VOLATILITY SPILLOVERS BETWEEN STOCK AND CURRENCY MARKETS: EVIDENCE FROM EMERGING EASTERN EUROPE

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The purpose of this study is in three folds. First we look at the linkage between Eastern European emerging equity markets and Russia, second we investigate the relationship among the currency markets of Poland, Hungry, Russia and Czech Republic. Finally, we examine the interdependence between Emerging Eastern European equity and currency markets. We estimate a bivariate VAR-GARCH-BEKK model proposed by Engle and Kroner (1995) using weekly returns. We find the evidence of direct linkage between the equity markets, both in regards of returns and volatility, as well as in currency markets. While analyzing the relationship between currency and stock markets we found unidirectional volatility spillovers from currency to stock markets.

JEL Classification: C32, G15

Keywords: GARCH-BEKK representation, volatility spillovers, stock market, currency exchange market, Emerging Eastern Europe, currency risk

1 INTRODUCTION

Emerging Eastern European stock markets have become an interest of international financial research and community during the last decade. These markets raise the financial market investors' attention due to diversification opportunities for international investors; they become more attractive and accessible for investing due to decreasing restrictions on transactions for international investors, series of reforms and increasing financial transparency. Expanding of the European Union (EU) began with the inner six member states in 1951. The EU's membership has grown to twenty seven members with the most recent joined countries in 2007 Bulgaria and Romania. Currently negotiations for accession are under consideration with several other countries. The European Union enlargement creates a

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unique landscape for new financial investigations and analysis, giving the opportunities for testing new appearing applications and model procedures. Countries, joining the European Union, provide for the researchers such fields for investigation as integration of new members into European financial system, comovements of these countries, contagion of financial processes and changes, influence of positive and negative news in one European Union member to another, etc.

One of the main issues, which have attracted a lot of researchers' attention, is the volatility spillovers on different financial markets. Earlier empirical research have found the existence of unidirectional and bidirectional spillovers between different international stock markets (e.g., Caporale et al. (2002), Li (2007), Xu and Fung (2002), Choudhry (2004), Darrat and Benkato (2003), Kasch-Haroutounian and Price (2001)). A bulk of studies focused their attention on volatility spillovers within the developed financial markets such as in Karolyi (1995), Elyasiani and Mansur (2003), Darrat and Benkato (2003), Kearney and Patton (2000), Dark et al. (2005), Lucey and Voronkova (2006), Francis et al. (2006) and Yang and Doong (2004). Yang and Doong (2004), Francis et al. (2006) and Dark et al. (2005) studied the volatility spillovers in developed countries between currency and stock markets. They found evidence of unidirectional and bidirectional return and volatility spillovers between these markets. Yang and Doong (2004) state that the exchange rate changes influence on the stock market with the less direct impact then the stock market on the currency exchange market. Such kind of transmission mechanism on developed markets is natural and expected as there is no such significant change on the developed currency markets.

There exists many volatility spillovers' studies on emerging stock and currency exchange markets as well, such as of Asia and Latin America (Hashmi and Tai (2007), Gebka and Serwa (2007), Choudhry (2000) and (2004), Caporale et al. (2002), Xu and Fung (2002), Li (2007), Pyun et al. (2000), Yang and Chang (2008), Morales (2008), Tai (2007), and Qayyum and Kemal (2006)). Yang and Chang (2008), Morales (2008), Tai (2007), Qayyum and Kemal (2006) found support of spillovers existence on Asian and Latin American financial markets. Morales (2008) and Tai (2007) found the evidence of volatility effects from the stock to currency markets. Yang (2008) in his work states that interaction between the information of stock and foreign exchange markets lead to asymmetric reactions of stock returns and their associated variability. However, they found support of bidirectional volatility spillovers on these markets as well (Qayyum and Kemal (2006)).

There are some other studies on volatility spillovers between stock markets. Previous literature provides the evidence of unidirectional volatility spillovers between stock markets. Li (2007) found the unidirectional interdependence between Chinese stock markets. Hashmi and Tai (2007) found support of this phenomenon among financial markets of Korea, Thailand, Singapore, Taiwan, Malaysia and China. Choudhry (2000) found support of increase in spillovers after the 1987 world wide stock exchange crash. Other researchers found the evidence of bidirectional influence on stock markets of India, Pakistan, Israel, Jordan, Indonesia, Japan, Korea, Thailand, Malaysia, Taiwan, Argentina, Brazil, Chile and Mexico (e.g., Choundhry (2004), Caporale et al. (2002), Gebka and Serwa (2007)). Xu and Fung (2002) studied China-backed stocks dual-listed in Hong Kong and New York and their information flows across financial markets. They state that stocks listed on the domestic market play more significant role of information transmission in the pricing process, while listed on the offshore market play a bigger role in volatility transmission. Choundhry (2004) studied spillovers effects from the point of view of political relationship between countries. He found the evidence of spillovers from a larger distant friendly country to smaller emerging markets.

A lot of work has been done on volatility spillovers, integration and information transmission on Eastern European stock markets as well (Fedorova and Vaihekoski (2009), Buttner and Hayo (2008), Patev et al. (2004), Orlowski (2003)). There exists literature on volatility spillovers, which do not provide neither evidence of volatility spillovers nor time-varying correlation between Eastern European Emerging markets[1]. Other literature gives the partial evidence of volatility spillovers for some particular countries but not for other countries. Syllignakis and Kouretas (2006) found that Central European countries have significant common component on the financial markets but neither Russia, nor Estonia. Rockinger and Urga (2001) state that shocks in the UK are positively related to Czech and Polish markets but not to Russian and Hungarian stock markets; also that bad news generates greater volatility spillovers than the good news. Scheicher (2001) reported low correlations between Eastern European and international stock markets. Wang and Moore (2009), Yang et al. (2006), Syriopoulos (2004) and (2006), Kasch-Haroutounian and Price (2001), Li and Majerowska (2008) found the evidence of volatility spillovers between different European stock markets

[1] Gupta and Jithendranathan (2008) did not find the interdependence between the UK, Russia and Hungary; Lucey and Voronkova (2008) state that Russian equity market remained isolated from the influence of international financial markets; Patev and Kanaryan (2003) stated that there are no volatility spillovers on Hungarian, Polish, Czech and Slovenian stock markets.

(Polish, Hungarian, Czech, Slovenian, Slovakian). Syriopoulos (2004) and Li and Majerowska (2008) found support of volatility spillover effects from developed to emerging stock markets. Darrat and Benkato (2003) and Lucey and Voronkova (2006) in their works studied the issues of developed markets integration with some of emerging stock markets. They found strong evidence of emerging markets integration with the developed markets during the last decade. The increase in integration scale based on their works starts after Asian crises and post-liberalization periods.

To study volatility spillover effect researchers have applied different methodologies such as VAR analysis (see, e.g. Syriopoulos (2007), Lucey and Voronkova (2006)) and another set of methodology such as ARCH (see, e.g. Patev et al. (2004), Scheicher (2001), Syllignakis and Kouretas (2006), and Urga (2001), Hashmi and Tay (2007), Li (2007), Gebka (2007), Tai (2007)). In addition researchers have been used different cointegration tests such as Johansen procedure, McCabe-Leybourne-Harris stochastic test, Gregory-Hansen residual based test, Breitung non-parametric test, regime-switching test have also been used in prior literature (Lucey and Voronkova (2006), (2008)).

This paper investigates the relationship between Eastern European stock markets and foreign exchange markets using the VAR-GARCH (1, 1) process, for which BEKK methodology is adopted, developed by Engle and Kroner (1995), as per the best of authors' knowledge this particular methodology has not been used to analyse the relationship between stock and currency markets of Eastern European countries. We investigate relationship between different stock markets, different currency exchange markets and between stock and currency exchange markets within one country, whether changes on one market influence on the performance of other market. There has been done before a few studies on volatility spillovers between stock and currency exchange markets in Emerging Eastern European countries such as Poland, Hungary, the Czech Republic and Russia.

The sample period is from 1995 to 2008 covering Poland, Hungary, the Czech Republic and Russia. All these countries experience changes in economies on the way from communist to capitalist regulation systems. Poland, Hungary and the Czech Republic recently joined the European Union. These countries have the biggest stock markets in Emerging Eastern Europe in terms of markets capitalization. All sample countries are growing fast given wide range of opportunities for local and foreign investors.

We believe that investors, portfolio managers and bankers using the whole available information for their financial decisions on stock and currency exchange markets influence on volatility performance on these markets. We found that all stock markets interact through their returns and volatilities. Currency exchange markets of these countries are highly interacted as well. Analyses of stock and currency exchange markets provide the evidence of volatility spillovers from currency markets to stock markets in all countries. In addition the Czech stock market significantly affects the foreign exchange market through volatility terms. Our findings are consistent with the previous research works (see, e.g. Yang and Doong (2004), Dark et al. (2005) and Francis et al. (2006)).

This paper is organized as following. The second section presents the theoretical background and the empirical formulation of the testable model. Section 3 introduces the sample countries, the data used in the study and its descriptive statistics. Section 4 provides the results from the analysis. Concluding remarks and suggestions for future research are offered in Section 5.

2 MODEL SPECIFICATION

The Autogressive Conditional Heteroscedasticity (ARCH) process proposed by Engle (1982) and the generalised ARCH (GARCH) by Bollerslev (1986) are well known in volatility modelling of stock returns. In examining volatility linkages between countries, however, a multivariate GARCH approach is preferred over univariate settings. Unfortunately, such models can only be estimated by imposing specific restrictions on the conditional variance-covariance matrix (e.g. positive definiteness). The early model proposal of Bollerslev et al. (1988) – ostensibly for checking the volatility linkage between countries – fails to assure the positive definiteness of the conditional variance matrix. Moreover, it does not allow cross-equation conditional variances and covariances to affect each other due to its oversimplifying restrictions. Most of these problems are avoided in the newer BEKK (Baba, Engle, Kraft and Kroner) parameterization proposed by Engle and Kroner (1995). Using quadratic forms to ensure positive definiteness, the BEKK model complies with the hypothesis of constant correlation and permits for volatility spillover across markets. There is a trade-off, however, between generality and increasing computational difficulty with higher dimensional systems.

We start our empirical specification with a bivariate VAR-GARCH (1, 1) model that accommodates each market's returns and the returns of other markets lagged one period.[2]

(1) $$r_t = \alpha + \beta r_{t-1} + u_t,$$

(2) $$u_t | \Omega_{t-1} \sim N(0, H_t),$$

where r_t is an $n\times 1$ vector of weekly returns at time t for each market. The $n\times 1$ vector of random errors μ_t represents the innovation for each market at time t with its corresponding $n\times n$ conditional variance-covariance matrix $\boldsymbol{H_t}$. The market information available at time t-1 is represented by the information set Ω_{t-1}. The $n\times 1$ vector, α, represents the constant. The own market mean spillovers and cross-market mean spillovers are measured by the estimates of matrix β elements, the parameters of the autoregressive term. This multivariate structure thus facilitates the measurement of the effects of innovations in the mean stock returns of one series on its own lagged returns and those of the lagged returns of other markets.

Given the above expression, and following Engle and Kroner (1995), the conditional covariance matrix can be stated as:

(3) $$H_t = C_0' C_0 + A_{11}' \varepsilon_{t-1} \varepsilon_{t-1}' A_{11} + G_{11}' H_{t-1} G_{11},$$

where the parameter matrices for the variance equation are defined as $\boldsymbol{C_0}$, which is restricted to be lower triangular and two unrestricted matrices $\boldsymbol{A_{11}}$ and $\boldsymbol{G_{11}}$. Thus, the second moment can be represented by:

(4) $$H_t = C_0' C_0 + \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}' \begin{bmatrix} \varepsilon_{1,t-1}^2 & \varepsilon_{1,t-1}, \varepsilon_{2,t-1} \\ \varepsilon_{1,t-1}, \varepsilon_{2,t-1} & \varepsilon_{2,t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} + \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}' H_{t-1} \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}.$$

The equation (4) for $\boldsymbol{H_t}$, further expanded by matrix multiplication, takes the following form:

(5) $$h_{11,t} = c_{11}^2 + a_{11}^2 \varepsilon_{1,t-1}^2 + 2a_{11}a_{21}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{21}^2 \varepsilon_{2,t-1}^2 + g_{11}^2 h_{11,t-1} + 2g_{11}g_{21}h_{12,t-1} + g_{21}^2 h_{22,t-1},$$

[2] This model is based on the bivariate GARCH (1,1)-BEKK representation proposed by Engle and Kroner (1995).

(6) $$h_{12,t} = c_{11}c_{21} + a_{11}a_{12}\varepsilon^2_{1,t-1} + (a_{21}a_{12} + a_{11}a_{22})\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{21}a_{22}\varepsilon^2_{2,t-1} + g_{11}g_{12}h_{11,t-1} + (g_{21}g_{12} + g_{11}g_{22})h_{12,t-1} + g_{21}g_{22}h_{22,t-1},$$

(7) $$h_{22,t} = c^2_{21} + c^2_{22} + a^2_{12}\varepsilon^2_{1,t-1} + 2a_{12}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a^2_{22}\varepsilon^2_{2,t-1} + g^2_{12}h_{11,t-1} + 2g_{12}g_{22}h_{12,t-1} + g^2_{22}h_{22,t-1}.$$

To test for a causality effect from the first market to the second market a_{12} and g_{12} are set to zero. The variance and covariance equations take the form:

(8) $$h_{11,t} = c^2_{11} + a^2_{11}\varepsilon^2_{1,t-1} + 2a_{11}a_{21}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a^2_{21}\varepsilon^2_{2,t-1} + g^2_{11}h_{11,t-1} + 2g_{11}g_{21}h_{12,t-1} + g^2_{21}h_{22,t-1},$$

(9) $$h_{12,t} = c_{11}c_{21} + a_{11}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{21}a_{22}\varepsilon^2_{2,t-1} + g_{11}g_{22}h_{12,t-1} + g_{21}g_{22}h_{22,t-1},$$

(10) $$h_{22,t} = c^2_{21} + c^2_{22} + a^2_{22}\varepsilon^2_{2,t-1} + g^2_{22}h_{22,t-1}.$$

Similarly, a_{21} and g_{21} are set equal to zero to test for a causality effect from the second market to the first. The maximum likelihood estimations are optimised with the Berndt, Hall, Hall and Hausman (BHHH) algorithm.[3] From equations (5) to (10) we obtain the conditional log likelihood function $L(\theta)$ for a sample of T observations:

(11) $$L(\theta) = \sum_{t=1}^{T} l_t(\theta),$$

(12) $$l_t(\theta) = -\log 2\pi - 1/2\log\left|H_t(\theta)\right| - 1/2\varepsilon_t^{'}(\theta)H_t^{-1}(\theta)\varepsilon_t(\theta),$$

where θ denotes the vector of all the unknown parameters. Numerical maximisation of equation (11) and (12) yields the maximum likelihood estimates with asymptotic standard errors.

Finally, to test the null hypothesis that the model is correctly specified, or equivalently, that the noise terms, μ_t, are random, the Ljung-Box Q-statistic is used. It is assumed to be asymptotically distributed as χ^2 with $(p - k)$ degrees of freedom, where k is the number of explanatory variables.

[3] We also tried the Marquardt maximum likelihood method, but the BHHH algorithm was found to perform better.

3 DATA AND DISCRIPTIVE STATISTICS

The tests in this paper are conducted on four major emerging countries from Eastern Europe. Sample period is from January 1995 to December 2008. Our analysis is from US investors' point of view i.e. all returns are measured in U.S. dollars. We use weekly total return indices, which frequently have been used in studies (see, e.g. Lucey and Voronkova (2005), Guptka and Jithedranathan (2008), Syllignakis and Kouretas (2006) and Beirne et al. (2009)), which are based on week-end observations of total return market indices throughout the paper.

As test assets in the analysis we utilize market portfolios from each one of the sample countries. As a proxy for the market stock return we use the Datastream indices. These indices were available for countries of investigation for the longer period and have frequently been used in similar studies (see, e.g. Saleem, 2009). Indices include gross dividends i.e. they measure the total pre-tax return for investors. All data is extracted from Datastream database.

3.1 Sample countries and test assets

In our study we select sample countries such as Russia, Poland, Hungary and the Czech Republic. All economies of these countries are in transition from communist system to capitalist one, but in many ways their development has diverged. For example, Poland, Hungary and the Czech Republic are relatively new European Union countries, joined in May 2004. Russia, on the other hand, is not a member of the EU and has no intention of becoming one. All countries have their own currencies.

Stock markets of sample countries were established at 19^{th} and at the beginning of 20^{th} centuries. However, during the communist regime, the stock exchanges were closed in all countries. The first ones to open their stocks markets after the end of communist era were Hungary and Poland in mid-1991. Russian stock market began its activity in 1992. The Prague Stock Exchange in the Czech Republic was opened last, in 1993.

Figure 1 shows the stock market capitalization (% of GDP, column graph) and GDP (in millions of US$, line graph) of these emerging countries over the sample period 1995-2007. Russian Federation outstands in relatively high market capitalization among others; while Poland, Hungary and the Czech Republic had approximately equal level of capitalization over the last five years (2003-2007).

The Figures 2 and 3 show historical changes of local return indices and exchange rates for the analyzed sample countries. Stock return graph exhibits a significant growth on the Russian stock market from the middle of 1996 comparing to other stock markets up till Russian financial crisis on 17 of August, 1998. Series of reforms were carried out at that time including denomination of Russian ruble what is reflected on the Figure 3 in significant weakening of ruble. Stock indices were growing and local currencies were getting stronger positions relative to USD dollar since then. In the middle of 2008 the situation on financial markets was changed again. This phenomenon found a reflection in the increase of local currencies exchange rates relative to USD dollar. The descriptive statistics for asset returns and exchange rate changes is introduced in Tables 1 and 2.

3.2 Correlation analysis

We start our investigation by studying time series development of correlations between stocks and currencies markets for each country. This analysis shows the evidence of correlation between the asset two markets (i.e., stock and currency market) in whole sample period. Figures 4 shows 52-week rolling-window correlation coefficients.

We see that the correlations have been volatile during the sample period. The whole period of correlation analysis 1996-2008 we divide into tree subsets. In the first subset is 1996-summer 2002, in this period the correlations between stock and exchange markets for each of analysed countries were rather volatile. In the second subset (summer 2002-summer 2007) distinctly we observe the increase in correlations between stock and exchange markets, correlations between Russian stock and currency markets are more volatile than between these markets in other countries. But after summer 2007 the interaction between stock and currency markets is again volatile. This might take place because of economic instability presence of equity and currency exchange markets in these countries and in the world.

4 EMPIRICAL RESULTS

4.1 Linkage between equity markets

Our empirical results answer the theoretical questions formulated in the previous sections. First, to examine the linkage between stock markets six pair-wise models are estimated utilizing bivariate VAR-GARCH(1, 1) frame work, for which a BEKK representation is adopted. The modelled pairs are Russia – Poland, Russia – Hungary, Russia – the Czech Republic, Poland – the Czech Republic, Poland – Hungary and Hungary – the Czech Republic, using weekly total return indices calculated by Datastream from January 1995 to December 2008.

First we look at matrix β in the mean equation, Eq. (1), captured by the parameters c_{ii} in Table 3, in order to see the relationship in terms of returns within the countries in each pair. Returns of Russia are found highly dependent on their first lags as the diagonal parameters c_{11} for all the modelled pairs with Russia are statistically significant, while the diagonal parameters c_{11} for all the modelled pairs with Poland except Russia also found statistically significant, suggesting that the returns of Poland also depend on their first lags. Similar results were found for Hungary and the Czech Republic. In contrast, the insignificant diagonal parameter c_{22} of Poland and Hungary when modelled with Russia; and Hungary and the Czech Republic when modelled with Poland indicates that their returns do not depend on their own past returns.

Next we examine the estimated results of the time-varying variance-covariance Eq. (4) in the system. The matrices A and G reported in Table 3 help examine the relationship in terms of volatility as stated in Eq. (4). The diagonal elements in matrix A capture the own ARCH effect, while the diagonal elements in matrix G measure the own GARCH effect. As shown in Table 3, the estimated diagonal parameters, a_{11}, a_{22} and g_{11}, g_{22} are all statistically significant, indicating a strong GARCH (1, 1) process driving the conditional variances of the six pair wise indices. In other words, own past shocks and volatility effect the conditional variance of Polish, Czech, Hungarian and Russian indices.

The off-diagonal elements of matrices A and G capture the cross-market effects such as shock and volatility spillovers among the four pairs. First, we document shock transmissions between Russia and other markets, we evidence unidirectional link between Russia and Poland and Russia and the Czech Republic, as well as, Russia and Hungary; interestingly the direction is from Russia to Poland, Hungary and the Czech Republic, as only the off-diagonal parameter a_{12} is statistically significant at 5% level of significance, meaning that Russian shocks (e.g., Russian crisis of 1998) have affected the mean returns in the Czech, Hungarian and Polish equity markets. While analyzing shock transmissions between Poland and the Czech Republic and the Czech Republic and Hungary we found bidirectional effects. Poland and Hungary exhibit unidirectional shock transmission.

Second, we explain the volatility spillovers between the modelled pairs. We found very interesting results, for example, Russian effect dominates in case of Russia and Poland as well as Russia and the Czech Republic and Russia and Hungary. Hungarian effect dominates in case of Hungary and the Czech Republic and the Czech Republic volatility spillovers to Poland in case of Poland and the Czech Republic modelled pair. Among Poland and Hungary we found bidirectional spillovers. These results show clear evidence of Eastern European markets integration within the region and with Russia as well.

4.2 Linkage between Currency markets

Next we answer our second question: the linkage between the currency markets of selected Eastern European markets and Russia. Again, utilizing the BEKK framework, we estimate six pair wise models explained in the previous section.

While documenting the shock transmissions between Russian ruble and other currencies, we found bidirectional correlation between Russian ruble and Czech koruna, at the same time, sudden shocks of Polish zloty and Hungarian forint were found effecting on the movements of Russian ruble, whereas the volatility in Russian currency market clearly spillovers between the modelled pairs. In case of three selected Eastern European currency markets, we evidence unidirectional volatility spillovers between Poland and Hungary as well as Hungary and the Czech Republic. Bidirectional volatility transmissions were found in case of Poland and the Czech Republic. Estimated results are reposted in Table 4. Again, our results show clear evidence of Eastern European currency markets integration within the region and with Russia as well.

4.3 Linkage between stock and currency markets

Finally, we examine the transmission of shocks and volatility between the stock market and currency market of Russia, Poland, Hungary and the Czech Republic. We present our analysis in the same fashion as in previous sections. Four pair wise models are estimated as before.

We start with the mean equation of the system, results reported in Table 5 show that only Russian and the Czech Republic stock returns depends on their first lags, while the respective currency market returns do not depend on their first lags. Hungarian stock and currency return both depend on their first lags, while no return dependency was found in case of polish currency market.

Next, we document the shocks and volatility spillovers represented by vector a_{ij} and g_{ij}. In all the modelled pairs we evidence strong ARCH and GARCH effect as in every case the diagonal elements of matrices A and G, a_{ij} and $g_{i\cdot}$, which capture the within the market effects such as shock and volatility spillovers among the two assets, are highly significant, which also indicates the suitability of our model selection.

Then, we explain the shock and volatility spillovers between the modelled pairs. The off-diagonal elements of matrices A capture the cross-market shock effects. Russian stock market and currency market as well as polish stock and currency market show evidence of bi-directional effects, meaning that changes in the currency market influence on the stock market as well; and in the same way fluctuations in the stock market affect the currency market. Currency market shocks were found dominating in case of Hungary and the Czech Republic. In the end, we present the off-diagonal elements of matrices G capture the cross-market volatility spillovers. In all the modelled pairs currency market volatility found significantly affecting the stock market, only the Czech Republic returns were found effecting the currency market.

4.4 Diagnostic tests

Panel B of Table 3, 4 and 5 presents the Ljung-Box Q-statistic used to test the null hypothesis that the model is correctly specified, or equivalently, that the noise terms are random. We report both standardised and standardised squared residuals up to lag 24 for each modelled pair. Results show no series dependence in the squared standardised residuals, indicating the appropriateness of the GARCH-BEKK model. Moreover, Johansen cointegration test also establish the interdependence among the markets and assets during the studied period. We report both the maximum eigenvalue and trace statistics in Table 5, panel D, which clearly reject the null of no cointegration at the 5% level of significance, which suggests a common stochastic trend between the markets and assets included in the system.

5 SUMMARY AND CONCLUSIONS

In this paper we study the relationship between Eastern European and Russian stock markets, foreign exchange markets and stock and foreign exchange markets using the GARCH model. The tests are conducted on four major emerging countries from Eastern Europe: Poland, Hungary, the Czech Republic and Russia. Sample period is from January 1995 to December 2008. First we look at the linkage between three Eastern European emerging equity markets and Russia, second we investigate the relationship among the currency markets of these countries. Finally, we examine the interdependence between equity markets and currency markets of Poland, Hungry, Russia and the Czech Republic. We estimate a bivariate VAR-GARCH-BEKK model proposed by Engle and Kroner (1995) by using weekly returns.

First we found the dependence of returns on almost the all Emerging Eastern European stock markets on their first lag values. This phenomenon did not find support on Polish and Hungarian stock markets modelled with Russian equity market; and Hungarian and Czech stock markets estimated with Polish market. We found the strong support of relevance GARCH (1, 1) specification in modeling volatility spillovers for Emerging Eastern European stock markets. Our empirical results reveal that shocks on Russian stock markets affect the mean returns on Czech, Hungarian and Polish equity markets. We also found support for bi-directional effect in Poland – the Czech Republic, Poland – Hungary and Hungary – the Czech Republic interdependences. The evidence of volatility spillovers was found to be bidirectional in case of Russia – Hungary and Poland – Hungary interdependence; while unidirectional effects were found from Russian to Polish, from Russian to Czech, from Hungarian to Czech and from Polish to Czech stock markets.

Analysis of linkages between currency markets gave the evidence of bidirectional spillovers between almost the all currency markets of our investigation. Only in Poland – the Czech Republic interdependence was found the support of volatility spillovers from Polish to Czech currency markets. These findings show that currency risk matters, which are consistent with the previous findings (see, e.g. in developed markets Antell and Vaihekoski (2007) and in emerging markets Saleem and Vaihekoski (2007), (2008)).

Linkages between stock and currency markets are highly significant in Emerging European stock markets. In all countries of our investigation we found the evidence of volatility spillovers from currency to stock markets. Besides that we found the support of Czech stock market influence on currency market through volatility terms. These results show the evidence of integration in emerging Eastern European stock markers, what is consistent with the previous research (see, e.g. Fedorova and Vaihekoski (2009), Brooks and Del Negro (2002)).

This research can be extended by investigation of interdependence of stock and currency markets not only within one country, but across different countries. Also this analysis will benefit from including other emerging markets into research investigation.

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Table 1. Descriptive statistics for the asset returns

Panel A reports descriptive statistics for the continuously compounded returns on risk-free asset and four Eastern European emerging market. Panel B reports pairwise correlations for the return series. Index series are from the Datastream. Sample period is from January 1995 to December 2008. All returns are calculated in U.S. dollars and they include dividends (i.e., total return). The risk-free rate is calculated from the Eurodollar rate. The sample includes 730 weekly observations. Mean and standard deviation have been annualized. The *p*-value for the Jarque-Bera test statistic of the null hypothesis of normal distribution is provided in the table.

Asset return series	**Mean** (%)	**Std. dev. (%)**	**Skewness**	**Excess Kurtosis**	**Normality** (p-value)	**Autocorrelation**[a] ρ_1	ρ_2	ρ_3	ρ_{27}	**Q(27)**[b]
Panel A: Summary statistics										
Risk-free rate	4.212	0.248	-0.597	1.826	<0.001	0.992*	0.983*	9.973*	0.823*	<0.001
Russia	16.635	43.748	-0.180	6.736	<0.001	0.142*	0.102*	0.010*	-0.040*	<0.001
Poland	8.117	33.287	-0.447	6.169	<0.001	0.013	0.079	-0.006	-0.048	0.259
Hungary	10.806	33.527	-1.245	12.928	<0.001	0.015	0.101*	-0.027*	0.022*	0.024
Czech Republic	14.456	26.417	-0.717	10.424	<0.001	0.032	0.096*	-0.027*	0.026	0.156

Panel B: Pairwise correlations	Rf	Russia	Poland	Hungary	Czech
Risk-free rate	1	-0.030	-0.027	-0.056	-0.116
Russia		1	0.400	0.478	0.425
Poland			1	0.663	0.607
Hungary				1	0.646
Czech Republic					1

a) Autocorrelation coefficients significantly (5%) different from zero are marked with an asterisk (*).
b) The *p*-value for the Ljung-Box test statistic for the null that autocorrelation coefficients up to 27 lags are zero.

Table 2. Descriptive statistics for bilateral exchange rate changes against the USD

Panel A reports descriptive statistics for the first logarithmic differences in several exchange rates against the USD. Panel B reports pairwise correlation coefficients between the variables. Sample period is from January 1995 to December 2008. The sample includes 730 weekly observations. Mean and standard deviation have been annualized. The *p*-value for the Jarque-Bera test statistic of the null hypothesis of normal distribution is provided in the table.

Currency exchange rate	**Mean** (%)	**Std. dev. (%)**	**Skewness**	**Excess Kurtosis**	**Normality** (p-value)	**Autocorrelation[a]** ρ_1	ρ_2	ρ_3	ρ_{27}	**Q(27)[b]**
Panel A: Summary statistics										
Russia	-14.881	18.379	-13.633	277.320	<0.001	0.070*	0.256*	0.145*	-0.011*	<0.001
Poland	-1.315	12.188	-1.453	17.587	<0.001	-0.061	0.040	0.098*	-0.020	0.514
Hungary	-3.724	11.927	-0.468	6.054	<0.001	0.024	-0.034	0.095*	-0.006	0.727
Czech Republic	2.844	11.6628	-0.090	13.377	<0.001	0.033	0.034	0.001	0.013	0.399
Panel B: Pairwise correlations	Russia	Poland	Hungary	Czech						
Russia	1	0.066	0.059	-0.049						
Poland		1	0.720	0.620						
Hungary			1	0.680						
Czech Republic				1						

a) Autocorrelation coefficients significantly (5%) different from zero are marked with an asterisk (*).
b) The *p*-value for the Ljung-Box test statistic for the null that autocorrelation coefficients up to 12 lags are zero.

Table 3. Mean and volatility spillovers for stock markets estimated from a bivariate GARCH(1, 1)-BEKK model of weekly return indices

The diagonal elements in matrix C represent the mean equation while matrix A captures own and cross-market ARCH effects. The diagonal elements in matrix G measure own and cross-market GARCH effects. LB and LB^2 presents the Ljung-Box Q-statistic for standardized and standardized squared residuals. (*) denotes the significance level at 5%, (**) denotes the significance level at 10%.

Panel A: GARCH(1, 1)-BEKK estimations												
	Russia-Poland		**Russia-Hungary**		**Russia-Czech R.**		**Poland-Hungary**		**Poland-Czech R.**		**Hungary-Czech R.**	
Parameters	Coef.	SE.	Coef.	SE.	Coef.	SE.	Coef.	SE.	Coef.	SE.	Coef.	SE.
μ_1	0.005*	(0.002)	0.007*	(0.002)	0.005*	(0.002)	0.004*	(0.001)	0.002	(0.002)	0.004*	(0.002)
μ_2	0.003**	(0.002)	0.004*	(0.001)	0.004*	(0.001)	0.004*	(0.001)	0.004*	(0.001)	0.005*	(0.001)
C_{11}	0.008*	(0.002)	0.007*	(0.002)	0.006*	(0.002)	0.010*	(0.002)	0.006*	(0.002)	0.016*	(0.003)
C_{12}	0.009*	(0.003)	0.021*	(0.002)	0.009*	(0.004)	0.014*	(0.003)	0.009*	(0.002)	-0.006	(0.005)
C_{22}	0.001	(0.014)	0.003 [a]	(0.030)	0.007*	(0.002)	0.075 [a]	(0.003)	0.003	(0.002)	0.009*	(0.004)
A_{11}	0.342*	(0.037)	0.325*	(0.0433)	0.259*	(0.032)	0.274*	(0.045)	0.158*	(0.029)	0.202*	(0.064)
A_{12}	0.162*	(0.067)	0.240*	(0.038)	0.069*	(0.024)	0.221*	(0.054)	0.071*	(0.031)	-0.122*	(0.054)
A_{21}	-0.088**	(0.048)	-0.085**	(0.044)	0.032	(0.088)	0.083	(0.052)	0.207*	(0.042)	0.364*	(0.064)
A_{22}	0.107*	(0.041)	0.278*	(0.058)	0.355*	(0.059)	0.279*	(0.058)	0.358*	(0.047)	0.388*	(0.049)
G_{11}	0.950*	(0.011)	0.952*	(0.009)	0.964*	(0.007)	0. 962*	(0.014)	0.982*	(0.007)	0.815*	(0.083)
G_{12}	-0.030*	(0.011)	-0.022*	(0.017)	-0.014*	(0.007)	-0.044*	(0.018)	-0.014	(0.010)	0.200*	(0.101)
G_{21}	-0.033	(0.023)	-0.006	(0.032)	-0.019	(0.047)	-0.063*	(0.028)	-0.064*	(0.022)	0.027	(0.085)
G_{22}	0.954*	(0.019)	0.733*	(0.053)	0.863*	(0.052)	0.869*	(0.043)	0.885*	(0.031)	0.723*	(0.107)
Panel B: Diagnostic tests												
LogLik	2433.647		2451.999		2626.917		2739.468		2872.394		2899.752	
LB_1	58.599*		59.893*		63.998*		31.349		31.070		38.436	
LB_2	30.383		35.180		32.341		39.250		32.315		35.062	
LB^2_1	18.995		23.224		21.342		14.858		13.914		14.589	
LB^2_2	23.614		12.551		20.657		10.176		19.971		20.891	

a) Value was multiplied by 100 000.

Table 4. Mean and volatility spillovers for currency markets estimated from a bivariate GARCH(1, 1)-BEKK model of weekly return indices

The diagonal elements in matrix C represent the mean equation while matrix A captures own and cross-market ARCH effects. The diagonal elements in matrix G measure own and cross-market GARCH effects. LB and LB^2 presents the Ljung-Box Q-statistic for standardized and standardized squared residuals. (*) denotes the significance level at 5%, (**) denotes the significance level at 10%.

Panel A: GARCH(1, 1)-BEKK estimations												
	Russia-Poland		**Russia-Hungary**		**Russia-Czech R.**		**Poland-Hungary**		**Poland-Czech R.**		**Hungary-Czech R.**	
Parameters	Coef.	SE.	Coef.	SE.	Coef.	SE.	Coef.	SE.	Coef.	SE.	Coef.	SE.
μ_1	-0.024	(0.018)	-0.028*	(0.012)	-0.093*	(0.020)	-0.095*	(0.047)	0.006	(0.050)	-0.204*	(0.046)
μ_2	0.087**	(0.048)	-0.012	(0.048)	0.092**	(0.051)	-0.152*	(0.046)	0.079	(0.052)	-0.003	(0.055)
C_{11}	0.144*	(0.038)	0.006	(0.033)	0.146*	(0.038)	0.428*	(0.100)	0.603*	(0.097)	-0.049	(0.044)
C_{12}	0.202*	(0.067)	0.138*	(0.036)	1.565*	(0.082)	-0.290*	(0.167)	0.481*	(0.089)	0.220*	(0.003)
C_{22}	0.111 [a]	(0.164)	-0.564 [a]	(0.842)	-0.049 [a]	(0.814)	0.168 [a]	(0.169)	0.165*	(0.049)	0.521 [a]	(1.313)
A_{11}	1.176*	(0.077)	1.056*	(0.057)	0.762*	(0.046)	0.175*	(0.045)	0.215*	(0.049)	0.268*	(0.049)
A_{12}	-0.069**	(0.039)	-0.037**	(0.021)	-0.088*	(0.027)	-0.082	(0.078)	0.332*	(0.044)	0.229*	(0.053)
A_{21}	0.199*	(0.017)	0.199*	(0.012)	-0.195*	(0.012)	0.274 *	(0.044)	0.330*	(0.048)	-0.029	(0.021)
A_{22}	0.313*	(0.028)	0.188*	(0.018)	-0.056**	(0.030)	0.077	(0.059)	-0.027	(0.049)	-0.225*	(0.004)
G_{11}	0.539*	(0.031)	0.605*	(0.020)	0.722*	(0.025)	0.776*	(0.065)	0.759*	(0.050)	1.199*	(0.016)
G_{12}	0.035*	(0.016)	0.016*	(0.009)	0.021	(0.037)	0.258**	(0.135)	-0.174*	(0.047)	1.181*	(0.056)
G_{21}	-0.022*	(0.010)	-0.009	(0.005)	-0.136**	(0.027)	0.129*	(0.040)	0.052**	(0.030)	-0.427*	(3.552 [a])
G_{22}	0.947*	(0.012)	0.979*	(0.004)	0.180	(0.246)	0.785*	(0.131)	0.989*	(0.024)	-1.188*	(0.065)
Panel B: Diagnostic tests												
LogLik	-2122.660		-2114.480		-2035.696		-2413.859		-2497.435		-2466.651	
LB_1	128.000*		150.954		259.866		23.656		28.141		26.431	
LB_2	22.570		28.970		28.156		27.495		23.537		26.324	
LB^2_1	2.542		4.279		30.988		21.290		18.128		9.464	
LB^2_2	12.534		14.491		119.145		16.575		35.140		33.351	

[a)] Value was multiplied by 10 000.

Table 5. Mean and volatility spillovers for stock and currency markets estimated from a bivariate GARCH(1, 1)-BEKK model of weekly return indices

The diagonal elements in matrix C represent the mean equation while matrix A captures own and cross-market ARCH effects. The diagonal elements in matrix G measure own and cross-market GARCH effects. LB and LB^2 presents the Ljung-Box Q-statistic for standardized and standardized squared residuals. (*) denotes the significance level at 5%, (**) denotes the significance level at 10%.

Panel A: GARCH(1, 1)-BEKK estimations

	Russia		Poland		Hungary		Czech Republic	
Parameters [a]	Coef.	SE.	Coef.	SE.	Coef.	SE.	Coef.	SE.
μ_1	0.004*	(0.002)	0.001	(0.001)	0.002	(0.001)	0.003*	(0.001)
μ_2	-0.090*	(0.012)	-0.049	(0.052)	-0.150*	(0.048)	0.098 **	(0.057)
C_{11}	0.006*	(0.001)	0.001	(0.001)	0.014*	(0.002)	0.008*	(0.002)
C_{12}	-0.009	(0.047)	0.282*	(0.086)	-0.055	(0.045)	0.233	(0.181)
C_{22}	0.002 [b]	(0.054)	-0.112 [b]	(0.938)	0.109*	(0.053)	0.014 [b]	(0.508)
A_{11}	0.217*	(0.021)	0.194*	(0.025)	0.452*	(0.048)	0.209*	(0.053)
A_{12}	3.464*	(0.277)	2.734*	(1.134)	0.959	(1.222)	-1.702	(2.305)
A_{21}	0.004*	(0.001)	0.002*	(0.001)	0.002*	(0.001)	0.005*	(0.001)
A_{22}	0.730*	(0.075)	0.275*	(0.043)	0.241*	(0.026)	0.182*	(0.040)
G_{11}	-0.975*	(0.005)	0.980*	(0.004)	0.819*	(0.041)	0.973*	(0.027)
G_{12}	0.151	(0.505)	-0.369	(0.247)	-0.074	(0.583)	8.348*	(1.418)
G_{21}	0.010*	(0.002)	-0.548 [b] **	(0.327 [b])	0.001**	(0.001)	-0.004*	(0.001)
G_{22}	0.783*	(0.025)	0.942*	(0.023)	0.967*	(0.008)	0.887*	(0.019)

Panel B: Diagnostic tests

	Russia	Poland	Hungary	Czech Republic
LogLik	405.934	31.514	35.475	186.567
LB_1	67.558*	30.648	40.523*	30.456
LB_2	219.233*	22.232	28.674	27.597
LB^2_1	45.894*	14.023	12.913	27.654
LB^2_2	16.205	15.745	10.380	20.029

PanelC: Johansen cointegration test

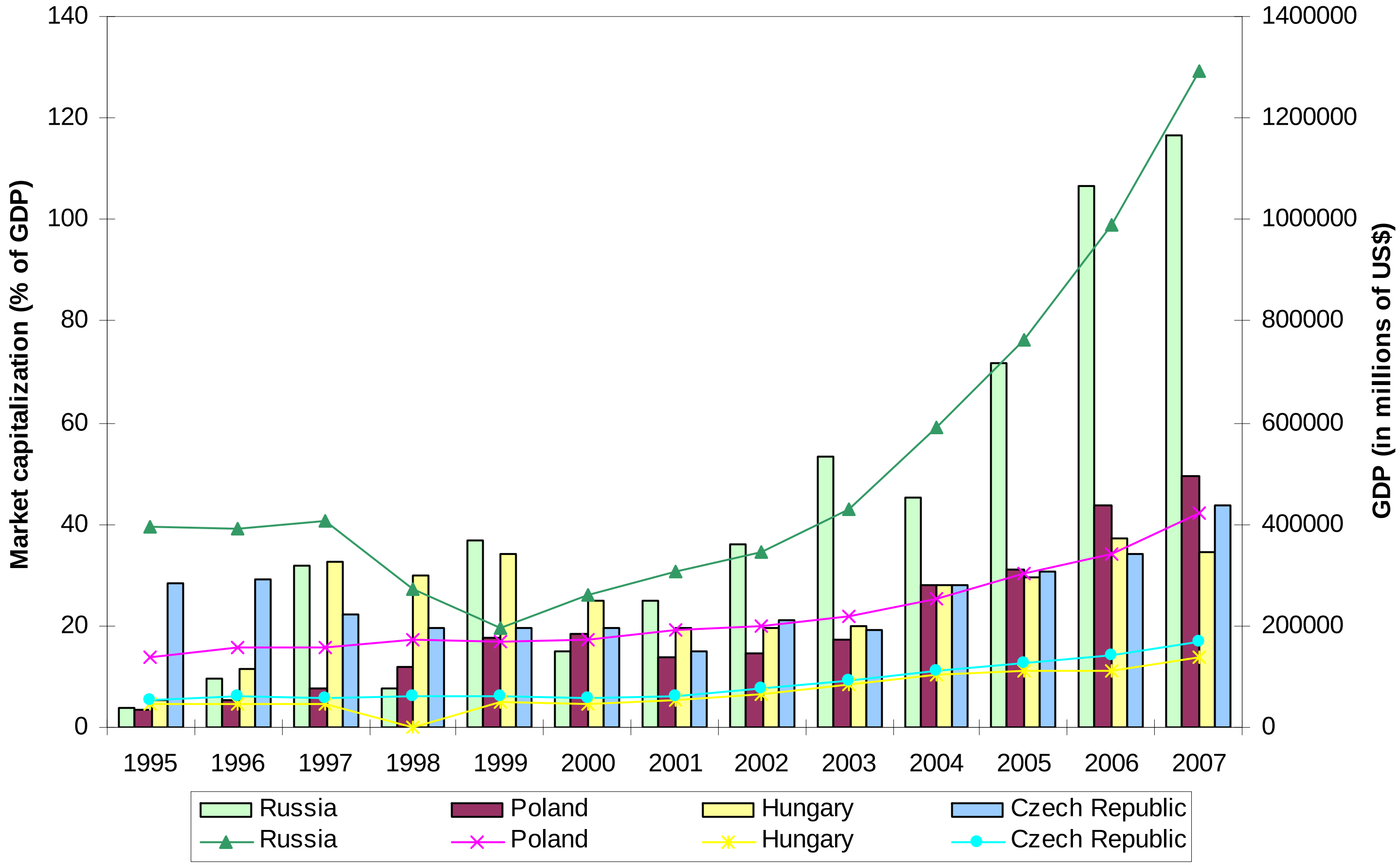
		Unrestricted Cointegration Rank Test (Trace)			Unrestricted Cointegration Rank Test (Maximum Eigenvalue)		
No. of CE(s)		Eigenvalue	Statistic	Critical Value	Eigenvalue	Statistic	Critical Value
None *	(H0: r = 0 , H1: r = 1)	0.241	999.010	159.530	0.241	200.278	52.363
At most 1 *	(H0: r ≤ 1 , H1: r = 2)	0.200	798.732	125.615	0.200	161.607	46.231
At most 2 *	(H0: r ≤ 2 , H1: r = 3)	0.187	637.126	95.754	0.187	149.914	40.078
At most 3 *	(H0: r ≤ 3 , H1: r = 4)	0.172	487.212	69.819	0.172	136.806	33.877
At most 4 *	(H0: r ≤ 4 , H1: r = 5)	0.136	350.406	47.856	0.136	105.055	27.584
At most 5 *	(H0: r ≤ 5 , H1: r = 6)	0.124	244.490	29.797	0.124	96.055	21.132
At most 6 *	(H0: r ≤ 6 , H1: r = 7)	0.106	148.435	15.495	0.106	80.842	14.265
At most 7 *	(H0: r ≤ 7 , H1: r = 8)	0.089	67.593	3.841	0.089	67.593	3.841

a) 1 represents the stock markets and 2 represents the currency markets.

b) Value was multiplied by 1000.

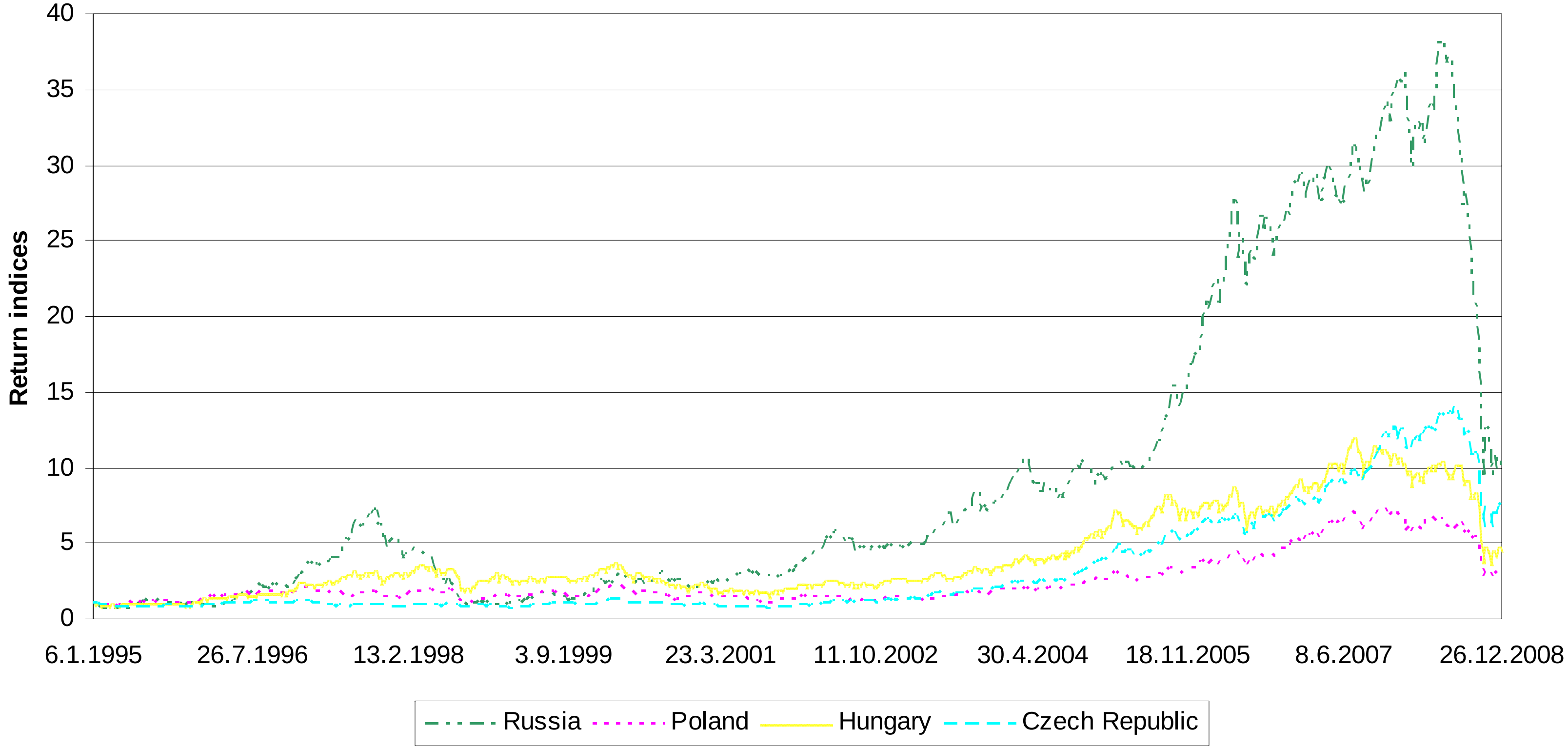
c) Trace test and Max-eigenvalue test indicates 8 cointegrating eqn(s) representing 4 stock and 4 currency exchange markets from Russia, Poland, Hungary and the Czech Republic at the 0.05 level.

Figure 1. Market capitalization and GDP



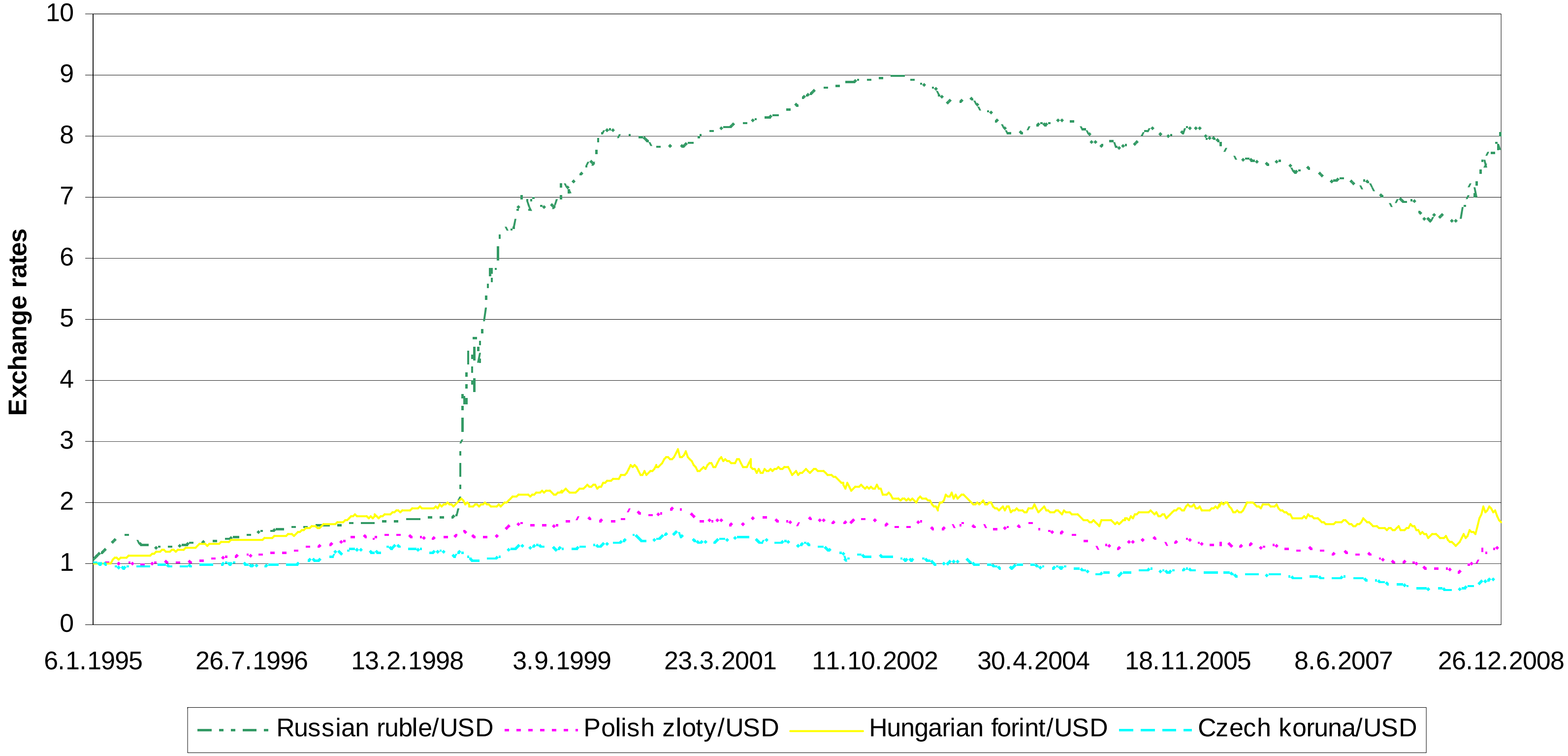
Source: World Development Indicators

Figure 2. Stock return indices



All indices are scaled to 100.

Figure 3. Exchange rates against the USD



All exchange rates are scaled to 1.

Figure 4. 52-week rolling correlation between local equity market and local currency markets returns.