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# Volatility Spillover Effect in the Context of European Union Enlargement

## Case Study of Equity and FX Market in Czech Republic, Hungary and Poland

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Abstract

In this paper the spillover process between developed and emerging economies in the European Union (EU), as well between emerging markets only, is analysed with focus on volatility spillover effect. Equity and foreign exchange markets are considered. Among emerging economies three most developed Central and Eastern European Countries (CEEC) are investigated: Czech Republic, Hungary and Poland. After application of two models based on AR(1)-GARCH(1,1) process, generally the evidence for still limited level of the integration between "new" and "old" European Union countries is found before and after May 1st, 2004. The same tendency is apparent in the relations only between CEECs, however with visible interdependence of Hungarian and Polish markets. Short complementary analysis in form of regime switching process estimation partly confirms above-mentioned findings.

Keywords: volatility spillover, GARCH, CEEC, EU, regime switching

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# 1. Introduction

*This part introduces the basic objectives of the paper and presents the reasons for the importance of understanding the volatility processes. Also the short summary of the main findings of the study is presented as well as the description of the outline of the paper.*

The importance of volatility modelling gains increasing attention in recent times. There are several reasons why understanding of volatility spillover is important. First, as Balasubramanyan (2004) writes, the motivation underlying studies on volatility spillover is to understand how joint movements in volatility influence the distribution of portfolio returns as this gives implications for portfolio selection, derivative pricing and daily risk management. Also Bala and Premaratne (2004) emphasize the importance of understanding the volatility processes as it is important for determining the cost of capital and for assessing investment and leverage decisions. Those are motivations recognizable mainly on the enterprise or individual investor level. Second, the awareness of the volatility spillover occurrence is immensely important from the policymakers point of view and their efforts to maintain financial stability of markets and conduct effective policy. Also Ng (2000) as well as Baele (2003) mention, as the main motivation for understanding the volatility processes, the necessity of acquiring that knowledge in order to optimally allocate the assets, construct the international hedging strategies or develop and evaluate regulatory proposals like capital controls or capital requirements. The second argument seems to be notably important from the emerging markets' perspective, as remaining stable is especially important in the developing economy. As in this study CEECs will act as developing countries and their interactions with developed countries of European Union will be considered, it is vital to mention that in the aspect of necessity of further development and more advanced processes of integration, stabilisation is one of the prerequisites for the accession to ERM II and, in result, implementation of euro.

The characteristics of the volatility of financial series in emerging markets are significantly different than those of developed economies – this fact can imply that the level of interdependence of two kinds of markets may be low. In this paper the spillover process between developed and emerging economies in the European Union, as well between emerging markets only, is analysed with focus on *volatility* spillover effect. Three most developed CEECs are investigated: Czech Republic, Hungary and Poland and equity as well as foreign exchange markets are considered. The basic objective of the study is to show the level of the progress in the economic integration in the mentioned above area.

Methodologically, the thesis is based on the papers of Christiansen (2003), Baele (2003) and Ng (2000) among others, who develop in their works the model implemented in the study. Complementary analysis in the form of regime switching process is conducted.

The main advantage of the paper and the novelty in the literature is the research in the area of the relation between new accession countries and hitherto existing members before and after day of European Union enlargement on May 1st 2004. The study examines if the accession changed the level of the financial integration between the members of those two groups of European Union countries.

After application of AR(1)-GARCH(1,1) models, generally the evidence for the still limited level of the integration between "new" and "old" European Union countries is found. The similar results are provided by estimation of simple regime switching process. Moreover, the integration measured by the volatility spillover effect does not seem to be more significant also between countries that joined the European Union as of May 1st, 2004, however there are stronger relations between Hungary and Poland than between each of those countries with Czech Republic. As very limited evidence had been found for growth of level of integration even after May 1st, 2004, it can be believed that not the accession to the European Union influence the strength of the process of the integration of financial markets and economies in general, but only accession to the monetary union. This can be confirmed by the fact that Hungary, that seems to be integrated on the highest level with "old" European Union countries, probably will be the first country accessing ERM II and, after, EMU. Among remaining two countries the sequence is as follows: Poland and as the last – Czech Republic.

The paper is organised as follows: in the next section the review of the literature is presented emphasising the emerging economies studies. In section 3 main concepts and some theoretical framework are sketched. In section 4 the econometrical model applied in the thesis and estimation methods are presented. Section 5 provides description of the data and section 6 - results of the study. Section 7 concludes and presents in addition the further research proposition in the investigated area.

## 2. Review of the literature

*In this part the review of the literature is presented. Focus is placed also on the main characteristics of the volatility in the emerging markets introduced in the literature up to date. The conclusion is drawn and further steps of the study presented.*

### 2.1 General overview

Although many authors analyse the spillover effect, the studies mainly are related to the equity or bond markets and restricted to the processes in the framework of the one kind of assets. Already Hilliard (1979) analysed the correlations between world stock industrial indices and, testing the daily data of ten world exchanges, he found the evidence for very close intra-continental relationship among market indices. Inter-continental relationships, however, were not found.[1] Barclay, Litzenberger and Warner (1990) studied stock return volatility and volume of assets traded both on New York and Tokyo Stock Exchange. Here, authors found strong interdependence in the form of correlation across return.

Among studies including, alongside the analysis of the conditional first moment, also the investigation of the conditional volatility, it is worth to mention the early study of Hamao, Masulis and Ng (1990), who analysed two first moments spillover effects between US, UK and Japanese stock return markets using GARCH(1,1)-M model. They reported highly significant spillover effects from US and UK markets to Japanese market. In more recent studies Christiansen (2003) investigates the European bond market from two dimensions: using the constant spillover effect model and changing spillover effect model that takes into consideration periods before and after introduction of euro. She considers both mean as well as volatility spillover effect and finds evidence for strong dependence of EMU countries on the European bond market influences after introduction of euro and higher dependence on US market in the case of non-EMU European countries. Baele (2003) extends the models by inclusion of the regime switching studies in the framework of the research of European equity market finding evidence for increasing European volatility spillover effect.

### 2.2 Volatility in the emerging markets

What is very important in the background of this thesis, is that the features of financial assets from emerging markets are different than those of assets from developed economies. Already Bekaert and Harvey (1997) mentions at least four unique characteristics of emerging market

[1] It is significant to mention that the decisive influence for the results may have the period of the studied data that represents a unfavourable time in the economy characterised by major recession and OPEC embargo. It is well known that the cross-country spillover effect can be stronger during the crisis time. Also the presented situation can be termed as contagion according to the very restrictive definition given by the World Bank http://www1.worldbank.org/economicpolicy/managing%20volatility/contagion/definitions.html(20-05-2005);

equity returns through pointing out low correlation with returns of developed markets, definitely higher unconditional volatility, higher average returns as well as more predictable returns. This fact is immensely important as shall differentiate the findings of the studies or publications of developed markets from those of emerging economies.

Morck, Yeung and Yu (2000) emphasize also very important characteristic of emerging markets financial returns, writing that generally the stock prices in the developed markets move in unsynchronised manner in contrast to the stock prices in the emerging markets that exhibit usually movement in the same direction. This aspect is very important in the analysis and helps to ask the question if indeed the spillover effect between emerging economies is more pronounced or if indeed the regional spillover effects are those with biggest intensity in the investigated area.

However, there exist only few papers related to the issues of emerging markets, especially those of CEECs. One of the papers investigating the transition economies stock markets, is publication by Rockinger and Urga (2001), where authors examine the potential increase of efficiency and integration with already developed markets.[2] They find that in Czech Republic and Poland there are no improvements in the efficiency on the contrary to Hungary that reached efficiency in the middle of 90's as well as Russia that, in the period of research, has shown signs of convergence on the way to efficiency in progress.[3]

The issue of efficiency is essential in finance in general. Flores and Szafarz (1997) write, that the examination of efficiency may partly at least explain the distortions and asymmetries in the returns. It is presumed, also in this thesis, that existence of such distortions and asymmetries serves as the proof for not adequate integration – in our case with developed markets. Authors investigate Polish equity market and conclude that the realised profits are here mainly speculative what partly has its source in lack of influence of fundamentals on that market.[4] Especially significant fact in the study is that the exchange rate did not influence the price of any studied shares. That fact can be of high significance in this thesis however it should be bear in mind that the examined exchange rate in our case is in relation to euro, instead of to the US dollar.

Murinde and Poshakwale (2001) reject typical characteristics for the developed stock markets, like day-of-the-week-effect with the emphasis on Monday and Friday, in the case of examined Poland and Hungary. However, they find the confirmation for higher integration between those markets and developed economies in the 90's, what is signalised by the marked decline in the conditional volatility in the Polish market after June 1995. The similar tendency, although not that consistent,

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[2] Aauthors apply the model to the Czech, Polish, Hungarian and Russian stock markets;

[3] That can seem a little bit surprising taking into consideration for instance fact that Warsaw Stock Exchange is the biggest among equity markets of new EU accession countries like Czech Republic, Hungary and Poland;

[4] As the paper examines the content of the information set used by the participants of the Warsaw Stock Exchange, it takes into the consideration three factors that could belong to it: exchange rate between PLN and USD, consumers' prices and the refinancing rate of Polish central bank – National Bank of Poland;

is observed on the Hungarian market. That fact contributes to the belief mentioned above that emerging markets experience higher returns' volatility and we can infer that integration with advanced markets decrease that instability.

Also Scheicher (2001) examines regional and global integration of Czech, Hungarian and Polish equity markets. The main conclusion from his study is that innovations to volatility have mainly regional character on the contrary to the return spillover that is of regional as well as global character.

Grambovas (2003) investigates links and interaction between exchange rates volatility and equity prices in emerging financial markets. He notes that the relation is supposed to be especially robust for the entities involved in international trade, where their corporate value is dependent on the behaviours of the exchange rates. Among CEECs, author finds strong relation between FX market and equity market in Hungary. Second investigated market – Czech Republic – does not reveal such a pattern. In that paper the percentage of "internationalisation" in the CEECs' equity indexes should be measured in order to determine the relation. The question should be posted if indeed exchange rate influences the value of the stocks. Also reverse relation may be examined, what will be presented in the further part of the study.

Kasch-Haroutounian and Price (1998), who examine volatility spillover effect on the equity markets in Czech Republic, Hungary and Poland, find return volatility spillovers from Hungary to Poland but not in the opposite direction. Moreover, their study provides evidence for the lack of asymmetries in the three CEEC markets. This characteristic of CEECs' markets distinguishes them from developed economies.

Results of the studies mentioned above frequently confirm the fact about significant differences in characteristics of volatility of emerging financial markets in comparison to the developed ones. It gives the clear picture of not integrated CEECs' markets with developed economies, what for some could seem unlikely after accession of those countries to the European Union. The question remains then if the pre-accession period really did not strengthen the integration between the two groups of countries? And if maybe just after accession period the new accession countries started to strengthen their relation with the old European Union members? That potential feature is checked by estimating the model with dummy variables, sharing the whole period of estimation on two periods – before and after accession of new countries to the European Union.

## 3. Conceptual and theoretical framework

*This part of the thesis introduces the concept of financial integration in Europe and empirical findings in the subject up to date. Also the aspect of differences between membership in European Union and European Monetary Union is highlighted. In the second part, the theoretical aspect of interdependence between equity and foreign exchange market is presented. At the end, the aspect of accession to the European Union is introduced and its inclusion in the empirical part.*

### 3.1 Financial market integration in Europe

Already Bekaert and Harvey (1997) stated that the increasing impact of world factors on volatility was consistent with greater market integration. The same approach is presented in the thesis. The special attention is paid to the equity and foreign exchange market, because of the fact that the evidence shows they are far less integrated comparing to the bond market.[5]

On the other hand side, Artis et.al (1999) and Peersman and Smets (2001) confirm the hypothesis that the economic cycles of the various European countries have become more and more synchronized and the main areas of the integration is monetary and financial, what in the light of this paper has special denotation: the further integration of new European Union countries, that leads to the implementation of euro.[6] Also the aspect of the changing level of integration between new EU members remains important. An important problem of this approach is that significant events may have been long anticipated, or may not be credible, or may just need time to become effective. Bekaert et al. (2002b) for instance look for a common, endogenous break in a large number of financial and macroeconomic time series to determine the moment when an equity market becomes most likely integrated with world capital markets. They find that the "true" integration dates occur usually later than official liberalization dates.

As writes Baele (2003), the previous studies have proved strong positive link between sensitivity of local returns to the common shocks and degree of economic and financial integration.[7] According to that fact, it is given in the literature that there is growing evidence that real convergence in Europe has not only been a pre-condition for successful monetary union, but that monetary union itself has strengthened real integration among its members. However, the question still remains what kind of integration was achieved and if the financial one was that, which increased significantly.[8] In the light of this paper, the issue that remains very important is if not only monetary union influenced the integration, but also if plans to implement euro or just

[5] Ibidem, p. 7;
[6] Baele, L., (2003), p. 3;
[7] Baele, L., (2003), p. 3;
[8] Fratzscher, M., (2001), p. 7;

accession to the European Union affect the integration of the financial markets and the volatility spillover effect.

In the light of the above-presented opinions that generally CEECs' financial markets react mainly to the own-country shocks, it could be expected, that the volatility spillover effect between "old" and "new" European Union countries would be influenced by not simply accession to the European Union but joining EMU. It can be hypothesized then, that the higher level of integration between two described groups of the countries will be noticeable just in the short period before accession to EMU or just after that act. It could indicate that the most integrated with "old" European Union is this of three CEECs, which in highest degree fulfil the EMU entry requirements.

Christiansen (2003), for instance, proves that the proportion of the variance of the unexpected return caused by European effect for individual economies differs between EMU countries and non-EMU countries (like Sweden and UK) from the group of old European Union members. Generally, for the EMU countries above-mentioned proportion caused by European effect is large, while for non-EMU countries – relatively small. Moreover, the own-country effects are significantly smaller for the EMU countries than for non-EMU countries. [9]

As the new accession countries are expected to join the monetary union in the due time it is quite important to determine how far their markets are integrated with that of euro area. It is believed that if the shock in the euro area is fast reflected in the accession country (so the correlation between markets is high), it indicates small probability that this country would bear high costs when adopting the euro, in other words – the joining the monetary union is advised. Before entry of the new members, Korhonen (2001) looked at the correlation at short-term business cycle (industrial production as the indicator of economic activity) in the euro area and the accession countries using the VAR methodology. He found the significant differences in the degree of correlation and concluded that the lack or small level of convergence of business cycles would entail large costs when joining the monetary union. Moreover, he found that generally relative influence of the euro area business cycle is larger for smaller countries. Although majority of former first group accession countries (Czech Republic, Estonia, Hungary, Poland and Slovenia) seem to be better integrated, the level of integration is still quite low.[10] The author, however, emphasized that the high level of integration is not necessary to enter into the monetary union as he found that Greece and Portugal are integrated with euro area business cycle on the similar level as most of accession countries.[11]. Kocenda (1999), who examined wider range of indicators,

[9] For more detailed research see Christiansen, C., (2003);
[10] Korhonen, I., (2001), p. 1 ;
[11] Ibidem, p. 2 ;

concluded that generally the accession countries did not converge that much with each other. Some authors like Boone and Maurel (1998, 1999) and Fidrmuc (2000), who examined business cycles, found that the strongest convergence link in the case of accession countries was established with Germany, even when the correlations with whole European Union were not high. Brada and Kutan (2001), who analysed movements in the monetary base, found however that the convergence of monetary policy is strong only between Malta and Cyprus in the relation to Germany, while that one of CEECs is of minor range.

Concluding the introduction to the conceptual framework of the thesis it can be said that, bearing in mind necessity of financial integration and being aware of not perfect assimilation of CEECs with European Union (EMU) countries, the analysis will be made in order to determine the level of integration up to date.

### 3.2 Relations between equity and foreign exchange market

As in the paper the relationships between two kinds of markets – equity and foreign exchange – are considered, this is vital to present the theoretical links between stock returns and exchange rate changes in international markets and explain the main processes that can take place in adjustments between those two. The expected direction of the influence between the markets will act as the basis for the building the economically justified econometric model estimated in the further part of the thesis. It is essential to mention important fact that in the study are considered two groups of markets of different power of influence. It is obvious that developed country (group of countries as in this case "old" European Union countries) may be more influential than developing one. As write, for instance, Francis, Hasan, and Hunter (2002), the issue of the influence between two markets – equity and foreign exchange - may be bi-directional. Authors in their article investigate the impact of the exchange rate changes on the conditional moments of equity returns, where the currency risk is one of the main pricing factors as suggested by international asset pricing models.[12] Also the inverse relationship is examined, however the impact of equity market volatility on the exchange rate changes usually seemed to be not clear. Generally, exchange rate theories do not include the equity markets as the influential ones. Nevertheless, most recent studies incorporate into the exchange rate theory the influential microstructural factor such as order flow – international equity market order flow influences the

[12] Quite often the results of empirical tests either fail to find the evidence that supports the exchange rate risk as the pricing factor on the equity market or find the confirmation that the risk existence helps to explain changes in the first moment of the equity returns. For detailed discussion and references see Francis, Hasan and Hunter, (2002), p.7;

currency order flow.[13] This fact can be significant as the fundamental theories usually fail to explain exchange rate movements. However, even though presented relations are probably the most important ones in determining the connections between two kinds of markets, it must not be forgotten that the higher volatility spillover effect can be caused also by sudden critical events on the financial markets. That effect is known in the literature as a *contagion*. In the case of this study also of some importance may be checking the hypothesis stating that during the period of higher exchange rate volatility the correlation between related two equity markets increases.

In the model presented in the study, simultaneously with the examination of the spillover effect between equity markets, the relationship between foreign exchange and equity markets is investigated. As suggested above, the bi-directional relationship is checked. However, in the sub-model investigating relationship between "old" and "new" European countries influence only from developed markets to the CEECs' markets is examined (the influence of euro volatility on the CEEC's equity market and the influence of the European equity index on the CEECs' currencies). In the sub-model that takes into consideration relations between CEEC's countries, the bi-directional link is studied together with both countries examined as influential economies as well as dependent ones.

### 3.3 Accession to the European Union

In the main hypothesis of the paper it could be stated that the accession of new ten countries to the European Union on May 1st 2004 increased their integration with the European markets and between themselves, what is implied by that fact, the volatility spillover effect would be more strong and significant. Moreover, the financial integration between markets of new European countries is supposed to be higher. The dummy variable spillover model is supposed to examine the likely changes in the reaction of the CEEC markets on the above-mentioned event.

The main reason for studying markets of Czech Republic, Poland and Hungary is the fact that those countries are the most advanced transition economies and all have, at least in part, common history. At the same time the differences in their international relations structure as well as economic policy allow to expect the diversified results in the investigation of the volatility spillover effect.

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[13] For the detailed discussion see Evans, M., D., D., Lyons, R., K., (2001), "Order Flow and Exchange Rates Dynamics", Journal of Political Economy and Francis, B., B., Hasan, I., Hunter, D., M., "Dynamic Relations Between International Equity and Currency Markets: The Role of Currency Order Flow";

# 4. Econometric Models and Methodology

*In this part of the study the discussion of available estimation methods and advantages of chosen one is presented. The model's formulas are given in detail as well as estimation methods are described together with justification why they are warranted. The discussion about imposed assumptions is included.*

## 4.1 Theoretical models

### 4.1.1 Univariate GARCH models

In the literature it is often emphasised that log-first differentiated financial time series have number of characteristics in common. There are at least three stylised facts that should be mentioned. The first one is non-normality of the unconditional distribution known as leptokurtosis or *fat tails*. Leptokurtic distribution has a kurtosis value greater than 3 that it is of normal distribution, which gives the distribution a high peak, a thin midrange, and fat (heavy) tails. This implies that there in financial time series is a higher probability for extreme events than in data that is normally distributed.[14] The second stylised fact is that volatility of the returns is time-varying. According to Schiecher (2001), there is a close relation between those two statistical properties, because a series with a time-dependent dispersion generates a non-normal unconditional distribution with fat tails.[15] The third stylized fact is known as *volatility clustering* that is represented by strong autocorrelation effect in residuals (squared residuals) – the current level of the volatility is positively correlated with its level during the preceding period. The one method to use in order to properly manage data characterised by those features are (Generalized) Autoregressive Conditional Heteroskedastic models that treat heteroskedasticity as a variance to be modelled.[16] Kasch-Hatouronian and Price (1998), among others, state that this class of models had proven to be particularly suited for modelling the behaviour of financial data series.[17]

*a. Symmetric models*

Construction of the GARCH model introduced by Bollerselev (1986) is based on its precedent – ARCH model developed earlier but independently by Engle (1982) – with addition of previous own lags to the equation of the conditional variance. The equations for the ARCH(p) model for AR process are defined as:

$$y_t = c_0 + c_1 y_{t-1} + \varepsilon_t$$

[14] Karlsson, L., (2002), p. 9;
[15] Schiecher, M., (2001), p. 30;
[16] Engle, R., (2001), p. 157;
[17] Kasch-Hatouronian, M., Price, S., (1998), p. 5;

where: $\varepsilon_t \sim N(0,\ \sigma_t^2)$ and

$$\sigma_t^2 = \omega + a_1\varepsilon_{t-1}^2 + a_2\varepsilon_{t-2}^2 + \ldots + a_p\varepsilon_{t-p}^2$$

$$\omega \geq 0;\ a_i \geq 0 \forall i = 0,1,2,\ldots,p;\ \sum_{i=1}^{p} a_i < 1$$

The constraint of positive parameter alpha provides positive variance, while sum of parameters smaller than one – stationary variance process.

The GARCH (p,q) process uses the following equation for the conditional variance:

$$\sigma_t^2 = \omega + a_1\varepsilon_{t-1}^2 + a_2\varepsilon_{t-2}^2 + \ldots + a_p\varepsilon_{t-p}^2 + \beta_1\sigma_{t-1}^2 + \beta_2\sigma_{t-2}^2 + \ldots + \beta_q\sigma_{t-q}^2$$

$$\omega \geq 0;\ a_i \geq 0 \forall i = 0,1,2,\ldots,p;\ \beta_j \geq 0 \forall j = 0,1,2,\ldots,q;\ \sum_{i=1}^{p} a_i + \sum_{j=1}^{q} \beta_j < 1$$

There are general constraints for alpha and beta parameters avoiding negative variance and sum of parameters smaller than one for stationary variance process. The alpha and beta parameters in the model are interpreted without difficulty, with the estimation of alpha showing the impact of current news on the conditional variance and the estimate of beta demonstrating the persistence of the volatility.[18] The case when the sum of alpha and beta coefficients equals one is referred to as Integrated GARCH (IGARCH) model, where the shocks have a persistent effect. The discussion about the negative coefficients is given in short in the further part of the GARCH models' description.

Among symmetric GARCH models there are few alternative specifications to the standard GARCH model, among them NGARCH (non-linear GARCH) that implies reduced response to extreme news, or GARCH-M (GARCH-in-mean), where the conditional variance enters the mean equation and allows the mean equation to be above/below its long run mean when volatility is high/low. GARCH-M model is often used on the financial markets when higher volatility should give higher return. As those models are not used in the paper, their existence is only briefly mentioned here.

*b. Asymmetric models*

In the symmetric model the conditional variance is a function of the size and not of the sign of lagged residuals. However, it has been suggested in the literature that the negative and positive shock to the financial time series influences the volatility in different way. The negative shocks

[18] Ibidem, p. 6; beta coefficient can also be interpreted as impact of "old" news on the conditional volatility;

are likely to cause higher volatility than positive shocks of the same magnitude.[19] This phenomenon is often termed as *leverage effect*.

There are several specifications of GARCH model that accommodate for the asymmetry. Among them the worth to be mentioned is EGARCH (Exponential GARCH) proposed by Nelson (1991) that include the exponential "leverage effect" and where conditional variance is always positive,[20] GJR model (known also as Threshold GARCH) by Glosten, Jagannathan and Runkle (1993) and Absolute Value GARCH by Nelson and Foster (1994). In the paper only GJR model is used as the complementary analysis checking for asymmetries in the estimated spillover models. GJR is the extension of simple GARCH model to allow for asymmetric effects by including an indicative dummy $S$.

The conditional variance of this model is:

$$\sigma_t^2 = \omega + \sum_{i=1}^{p}(a_i \varepsilon_{t-i}^2 + \delta_i S_{t-i}^- \varepsilon_{t-i}^2) + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2$$

$$\omega \geq 0;\ \ a_i + \delta_i \geq 0 \forall i = 0,1,2,..., p;\ \ \beta_j \geq 0 \forall j = 0,1,2,..., q;\ \ \sum_{i=1}^{p} a_i (1+\delta_i) + \sum_{j=1}^{q} \beta_j < 1$$

where $S$ is equal one when there is negative shock and zero when the shock is positive. For the leverage effect coefficient $\delta$ is higher than zero and different than zero when the news impact is asymmetric. The interpretation of given constraints is similar to those given for two first models.

*c. Non-negativity assumptions in GARCH process*

The non-negativity assumptions stated above for the GARCH models are very important in the estimation process. It is quite uncommon to obtain a negative intercept omega in the GARCH equations, whereas it happens frequently for the alpha and beta parameters. As long as conditional variance is positive for all $t$ this is not a problem in itself, but the interpretations of the parameters are not reassuring in this case. Hence, negative coefficients are generally viewed as misspecification problems in the model (except for the EGARCH model that does not require any constraint on the model parameter to insure positive variance). When it comes to sum of alpha and beta higher than one this is also regarded as a misspecification problem and explosive volatility is not a convincing argument. There can be two procedures suggested in this case. First one is removal of main outliers that may interfere in the estimation process or application of the model for the series being a mixture of the several distributions (regime switching models).

[19] Brooks, Ch., (2002), p. 469;

[20] Always positive conditional variance and exponential leverage effect are guaranteed by the fact that the left hand side of the conditional variance equation is log of it;

Second procedure may be trying out an alternative distribution with fatter tail (more kurtosis) such as the Student t distribution when residuals are not distributed according to $\sim N(0, cond.variance)$.[21]

4.1.2 Complementary analysis – regime switching process

In order to see if the GARCH process estimations can be reliable, the complementary analysis is conducted in form of elements of regime switching process.[22] The aim is to see the patterns in the probability of high volatility regime for the markets and if they coincide between investigated economies. This part of the thesis is additional one and is presented in short, however some introduction is necessary. It is important to bear in mind that this part acts exclusively as complementary one and will not be developed in detail in this paper, however may be good material for further research.

The regime switching models have been developed in the response of shortages of GARCH models such as, among others, not fully covered leptokurtosis. Generally, the assumption in regime switching process is that the rapid changes in a variable can be result from switching from one distribution to another.[23] The distribution, from which the sample observation is drawn, is indicated by unobservable variable $S_t$ that in our case takes values 1 and 2. At the beginning, it is necessary to identify the probability that sample observation comes from first or second distribution. That probability is defined as:

$$\Pr\{S_t = i | y_t; \theta\} = \frac{\pi_i * f(y_t | S_t = i; \theta)}{f(y_t; \theta)}$$

where vector $\theta$ collects characteristics of two distributions

$$\theta \equiv (\mu_i, \mu_j, \delta_i^2, \delta_j^2, \pi_i, \pi_j);$$

In the above-given formula $\mu_i$ is the mean of normal distribution with the variance $\delta^2_i$.. The symbol $\pi_i$ indicates the unconditional probability of being in state $i$ and $f(y)$ is probability distribution function.

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21 This information has been received after consultation with Ulf Erlandsson, PhD, in the course of the lectures in "Time Series Analysis" at the Department of Economics;

22 There are many other models that could act as complementary analysis to the main model. Initially the multivariate GARCH (diagonal BEKK) was supposed to be calculated, however in few cases it did not converge;

23 The introduction of regime switching models presented in this part is based on Erlandsson, U., (2000);

Joint probability distribution function, included in the formula above, is initially defined as:

$$f(y_t;\theta) = \pi_i\left[\frac{1}{\sqrt{2\pi\sigma_i^2}} * \exp\left(\frac{-(y_t-\mu_i)^2}{2\sigma_i^2}\right)\right] + \pi_j\left[\frac{1}{\sqrt{2\pi\sigma_j^2}} * \exp\left(\frac{-(y_t-\mu_j)^2}{2\sigma_j^2}\right)\right]$$

$$\pi_j = \pi_i - 1$$

The useful tool, that describes the dynamics of *St* and how the current regime is chosen, is first order Markov chain. It is assumed here that current state is dependent only on the previous one, what indicates no path-dependence:

$$P\{S_t = i | S_{t-1} = j\} = p_{ij}$$

It is given that the probability of switching between two states in the next period is transition probability $p_{ij}$. All transition probabilities for two states, as in case presented in the thesis, are included in transition probability matrix P:

$$P = \begin{bmatrix} p_{11} & p_{21} \\ p_{12} & p_{22} \end{bmatrix} = \begin{bmatrix} p_{11} & 1-p_{22} \\ 1-p_{11} & p_{22} \end{bmatrix}$$

Transitions probabilities are assumed to be constant and $p_{11}$ and $p_{22}$ are "stay" probabilities that indicate no change in the regime.

This structure suggests the estimation method for regime switching process with different means and different variances that allows to receive "new" probabilities that describe how to determine if sample observation comes from first or second distribution. Simply, now it is possible to define the probabilities of given regime depending on the regime from period before (using Markov chain rule) and after use them for calculating "new" probabilities describing the regime from which comes the sample observation. Probabilities of given regime, depending on the regime from the period before, are defined below:

$$\Pr\{S_t = 1 | S_{t-1}\} = \Pr\{S_t = 1 | y_{t-1}\} * p_{11} + \Pr\{S_t = 2 | y_{t-1}\} * p_{12} \Rightarrow a^1_{t|t-1}$$

$$\Pr\{S_t = 2 | S_{t-1}\} = \Pr\{S_t = 2 | y_{t-1}\} * p_{22} + \Pr\{S_t = 1 | y_{t-1}\} * p_{21} \Rightarrow a^2_{t|t-1}$$

Probabilities describing the regime from which comes the sample observation, that are used in analysis applied in the paper, are specified as:

$$\Pr\{S_t = 1 | y_t;\theta\} = \frac{a^1_{t|t-1} * f(y_t | S_t = 1;\theta)}{a^1_{t|t-1} * f(y_t | S_t = 1;\theta) + a^2_{t|t-1} * f(y_t | S_t = 2;\theta)}$$

$$\Pr\{S_t = 2 | y_t;\theta\} = \frac{a^2_{t|t-1} * f(y_t | S_t = 2;\theta)}{a^1_{t|t-1} * f(y_t | S_t = 1;\theta) + a^2_{t|t-1} * f(y_t | S_t = 2;\theta)}$$

where $a^1_{t|t-1} * f(y_t | S_t = 1;\theta) + a^2_{t|t-1} * f(y_t | S_t = 2;\theta) \Rightarrow B_t$

The components of probability distribution function have been already presented above.[24]

### 4.2 Procedures

The parameters in all GARCH estimations are calculated by Quasi-Maximum Likelihood (QML) procedure (that corrects the standard errors on parameters) as proposed by Bollerselev and Wooldridge (1992), as it is suspected that the residuals are highly leptokurtic and conditionally not normally distributed. The regime switching process estimation uses Maximum Likelihood (ML). As ML/QML formulas in this case are rather standard ones, they are not presented in detail here. The advantage of Maximum Likelihood (ML) estimation procedure versus commonly used Ordinary Least Squares (OLS) lies in being able to estimate many non-linear models, to model different underlying distributions generating the errors and being consistent even under misspecification of the distribution. ML estimation allows to compute the variance-covariance matrix of parameters easily, which is not the case for other non-linear estimation method. The drawback of ML against OLS is that it is computationally intensive (i.e. takes longer time), and has worse small sample properties. Moreover, as OLS minimises the residual sum of squares that depends only on the parameters in the conditional mean and not the conditional variance, RSS minimisation is no longer an appropriate objective.

In order to optimise the log likelihood function Berndt, Hall, Hall and Hausman (1974) optimisation algorithm is used and the estimation is run few times with different starting values in order to avoid local maximum. Different starting values, however, do not influence the results of estimations.[25]

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[24] As Maximum Likelihood estimator for the model acts sum of logarithm of $B_t$

[25] Different starting values were provided by the econometric software in the case of GARCH process; in regime switching process estimation, they were chosen manually;

### 4.3 Methodology and specification of models

4.3.1 Univariate GARCH models

In the empirical part the spillover effect using AR(1)-GARCH(1,1) model is examined. The focus on GARCH (1,1), without checking in this case neither the information criteria nor the maximum likelihood value for different options of lags of the process for each time series, is justified by the fact that that process is widely used and highly favoured in academic discussions as well as in practice in most cases.[26] As writes Starica (2003), the GARCH (1,1) process in the academic literature seems to be recognized as "a realistic data generating process for financial returns".[27]Usually, as many authors mention, GARCH (1,1) is sufficient to capture the volatility clustering in the data.[28] In the further part of the thesis it is shown that it is not always the case. However, in order to construct one model for so many time series, the GARCH (1,1) seems to be the most appropriate one. The model includes the AR(1) element, that allows to asses if there exists mean spillover effect in the investigated markets.[29] However, the emphasis in the study is placed mainly on the volatility spillover effect.

As mentioned already shortly above, there are two main areas of influence in the study: from "old" European Union countries to the newly accessed and *between* new members – CEECs. In the framework of each part there are three relations to be considered: between equity markets, from equity market to the foreign exchange market and from foreign exchange market to equity market. In the framework of the first area only the influence from EU to the new countries is considered and not reverse as it would not have economic justification - the direction is assumed as based on common sense, it is highly impossible that developing CEE markets influence financial markets of the European Union in significant manner. The influences between CEECs are examined bi-directionally where all countries are examined as influential as well as dependent.

There are two main models of the first part: constant spillover model, where the spillover parameters remain constant for the whole sample period,[30] and dummy variable model where the volatility coefficients differ in two periods: before and after May 1st 2004, when ten new countries accessed European Union. Both examine the relations pointed above.

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[26] Engle, R., Ng, V., K., (1993), p. 1752;

[27] Starica, C., (2003), p. 5;

[28] Brooks, Ch., (2004), p. 455;

[29] Again, neither Schwartz Information Criteria nor Akaike Information Criteria have been checked in order to choose appropriate lag order for the AR specification. Lag order has been chosen for the simplicity;

[30] That terminology was used by Christiansen (2003);

*a. AR(1) – GARCH (1,1) model*

The following two-step model is used[31]:

$$R_{i,t} = \mu_{0,i} + \mu_{1,i} R_{i,t-1} + \varepsilon_{i,t}$$

$$\sigma^2_{i,t} = \omega_i + a_i \varepsilon^2_{i,t-1} + \beta_i \sigma^2_{i,t-1}$$

$$R_{j,t} = \mu_{0,j} + \mu_{1,j} R_{j,t-1} + \gamma_j R_{i,t-1} + \varphi_j \varepsilon_{i,t} + \varepsilon_{j,t}$$

$$\sigma^2_{j,t} = \omega_j + a_j \varepsilon^2_{j,t-1} + \beta_j \sigma^2_{j,t-1}$$

where transcript *i* indicates the market where the spillover effect has its origin and *j* - the influenced country. The idiosyncratic shocks *ε* have mean 0 and conditional variance evolving according to the GARCH(1,1) model. In the first step, the univariate AR(1)-GARCH(1,1) model is calculated for the market where the spillover effect has its origin. In the second step, where the model is estimated for the dependent market, the *i* residual is included in the mean equation, where represents the volatility spillover effect from the influential to the dependent market. That means that one market depends on the idiosyncratic shock of the other. The mean spillover effect from influential to the dependent market is indicated by lagged *i* return.

In order to estimate the proportion of the variance of unexpected return in dependent market that is caused by the influential market volatility spillover effects, the variance ratios of the following formulas are applied:

$$VR^i_{j,t} = \frac{\varphi_j^2 \sigma^2_{i,t}}{h_{j,t}}, \qquad VR^j_{j,t} = \frac{\sigma^2_{j,t}}{h_{j,t}} \Rightarrow 1 - VR^i_{j,t}$$

where *h j, t* is defined as the conditional variance of the unexpected return of dependent market based on the information available at time *t-1*. The formula for the conditional variance is as follows:

$$h_{j,t} = E(e^2_{j,t} \mid I_{t-1}) = \varphi_j^2 \sigma^2_{i,t} + \sigma^2_{j,t}$$

where *e j, t* squared is defined as unexpected return for dependent market:

$$e^2_{j,t} = \varphi_j \varepsilon_{i,t} + \varepsilon_{j,t}$$

[31] Initially, the three-step model was planned to be estimated – from the equity market of one country, through the exchange rate of the currencies, to the equity market of the second country. However, that model did not allow for the estimation of the impact of equity market on FX market that checks for order flow effects on the markets. Moreover, the estimations became less clear than in two step model.

It is visible that conditional variance of unexpected return in dependent market depends on the variance of the contemporary idiosyncratic shocks from influential market as well as from dependent one.

*b. AR(1) – GARCH (1,1) dummy model*

In order to confirm or reject the statement, that the accession of the new countries to the European Union on May 1st, 2004 increases the volatility spillover effect between "new" and "old" countries as well as just between "new" European Union members, the AR(1) – GARCH(1,1) model with dummy variable is estimated. The dummy variable takes value 0 in the period before the European Union enlargement, from February 16th 1995 until April 30th 2004, and value 1 in the period from May 1st 2004 until February 10th 2005. All procedures are like in, presented above, constant spillover model. The formulas applied in AR(1)-GARCH(1) dummy model are presented below.

$$R_{i,t} = \mu_{0,i} + \mu_{1,i}R_{i,t-1} + \varepsilon_{i,t}$$

$$\sigma^2_{i,t} = \omega_i + a_i\varepsilon^2_{i,t-1} + \beta_i\sigma^2_{i,t-1}$$

$$R_{j,t} = \mu_{0,j} + \mu_{1,j}R_{j,t-1} + (\gamma_{0,j} + \gamma_{1,j}D_{t-1})R_{i,t-1} + (\varphi_{0,j} + \varphi_{1,j}D_{t-1})\varepsilon_{i,t} + \varepsilon_{j,t}$$

$$\sigma^2_{j,t} = \omega_j + a_j\varepsilon^2_{j,t-1} + \beta_j\sigma^2_{j,t-1}$$

The dummy model exploring the relation between EU countries and CEECs' financial markets as well as only between CEECs' economies, examines whether there is difference in spillover parameters between two considered periods – before and after accession of the CEECs to the European Union. Considering the fact that the equation for the AR(1)-GARCH(1,1) process for the European equity market is the same as for the previous (non-dummy) model, in that section the second step of estimations is considered. The variance ratio formulas are presented below:

$$VR^i_{j,t} = \frac{(\varphi_{0,j} + \varphi_{1,j}D_{t-1})^2\sigma^2_{i,t}}{h_{j,t}}, \quad VR^j_{j,t} = \frac{\sigma^2_{j,t}}{h_{j,t}} \Rightarrow 1 - VR^i_{j,t}$$

The unexpected return and conditional volatility are defined as follows:

$$e^2_{j,t} = (\varphi_{0,j} + \varphi_{1,j}D_{t-1})\varepsilon_{i,t} + \varepsilon_{j,t}$$

$$h_{j,t} = E(e^2_{j,t} \mid I_{t-1}) = (\varphi_{0,j} + \varphi_{1,j}D_{t-1})^2\sigma^2_{i,t} + \sigma^2_{j,t}$$

*c. Asymmetries*

In order to determine in depth the characteristics of studied markets as well as to check the appropriateness of applied symmetrical GARCH (1,1) model, the tests for asymmetries in volatilities are employed. The common practice in testing for asymmetries in calculated model is examining the cross-correlation of squared standardized residuals at time *t* and lagged standardized residuals. According to Brooks (2002), in order to reject the existence of asymmetry effects, all correlations should be insignificantly different from zero.[32] Significant and negative cross-correlations indicate leverage effect, while significant but positive cross-correlations – asymmetric effect. This method is applied simultaneously with GJR model that has been presented above.[33]

### 4.3.2 Complementary analysis – regime switching process

In the complementary analysis the regime switching process with changing mean and changing variance is estimated for each financial data series. The process is standard and has been presented already above. The detailed programming for EViews has been included in Appendix III.[34]

After calculation of probabilities of high and low volatility regime for each of financial data series, it is checked if the periods with high volatility regime coincide between different markets, what could indicate volatility spillover effect. The dummy variable is defined – it takes value one when the market is in high volatility regime and zero otherwise. The dummy variables between pairs of markets are multiplied and the result that is equal one means that both countries are in high volatility regime at given observation. In order to receive the rate of coinciding volatility regime between markets, all results for given pair of countries are summed up and divided by the number of observations.

[32] Brooks, Ch., (2002), p. 478;

[33] Generally it is known that the developing countries' financial data series do not show that strong asymmetries like those of developed countries. However, in order not to infer wrongly, the checking procedure will be carried;

[34] The programming is slightly modified version of this presented by Ulf Erlandsson, PhD, during course "Time Series Analysis" at the Department of Economics, Lund University;

# 5. Data

*In this section characteristics and description of used data are presented. Statistical tests for financial data series are applied in order to justify the application of chosen econometrical model.*

## 5.1 General overview

Continuously compounded return series for the equity markets are obtained by log-first differentiation of price indices quoted by HSBC for emerging markets of Central and Eastern Europe and FTSEurofirst 100 price index for Euro Zone countries and United Kingdom.[35] Price indices are those where paid dividends are not included. However, as correlation values between some of the price indices and total return indices from the same market show, the difference between those two usually is not that considerable.[36] The indices are quoted in euro, however for the purpose of measuring the influence of European currency on the equity markets of three CEECs – in local currency. The log-first differentiation is also used in order to receive continuously compounded return series for exchange rates of national currencies of emerging economies and euro. The series cover ten-years period – from February 16th, 1995 until February 15th, 2005, what amounts to 2609 observations. All the data comes from EcoWin. Before log-first differentiation, the data has been transformed into weekly frequency by taking the Thursday closing rate in five-day working week. That has reduced the series to 522 observations.[37] According to Scheicher (2001), the daily frequency, that gives larger amount of observations, could provide the interference on the spillover effects by means of tests with more power. However, as it is often emphasized, also the usage of high frequency data can imply that the data are non-synchronous and noisy.[38] The data series applied in the study are presented in the figures below.

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[35] Application of the index that includes U.K. market is important because of high significance of that economy in the European equity markets' performance;

[36] Correlation is also calculated between HSBC indices for both analysed Eastern European country and equity indices quoted by national stock exchanges (PX50 for Czech Republic, BUX for Hungary and WIG for Poland). The correlations are very high - 0.988898 for Czech Republic, 0.991466 for Hungary and 0.925392 for Poland. That fact justifies application of HSBC indices in the study and also confirms the fact that differences between price indices and total return indices are not significant – the WIG index is total return index and its correlation with country HSBC price indices is one of the highest;

[37] The weekly data series cover period from February 16th, 1995 until February 10th, 2005, as this is the last Thursday in the series;

[38] See among others Christiansen, C., (2003), p. 10; in initially conducted calculations on the daily data the LM statistics for the data series are much more higher than for the weekly data series (weekly data series LM statistics are presented in the further part of the paper) as well as the volatility in the used GARCH model is explosive;

**Figure 1.** The weekly FX market returns

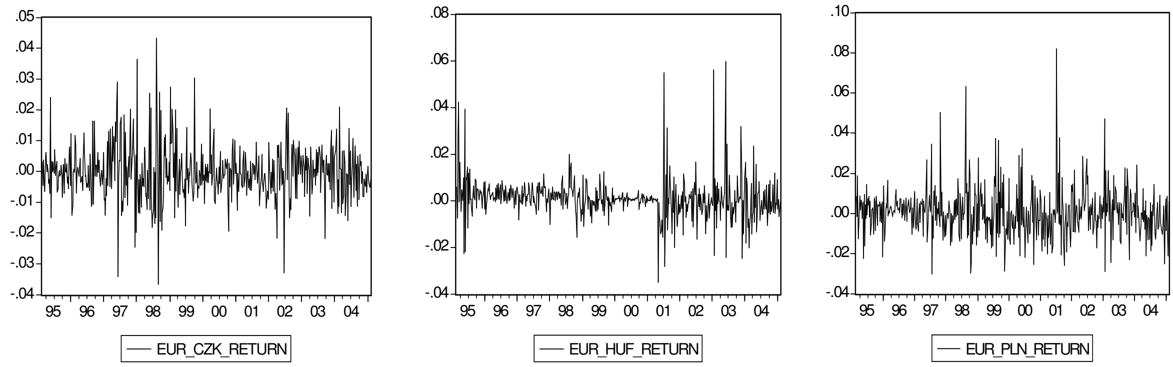



**Figure 2.** The weekly equity market returns in euro

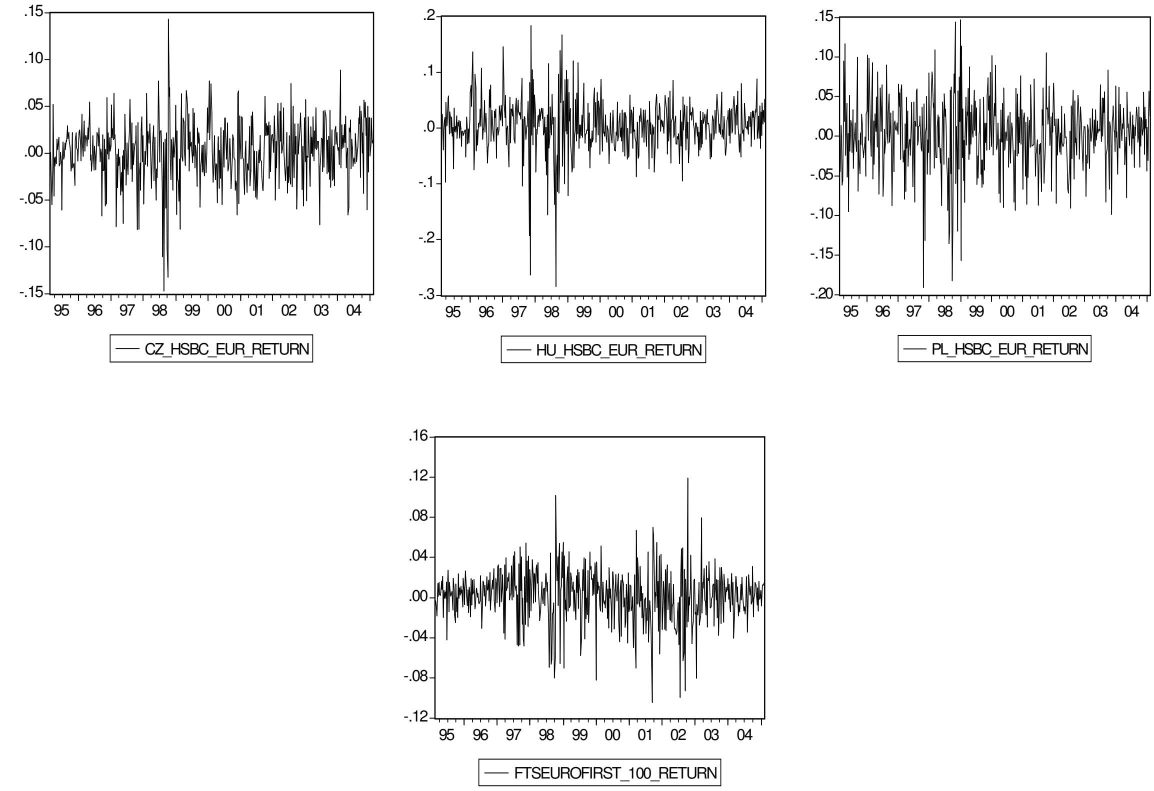
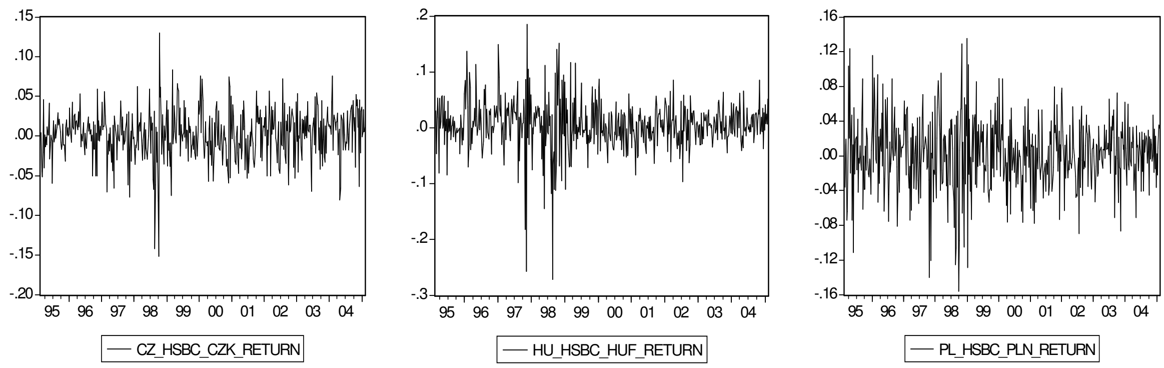



**Figure 3.** The weekly equity market returns in local currency



Figures presented above show relatively stable mean values of the series, while the volatility changes over time and large (small) changes tend to be followed by large (small) changes of both signs. The fact like that is defined as volatility clustering and is typical for the financial time series. Generally, all CEECs' equity markets show high level of volatility during whole studied period in comparison to the European Union countries. That fact will be also confirmed in the descriptive statistics of the return series. Also, there are noticeable similarities between CEECs' equity markets, where all of them react with very high volatility at the end of year 1998 what represents reaction on the Russian crisis in August 1998. [39] Additionally, Polish and Hungarian markets show higher volatility at the end of 1997 as the reaction on the Asian crisis. That observation is lacking in Czech market, what can give initial evidence about higher level of integration between Poland and Hungary then each of those markets with Czech one. The European equity market performance differs significantly from those of CEECs. Foreign exchange markets present different patterns and seem to be not correlated with each other and not influential on the equity markets. Even significant financial crisis in Czech Republic at the beginning of 1997 does not find its reflection in any of the financial markets of CEEC. That fact can signalise, for instance, separation of Czech foreign exchange market from other investigated countries. However, the mentioned above influences and relations are checked in the empirical part of this paper.

In the process of the application of the data series to the models specified above, in order to reduce the interference on the extreme levels, in total eight main outliers have been removed. From the series representing Hungarian equity index (both in euro as well as in local currency in order to keep the results comparable) two main extreme observations had been removed – of November 13th, 1997 and August 27th, 1998. As it is questionable whether the extreme values should be removed or remain in the analysed series, it is necessary to justify such an action. In this case it is evident that two disturbances represented Asian crisis event and Russian crisis one, however after removal the volatility in the periods still remains very high. Those two outliers caused significant disturbance in the appropriate fit of GARCH (1,1) model. Removal of the outliers allows for the application of the model. The same situation relates to Polish equity index (also both in euro as well as in local currency for the reason given above), where extreme observations of October 30th, 1997 and December 1st, 1998 has been removed, and to Polish foreign exchange market and observations of October 30th 1997, August 20th 1998, July 12th 2001 and January 23rd 2003. Elimination of those observations leaves anyway the volatility in the periods very high and, in result, does not influence the inference.

[39] Please note that the scaling on the graphs is different depending on the index presented, so the first glance can be misleading;

## 5.2 Statistical properties of the financial data series

Table 1 presents statistical properties of the returns.

**Table 1.** Summary statistics of the financial series data

| **Exchange rate returns** | Mean | Maximum | Minimum | Std. Dev. | Skewness | Kurtosis | J-B |
|---|---|---|---|---|---|---|---|
| EUR/CZK | -0.03% | 4.32% | -3.65% | 0.90% | 0.43 | 5.78 | 183.90* |
| EUR/HUF | 0.10% | 5.97% | -3.50% | 0.86% | 1.66 | 15.30 | 3523.25* |
| EUR/PLN | 0.01% | 3.76% | -3.01% | 1.07% | 0.24 | 4.00 | 26.62* |
| **Equity indices returns** | Mean | Maximum | Minimum | Std. Dev. | Skewness | Kurtosis | J-B |
| Europe (in EUR) | 0.15% | 11.89% | -10.44% | 2.66% | -0.36 | 5.13 | 109.40* |
| Czech Republic (in EUR) | 0.23% | 14.31% | -14.73% | 3.22% | -0.40 | 4.92 | 93.88* |
| Hungary (in EUR) | 0.54% | 18.35% | -19.34% | 4.65% | -0.02 | 5.27 | 111.78* |
| Poland (in EUR) | 0.25% | 14.67% | -15.67% | 4.31% | -0.16 | 3.85 | 17.96* |
| **Equity indices returns** | Mean | Maximum | Minimum | Std. Dev. | Skewness | Kurtosis | J-B |
| Czech Republic (in CZK) | 0.20% | 12.98% | -15.16% | 3.03% | -0.44 | 5.35 | 137.08* |
| Hungary (in HUF) | 0.64% | 18.56% | -18.19% | 4.14% | 0.09 | 5.36 | 122.10* |
| Poland (in PLN) | 0.28% | 13.51% | -12.89% | 3.96% | -0.05 | 3.80 | 14.24* |

*p-value 0.00

The interpretations of mean values, which indicate change of the asset value in the given period, in this study are of minor importance, because of very long period and relatively high frequency of the data. That fact does not allow to identify undoubtedly the direction and strength of the changes. Standard deviation values, measuring dispersion in the series, confirm widely recognised fact that the equity returns are generally more volatile than exchange rate changes.[40]

As it is typical for the financial data, the presented above financial series show excess kurtosis in the form of leptokurtosis. The Jarque-Bera tests for normality indicate that none of the returns is normally distributed, as they all have excess kurtosis and are skewed[41]. The characteristics are typical for financial data series.

Although it is widely believed that the asset prices contain the unit root, asset return series usually are stationary. However, that fact does not imply that the returns are independent.[42] The return series are tested for the existence of unit root using Phillips-Perron test that circumvents the assumption imposed in commonly used Augmented Dickey-Fuller test, that residuals are statistically independent and have constant variance. That condition seemed highly unlikely in the case of financial return series.[43] As the trend is not visible in any of the return series, it is also not included as the external variable in the tested model. The inclusion of the intercept could be controversial as the mean in all the cases is not equal zero – the deviations though are very small.

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[40] Francis, B., Hasan, I., Hunter, D., (2002), p. 12;
[41] Jarque-Bera test statistic is distributed as Chi-squared with 2 degrees of freedom;
[42] Brooks, Ch., (2004), p. 649;
[43] The dependence is visible when testing for autocorrelation;

Two options – with and without intercept are checked giving the same result rejecting the null of unit root for all return series.[44] It is important to remember that including of the irrelevant regressor could reduce the power of the test to reject the null of unit root. This is not the case, however, in this study as the evidence confirming stationarity of data series is strong in both options.

Presence of volatility clustering (visible on the Figures above), that represents strong autocorrelation effect in squared residuals, is detected and confirmed by Lagrange multiplier test for autoregressive conditional heteroskedasticity in the residuals (Engle 1982).[45] The residuals are estimated by running the regression of the return on a constant.[46] 4 and 8 lags are applied in the test and the LM test statistic is reported. Additionally, the time-varying volatility in the returns is indicated by significant Ljung-Box Q statistic detecting autocorrelation in squared returns.[47] The results of the tests are presented in Table 2.

**Table 2.** ARCH effects in the residuals and AC in squared returns

| Exchange rate returns | LM-ARCH(4) | LM-ARCH(8) | Q(4)sq.return | Q(8)sq.return |
|---|---|---|---|---|
| CZK/EUR | 52.137* | 55.434* | 75.035* | 105.230* |
| HUF/EUR | 24.782* | 30.216* | 26.651* | 30.196* |
| PLN/EUR | 17.374* | 21.094* | 20.669* | 27.682* |

| Equity indices returns | LM-ARCH(4) | LM-ARCH(8) | Q(4)sq.return | Q(8)sq.return |
|---|---|---|---|---|
| Europe (in EUR) | 42.621* | 68.384* | 54.427* | 124.130* |
| Czech Republic (in EUR) | 60.548* | 84.812* | 77.270* | 120.210* |
| Hungary (in EUR) | 52.185* | 56.759* | 86.827* | 108.550* |
| Poland (in EUR) | 26.114* | 39.059* | 32.868* | 58.043* |

| Equity indices returns | LM-ARCH(4) | LM-ARCH(8) | Q(4)sq.return | Q(8)sq.return |
|---|---|---|---|---|
| Czech Republic (in CZK) | 61.323* | 86.188* | 76.375* | 118.940* |
| Hungary (in HUF) | 58.711* | 61.411* | 100.300* | 120.370* |
| Poland (in PLN) | 25.802* | 39.364* | 34.040* | 58.757* |

*p-value 0.00

For all return series the LM statistic is highly significant suggesting the presence of ARCH errors in all return series. The same conclusion could be drawn when running autocorrelation tests of initial return series – the autocorrelations of squared return series are strong and significant. The autocorrelation of not squared return series is also often significant, what indicates that AR specification is useful.[48] Mentioned above characteristics of the financial series justify the application of AR(1)-GARCH (1,1) model.

[44] The results are not presented here, however are available upon the request;
[45] Introduced by Engle, R., F., (1982);
[46] Brooks, Ch., (2004), p. 449;
[47] LM test statistic (amount of observations times the R squared from test regression) as well as Ljung-Box Q statistic are distributed as Chi-squared with q degrees of freedom, where q is equal to the number of lags applied in the tests;
[48] Those results have not been reported however are available on the request;

# 6. Empirical work

*This section applies models presented in previous parts of the thesis. The results of estimations as well as interpretation of the outcome are provided.*

## 6.1 The constant spillover model (CSM)

### 6.1.1 CEECs and "old" European Union countries

The results of the model that investigates the influences of European Union markets on the economies of CEECs are reported in the Table I in Appendix I at the end of the thesis.[49]

*a. Europe/equity to CEEC/equity*

In the process of examining the influence of European equity market on each of the CEECs' equity market, in the first step the univariate model for European equity return is calculated. The AR(1) parameter $\mu_1$ in the equation is negative but significant[50]. It might mean that the market is not fully "efficient" as there exists autocorrelation in the return series and, in result, the possibilities of profit. The volatility is very persistent with sum of alpha and beta around 0.98.

In order to check the appropriate specification of the model and detect any misspecifications, the properties of standardized residuals are examined, what is the standard procedure in such cases. The procedure is especially important since the residuals from the first-step sub-model are implemented as volatility spillover indicators in the second step. LM ARCH test as well as Ljung-Box Q statistics (both tested for 4 and 8 lags) confirm well-specified model. The results of tests that check for the misspecifications of the models are not reported in the paper due to space constraints however they are available upon request.

In the second step three models are calculated, one for each CEEC. In the case of Czech Republic, similarly to the first step equation, $\mu_1$ parameter is significant signalising not sufficient efficiency of the Czech equity market. For all three markets volatility spillover coefficients $\varphi_j$ are positive and significant. Mean spillover parameters $\gamma_j$ are non-significant, however, as mentioned above, the mean spillover effect is not the focus of this study. The LR joint test for no spillover at all definitely rejects the null hypothesis $\gamma_j = \varphi_j = 0$.

As the relative size of the parameters is not particularly relevant to evaluate quantitative influence of European equity market on the CEECs' equity markets, that is necessary to calculate variance ratios to present volatility spillover effect on the variance of the unexpected return of each country. The mean, maximum and minimum values of variance ratios are presented in the first

[49] All the spacious tables and figures are included at the end of the thesis. Roman numbers indicate those; P-values refer to the t-statistics;

[50] Significance in all calculations include in the paper is considered on the 5% level;

part of the Table 3 below. Moreover, the appropriate graphs are presented in Figure I in Appendix II. The calculations are consistent due to the significance of earlier estimated parameters.

The values of variance ratios indicate rather moderate level of the volatility spillover from European equity market to the CEECs' equity markets, however most probably the level increases with time. The highest level of spillover presents Hungarian market (20.21%), a little bit lower – Polish market (17.62%) and the lowest – Czech market (10%). Generally, the tendencies in behaviours of Hungarian and Polish market are similar what is noticeable on the Figure I. The markets react strongly on the high variance of European equity market at the end of year 2001 (that indicates the reaction of the world markets on the terrorists' attack on the WTC in September 2001) as well as at the end of 2002 and beginning of 2003. The values of the variance ratios oscillate around 60%. Especially second period of high volatility, which might have been caused (among others) by closing the negotiations with ten new European Union accession countries in December 2002, seems to cause very persistent volatility spillover effect for both CEECs' markets. That observation seems to be consistent also with the stated before hypothesis saying that there is higher correlation between equity markets, when the exchange rate of two currencies experience higher volatility (see graphs of EUR/HUF and EUR/PLN in Figure 1 for confirmation).

The level of volatility spillover from European equity market to the CEECs' equity markets increases with time (as the European disturbances from year 1998 are not that significant for new accession countries) and in the volatile periods (what can be termed as the contagion effect). All three markets show those characteristics, however Czech market is noticeably the least integrated with European one.

*b. Europe/equity to CEEC/FX*

In the part investigating the relation between European equity market and CEECs' foreign exchange markets the first step univariate model is the same as in the relation between equity markets presented above.

In the second step, the AR(1) parameter $\mu_1$ for all countries is negative and non-significant, what indicates that CEECs' foreign exchange markets are efficient. The mean spillover parameters are not significant in all cases, while volatility spillover parameters - significant only for Hungary and Poland with exclusion of Czech market. The LR joint test for no spillover at all rejects the null hypothesis only for those two markets.

The second part of Table 3, as well as Figure I, confirm the volatility spillover effect for Hungarian and Polish foreign exchange markets on lower level than those of equity markets.

The mean of variance ratio for Hungarian market equals 14.67% with maximum 50.97% while for Polish market – 9.74% with maximum 36.81%. Both markets react the strongest on the European equity market disturbances at the beginning of year 1999, what indicates the disturbances caused by implementation of common currency euro. That fact would suggest growing level of the dependence on euro of Hungarian and Polish FX markets.[51] The theory of international equity market order flow, which influences the currency order flow, can have its application for Hungarian and Polish markets only after confirmation of their high internationalisation. Non-significance of the volatility spillover effect to Czech market is caused probably by the smallest size of all three CEECs' markets.

*c. Europe/FX to CEEC/equity*

In the part examining the links between European foreign exchange market and local equity markets, three separate univariate models are calculated in the first basic step. Two financial data series used here for modelling are: euro in terms of local currency for European FX market and equity market index for each of CEEC countries also in terms of local currency, what requires separate calculations for each of FX markets. AR(1) terms in all models are non-significant. The LM ARCH test and Ljung-Box Q statistics for residuals provide evidence for lack of misspecifications of the models.

The results obtained in the second step of calculations provide evidence for volatility spillover in Hungary and Poland (the coefficients are however negative). Czech Republic calculations, as above, are not significant. There is no mean spillover effect in any of the investigated markets. LR joint test rejects the null hypothesis of no spillover effect only in case of Poland. However, as main focus in the study is volatility spillover effect (not mean spillover effect), the results for Hungarian market are taken into consideration.

Although the coefficients $\varphi_j$ for Hungary and Poland are significant, the results presented in Table 3 and in Figure 1 show virtually no volatility spillover effect to those equity markets from European foreign exchange market. The highest value is presented for Polish market where variance ratio equals 2.77%. For Hungarian market the value presented is 0.81%.

Obtained results reject the theory about currency risk as one of the main pricing factors as suggested by international asset pricing models. That finding, however, is consistent with those of Flores and Szafarz (1997). As given in one of the previous parts of the study, authors investigated Polish equity market and concluded that the realised profits are here mainly speculative, what partly has its source in lack of influence of fundamentals on that market. One of the most significant facts was just that the exchange rate did not influence the price of studied shares.

[51] See further comments about the exchange rate regimes in each country;

**Table 3.** VR – volatility spillover between new and old member countries of EU – **CSM**

| | VR Europe eq. to CEEC eq. | | | VR own influence CEEC eq. | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 10.00% | 43.56% | 2.19% | **90.00%** | 97.81% | 56.44% |
| Hungary | **20.21%** | 64.33% | 2.91% | 79.79% | 97.09% | 35.67% |
| Poland | 17.62% | 60.56% | 3.22% | 82.38% | 96.78% | 39.44% |

| | VR Europe eq. to CEEC/EUR FX | | | VR own influence CEEC/EUR FX | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 0.21% | 1.72% | 0.03% | **99.79%** | 99.97% | 98.28% |
| Hungary | **14.67%** | 50.97% | 0.48% | 85.33% | 99.52% | 49.03% |
| Poland | 9.74% | 36.81% | 2.62% | 90.26% | 97.38% | 63.19% |

| | VR Europe FX to CEEC eq. | | | VR own influence CEEC eq. | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 0.64% | 2.74% | 0.12% | 99.36% | 99.88% | 97.26% |
| Hungary | 0.81% | 5.82% | 0.05% | **99.19%** | 99.95% | 94.18% |
| Poland | **2.77%** | 7.33% | 0.95% | 97.23% | 99.05% | 92.67% |

### 6.1.2 CEECs

Table II in Appendix I reports the results of the model investigating the links between three CEECs.

*a. CEEC/ equity to CEEC/ equity*

Examination of the relations between CEEC equity markets includes testing the bi-directional links, where all countries are examined as influential as well as dependent. In the first step of the calculation three univariate models for each of CEECs equity market are estimated. Among them only in the case of Czech market $\mu_1$ parameter is significant, what is consistent with previous findings. All three models are tested with LM ARCH test as well as Ljung – Box Q statistic that provide the evidence for no misspecification.

The second step estimations for Czech equity market (acting as influential one) give significant and positive volatility spillover parameters in Hungary as well as in Poland. The mean spillover coefficient is significant only for Polish market but joint LR test rejects null hypothesis of no spillover at all in both cases.

The rate of volatility spillover from Czech equity market to Hungarian equity market is estimated as 20.02% with maximum at 42.66%, while the rate for Polish market is equal 21.32% with maximum at 54.66%. The results are given in Table 4a below as well as in Figure IIa in Appendix II. Generally, volatility spillover rate to both markets remains almost on the same level and, again, tendencies in behaviours of Hungarian and Polish market are similar, what is visible in Figure IIa. Both markets react strongly for the disturbances on the Czech equity market in second part of year 1998 caused by Russian crisis. The rate of volatility spillover for Hungarian, as well as Polish market, follow slowly increasing trend.[52]

The same procedure in second step of estimation is repeated for Hungarian and Polish market as influential ones. In both sub-models all volatility spillover parameters are positive and significant. LR test rejects the null hypothesis in all cases. The volatility spillover rate from Hungarian market equals 15.36% on average for Czech Republic and 30.57% for Poland. The rates from Polish market equal 19.53% for Czech Republic and 30.13% for Hungary. The strong bi-directional relation between Polish and Hungarian markets is apparent, what confirms earlier findings about closer relationship between those two markets than any of them with Czech market. However, it is important to mention decreasing tendency in influence form Hungary to Poland and increasing in opposite direction. Also the influences from Hungary and Poland to Czech Republic reveal decreasing trend. That fact might be the forecast of strengthening Czech equity market and its rising influences in the region.

In general, the rates of volatility spillover effect between CEECs equity markets are higher than those between "old" European Union equity market and CEECs. However, the differences are not very big, what would indicate the necessity of further financial and economical integration between "new" members of European Union.

**Table 4.** VR - volatility spillover effect between CEECs – **CSM**

**a.** VR - volatility spillover from one CEECs' equity market to the other CEEC's equity market

| | **VR Czech Rep. Eq. to CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Hungary | 20.02% | 42.66% | 5.47% | **79.98%** | 94.53% | 57.34% |
| Poland | **21.32%** | 54.66% | 8.05% | 78.68% | 91.95% | 45.34% |

| | **VR Hungary eq. to CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 15.36% | 40.94% | 3.91% | **84.64%** | 96.09% | 59.06% |
| Poland | **30.57%** | 52.15% | 13.09% | 69.43% | 86.91% | 47.85% |

| | **VR Poland eq. To CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 19.53% | 48.05% | 8.47% | **80.47%** | 91.53% | 51.95% |
| Hungary | **30.13%** | 48.71% | 14.85% | 69.87% | 85.15% | 51.29% |

*b. CEEC/ equity to CEEC/ FX*

As the influential market equations here are the same as in the previous part, the analysis starts from second step of estimation. In three sub-models all volatility spillover parameters are positive and significant. Sub-model describing influence of Polish equity market on Hungarian FX market reveals in addition positive and significant mean spillover parameter. Also the LR joint test rejects

[52] This is noticeable that Czech crisis in the beginning of 1997 that caused disturbances mainly on the foreign exchange market does not influence significantly Czech equity market and, further other CEEC equity markets;

the hypothesis about lack of no spillover effect at all for all of relations excluding this one that investigates spillover from Polish equity market to Czech FX market. As the study focuses on the volatility spillover, this fact does not influence the conclusion as far as the volatility spillover parameter for the relation is significant. The values of variance ratios are presented in Table 4b as well as in graphs included in Figure II b. The analysis of the volatility spillover processes is presented in the next section, where the reverse relations are estimated. It allows to compare the results in order to conclude about the existence of bi-directional links.

**Table 4.** VR - volatility spillover effect between CEECs – **CSM**
**b.** VR - volatility spillover from one CEECs' equity market to the other CEEC's FX market

| | **VR Czech Rep. eq. to CEEC FX** | | | **VR own influence CEEC FX** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Hungary | **6.67%** | 30.75% | 0.15% | 93.33% | 99.85% | 69.25% |
| Poland | 6.11% | 26.93% | 1.95% | **93.89%** | 98.05% | 73.07% |

| | **VR Hungary eq. to CEEC FX** | | | **VR own influence CEEC FX** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 1.38% | 4.05% | 0.20% | **98.62%** | 99.80% | 95.95% |
| Poland | **7.18%** | 18.67% | 2.72% | 92.82% | 97.28% | 81.33% |

| | **VR Poland eq. To CEEC FX** | | | **VR own influence CEEC FX** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 1.18% | 3.11% | 0.18% | **98.82%** | 99.82% | 96.89% |
| Hungary | **9.13%** | 26.51% | 0.20% | 90.87% | 99.80% | 73.49% |

*c. CEEC/ FX to CEEC/ equity*

Three univariate models for each of CEECs foreign exchange market are estimated in the first stage of examining the influences of FX market on the equity. LM ARCH test and Ljung – Box Q statistics applied for the residuals of those models do not provide the evidence for any misspecification.

Volatility spillover parameters received in the second stage of estimations are not significant for relations with their origin on the Czech foreign exchange market, additionally LR joint test does not reject the null hypothesis about no spillover effect at all in the case of spillover to Polish equity market. All other four volatility spillover parameters (for relations from Hungarian and Polish foreign exchange markets) are positive and significant and the LR joint test statistics provide the evidence for rejecting the null hypothesis in all four cases. Those results make estimations of variance ratios consistent. All the necessary estimations are reported in Table 4c and in Figure II c.

The relations between Czech FX market and other countries' equity markets are bi-directionally not significant, what is indicated by very low or non-significant estimations. The variance ratios for the relation from Czech FX market to Hungary and Poland are not significant and equal 1.19% and 0.95%. The rate of the volatility spillover from Hungarian equity market to Czech FX market oscillates around 1.38%, from Polish equity market – 1.18%. This evidence confirms separation of Czech Republic foreign exchange market from other financial markets of CEECs.

The influences between Hungarian foreign exchange market and other countries' equity markets are significant bi-directionally, but not that high as well. The highest variance ratio is noted in the case investigating the influence of Polish equity market on Hungarian foreign exchange market (9.13%), but the highest levels were achieved in 1999 and the ratio has tendency to decline. The same path is followed by the variance ratio in the case of influence of Czech Republic equity market on Hungarian foreign exchange market – the value oscillates around 6.67% with the peak at the end of 1998 (Russian crisis). The levels of influence from Hungarian foreign exchange market are lower and equal 3.46% for Czech Republic and 4.87% for Poland. However, with time the Hungarian foreign exchange market seems to become more important, especially in the course of the last two years.

The relation between Polish foreign exchange market and Czech and Hungarian equity markets again can be considered as bi-directional, but with not very high rates of influence. The volatility ratio from Polish foreign exchange market to Czech Republic equals 4.28%, to Hungary – 6.88%. The reverse relation yields following results: 6.11% from Czech equity market to Polish foreign exchange market and 7.18% from Hungarian equity market. The relations are similar to those present on Hungarian FX market, where currently foreign exchange market becomes more important in the course of the last few years. That tendency seems to be the proof of the improvement of the efficiency of the markets and their slowly growing integration, where the currency risk is the pricing factor of the equities.

Also in the study of the relations between equity and foreign exchange markets, markets of Hungary and Poland show the highest levels of dependence.

**Table 4.** VR - volatility spillover effect between CEECs – **CSM**
**c.** VR - volatility spillover from one CEECs' FX market to the other CEEC's equity market

| | **VR Czech Rep. FX to CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Hungary | **1.19%** | 4.82% | 0.37% | 98.81% | 99.63% | 95.18% |
| Poland | 0.95% | 4.38% | 0.27% | **99.05%** | 99.73% | 95.62% |

| | **VR Hungary FX to CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 3.46% | 15.13% | 0.38% | **96.54%** | 99.62% | 84.87% |
| Poland | **4.87%** | 28.87% | 1.07% | 95.13% | 98.93% | 71.13% |

| | **VR Poland FX to CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 4.28% | 12.04% | 0.87% | **95.72%** | 99.13% | 87.96% |
| Hungary | **6.88%** | 16.14% | 1.44% | 93.12% | 98.56% | 83.86% |

### 6.2 The dummy variable model (DVM)

The estimations of dummy models, that were supposed to help answering the question if the accession of three CEEC countries to European Union increases the integration between its members, are reported in Tables III and IV in Appendix I. As the estimations only in few cases provide the evidence of slightly higher integration of studied markets, they are commented shortly when necessary.

6.2.1 CEECs and "old" European Union countries

Examination of the relations between European and CEEC markets in the framework of dummy variable model provides results where the parameters of changes in mean and volatility spillover effects after accession European Union ($\gamma_{1j}$ and $\varphi_{1j}$) are not significant and joint Wald test does not reject the hypothesis about lack of volatility spillover effect at all.[53] There are however two exceptions: relation between European equity market and Czech equity market, where the parameter of volatility spillover effect after May 1st, 2004 is positive and significant, and the same parameter in the relation between European foreign exchange market and Hungarian equity (negative and significant). Both changes indicate growing level of integration and internationalisation of the mentioned above markets. In the case of Czech Republic the variance ratio grows from 10% to 10.74% while the Hungarian market variance ratio – from 0.81% to 2.42%. Slightly changed values of variance ratios are presented in Table 5 and significantly changed variance ratios are plotted in Figure III in Appendix II.

**Table 5.** VR – volatility spillover between new and old member countries of EU – **DVM**

| | **VR Europe eq. to CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| ***Czech Rep.*** | ***10.74%*** | ***42.09%*** | ***2.12%*** | ***89.26%*** | ***97.88%*** | ***57.91%*** |
| Hungary | **19.96%** | 64.69% | 2.27% | 80.04% | 97.73% | 35.31% |
| Poland | 18.05% | 60.09% | 3.10% | 81.95% | 96.90% | 39.91% |

| | **VR Europe eq. to CEEC/EUR fx** | | | **VR own influence CEEC/EUR fx** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 0.22% | 1.87% | 0.03% | **99.78%** | 99.97% | 98.13% |
| Hungary | **14.71%** | 51.20% | 0.48% | 85.29% | 99.52% | 48.80% |
| Poland | 10.56% | 39.98% | 0.65% | 89.44% | 99.35% | 60.02% |

| | **VR Europe FX to CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 0.73% | 3.15% | 0.14% | **99.27%** | 99.86% | 96.85% |
| ***Hungary*** | ***2.42%*** | ***36.02%*** | ***0.03%*** | ***97.58%*** | ***99.97%*** | ***63.98%*** |
| Poland | **2.87%** | 8.06% | 0.67% | 97.13% | 99.33% | 91.94% |

[53] The Wald test is used instead of LR test applied in constant spillover model due to the software restrictions;

### 6.2.2 CEECs

The situation on the CEECs' markets after accession of those countries to the European Union is similar to this presented before – again parameters of changes in mean and volatility spillover effects ($\gamma_{1j}$ and $\varphi_{1j}$) are not significant and joint Wald test does not reject the hypothesis about lack of volatility spillover effect at all. The two exceptions are: relation describing influence from Polish equity market to Hungarian foreign exchange market and reverse one. The variance ratio changes from 9.13 % to 10.86% in the first case and from 4.87% to 5.94% in the second case. That fact confirms previous evidence about especially strong links between Poland and Hungary as well as growing importance of Hungarian foreign exchange market.

New variance ratios are presented in Table 6 below and significantly changed variance ratios are plotted in Figure IV in Appendix II.

**Table 6.** VR - volatility spillover effect between CEECs - **DVM**

**a.** VR - volatility spillover from one CEECs' equity market to the other CEEC's equity market

| | **VR Czech Rep.eq. to CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Hungary | **20.20%** | 44.56% | 5.87% | 79.80% | 94.13% | 55.44% |
| Poland | 18.93% | 50.11% | 7.18% | 81.07% | 92.82% | 49.89% |

| | **VR Hungary eq. to CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 15.58% | 40.65% | 3.92% | 84.42% | 96.08% | 59.35% |
| Poland | **28.15%** | 49.58% | 12.07% | 71.85% | 87.93% | 50.42% |

| | **VR Poland eq. to CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 20.32% | 46.68% | 8.45% | 79.68% | 91.55% | 53.32% |
| Hungary | **29.99%** | 48.55% | 14.71% | 70.01% | 85.29% | 51.46% |

**b.** VR - volatility spillover from one CEECs' equity market to the other CEEC's FX market

| | **VR Czech Rep.eq. to CEEC FX** | | | **VR own influence CEEC FX** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Hungary | **6.78%** | 31.18% | 0.15% | 93.22% | 99.85% | 68.82% |
| Poland | 6.35% | 26.79% | 1.77% | 93.65% | 98.23% | 73.21% |

| | **VR Hungary eq. to CEEC FX** | | | **VR own influence CEEC FX** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 1.37% | 4.08% | 0.21% | 98.63% | 99.79% | 95.92% |
| Poland | **7.25%** | 18.75% | 2.73% | 92.75% | 97.27% | 81.25% |

| | **VR Poland eq. to CEEC FX** | | | **VR own influence CEEC FX** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 1.47% | 10.15% | 0.16% | 98.53% | 99.84% | 89.85% |
| ***Hungary*** | ***10.86%*** | ***48.70%*** | ***0.18%*** | ***89.14%*** | ***99.82%*** | ***51.30%*** |

**c.** VR - volatility spillover from one CEECs' FX market to the other CEEC's equity market

| | **VR Czech Rep. FX to CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Hungary | **1.19%** | 5.13% | 0.17% | 98.81% | 99.83% | 94.87% |
| Poland | 0.96% | 4.43% | 0.26% | **99.04%** | 99.74% | 95.57% |

| | **VR Hungary FX to CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 3.76% | 17.34% | 0.36% | **96.24%** | 99.64% | 82.66% |
| ***Poland*** | ***5.94%*** | ***47.85%*** | ***0.71%*** | ***94.06%*** | ***99.29%*** | ***52.15%*** |

| | **VR Poland FX to CEEC eq.** | | | **VR own influence CEEC eq.** | | |
|---|---|---|---|---|---|---|
| **Country** | Mean | Max | Min | Mean | Max | Min |
| Czech Republic | 4.28% | 11.91% | 0.86% | **95.72%** | 99.14% | 88.09% |
| Hungary | **7.06%** | 17.57% | 1.61% | 92.94% | 98.39% | 82.43% |

### 6.3 Statistical properties of the GARCH models

In order to accept the symmetric AR(1)-GARCH(1,1) model as appropriate one for the conducted analysis, the statistical properties of the residuals are considered. As mentioned before, the LM ARCH test and Ljung – Box Q statistics applied to residuals do not provide evidence for misspecification in any case. Nevertheless, the kurtosis is not covered by the model (even if the distribution is more normally distributed), what is indicated by the descriptive statistics (not reported here). As it is known however, this is stylised fact that even after accounting for conditional heteroscedasticity with GARCH model the residuals may be still leptokurtic.[54] That fact is discussed shortly in the research proposal. In the closing of the section it is also necessary to mention that all models fulfil the non-negativity assumptions of GARCH processes and there is no explosive volatility in any of the estimated models (however, usually volatility is very persistent).

### 6.4 Asymmetries

The calculations of the cross-correlations and asymmetric GJR model are conducted for all parts of main models estimated in the study. The results are presented in the Tables V-VIII in Appendix I.

It is assumed that both asymmetric component of GJR model as well as cross-correlations between the squared standardized residuals and the lagged standardized residuals of the before applied symmetric AR(1)-GARCH(1,1) have to be significant in order to signalise the asymmetry. Moreover, it is necessary to mention that, in order to recognize the leverage effect, the correlations should be negative. Generally, it is proved that the estimated models do not contain

[54] See Lecture Notes 'Time Series Analysis' (Department of Economics, Lund University) by Ulf Erlandsson on 10th of May 2005. Also see in Bollerslev, T., (1987), "A Conditionally Heteroskedastic Time Series Model for Speculative Prices and Rates of Return", The Review of Economics and Statistics, p. 542;

asymmetric effects. Among the exceptions is the foreign exchange market of Polish zloty (PLN) to euro that, in the models examining its influences on CEECs' equity markets, reveals significant cross correlations and significantly positive leverage effect terms. The base AR(1)-TARCH(1,1) model for Polish zloty to euro gives similar results, what would confirm drawn conclusion. Additionally, the asymmetric element of the model representing influence of European equity market on PLN/EUR exchange rate is significant, however here the correlations are not negative. The above-presented results are consistent with those of prior studies, where asymmetry of the financial data series was rather the characteristic of developed financial markets than developing economies.[55] Confirmation of the symmetric response of the studied markets justifies the application of symmetric GARCH model and does not change the interpretations.

### 6.5 Complementary analysis – regime switching process

The estimation of regime switching process with changing mean and changing variance is conducted for all financial data series in order to see the pattern in the probability of high volatility regime for the markets. The graphs that present the results are included in Figure V in Appendix II. Also, the Wald test is applied checking for equal mean and equal variance for each of the series. For all series, excluding equity index for Czech Republic, the null hypothesis about equal variances is rejected, what would confirm appropriateness of modelling the series as consisting of two distributions. The hypothesis of equal mean is rejected, however, only for European equity index and EUR/PLN exchange rate.

#### 6.5.1 CEECs and "old" European Union countries

The results of calculations of the rate that measures matching the high volatility regime between markets for the relations between CEECs and "old" European countries are presented in Table 7 below.

**Table 7.** Comparison of regimes between markets of new and old member countries of EU

| Country | Europe eq. and CEEC eq. |
|---|---|
| Czech Republic | 2.11% |
| Hungary | 9.21% |
| Poland | **28.98%** |

| Country | Europe eq. and EUR/CEEC FX |
|---|---|
| Czech Republic | 13.82% |
| Hungary | 9.98% |
| Poland | **32.63%** |

[55] See among others Kasch-Hatouronian, M., Price, S., (1998);

Generally, the results show the highest level of matching in the high volatility regimes in case of Polish equity market as well as Polish FX market (instead of Hungary, as in the AR(1)-GARCH(1,1) model). Quite surprisingly Czech Republic FX market volatility shows relatively high rate of matching the volatility with European equity market, what is on the contrary with earlier findings that there are almost no volatility spillover effect to that market from European equity market. The highest average rates presented in Table 7 oscillate around 30%, what is slightly higher than earlier findings. The interpretation of the results is given in the next subsection.

6.5.2 CEECs

The results of calculations of the rate that measures matching the volatility regime between markets for the relations between CEECs are presented in the Table 8.

**Table 8.** Comparison of regimes between markets of CEECs

| | **CEEC eq. and CEEC eq.** | | |
|---|---|---|---|
| **Country** | Czech Rep.eq. | Hungary eq. | Poland eq. |
| Czech Rep.eq. | | | |
| Hungary eq. | 2.11% | | |
| Poland eq. | 2.11% | **13.44%** | |

| | **CEEC eq. and CEEC FX** | | |
|---|---|---|---|
| **Country** | Czech Rep.eq. | Hungary eq. | Poland eq. |
| Czech Rep. FX | | 9.40% | **24.18%** |
| Hungary FX | 0.96% | | 16.31% |
| Poland FX | 2.11% | 13.05% | |

Again, quite non-expected is the highest rate of matching the high volatility regime between Czech FX market and, in this case, Polish equity market. Moreover, it can be concluded that the results given above act as the confirmation of strong relationship between Hungarian and Polish markets – appropriate rates are on relatively high level. The significant volatility spillover effect found before confirms, that high level of coinciding between high volatility regimes of mentioned above two economies is linked with interdependence between the markets and their influences on each other. Following the same reasoning, definitely different results for Czech FX market in two applied models (AR(1)-GARCH(1,1) and regime switching process) can be real proof for the separation of that market from other ones – although there is very high coinciding of the high volatility regimes between the Czech FX market with other investigated economies, the *spillover* of that volatility is almost none. It might mean that the market reacts independently on the same events on third markets (for instance Asian or Russian) as other economies, however without any indirect influences from markets, where the disturbance do not have their origin. Also, the highest rates of matching the volatility regime in the case of Polish markets and Czech FX market can be biased in effect of markets' high volatility regime during almost *whole* period investigated in the study. The high volatility of Czech and Polish FX markets is caused probably by the exchange rate regime accepted by those countries: Czech Republic accepted managed float while Poland – free float.

Generally, it can be concluded, that although regime switching process is very useful in modelling volatility (on very volatile markets especially), probably in the form presented in the thesis it is not appropriate for measuring independently volatility *spillover effect*, especially in the case of very volatile markets (like Polish ones and Czech FX market). In that form it can act only as complementary analysis for the main model. The aspect of finding appropriate formula of regime switching model for measuring volatility spillover effect on the volatile (emerging) markets can be issue to be investigated in the framework of further research.

# 7. Conclusions

## 7.1 General conclusion

As mentioned above, the awareness of the volatility spillover occurrence is immensely important from the policymakers point of view and their efforts to maintain the markets' financial stability and conduct effective policy. In the light of the accession of new countries to the European Union arise the questions regarding the stability of the region and necessary integration. Current researches show, however, that the area is not really correlated although the integration seems to be very important in that case.

Investigation conducted in the framework of this study in significant part confirms above-presented statement. In the relations between "old" European Union countries and CEECs the most significant links, although still of moderate level, are present between equity markets. The level of volatility spillover from European equity market to the CEECs' equity markets increases with time and is the most apparent on Hungarian and Polish market, which are two equity markets among all CEECs with highest capitalisation. Czech market is noticeably the least integrated with European one as for now, however its correlation with European equity market rises after European Union enlargement.

The level of dependence between European equity market and CEECs' FX markets is surprisingly high, although much lower than between equity markets. The most influenced FX markets are Hungarian and Polish, what suggests growing level of the dependence on euro of the markets and, at the same time, their growing integration and internationalisation. The dependence on euro in the case of Hungarian economy is clear: Hungary shadows from 2001 the ERM II exchange rate mechanism with the fixed parity against euro.

The influence of European FX market on CEECs' equity markets is almost none, however after enlargement of European Union it increases in the case of Hungarian market. The reasons may be similar to those given above.

A little bit higher level of integration than with European market is apparent between equity markets of CEECs. Also here stronger relations are found between Hungary and Poland than between any of those countries and Czech Republic. However, as was mentioned already above, the influences from Hungary and Poland to Czech Republic reveal decreasing trend. That fact might be the forecast of strengthening Czech equity market and its rising influences in the region.

The relations between FX markets and equity markets are significant again mainly in the case of Hungary and Poland. The highest variance ratio is noted in the case investigating the influence of Polish equity market on Hungarian foreign exchange market. That ratio, as well as reverse influence, are growing after European Union enlargement (especially influence of Polish equity market on Hungarian foreign exchange market what is visible on Figure IV), what seems to be the proof of the improvement of the efficiency of the markets and their slowly growing integration.

The relations between Czech FX market and other countries' equity markets are bi-directionally not significant, what could confirm the hypothesis stated at the initial data analysis about separation of Czech FX market from other economies.

To sum up, the volatility spillover effect between studied markets is still low, even after accession of CEECs to the European Union, however for some markets mentioned above shows forecasts of growth. That tendency to grow might be the sign of closer accession to the EMU. It is necessary to remember also that the accession to EMU may be much more important in the process of integration than accession to the European Union. The level of progression in the preparation to accession to ERM II and, consequently, to EMU is very important factor of integration between markets. The most advanced countries, Poland and Hungary, show relatively highest level of volatility spillover effect between markets. The level of advancement in process of accession is presented in Table IX in Appendix I.

The results obtained in the process of estimation of AR(1)-GARCH(1,1) model have been partly confirmed by complementary analysis in form of regime switching process.

At the end, it is necessary to mention that investigated developing markets still show characteristics typical for emerging markets like higher volatility and lack of asymmetries. That is why the financial data series may require different modelling that the series of developed countries.

As for the dummy model much smaller sample of the data has been used for the second part, probably similar model should be investigated after longer time of European Union enlargement to confirm obtained results. However, as indicates research proposal below, there can be found model that will describe developing economies with higher precision.

### 7.2 Research proposal

As the role of CEECs starts to get more importance in the aspect of whole European Union, it is very important to bear in mind that the characteristics of the volatility of the financial series in emerging markets are significantly different than this of developed economies. That fact implies necessity of application of appropriate econometric model that will capture characteristics like, for instance, higher volatility that was apparent in the presented paper (before removal of the outliers and in the regime switching process estimations).

The quantitative methods present great use for answering many questions connected with the volatility spillover effect, however they meet many constraints in the application procedure.

Further researches on their capacity in describing as well as forecasting the financial processes in the CEECs' markets seem to be necessary. Moreover, in spite of intuitive appeal of GARCH models, some data is not very well described by such models (for instance there often seems to be even more leptokurtosis than they can explain).[56] That is the main reason why the use of models where observations are drawn from more than two distributions, regime switching models, started to be more and more popular.

The phenomenon of leptokurtic data even after process of modelling is evident in this study. Estimates of GARCH models quite often imply an explosive conditional variance, what has the implications for forecasting volatility. What is important in that case, is to find the model that will be able to handle with those problems and any others connected with specific characteristics of emerging markets financial series. Also, applied in the thesis, regime switching process suffered of inability to measure independently volatility *spillover effect*. The aspect of finding appropriate formula of regime switching model for measuring volatility spillover effect on the volatile developing markets can be also the issue to be investigated in the framework of further research.

The further development of the ideas included in the thesis mainly concerns the development of methods for the analysis of time series, with the focus on the implementation of econometric methods on the EU financial markets with impact on CEECs. The research should involve the development of existing econometric methods that are based on ARCH/GARCH as well as regime switching models.[57] Such developments support the work on empirical applications such as volatility modelling, detecting relationships between economic variables, measuring business cycles and their spillover.

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[56] Erlandsson, U., (2000), p. 4 ;

[57] VAR modelling can be considered as well ;

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**Institutional websites**

World Bank www.worldbank.org

**Applicable databases**

EcoWin

## APPENDIX I TABLES

**Table I.** The volatility spillover between "new" and "old" member countries of EU – **CSM**

**Europe/equity market to CEEC equity market market**

| | $\mu_0$ | $\mu_1$ | $\gamma_j$ | $\varphi_j$ | $\omega*100$ | $a$ | $\beta$ | $a+\beta$ | LR TEST |
|---|---|---|---|---|---|---|---|---|---|
| INF | **0.00** | **-0.13** | | | 0.00 | **0.16** | **0.82** | 0.98 | |
| p-value | **0.34%** | **1.06%** | | | 5.50% | **0.03%** | **0.00%** | | |
| Czech Republic DEP | **0.00** | **0.11** | -0.04 | **0.38** | **0.02** | **0.10** | **0.70** | 0.80 | **50.39** |
| p-value | **3.43%** | **1.69%** | 49.28% | **0.00%** | **3.61%** | **3.79%** | **0.00%** | | **0.00%** |
| Hungary DEP | **0.01** | -0.03 | 0.01 | **0.70** | 0.01 | **0.09** | **0.84** | 0.93 | **128.89** |
| p-value | **0.02%** | 56.64% | 82.74% | **0.00%** | 11.58% | **3.94%** | **0.00%** | | **0.00%** |
| Poland DEP | **0.00** | -0.01 | 0.02 | **0.67** | 0.00 | **0.04** | **0.95** | 0.99 | **111.05** |
| p-value | **2.65%** | 89.75% | 73.04% | **0.00%** | 32.91% | **2.59%** | **0.00%** | | **0.00%** |

**Europe/equity market to CEEC FX market**

| | $\mu_0$ | $\mu_1$ | $\gamma_j$ | $\varphi_j$ | $\omega*100$ | $a$ | $\beta$ | $a+\beta$ | LR TEST |
|---|---|---|---|---|---|---|---|---|---|
| INF | **0.00** | **-0.13** | | | 0.00 | **0.16** | **0.82** | 0.98 | |
| p-value | **0.34%** | **1.06%** | | | 5.50% | **0.03%** | **0.00%** | | |
| Czech Republic DEP | 0.00 | -0.07 | 0.00 | 0.01 | 0.00 | **0.11** | **0.84** | 0.95 | 0.99 |
| p-value | 26.07% | 19.95% | 85.65% | 31.38% | 11.09% | **1.16%** | **0.00%** | | 60.82% |
| Hungary DEP | **0.00** | -0.01 | 0.02 | **0.10** | 0.00 | **0.11** | **0.88** | 0.9997 | **75.83** |
| p-value | **0.00%** | 85.39% | 13.19% | **0.11%** | 13.35% | **0.00%** | **0.00%** | | **0.00%** |
| Poland DEP | 0.00 | -0.04 | 0.01 | **0.13** | 0.00 | 0.03 | **0.95** | 0.98 | **49.15** |
| p-value | 39.09% | 39.97% | 59.06% | **0.00%** | 60.58% | 23.32% | **0.00%** | | **0.00%** |

**Europe/FX market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_j$ | $\varphi_j$ | $\omega*100$ | $a$ | $\beta$ | $a+\beta$ | LR TEST |
|---|---|---|---|---|---|---|---|---|---|
| *Czech Republic INF** | 0.00 | -0.06 | | | 0.00 | **0.10** | **0.85** | 0.95 | |
| p-value | 28.67% | 20.70% | | | 12.43% | **1.18%** | **0.00%** | | |
| Czech Republic DEP | 0.00 | 0.09 | -0.20 | -0.26 | **0.03** | **0.18** | **0.53** | 0.70 | 5.44 |
| p-value | 12.44% | 6.26% | 25.97% | 9.97% | **1.08%** | **2.06%** | **0.03%** | | 6.58% |
| *Hungary INF** | **0.00** | -0.07 | | | 0.00 | **0.08** | **0.89** | 0.97 | |
| p-value | **0.04%** | 39.40% | | | 26.39% | **2.01%** | **0.00%** | | |
| Hungary DEP | **0.00** | 0.00 | -0.16 | **-0.35** | **0.01** | **0.10** | **0.86** | 0.96 | 5.18 |
| p-value | **0.59%** | 92.53% | 34.06% | **1.47%** | **4.66%** | **0.51%** | **0.00%** | | 7.51% |
| *PolandINF** | 0.00 | -0.01 | | | 0.00 | **0.10** | **0.77** | 0.87 | |
| p-value | 94.98% | 89.57% | | | 6.77% | **1.53%** | **0.00%** | | |
| Poland DEP | 0.00 | -0.03 | -0.16 | **-0.58** | 0.00 | 0.04 | **0.94** | 0.98 | **15.38** |
| p-value | 12.93% | 51.15% | 28.11% | **0.01%** | 18.99% | 6.23% | **0.00%** | | **0.05%** |

* Please note that each of three studied relations investigating the influence of changes in euro on the CEECs' equity market requires separate first equation

**Table II.** The volatility spillover between CEEC - **CSM**

**a.** The volatility spillover from one CEECs' equity market to the other CEEC's equity market – **CSM**

**Czech Rep./equity market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_j$ | $\varphi_j$ | $\omega*100$ | $a$ | $\beta$ | $a+\beta$ | LR TEST |
|---|---|---|---|---|---|---|---|---|---|
| INF | 0.00 | **0.11** | | | **0.02** | **0.13** | **0.66** | 0.79 | |
| p-value | 6.84% | **2.66%** | | | **2.63%** | **2.37%** | **0.00%** | | |
| Hungary DEP | **0.00** | -0.06 | 0.08 | **0.57** | 0.00 | 0.07 | **0.91** | 0.98 | **118.53** |
| p-value | **1.94%** | 19.86% | 15.48% | **0.00%** | 21.51% | 7.28% | **0.00%** | | **0.00%** |
| Poland DEP | **0.00** | -0.06 | **0.20** | **0.62** | 0.00 | 0.03 | **0.96** | 0.99 | **104.50** |
| p-value | 67.68% | 16.21% | **0.02%** | **0.00%** | 33.88% | 9.67% | **0.00%** | | **0.00%** |

**Hungary/equity market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_j$ | $\varphi_j$ | $\omega*100$ | $a$ | $\beta$ | $a+\beta$ | LR TEST |
|---|---|---|---|---|---|---|---|---|---|
| INF | **0.00** | 0.01 | | | 0.01 | **0.07** | **0.89** | 0.96 | |
| p-value | **1.55%** | 79.51% | | | 8.31% | **2.05%** | **0.00%** | | |
| Czech Republic DEP | 0.00 | 0.06 | **0.09** | **0.29** | **0.02** | **0.18** | **0.58** | 0.76 | **97.78** |
| p-value | 23.29% | 21.05% | **1.32%** | **0.00%** | **3.34%** | **1.26%** | **0.01%** | | **0.00%** |
| Poland DEP | 0.00 | 0.03 | -0.01 | **0.58** | 0.00 | **0.04** | **0.94** | 0.98 | **157.15** |
| p-value | 40.81% | 53.21% | 90.60% | **0.00%** | 21.69% | **2.23%** | **0.00%** | | **0.00%** |

**Poland/equity market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_j$ | $\varphi_j$ | $\omega*100$ | $a$ | $\beta$ | $a+\beta$ | LR TEST |
|---|---|---|---|---|---|---|---|---|---|
| INF | 0.00 | 0.01 | | | 0.01 | 0.06 | **0.88** | 0.94 | |
| p-value | 30.43% | 79.02% | | | 7.49% | 6.06% | **0.00%** | | |
| Czech Republic DEP | **0.00** | 0.02 | 0.04 | **0.32** | 0.02 | 0.09 | **0.66** | 0.75 | **104.61** |
| p-value | **4.03%** | 68.56% | 24.41% | **0.00%** | 6.71% | 15.63% | **0.00%** | | **0.00%** |
| Hungary DEP | **0.00** | 0.01 | -0.01 | **0.52** | 0.00 | 0.04 | **0.94** | 0.99 | **177.20** |
| p-value | **0.17%** | 79.77% | 83.81% | **0.00%** | 16.73% | 11.69% | **0.00%** | | **0.00%** |

**b.** The volatility spillover from one CEECs' equity market to the CEEC's FX market - **CSM**

**Czech Rep./equity market to CEEC FX market**

| | $\mu_0$ | $\mu_1$ | $\gamma_j$ | $\varphi_j$ | $\omega*100$ | $a$ | $\beta$ | $a+\beta$ | LR TEST |
|---|---|---|---|---|---|---|---|---|---|
| INF | 0.00 | **0.11** | | | **0.02** | **0.13** | **0.66** | 0.79 | |
| p-value | 6.84% | **2.66%** | | | **2.63%** | **2.37%** | **0.00%** | | |
| Hungary DEP | **0.00** | -0.02 | 0.01 | **0.06** | 0.00 | 0.42 | 0.40 | 0.81 | **7.76** |
| p-value | **0.06%** | 84.32% | 42.93% | **0.28%** | 7.83% | 10.68% | 6.00% | | **2.07%** |
| Poland DEP | 0.00 | -0.03 | 0.02 | **0.08** | 0.00 | **0.10** | **0.74** | 0.84 | **33.89** |
| p-value | 95.91% | 43.92% | 7.37% | **0.00%** | 12.41% | **3.40%** | **0.00%** | | **0.00%** |

**Hungary/equity market to CEEC FX market**

| | $\mu_0$ | $\mu_1$ | $\gamma_j$ | $\varphi_j$ | $\omega*100$ | $a$ | $\beta$ | $a+\beta$ | LR TEST |
|---|---|---|---|---|---|---|---|---|---|
| INF | **0.00** | 0.01 | | | 0.01 | **0.07** | **0.89** | 0.96 | |
| p-value | **1.55%** | 79.51% | | | 8.31% | **2.05%** | **0.00%** | | |
| Czech Republic DEP | 0.00 | -0.07 | 0.01 | **0.02** | 0.00 | **0.13** | **0.79** | 0.93 | **9.18** |
| p-value | 39.43% | 16.56% | 14.46% | **3.29%** | 8.60% | **1.47%** | **0.00%** | | **1.01%** |
| Poland DEP | 0.00 | -0.04 | 0.01 | **0.06** | 0.00 | 0.04 | **0.94** | 0.98 | **40.26** |
| p-value | 17.79% | 38.22% | 24.77% | **0.00%** | 48.93% | 17.02% | **0.00%** | | **0.00%** |

**Poland/equity market to CEEC FX market**

| | $\mu_0$ | $\mu_1$ | $\gamma_j$ | $\varphi_j$ | $\omega*100$ | $a$ | $\beta$ | $a+\beta$ | LR TEST |
|---|---|---|---|---|---|---|---|---|---|
| INF | 0.00 | 0.01 | | | 0.01 | 0.06 | **0.88** | 0.94 | |
| p-value | 30.43% | 79.02% | | | 7.49% | 6.06% | **0.00%** | | |
| Czech Republic DEP | 0.00 | -0.07 | 0.00 | **0.02** | 0.00 | **0.13** | **0.80** | 0.93 | 5.53 |
| p-value | 31.89% | 18.97% | 94.53% | **4.34%** | 7.53% | **1.47%** | **0.00%** | | 6.30% |
| Hungary DEP | **0.00** | -0.09 | **0.02** | **0.05** | 0.00 | 0.36 | 0.44 | 0.80 | **24.31** |
| p-value | **0.05%** | 16.37% | **4.10%** | **0.00%** | 12.21% | 25.58% | 8.10% | | **0.00%** |

**c.** The volatility spillover from CEECs' FX to the CEEC's equity market - **CSM**

**Czech Rep./FX market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_j$ | $\varphi_j$ | $\omega*100$ | $a$ | $\beta$ | $a+\beta$ | LR TEST |
|---|---|---|---|---|---|---|---|---|---|
| INF | 0.00 | -0.06 | | | 0.00 | **0.10** | **0.85** | 0.95 | |
| p-value | 28.67% | 20.70% | | | 12.43% | **1.18%** | **0.00%** | | |
| Hungary DEP | 0.00 | 0.01 | -0.06 | 0.51 | 0.01 | **0.08** | **0.88** | 0.96 | **6.25** |
| p-value | 1.27% | 85.05% | 76.53% | 7.91% | 8.33% | **2.10%** | **0.00%** | | **4.40%** |
| Poland DEP | 0.00 | 0.00 | 0.13 | 0.46 | 0.01 | **0.06** | **0.88** | 0.94 | 5.41 |
| p-value | 18.87% | 98.16% | 55.25% | 5.94% | 11.45% | **2.36%** | **0.00%** | | 6.68% |

**Hungary/FX market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_j$ | $\varphi_j$ | $\omega*100$ | $a$ | $\beta$ | $a+\beta$ | LR TEST |
|---|---|---|---|---|---|---|---|---|---|
| INF | **0.00** | -0.07 | | | 0.00 | **0.08** | **0.89** | 0.97 | |
| p-value | **0.04%** | 39.38% | | | 26.39% | **2.01%** | **0.00%** | | |
| Czech Republic DEP | 0.00 | 0.09 | 0.14 | **0.64** | **0.02** | **0.13** | **0.64** | 0.78 | **18.75** |
| p-value | 9.87% | 5.30% | 29.94% | **0.03%** | **2.52%** | **2.58%** | **0.00%** | | **0.01%** |
| Poland DEP | 0.00 | -0.02 | 0.22 | **1.03** | 0.01 | **0.07** | **0.88** | 0.94 | **26.91** |
| p-value | 38.86% | 62.85% | 32.19% | **0.00%** | 12.21% | **1.08%** | **0.00%** | | **0.00%** |

**Poland/FX market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_j$ | $\varphi_j$ | $\omega*100$ | $a$ | $\beta$ | $a+\beta$ | LR TEST |
|---|---|---|---|---|---|---|---|---|---|
| INF | 0.00 | -0.01 | | | 0.00 | 0.10 | 0.77 | 0.87 | |
| p-value | 94.98% | 89.57% | | | 6.77% | **1.53%** | **0.00%** | | |
| Czech Republic DEP | **0.00** | 0.08 | 0.17 | **0.59** | **0.02** | **0.13** | **0.64** | 0.76 | **23.86** |
| p-value | **4.34%** | 8.75% | 16.80% | **0.00%** | **3.73%** | **4.03%** | **0.00%** | | **0.00%** |
| Hungary DEP | **0.00** | 0.03 | -0.16 | **0.96** | 0.00 | **0.05** | **0.92** | 0.98 | **39.17** |
| p-value | **1.20%** | 57.44% | 28.35% | **0.00%** | 13.43% | **4.36%** | **0.00%** | | **0.00%** |

**Table III.** The volatility spillover between "new" and "old" member countries of EU – **DVM**

**Europe/equity market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_{0,j}$ | $\gamma_{1,j}$ | $\varphi_{0,j}$ | $\varphi_{1,j}$ | $\omega * 100$ | $a$ | $\beta$ | $a+\beta$ | WALD test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | **0.00** | **-0.13** | | | | | 0.00 | **0.16** | **0.82** | 0.98 | |
| p-value | **0.34%** | **1.06%** | | | | | 5.50% | **0.03%** | **0.00%** | | |
| Czech Republic DEP | **0.00** | **0.11** | -0.04 | -0.01 | **0.36** | **0.52** | **0.02** | 0.09 | **0.74** | 0.83 | 3.87 |
| p-value | **2.81%** | **2.06%** | 51.50% | 97.53% | **0.00%** | **4.96%** | **4.61%** | 5.24% | **0.00%** | | 14.41% |
| Hungary DEP | **0.01** | -0.03 | 0.02 | -0.29 | **0.71** | -0.32 | 0.01 | **0.10** | **0.83** | 0.92 | 1.36 |
| p-value | **0.02%** | 57.16% | 75.02% | 38.77% | **0.00%** | 29.96% | 12.39% | **3.95%** | **0.00%** | | 50.78% |
| Poland DEP | **0.00** | -0.01 | 0.03 | -0.21 | **0.66** | 0.29 | 0.00 | **0.04** | **0.95** | 0.99 | 2.04 |
| p-value | **2.52%** | 90.41% | 66.34% | 42.43% | **0.00%** | 30.87% | 31.68% | **2.08%** | **0.00%** | | 36.06% |

**Europe/equity market to CEEC FX market**

| | $\mu_0$ | $\mu_1$ | $\gamma_{0,j}$ | $\gamma_{1,j}$ | $\varphi_{0,j}$ | $\varphi_{1,j}$ | $\omega * 100$ | $a$ | $\beta$ | $a+\beta$ | WALD test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | **0.00** | **-0.13** | | | | | 0.00 | **0.16** | **0.82** | 0.98 | |
| p-value | **0.34%** | **1.06%** | | | | | 5.50% | **0.03%** | **0.00%** | | |
| Czech Republic DEP | 0.00 | -0.07 | 0.00 | 0.01 | 0.01 | -0.02 | 0.00 | **0.11** | **0.84** | 0.95 | 0.12 |
| p-value | 26.20% | 19.52% | 84.10% | 85.40% | 30.10% | 75.28% | 11.02% | **1.17%** | **0.00%** | | 94.20% |
| Hungary DEP | **0.00** | -0.01 | 0.02 | -0.09 | **0.10** | 0.00 | 0.00 | **0.12** | **0.88** | 1.00 | 1.92 |
| p-value | **0.00%** | 87.44% | 10.58% | 16.56% | **0.11%** | 98.00% | 7.90% | **0.00%** | **0.00%** | | 38.23% |
| Poland DEP | 0.00 | -0.04 | 0.02 | -0.02 | **0.14** | -0.07 | 0.00 | 0.03 | **0.95** | 0.98 | 2.40 |
| p-value | 36.70% | 35.49% | 46.97% | 75.76% | **0.00%** | 12.21% | 60.19% | 23.51% | **0.00%** | | 30.18% |

**Europe/FX market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_{0,j}$ | $\gamma_{1,j}$ | $\varphi_{0,j}$ | $\varphi_{1,j}$ | $\omega * 100$ | $a$ | $\beta$ | $a+\beta$ | WALD test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Czech Republic INF** | 0.00 | -0.06 | | | | | 0.00 | **0.10** | **0.85** | 0.95 | |
| p-value | 28.67% | 20.70% | | | | | 12.43% | **1.18%** | **0.00%** | | |
| Czech Republic DEP | 0.00 | 0.09 | -0.24 | 0.76 | -0.28 | 0.51 | **0.02** | **0.18** | **0.54** | 0.72 | 2.41 |
| p-value | 10.13% | 6.18% | 19.61% | 15.48% | 8.58% | 43.41% | **1.04%** | **1.82%** | **0.01%** | | 30.02% |
| *Hungary INF** | **0.00** | -0.07 | | | | | 0.00 | **0.08** | **0.89** | 0.97 | |
| p-value | **0.04%** | 39.40% | | | | | 26.39% | **2.01%** | **0.00%** | | |
| Hungary DEP | **0.00** | 0.01 | -0.19 | 0.64 | -0.23 | **-1.81** | 0.00 | **0.09** | **0.89** | 0.97 | **12.48** |
| p-value | **1.09%** | 80.84% | 23.30% | 20.42% | 9.58% | **0.12%** | 6.83% | **0.53%** | **0.00%** | | **0.20%** |
| *PolandINF** | 0.00 | -0.01 | | | | | 0.00 | **0.10** | **0.77** | 0.87 | |
| p-value | 94.98% | 89.57% | | | | | 6.77% | **1.53%** | **0.00%** | | |
| Poland DEP | 0.00 | -0.03 | -0.14 | -0.20 | **-0.61** | 0.31 | 0.00 | 0.04 | **0.94** | 0.98 | 0.70 |
| p-value | 12.95% | 51.23% | 38.17% | 58.86% | **0.02%** | 50.42% | 19.93% | 6.30% | **0.00%** | | 70.55% |

**Table IV.** The volatility spillover between CEEC - **DVM**

**a.** The volatility spillover from one CEECs' equity market to the other CEEC's equity market – **DVM**

**Czech Rep./equity market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_{0,j}$ | $\gamma_{1,j}$ | $\varphi_{0,j}$ | $\varphi_{1,j}$ | $\omega * 100$ | $a$ | $\beta$ | $a+\beta$ | WALD test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | 0.00 | **0.11** | | | | | **0.02** | **0.13** | **0.66** | 0.79 | |
| p-value | 6.84% | **2.66%** | | | | | **2.63%** | **2.37%** | **0.00%** | | |
| Hungary DEP | **0.00** | **-0.07** | 0.08 | -0.03 | **0.59** | -0.22 | 0.00 | 0.07 | **0.91** | 0.98 | 1.65 |
| p-value | **1.22%** | 18.92% | 15.04% | 87.53% | **0.00%** | 21.71% | 22.28% | 7.41% | **0.00%** | | 43.83% |
| Poland DEP | 0.00 | -0.05 | **0.19** | -0.04 | **0.57** | -0.07 | 0.00 | **0.04** | **0.94** | 0.98 | 0.24 |
| p-value | 37.32% | 21.34% | **0.09%** | 80.20% | **0.00%** | 62.40% | 26.57% | **3.34%** | **0.00%** | | 88.64% |

**Hungary/equity market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_{0,j}$ | $\gamma_{1,j}$ | $\varphi_{0,j}$ | $\varphi_{1,j}$ | $\omega * 100$ | $a$ | $\beta$ | $a+\beta$ | WALD test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | **0.00** | 0.01 | | | | | 0.01 | **0.07** | **0.89** | 0.96 | |
| p-value | **1.55%** | 79.51% | | | | | 8.31% | **2.05%** | **0.00%** | | |
| Czech Republic DEP | 0.00 | 0.06 | **0.08** | 0.07 | **0.28** | 0.06 | **0.02** | **0.18** | **0.58** | 0.76 | 0.32 |
| p-value | 26.05% | 22.12% | **1.69%** | 66.53% | **0.00%** | 68.19% | **3.55%** | **1.39%** | **0.01%** | | 85.28% |
| Poland DEP | 0.00 | 0.01 | 0.02 | 0.02 | **0.55** | -0.03 | 0.00 | **0.04** | **0.94** | 0.98 | 0.07 |
| p-value | 33.18% | 81.57% | 71.90% | 87.18% | **0.00%** | 85.63% | 22.35% | **2.55%** | **0.00%** | | 96.44% |

**Poland/equity market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_{0,j}$ | $\gamma_{1,j}$ | $\varphi_{0,j}$ | $\varphi_{1,j}$ | $\omega * 100$ | $a$ | $\beta$ | $a+\beta$ | WALD test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | 0.00 | 0.01 | | | | | 0.01 | 0.06 | **0.88** | 0.94 | |
| p-value | 30.43% | 79.02% | | | | | 7.49% | 6.06% | **0.00%** | | |
| Czech Republic DEP | **0.00** | 0.03 | 0.04 | -0.03 | **0.31** | 0.23 | 0.02 | 0.08 | **0.69** | 0.77 | 2.75 |
| p-value | **4.82%** | 61.69% | 27.47% | 81.30% | **0.00%** | 10.13% | 7.96% | 19.09% | **0.00%** | | 25.30% |
| Hungary DEP | **0.00** | 0.01 | 0.00 | -0.18 | **0.52** | -0.01 | 0.00 | 0.04 | **0.94** | 0.98 | 1.32 |
| p-value | **0.11%** | 80.43% | 95.99% | 31.42% | **0.00%** | 96.95% | 16.87% | 11.55% | **0.00%** | | 51.71% |

## **b.** The volatility spillover from one CEECs' equity market to the CEEC's FX market – **DVM**

**Czech Rep./equity market to CEEC FX market**

| | $\mu_0$ | $\mu_1$ | $\gamma_{0,j}$ | $\gamma_{1,j}$ | $\varphi_{0,j}$ | $\varphi_{1,j}$ | $\omega * 100$ | $a$ | $\beta$ | $a+\beta$ | WALD test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | 0.00 | **0.11** | | | | | **0.02** | **0.13** | **0.66** | 0.79 | |
| p-value | 6.84% | **2.66%** | | | | | **2.63%** | **2.37%** | **0.00%** | | |
| Hungary DEP | **0.00** | -0.01 | | -0.02 | **0.06** | 0.00 | 0.00 | 0.43 | 0.39 | 0.81 | 0.31 |
| p-value | **0.09%** | 89.33% | 39.10% | 59.44% | **0.47%** | 93.74% | 7.73% | 9.85% | 6.64% | | 85.48% |
| Poland DEP | 0.00 | -0.03 | 0.02 | 0.10 | **0.08** | 0.02 | 0.00 | **0.12** | **0.72** | 0.83 | **7.17** |
| p-value | 75.78% | 47.10% | 24.32% | 5.02% | **0.00%** | 64.53% | 10.15% | **2.07%** | **0.00%** | | **2.78%** |

**Hungary/equity market to CEEC FX market**

| | $\mu_0$ | $\mu_1$ | $\gamma_{0,j}$ | $\gamma_{1,j}$ | $\varphi_{0,j}$ | $\varphi_{1,j}$ | $\omega * 100$ | $a$ | $\beta$ | $a+\beta$ | WALD test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | **0.00** | 0.01 | | | | | 0.01 | **0.07** | **0.89** | 0.96 | |
| p-value | **1.55%** | 79.51% | | | | | 8.31% | **2.05%** | **0.00%** | | |
| Czech Republic DEP | 0.00 | -0.07 | 0.01 | 0.00 | **0.02** | 0.00 | 0.00 | **0.13** | **0.79** | 0.93 | 0.03 |
| p-value | 39.00% | 16.43% | 14.79% | 88.17% | **3.92%** | 89.45% | 8.61% | **1.47%** | **0.00%** | | 98.32% |
| Poland DEP | 0.00 | -0.04 | 0.01 | 0.04 | **0.06** | 0.00 | 0.00 | 0.04 | **0.94** | 0.98 | 0.59 |
| p-value | 16.47% | 37.66% | 30.20% | 48.15% | **0.00%** | 98.08% | 49.06% | 16.90% | **0.00%** | | 74.32% |

**Poland/equity market to CEEC FX market**

| | $\mu_0$ | $\mu_1$ | $\gamma_{0,j}$ | $\gamma_{1,j}$ | $\varphi_{0,j}$ | $\varphi_{1,j}$ | $\omega * 100$ | $a$ | $\beta$ | $a+\beta$ | WALD test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | 0.00 | 0.01 | | | | | 0.01 | 0.06 | **0.88** | 0.94 | |
| p-value | 30.43% | 79.02% | | | | | 7.49% | 6.06% | **0.00%** | | |
| Czech Republic DEP | 0.00 | -0.07 | 0.00 | 0.04 | 0.02 | 0.03 | 0.00 | **0.13** | **0.80** | 0.93 | 3.13 |
| p-value | 38.76% | 18.91% | 92.06% | 10.54% | 6.42% | 28.76% | 7.51% | **1.42%** | **0.00%** | | 20.93% |
| Hungary DEP | **0.00** | -0.07 | **0.02** | -0.03 | **0.05** | **0.10** | 0.00 | 0.37 | 0.43 | 0.80 | **22.91** |
| p-value | **0.05%** | 31.53% | **3.65%** | 21.41% | **0.00%** | **0.01%** | 11.86% | 23.81% | 7.97% | | **0.00%** |

## **c.** The volatility spillover from CEECs' FX to the CEEC's equity market - **DVM**

**Czech Rep./FX market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_{0,j}$ | $\gamma_{1,j}$ | $\varphi_{0,j}$ | $\varphi_{1,j}$ | $\omega * 100$ | $a$ | $\beta$ | $a+\beta$ | WALD test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | 0.00 | -0.06 | | | | | 0.00 | **0.10** | **0.85** | 0.95 | |
| p-value | 28.67% | 20.70% | | | | | 12.43% | **1.18%** | **0.00%** | | |
| Hungary DEP | **0.00** | 0.01 | -0.05 | -0.19 | 0.53 | -0.30 | 0.01 | **0.07** | **0.89** | 0.96 | 0.27 |
| p-value | **1.01%** | 86.33% | 83.00% | 81.81% | 8.25% | 62.82% | 8.52% | **2.18%** | **0.00%** | | 87.56% |
| Poland DEP | 0.00 | 0.00 | 0.21 | -1.00 | 0.47 | -0.02 | 0.01 | **0.07** | **0.87** | 0.94 | 1.62 |
| p-value | 14.27% | 99.45% | 33.84% | 23.27% | 6.95% | 97.44% | 11.11% | **1.80%** | **0.00%** | | 44.52% |

**Hungary/FX market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_{0,j}$ | $\gamma_{1,j}$ | $\varphi_{0,j}$ | $\varphi_{1,j}$ | $\omega * 100$ | $a$ | $\beta$ | $a+\beta$ | WALD test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | **0.00** | -0.07 | | | | | 0.00 | **0.08** | **0.89** | 0.97 | |
| p-value | **0.04%** | 39.38% | | | | | 26.39% | **2.01%** | **0.00%** | | |
| Czech Republic DEP | 0.00 | 0.09 | 0.17 | -0.68 | **0.61** | 0.65 | **0.02** | **0.12** | **0.68** | 0.80 | 2.43 |
| p-value | 10.18% | 5.05% | 21.33% | 31.88% | **0.09%** | 36.53% | **2.81%** | **3.71%** | **0.00%** | | 29.60% |
| Poland DEP | 0.00 | -0.01 | 0.24 | -0.51 | **0.85** | **1.94** | 0.01 | **0.07** | **0.89** | 0.96 | **16.36** |
| p-value | 57.61% | 82.81% | 29.31% | 37.38% | **0.09%** | **0.12%** | 10.50% | **0.29%** | **0.00%** | | **0.03%** |

**Poland/FX market to CEEC equity market**

| | $\mu_0$ | $\mu_1$ | $\gamma_{0,j}$ | $\gamma_{1,j}$ | $\varphi_{0,j}$ | $\varphi_{1,j}$ | $\omega * 100$ | $a$ | $\beta$ | $a+\beta$ | WALD test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| INF | 0.00 | -0.01 | | | | | 0.00 | 0.10 | 0.77 | 0.87 | |
| p-value | 94.98% | 89.57% | | | | | 6.77% | **1.53%** | **0.00%** | | |
| Czech Republic DEP | **0.00** | 0.08 | 0.18 | -0.16 | **0.59** | 0.05 | **0.02** | **0.13** | **0.64** | 0.77 | 0.20 |
| p-value | **4.18%** | 8.79% | 15.47% | 67.71% | **0.00%** | 88.97% | **3.71%** | **4.00%** | **0.00%** | | 90.46% |
| Hungary DEP | **0.00** | 0.03 | -0.14 | -0.28 | **1.02** | -0.50 | 0.00 | **0.05** | **0.92** | 0.98 | 1.01 |
| p-value | **0.61%** | 59.76% | 39.90% | 59.09% | **0.00%** | 38.41% | 13.88% | **4.50%** | **0.00%** | | 60.43% |

**Table V.** Asymmetries in relations between "old" and "new" EU countries: GJR model and cross-correlations

**Europe/equity market to CEEC equity market**

| | $\delta$ | cross-correlation |
|---|---|---|
| INF | 0.09 | **yes** |
| p-value | 27.17% | |
| Czech Republic DEP | 0.08 | no |
| p-value | 32.33% | |
| Hungary DEP | 0.02 | no |
| p-value | 75.13% | |
| Poland DEP | 0.03 | no |
| p-value | 16.79% | |

**Europe/equity market to CEEC FX market**

| | $\delta$ | cross-correlation |
|---|---|---|
| INF | 0.09 | *yes* |
| p-value | 27.17% | |
| Czech Republic DEP | -0.05 | no |
| p-value | 54.29% | |
| Hungary DEP | -0.12 | no |
| p-value | 16.90% | |
| Poland DEP | **0.20** | **yes/non-negative** |
| p-value | **1.69%** | |

**Europe/FX market to CEEC equity market**

| | $\delta$ | cross-correlation |
|---|---|---|
| *Czech Republic INF* | 0.04 | no |
| p-value | 61.28% | |
| Czech Republic DEP | 0.11 | no |
| p-value | 21.82% | |
| *Hungary INF* | 0.07 | no |
| p-value | 48.91% | |
| Hungary DEP | 0.01 | no |
| p-value | 89.29% | |
| *PolandINF* | **-0.23** | **yes/non-negative** |
| p-value | **0.64%** | |
| Poland DEP | -0.01 | **yes** |
| p-value | 81.64% | |

**Table VI.** Asymmetries in relations from one CEECs' equity market to the other CEEC's equity market: GJR model and cross-correlations

**Czech Rep./equity market to CEEC equity market**

| | $\delta$ | cross-correlation |
|---|---|---|
| INF | 0.15 | no |
| p-value | 10.00% | |
| Hungary DEP | -0.01 | **yes/non-negative** |
| p-value | 86.41% | |
| Poland DEP | 0.02 | no |
| p-value | 68.63% | |

**Hungary/equity market to CEEC equity market**

| | $\delta$ | cross-correlation |
|---|---|---|
| INF | 0.04 | no |
| p-value | 49.30% | |
| Czech Republic DEP | 0.13 | **yes** |
| p-value | 18.38% | |
| Poland DEP | 0.02 | **yes** |
| p-value | 61.71% | |

**Poland/equity market to CEEC equity market**

| | $\delta$ | cross-correlation |
|---|---|---|
| INF | 0.01 | no |
| p-value | 87.54% | |
| Czech Republic DEP | 0.12 | no |
| p-value | 18.35% | |
| Hungary DEP | -0.04 | no |
| p-value | 22.19% | |

**Table VII.** Asymmetries in relations from one CEECs' equity market to the other CEEC's FX market: GJR model and cross-correlations

| **Czech Rep./equity market to CEEC FX market** | | |
|---|---|---|
| | $\delta$ | cross-correlation |
| INF | 0.15 | no |
| p-value | 10.00% | |
| Hungary DEP | 0.91 | no |
| p-value | 11.49% | |
| Poland DEP | **0.20** | **yes** |
| p-value | **3.33%** | |

| **Hungary/equity market to CEEC FX market** | | |
|---|---|---|
| | $\delta$ | cross-correlation |
| INF | 0.04 | no |
| p-value | 49.30% | |
| Czech Republic DEP | -0.04 | no |
| p-value | 65.74% | |
| Poland DEP | **0.19** | **yes** |
| p-value | **1.68%** | |

| **Poland/equity market to CEEC FX market** | | |
|---|---|---|
| | $\delta$ | cross-correlation |
| INF | 0.01 | no |
| p-value | 87.54% | |
| Czech Republic DEP | -0.05 | no |
| p-value | 57.20% | |
| Hungary DEP | 0.01 | no |
| p-value | 97.63% | |

**Table VIII.** Asymmetries in relations from one CEECs' FX market to the other CEEC's equity market: GJR model and cross-correlations

| **Czech Rep./FX market to CEEC equity market** | | |
|---|---|---|
| | $\delta$ | cross-correlation |
| INF | -0.04 | no |
| p-value | 61.79% | |
| Hungary DEP | 0.04 | no |
| p-value | 43.39% | |
| Poland DEP | 0.01 | no |
| p-value | 84.65% | |

| **Hungary/FX market to CEEC equity market** | | |
|---|---|---|
| | $\delta$ | cross-correlation |
| INF | -0.07 | no |
| p-value | 51.53% | |
| Czech Republic DEP | 0.14 | no |
| p-value | 11.10% | |
| Poland DEP | -0.03 | no |
| p-value | 57.60% | |

| **Poland/FX market to CEEC equity market** | | |
|---|---|---|
| | $\delta$ | cross-correlation |
| INF | **0.23** | **yes** |
| p-value | **0.67%** | |
| Czech Republic DEP | 0.16 | **yes** |
| p-value | 9.67% | |
| Hungary DEP | 0.01 | no |
| p-value | 89.43% | |

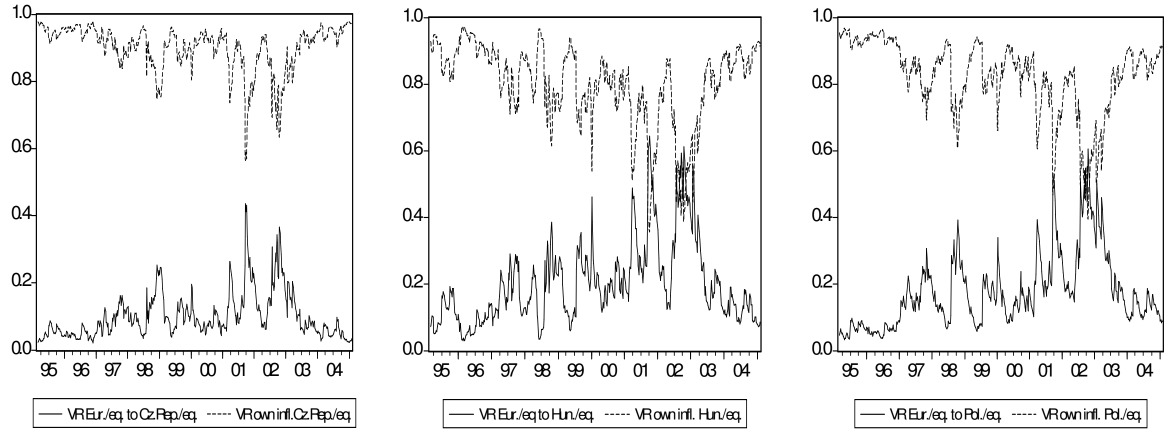
**Table IX.** Strategies of accession to ERM II and EMU

| | ERM II entry | Length of ERM II | EURO |
|---|---|---|---|
| Czech Republic | latest in 2 years | 2 years (shortest) | as soon as ready 2009-2010 |
| **Hungary** | **ASAP** | **as necessary** | **ASAP 2008** |
| Poland | latest in 2 years | 2 years (shortest) | as soon as ready 2008-2009 |

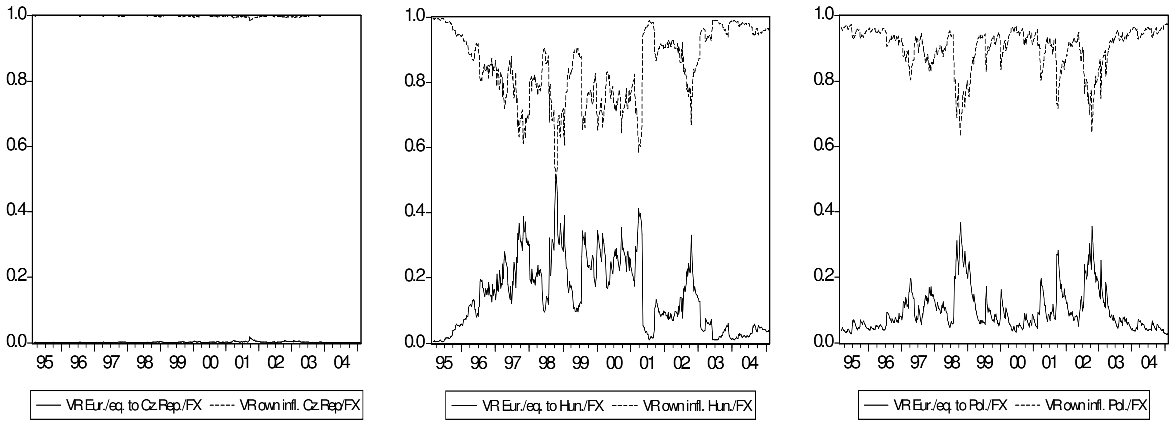
## APPENDIX II FIGURES

**Figure I.** VR – volatility spillover between new and old member countries of EU – **CSM**

### Europe/eq. to CEEC/eq.




### Europe / eq. to CEEC/EUR FX




### Europe/ FX to CEEC/ eq.

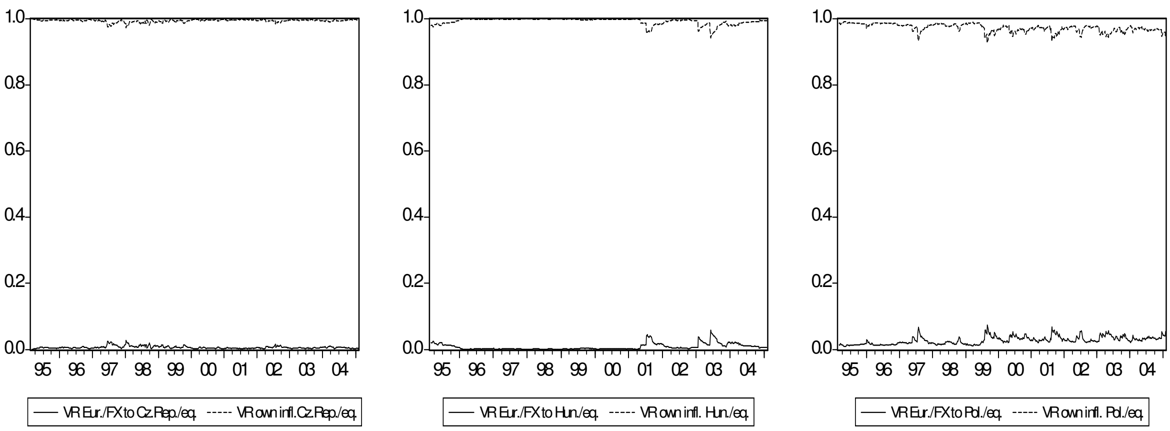
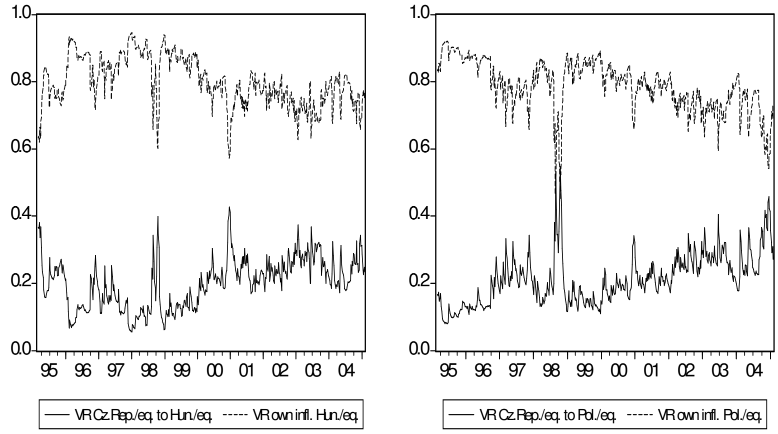


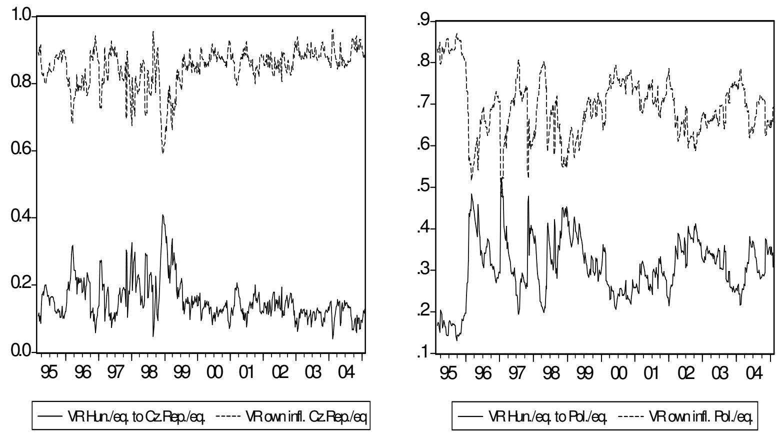
**Figure II.** VR - volatility spillover effect between CEECs – **CSM**

**a.** VR - volatility spillover from one CEECs' equity market to the other CEEC's equity market

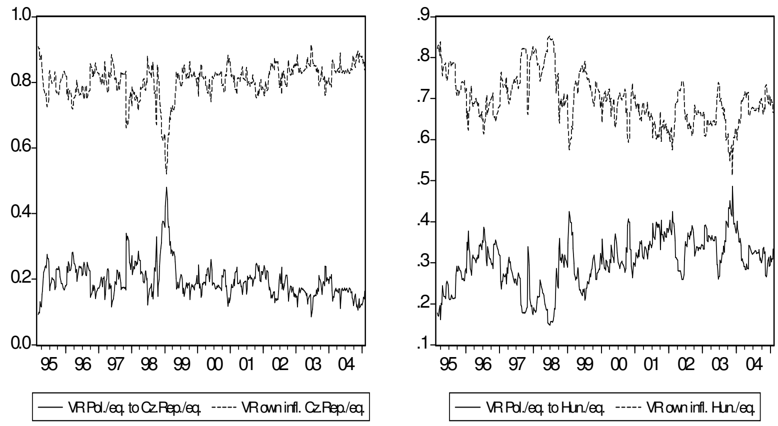
**Czech Republic/ eq. to CEEC/ eq.**




**Hungary/ eq. to CEEC/ eq.**

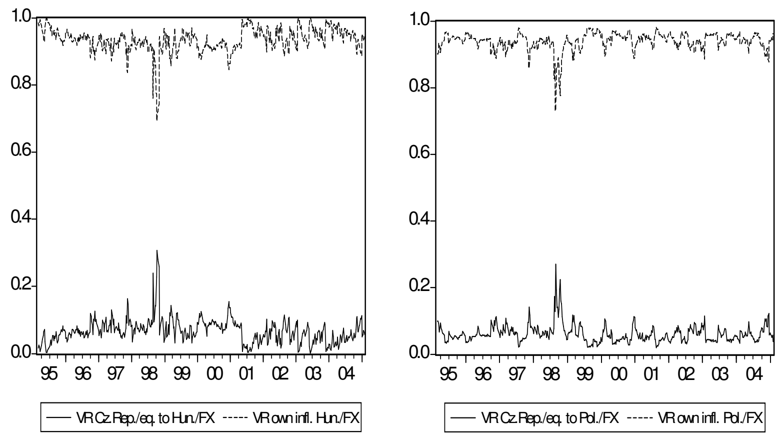



**Poland/ eq. to CEEC/ eq.**

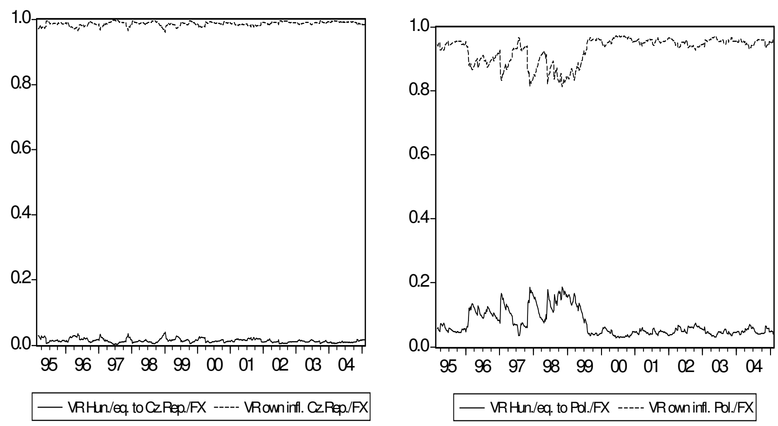


**b.** VR - volatility spillover from one CEECs' equity market to the other CEEC's FX market

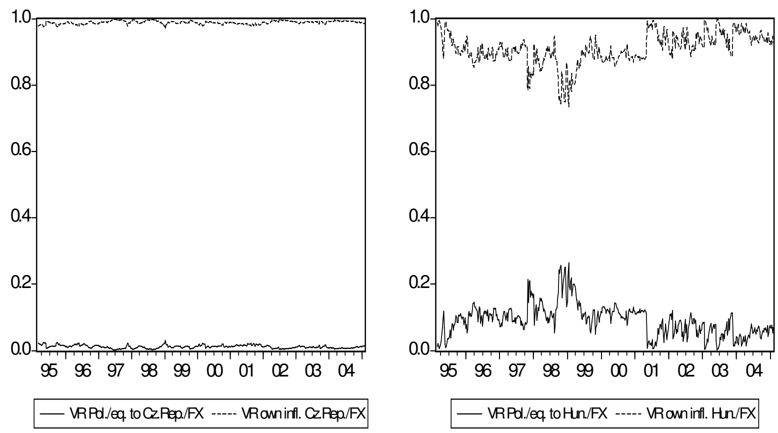
### Czech Republic/ eq. to CEEC/ FX




### Hungary/ eq. to CEEC/ FX

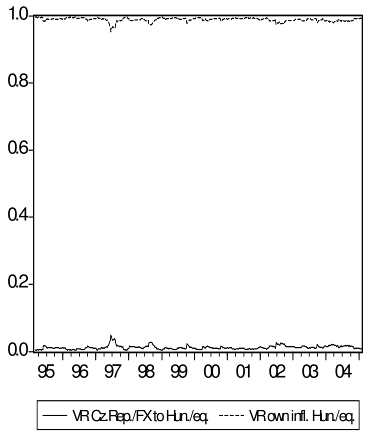


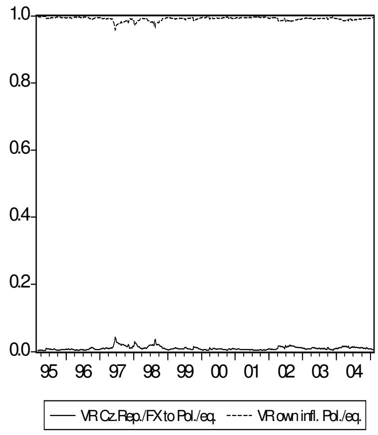

### Poland/ eq. to CEEC/ FX



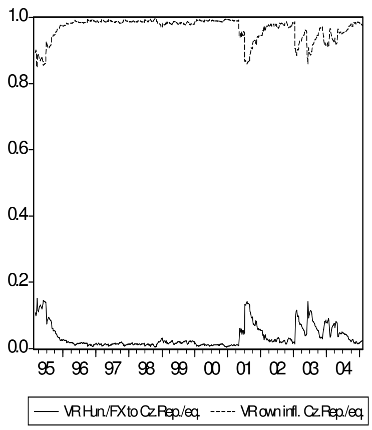
**c.** VR - volatility spillover from one CEECs' FX market to the other CEEC's equity market

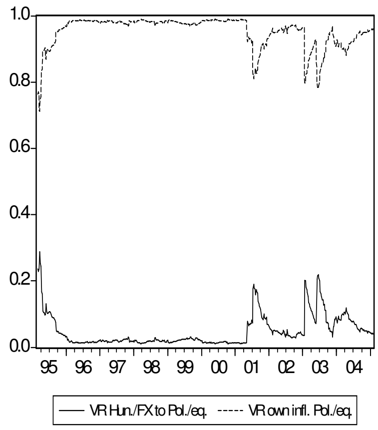
**Czech Republic/ FX to CEEC/ eq.**



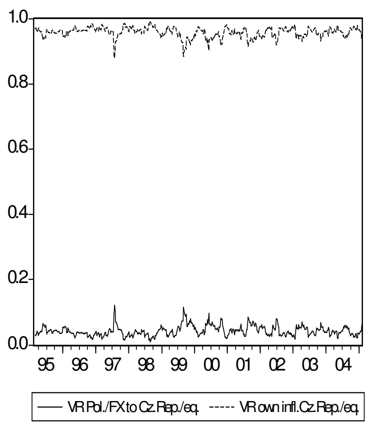




**Hungary/ FX to CEEC/ eq.**




**Poland/ FX to CEEC/ eq.**



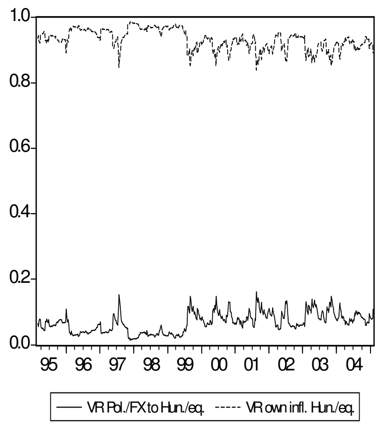
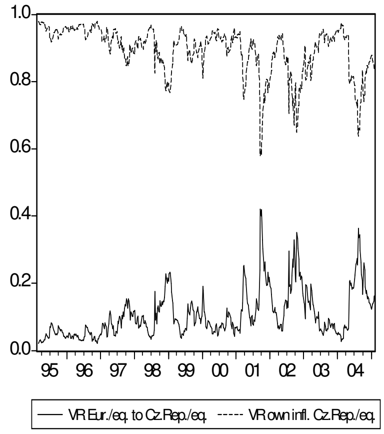



**Figure III.** VR – volatility spillover between new and old member countries of EU – **DVM (only significant changes)**

**Europe/ eq. to Czech Republic/ eq.**




**Europe/FX to Hungary/eq.**

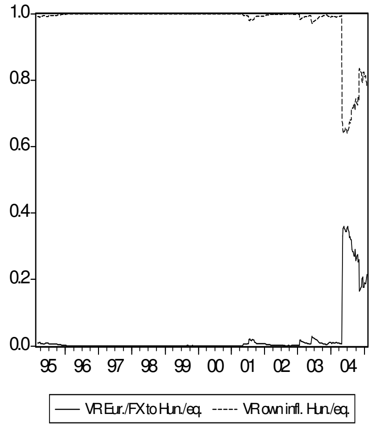
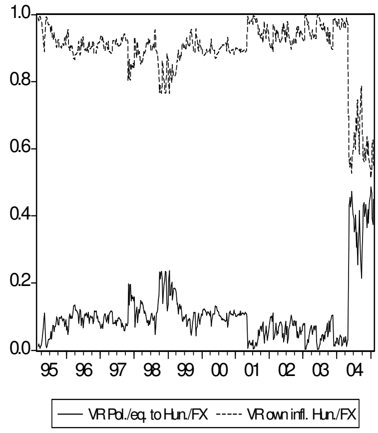



**Figure IV.** VR - volatility spillover effect between CEECs – **DVM (only significant changes)**

**Poland/eq. to Hungary/FX**




**Hungary/FX to Poland/eq.**

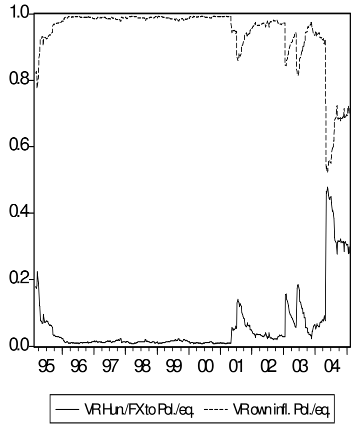
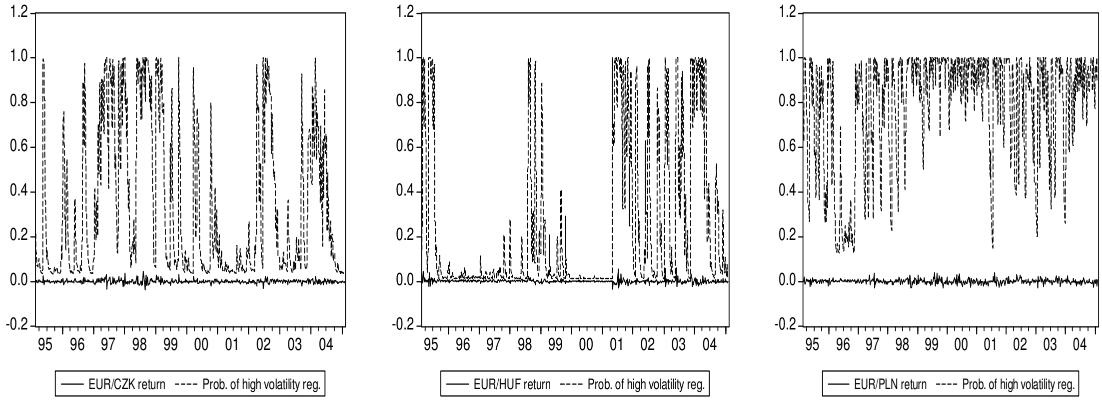


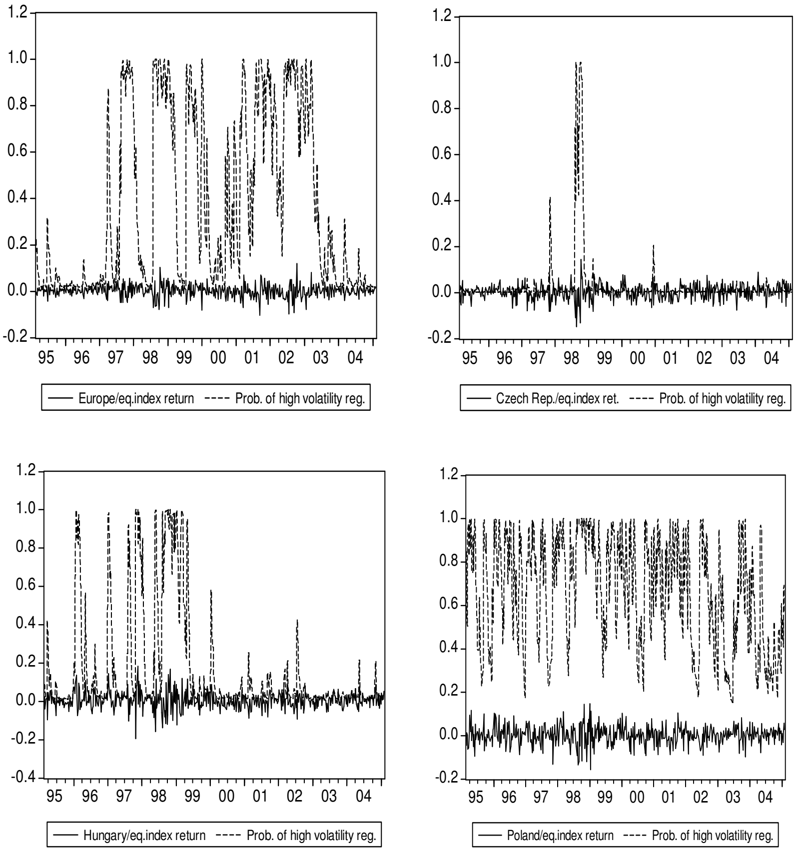
**Figure V.** Regime switching process – probability of high volatility regime

**a.** Exchange rate returns




| WALD TEST (Chi-square) | EUR/CZK | EUR/HUF | EUR/PLN |
|---|---|---|---|
| equal mean | 2.84 | 0.01 | **8.87** |
| *p-value* | 9.21% | 92.68% | **0.29%** |
| equal variance | **54.21** | **74.57** | **136.57** |
| *p-value* | **0.00%** | **0.00%** | **0.00%** |

**b.** Equity returns




| WALD TEST (Chi-square) | Europe/eq. | Cz.Rep./eq. | Hungary/eq. | Poland/eq. |
|---|---|---|---|---|
| equal mean | **6.22** | 0.84 | 0.88 | 0.96 |
| *p-value* | **1.26%** | 35.92% | 34.79% | 32.62% |
| equal variance | **64.01** | 2.64 | **13.12** | **59.49** |
| *p-value* | **0.00%** | 10.43% | **0.03%** | **0.00%** |

## APPENDIX III PROGRAMMING

**I.** Regime switching process with different mean and different variance (slightly changed version of programming presented by Ulf Erlandsson, PhD, Department of Economics, Lund University)

```
'Create a dummy-variable for the first observation
series d1 = 0
smpl @first @first
d1 = 1
smpl @all
'Set starting values for the maximization
coef (6) c
c(1)=0.002
c(2)=0.001
c(3)=0.01
c(4)=0.08
c(5)=1
c(6)=1
'Define pi
!pi=3.1415926535898
'Remove the rs log-likelihood object (so we start from scratch)
'If you run the program for the first time, write " 'delete rs" instead
delete rs
'Create the log-likelihood object rs
logl rs
rs.append @logl rslogl1
'Compute residuals for respective regime (variable x)
rs.append res1=x-c(1)
rs.append res2=x-c(2)
'Compute variance
rs.append var1=c(3)^2
rs.append var2=c(4)^2
'Transform the parameters c(4) and c(5) using a logit
transformation to obtain boundaries [0,1]
rs.append p11=exp(c(5))/(1+exp(c(5)))
rs.append p22=exp(c(6))/(1+exp(c(6)))
'Unconditional probability of state 1
rs.append ergo=(1-p22)/(2-p11-p22)
'Calculation of f(y_t|S_t=i)
rs.append eta1=1/(@sqrt(2*!pi*var1))*@exp(-(res1^2)/(2*var1))
rs.append eta2=1/(@sqrt(2*!pi*var2))*@exp(-(res2^2)/(2*var2))
'Calculation of the denominator in Pr(S_t=i|y_t)
rs.append bt=@recode(d1=1,ergo*eta1+(1-ergo)*eta2, xittpo1(-1)*eta1+xittpo2(-1)*eta2)
'Calculation of  Pr(S_t=i|y_t)
'the "@recode(condition,a,b)" function has the value a if condition is fulfilled, and b otherwise
'here: if we are at the first observation, use long-run probabilities of states,
'otherwise, calculate traditional Pr(S_t=i|y_t)
rs.append xitt1=@recode(d1=1,(ergo*eta1)/bt,(xittpo1(-1)*eta1)/bt)
rs.append xitt2=@recode(d1=1,((1-ergo)*eta2)/bt,(xittpo2(-1)*eta2)/bt)
'Calculation of Pr(S_(t+1)=i|S_t)
rs.append xittpo1=xitt1*p11+xitt2*(1-p22)
rs.append xittpo2=xitt2*p22+xitt1*(1-p11)
'The log likelihood object
rs.append rslogl1=@log(bt)
rs.ml(h,b,showopts, m=500, c=0.0001)
show rs.output
```