 2.0 by K. Sheppard.

## 4. THE DATA

The data consist of daily exchange rates of Czech koruna (CZK), Hungarian forint (HUF), Polish zloty (PLN), Russian ruble (RUB) and Slovak koruna (SKK) against the US dollar (USD) and euro (EUR). In each case the elements of time series under scrutiny are the prices of 1 USD in the corresponding domestic currency. The period under analysis is 14.11.1996 – 27.02.2004. It gives 1870 observations in each time series. The analysis is based on the percentage logarithmic returns $r_t$, given by the formula

$$r_t = 100(\ln(p_t) - \ln(p_{t-1})),$$

where $p_t$ means the value of exchange rate on day $t$.

The descriptive statistics of the returns are presented in Table 1.

Table 1. Descriptive statistics of returns

| Data | Min | Max | Mean | Std | Kurtosis | Skewness |
|---|---|---|---|---|---|---|
| EUR/CZK | –2.7919 | 8.8903 | –0.0028 | 0.5339 | 46.603 | 2.5741 |
| EUR/HUF | –2.6219 | 6.3644 | 0.0136 | 0.4753 | 33.191 | 2.4671 |
| EUR/PLN | –3.1100 | 5.5271 | 0.0170 | 0.7003 | 7.4788 | 0.7580 |
| EUR/RUB | –33.0391 | 30.1915 | 0.0872 | 2.1445 | 96.316 | 1.5236 |
| EUR/SKK | –3.4653 | 6.2110 | 0.0019 | 0.4764 | 34.225 | 1.9180 |
| USD/CZK | –2.9196 | 9.5904 | –0.0019 | 0.7794 | 15.9428 | 0.8829 |
| USD/HUF | –3.2520 | 5.7415 | 0.0145 | 0.7042 | 9.1738 | 0.5592 |
| USD/PLN | –3.4125 | 4.2208 | 0.0179 | 0.6304 | 6.8919 | 0.3112 |
| USD/RUB | –33.163 | 28.959 | 0.0881 | 2.0534 | 107.97 | 1.3638 |
| USD/SKK | –3.5921 | 6.0160 | 0.0028 | 0.7055 | 9.6405 | 0.4639 |

An important part of our analysis concerns the contagion effect between the markets under scrutiny. For this reason, we present some information about the financial crises that occurred in the investigated period. Our evaluation of the crisis periods is strongly influenced by the results of Serwa and Bohl (2003). From our point of view, the most important are the situations when a crisis started in the country from the considered group.

There are three such currency crises: the Czech koruna in May 1997, the Russian ruble in 1998 and the Hungarian forint crisis in 2003.

Table 2. Rough information about the crisis periods and corresponding observations in presented data set

| Crisis | Period (approximately) | Observations |
|---|---|---|
| Czech koruna crisis | May 1997 | 115–131 |
| Asian flu | July – December 1997 | 157–282 |
| Russian cold | June – September 1998 | 386–470 |
| Brazilian fever | November 1998 – March 1999 | 491–581 |
| Turkish collapse | December 2000 – March 2001 | 1029–1110 |
| September 11 | September 2001 | 1231–1254 |
| Argentina | January – February 2002 | 1300–1353 |
| Forint crisis | June 2003 | 1679–1700 |

## 5. EMPIRICAL RESULTS

Our analysis of co-movement between the Central European currency markets is based on the two groups of five exchange rates presented in Table 1. According to the assumption of DCC model, we fit the VAR model to each group of time series. Then we apply the Engle and Sheppard (2001) constant correlation test to the VAR residuals. The null hypothesis of constant correlation is strongly rejected in both cases (Table 3). These results justify the modeling of dynamic correlations.

Table 3. Results from Engle-Sheppard's constant conditional correlation test

| Reference currency | Test statistics | p-value |
|---|---|---|
| EUR | 16.0521 | 0.0003 |
| USD | 24.0262 | 0.0000 |

The parameters of univariate GARCH and DCC models are presented in Tables 4 and 7. Apart from the dynamic conditional correlations, we estimate the constant conditional correlations for exchange rates in each group, using Bollerslev's CCC model. The values presented in Tables 5 and 8 can be treated as representing the average level of the dynamic conditional correlations.

Table 4. Parameters of fitted GARCH models and DCC model. The analysis of dynamic correlations between EUR/CZK, EUR/HUF, EUR/PLN, EUR/RUB and EUR/SKK

| GARCH | CZK | HUF | PLN | RUB | SKK |
|---|---|---|---|---|---|
| $\omega$ | 0.0168 (0.0043) | 0.0446 (0.1651) | 0.0459 (0.0093) | 0.0258 (0.0068) | 0.0117 (0.0058) |
| $\alpha_1$ | 0.1882 (0.0477) | 0.2868 (0.0928) | 0.1359 (0.0241) | 0.1435 (0.0289) | 0.3074 (0.1074) |
| $\beta_1$ | 0.7677 (0.0243) | 0.5390 (0.0957) | 0.7745 (0.0118) | 0.8372 (0.0099) | 0.6926 (0.0741) |
| Parameters of DCC model | | | | | |
| $\alpha$ | 0.0166 (0.0056) | | | | |
| $\beta$ | 0.9623 (0.0164) | | | | |

Table 5. Constant conditional correlations between EUR/CZK, EUR/HUF, EUR/PLN, EUR/RUB and EUR/SKK

| | SKK | RUB | PLN | HUF |
|---|---|---|---|---|
| CZK | 0.3138 (0.0347) | 0.1290 (0.0290) | 0.2310 (0.0291) | 0.1549 (0.0749) |
| HUF | 0.2485 (0.0680) | 0.1860 (0.0445) | 0.3198 (0.0477) | |
| PLN | 0.2026 (0.0369) | 0.4775 (0.0312) | | |
| RUB | 0.1655 (0.0345) | | | |

The plots in Figures 1–10 show the estimates of conditional correlations for the exchange rates against euro. The constant conditional correlations have rather low, positive values (0.1–0.2), except for the correlation between EUR/PLN and EUR/RUB – about 0.5. The fluctuations of dynamic correlations are quite strong. As concerns the contagion effect, during the time of almost all crises one can observe a significant jump to high positive level in dynamic correlations in the case of EUR/CZK-EUR/PLN, EUR/HUF-EUR/PLN and EUR/PLN- EUR/SKK. At the same time, there is surely no increase in correlations between EUR/CZK and EUR/HUF. The results concerning the remaining pairs of exchange rates are rather ambiguous (Table 6).

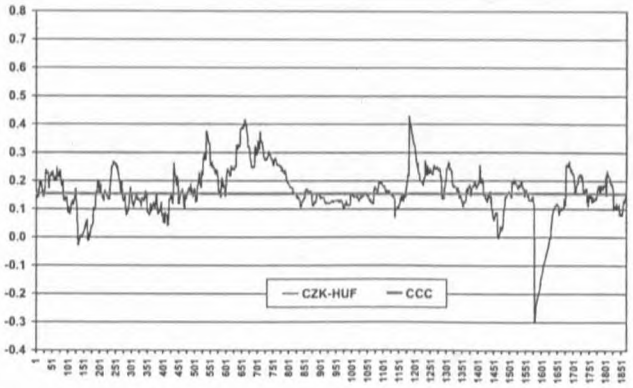


Fig. 3. Conditional dynamic correlations between EUR/CZK and EUR/HUF with the level of constant conditional correlation (CCC)

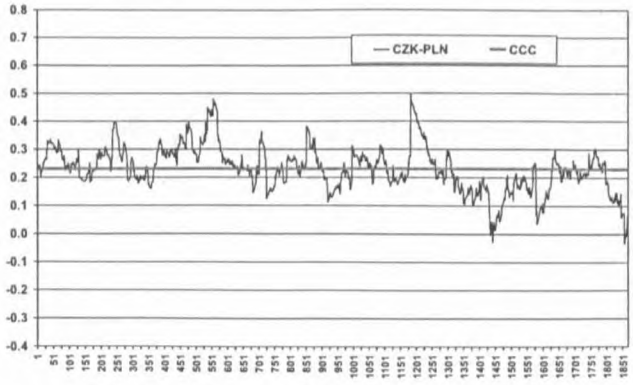


Fig. 4. Conditional dynamic correlations between EUR/CZK and EUR/PLN with the level of constant conditional correlation (CCC)

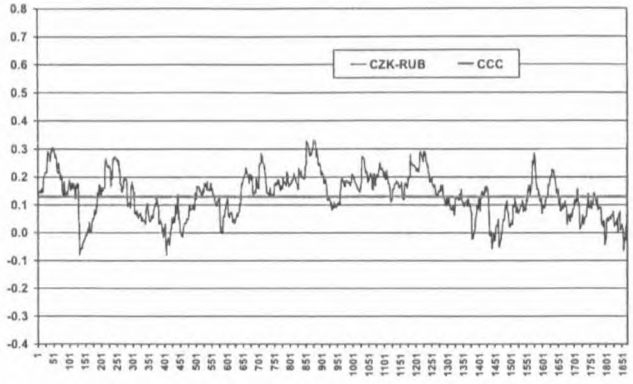


Fig. 5. Conditional dynamic correlations between EUR/CZK and EUR/RUB with the level of constant conditional correlation (CCC)

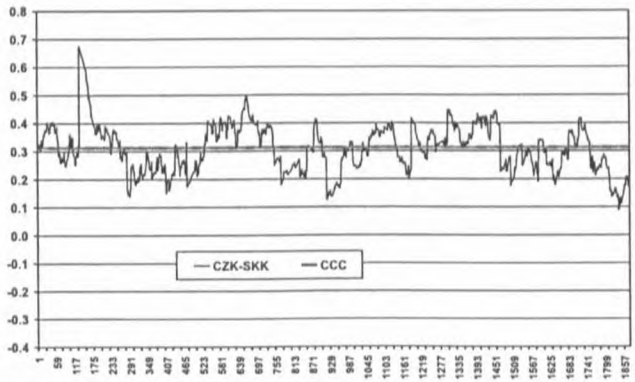


Fig. 6. Conditional dynamic correlations between EUR/CZK and EUR/SKK with the level of constant conditional correlation (CCC)

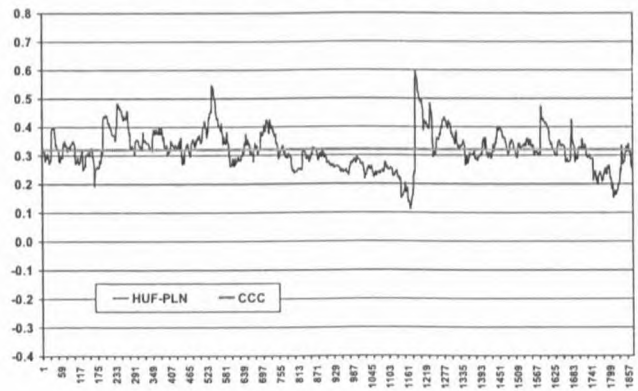


Fig. 7. Conditional dynamic correlations between EUR/HUF and EUR/PLN with the level of constant conditional correlation (CCC)

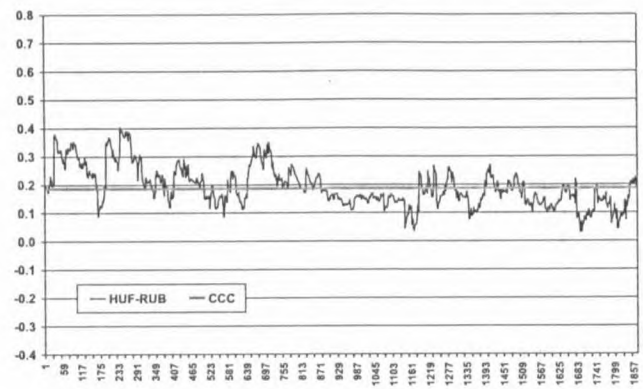


Fig. 8. Conditional dynamic correlations between EUR/HUF and EUR/RUB with the level of constant conditional correlation (CCC)

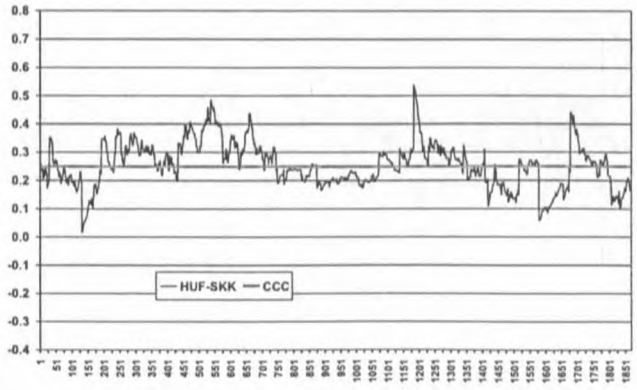


Fig. 9. Conditional dynamic correlations between EUR/HUF and EUR/SKK with the level of constant conditional correlation (CCC)

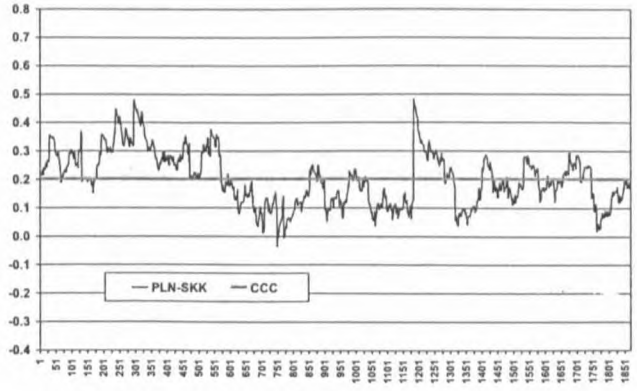


Fig. 10. Conditional dynamic correlations between EUR/PLN and EUR/SKK with the level of constant conditional correlation (CCC)

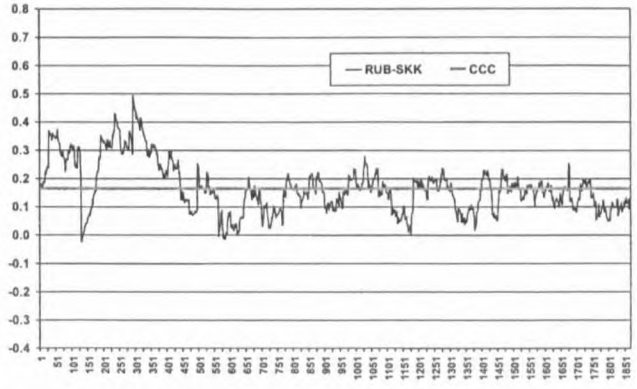


Fig. 11. Conditional dynamic correlations between EUR/RUB and EUR/SKK with the level of constant conditional correlation (CCC)

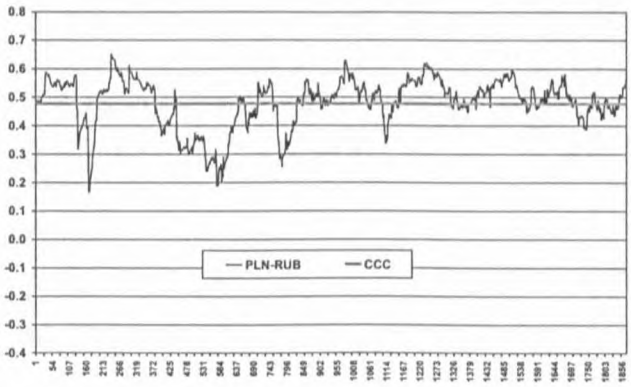


Fig. 12. Conditional dynamic correlations between EUR/PLN and EUR/RUB with the level of constant conditional correlation (CCC)

Table 6. Exchange rates against euro

| EUR | Czech | Asia | Rusia | Brazil | Turkey | September 11 | Argentina | Hungary |
|---|---|---|---|---|---|---|---|---|
| CZK-HUF | ↓ | ↑ | ↑ | ↓ | ↓ | ↓ | ↑ | ↑ |
| CZK-PLN | ↔ | ↑ | ↔ | ↑ | ↔ | ↔ | ↑ | ↔ |
| CZK-RUB | ↓ | ↑ | ↓ | ↔ | ↓ | ↑ | ↓ | ↓ |
| CZK-SKK | ↑ | ↓ | ↓ | ↑ | ↓ | ↓ | ↑ | ↑ |
| HUF-PLN | ↓ | ↑ | ↑ | ↑ | ↓ | ↑ | ↓ | ↑ |
| HUF-RUB | ↑ | ↑ | ↑ | ↓ | ↓ | ↑ | ↓ | ↓ |
| HUF-SKK | ↓ | ↑ | ↑ | ↑ | ↓ | ↓ | ↔ | ↑ |
| PLN-RUB | ↑ | ↑ | ↓ | ↓ | ↓ | ↑ | ↓ | ↑ |
| PLN-SKK | ↑ | ↑ | ↑ | ↑ | ↓ | ↑ | ↓ | ↑ |
| RUB-SKK | ↑ | ↑ | ↓ | ↔ | ↔ | ↔ | ↓ | ↑ |

Note: Behavior of dynamic correlations during period of crises presented in Table 2: ↑ – significant increase; ↔ – increase, but not very high; ↓ – no increase or even decrease in dynamic conditional correlation level.

Tables 7 and 8 show the parameters of the DCC models and constant conditional correlations estimated for exchange rates against USD. Corresponding plots of conditional correlations are presented in Figures 13–22.

Table 7. Parameters of fitted GARCH models and DCC model. The analysis of dynamic correlations between USD/CZK, USD/HUF, USD/PLN, USD/RUB and USD/SKK

| GARCH | CZK | HUF | PLN | RUB | SKK |
|---|---|---|---|---|---|
| $\omega$ | 0.0801 (0.0146) | 0.0229 (0.0062) | 0.0512 (0.0097) | 0.0025 (0.0008) | 0.0632 (0.0188) |
| $\alpha_1$ | 0.1136 (0.0486) | 0.0672 (0.0158) | 0.1984 (0.0416) | 0.2211 (0.0350) | 0.0598 (0.0253) |
| $\beta_1$ | 0.7571 (0.0136) | 0.8875 (0.0020) | 0.6780 (0.0315) | 0.7789 (0.0185) | 0.8127 (0.0088) |
| Parameters of DCC model | | | | | |
| $\alpha$ | 0.0373 (0.0070) | | | | |
| $\beta$ | 0.9205 (0.0242) | | | | |

Table 8. Constant conditional correlations between USD/CZK, USD/HUF, USD/PLN, USD/RUB and USD/SKK

| | SKK | RUB | PLN | HUF |
|---|---|---|---|---|
| CZK | 0.7101 (0.0340) | –0.0003 (0.9901) | 0.4100 (0.0279) | 0.6428 (0.0485) |
| HUF | 0.6659 (0.0471) | -0.0052 (0.8212) | 0.4408 (0.0228) | |
| PLN | 0.3689 (0.0352) | 0.0393 (0.0221) | | |
| RUB | –0.0079 (0.7212) | | | |

The linkages between analyzed currencies modeled on the basis of exchange rates against USD are mostly stronger (mean level about 0.4–0.7) than those against the euro. The correlations between the Central European and Russian exchange rates change the signs and their mean level is about zero

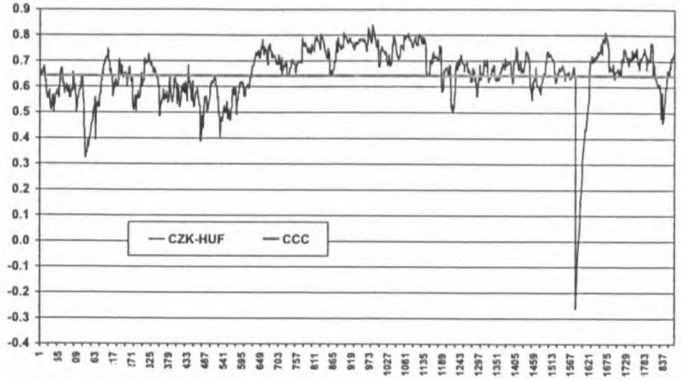


Fig. 13. Conditional dynamic correlations between USD/CZK and USD/HUF with the level of constant conditional correlation (CCC)

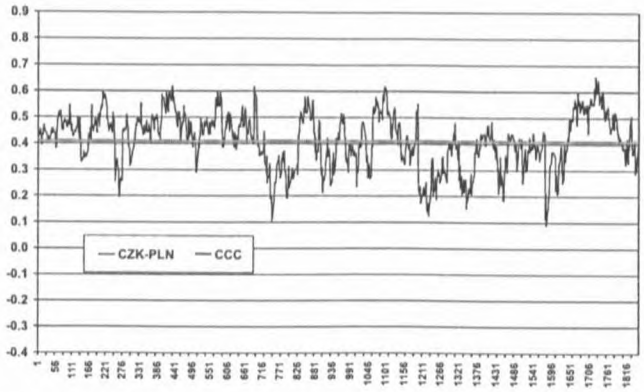


Fig. 14. Conditional dynamic correlations between USD/CZK and USD/PLN with the level of constant conditional correlation (CCC)

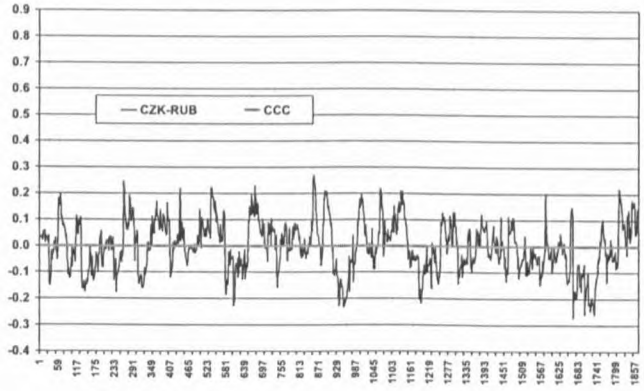


Fig. 15. Conditional dynamic correlations between USD/CZK and USD/RUB with the level of constant conditional correlation (CCC)

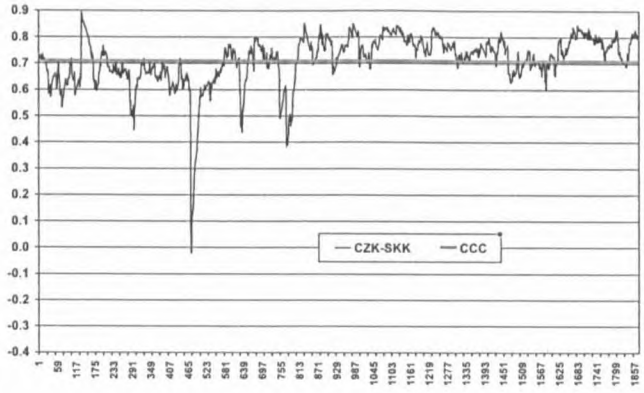


Fig. 16. Conditional dynamic correlations between USD/CZK and USD/SKK with the level of constant conditional correlation (CCC)

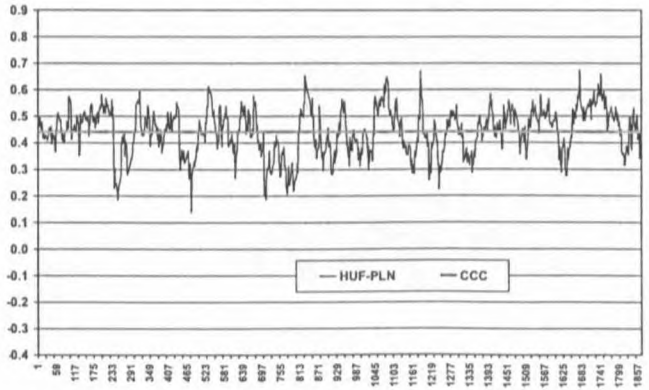


Fig. 17. Conditional dynamic correlations between USD/HUF and USD/PLN with the level of constant conditional correlation (CCC)

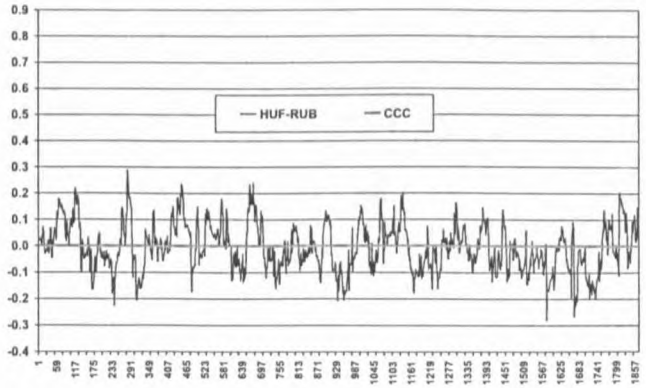


Fig. 18. Conditional dynamic correlations between USD/HUF and USD/RUB with the level of constant conditional correlation (CCC)

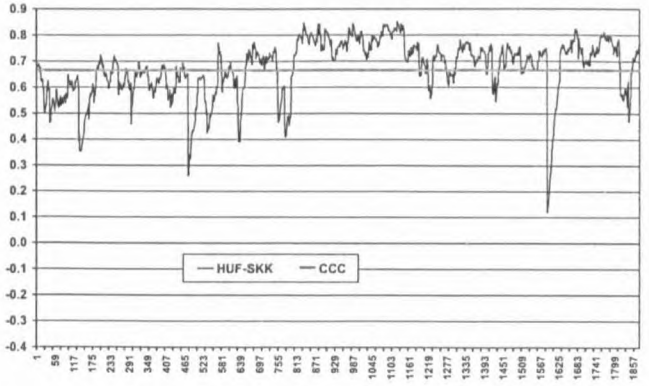


Fig. 19. Conditional dynamic correlations between USD/HUF and USD/SKK with the level of constant conditional correlation (CCC)

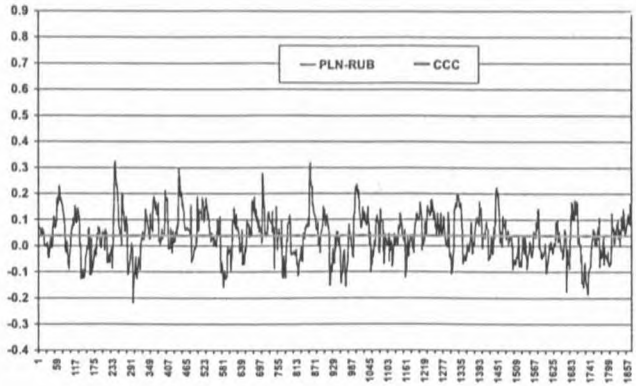


Fig. 20. Conditional dynamic correlations between USD/PLN and USD/RUB with the level of constant conditional correlation (CCC)

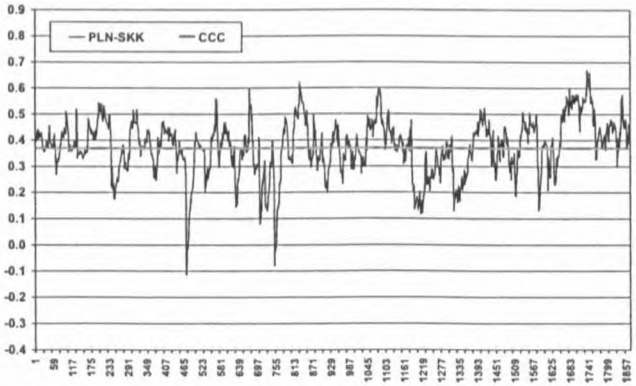


Fig. 21. Conditional dynamic correlations between USD/PLN and USD/SKK with the level of constant conditional correlation (CCC)

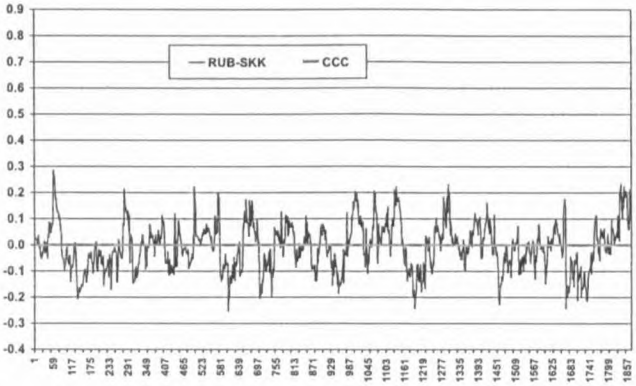


Fig. 22. Conditional dynamic correlations between USD/SKK and USD/RUB with the level of constant conditional correlation (CCC)

Table 9 describes the changes of dynamic conditional correlations between the exchange rates against the USD. The shadowed rows present pairs of exchange rates for which the correlation level mostly increase during the crises period. Here we have six pairs of currencies presenting such behavior: CZK-PLN, CZK-RUB, HUF-PLN, HUF-RUB, PLN-RUB and PLN-SKK.

Table 9. Exchange rates against USD

| EUR | Czech | Asia | Rusia | Brazil | Turkey | September 11 | Argentina | Hungary |
|---|---|---|---|---|---|---|---|---|
| CZK-HUF | ↓ | ↑ | ↓ | ↓ | ↓ | ↓ | ↓ | ↑ |
| CZK-PLN | ↑ | ↑ | ↑ | ↑ | ↑ | ↓ | ↓ | ↑ |
| CZK-RUB | ↑ | ↑ | ↑ | ↑ | ↑ | ↔ | ↔ | ↓ |
| CZK-SKK | ↑ | ↔ | ↓ | ↓ | ↓ | ↑ | ↓ | ↑ |
| HUF-PLN | ↔ | ↑ | ↑ | ↑ | ↑ | ↓ | ↓ | ↑ |
| HUF-RUB | ↑ | ↑ | ↑ | ↓ | ↑ | ↓ | ↑ | ↓ |
| HUF-SKK | ↓ | ↔ | ↓ | ↓ | ↑ | ↓ | ↓ | ↑ |
| PLN-RUB | ↔ | ↑ | ↑ | ↔ | ↑ | ↔ | ↑ | ↑ |
| PLN-SKK | ↔ | ↑ | ↔ | ↑ | ↑ | ↓ | ↓ | ↑ |
| RUB-SKK | ↓ | ↑ | ↔ | ↑ | ↑ | ↓ | ↑ | ↓ |

Note: Behavior of dynamic correlations during period of crises presented in Table 2: ↑ – significant increase; ↔ – increase, but not very high; ↓ – no increase or even decrease in dynamic conditional correlation level

The analysis of dynamic conditional correlations leads us to a conclusion that CZK, HUF, PLN and SKK co-move much more against USD than against the euro. According to Eun and Lai (2004), it reflects the fact that all above mentioned currencies are strongly connected with euro, which is the dominating currency in the considered region. One can suppose that the correlation level will even decrease after joining the EU by Czech Republic, Hungary, Poland and Slovakia. The sign of dynamic correlation between exchange rates of Central European countries and Russia changes over time. In such situation the limitation of analysis to constant conditional correlation would result in conclusion of no interdependence.

The fact that the degree of co-movement of exchange rates depends on the choice of the reference currency makes investigation of contagion effect very sophisticated. It is not our goal to study this problem in general in this paper. Actually, we only point the situations when there is no contagion because the correlation level during crisis does not increase. Our results

allow us to claim that there is no contagion in the case of pairs: HUF-CZK and RUB-CZK. We can observe an increase in positive correlation of exchange rates against USD and EUR between the Polish zloty and the Hugarian forint as well as between the Polish zloty and the Slovak koruna and the Polish zloty and the Czech koruna. Thus there is a possibility that contagion effect can exist in the case of these pairs of currency markets. In the case of the remaining pairs the dependencies are not so clear. During some crises the dynamic conditional correlation level increases while during the other it decreases.

## 6. CONCLUSIONS

The mechanism of currency co-movement is essential for diversifiability of currency exchange risk, which occurs during cross-border investments and trade, and so it is a subject of special interests of financial researchers and practitioners. The cross-market linkages can be measured by a number of different statistics such as the correlation in asset returns, the transmission of shocks or volatility, or the probability of a speculative attack. In this paper we describe the co-movement of Central European and Russian financial markets by directly modeling dynamic conditional correlations between the returns of exchange rates. The main problem occurring during the analysis of currency market linkages is that the co-movement of currencies is always against a third currency. The choice of this third currency essentially influenced the results of investigation. Our results show the significant differences in behavior of analyzed exchange rates against the US dollar and against the euro. CZK, HUF PLN and SKK co-move much more against the USD than against the euro. This phenomenon is a result of the dominating position of euro in considered region. The financial markets of Czech Republic, Hungary, Poland and Slovakia show the high degree of inter-dependence. The Russian currency does not indicate any permanent linkages with the other currencies under scrutiny.

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## WSPÓŁZALEŻNOŚCI MIĘDZY STOPAMI ZWROTU KURSÓW WALUTOWYCH W KRAJACH EUROPY CENTRALNEJ

(Streszczenie)

Analiza korelacji warunkowych między zwrotami kursów walutowych daje nam istotną informację na temat współzależności pomiędzy rynkami walutowymi. W niniejszym artykule opisujemy ten rodzaj zależności w przypadku rynków walutowych w krajach Europy Centralnej, posługując się modelem dynamicznych korelacji warunkowych (DCC), wprowadzonym przez Engle'a. Badamy zmiany w poziomie korelacji warunkowych między kursami analizowanych walut względem euro i dolara amerykańskiego, w okresach stabilności rynków i w okresach kryzysów. Uzyskane wyniki wskazują, że analizowane kursy walutowe podążają za odpowiadającymi kursami euro. Otrzymujemy również pewne wyniki dotyczące efektu zarażania pomiędzy rozważanymi rynkami.