Econometric Analysis of Linkages among Central European Stock Markets: an Impact of the Global Financial Crisis

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Abstract
Recent global financial crisis and subsequent debt crisis has led to spillover of shocks between particular equity markets worldwide. Previous research works were primarily focused on equity markets of the new EU member states and their integration into the global market or the euro area only. This paper investigates, describes and compares mutual interactions among new EU member states in Central Europe and global stock markets during period of 2004-2012 years. In this paper the methods of regression and correlation analysis, cointegration analysis and vector autoregression will be used. During the period of the global financial crisis an influence of shocks from other countries rapidly increased so that Central European stock markets became more sensitive to regional information. With regard to interconnection of Central European stock markets with global markets, an assumption that Central European stock markets are rather affected by the U.S. stock market than the Eurozone area was confirmed. In times of the global financial crisis respective markets are treated as one region since negative event on one market affected situation on other markets.

Keywords: cointegration, global financial crisis, regression analysis, stock market, VAR model
JEL codes: F36, G01, G15

1. Introduction

The process of globalization of the world economy is linked to the integration of national financial markets. Since barriers to international capital movements are breaking down there is an increase of international investment which cause synchronization of trends in equity markets. National stock markets are thus increasingly influenced by events in foreign markets which may lead to the spread of financial contagion from one economy to another. High degree of integration among particular markets contributes to higher rate of transmission of shocks to economies. The interrelation of capital markets plays an important role in the overall stability of the economy, as demonstrated during period of the global financial crisis and successive economic stagnation.

Degree of interdependence of capital markets is an important issue especially for the new EU member states in Central Europe (CEE), including Czech Republic, Poland and Hungary, since they are mostly open economies and financial contagion was spilling over relatively quickly in these economies. The question of integration with global capital market became very important task, especially for central banks. Czech National Bank (CNB), see CNB (2011), notes that an integration of financial markets of new EU countries and the Eurozone markets continues with relatively high speed of adjustment of stock markets on events in the euro area. The global financial crisis, however, led to a temporary divergence of stock markets. Similar results were achieved Babecký et al. (2010) who found out that a process of integration of new EU countries and Eurozone markets continues even during the financial crisis period.

Baele et al. (2004), Calin-Vlad (2011) and Voronkova (2004) investigated degree of market integration with the Eurozone area using yield differentials, dispersions of stock indices, regression analysis and other quantitative factors. Their results lead to a fact that mutual integration gradually increased and an introduction of the euro currency has strengthened this trend. According Baltzer et al. (2007) integration of financial markets of new EU countries and Eurozone markets increased, nevertheless, economic and political events in the USA are more important. Birg and Lucey (2006) divided new EU countries to those that are integrated with the euro area and the global market as well, and those that are integrated with the Eurozone only (Slovakia, Slovenia and Latvia). Égerd and Kočenda (2007) found out that development among new EU countries and developed countries and among each other are not strongly correlated when using intraday data. Chaloupka (2012) found out that new EU countries are perceived by investors rather as Eastern Europe than part of the European Union. In times of the global financial crisis respective markets are then treated as one region since negative event in one market strongly affects market development in other markets. According existing research a degree of interdependence of stock markets of new member countries with global market and the euro area market is growing. However, for the development of these markets there are still important also local events. These papers are, however, only marginally engaged in the issue of interaction between the equity markets of new EU member countries. Therefore, it is not clear whether these markets are influenced purely by national events, or rather are influenced by regional events as well.

The aim of this paper is to estimate, describe and compare interactions among new EU member states in Central Europe, namely Czech Republic, Poland and Hungary, global financial market represented by the U.S. stock market and the Eurozone stock market represented by German stock market during the period of 2004-2012 years. In this paper the methods of regression and correlation analysis, cointegration analysis and vector autoregression will be used.

The studies conducted in this paper can be summarized as follows. In Section 2, econometric methods applied in this paper will be described, followed by subsection devoted to data samples used in this paper, while empirical analysis is provided in Section 3. First, mutual relationships will be explored using correlation analysis and the regression model used by the CNB. As a next step a potential existence of cointegration relationships between paired markets is tested, followed by vector autoregression model. This model is then used to explore causality in Granger sense.

2. Methods and data sample

The aim of this section is to describe methods that will be used for econometric analysis of the linkages among CEE stock markets. In this paper, it includes the methods of regression and correlation analysis, cointegration analysis, Granger causality testing, followed by VAR model.

2.1 Regression and correlation analysis

The regression and correlation analysis is a useful tool for quantifying relationships between variables. The main objective of the regression and correlation analysis is to examine relationships between two or more usually quantitative variables.

In this paper we will use a regression model applied by CNB, see CNB (2011). This model explores development of γ coefficient and is given by:

$$\Delta Y_{c,t} = \alpha_{c,t} + \gamma_{c,t} \Delta Y_{b,t} + \varepsilon_{c,t}, \tag{1}$$

where Δ represents changes of variables, $\alpha_{c,t}$ is a constant, $Y_{c,t}$ is a yield of asset of country c at time t, $Y_{b,t}$ means a yield of benchmark asset at time t and $\varepsilon_{c,t}$ represents a specific impact of country c. Coefficient $\gamma_{c,t}$ denotes a change of return of respective index if a unit change of benchmark asset happens. When assuming the growth of integration the following conditions must be hold, see Baele (2004):

a) $\alpha_{c,t}$ must converge to zero value,

b) $\gamma_{c,t}$ have to converge to the value of 1,

c) variability ratio $VR_{c,t}$:

$$VR_{c,t} = \frac{\gamma_{c,t}^2 \, var\left(\Delta Y_{b,t}\right)}{var\left(\Delta Y_{c,t}\right)}, \tag{2}$$

where $var\left(\Delta Y_{b,t}\right)$ is a variability of a benchmark portfolio and $var\left(\Delta Y_{c,t}\right)$ represents a variability of national market, tends to converge to the value of 1. If a national market is fully integrated a change of return of benchmark should be equal to changes on particular national markets, and a value of gamma coefficient should be equal to one. If a value of gamma coefficient is higher than one it means that local assets react on mutual events more than benchmark assets. Negative values denote asymmetric reaction on innovations.

2.2 Cointegration analysis

Cointegration is a statistical property of time series variables. Two or more time series are cointegrated if they share a common stochastic drift. If two or more series are individually integrated but some linear combination of them has a lower order of integration, then the series are said to be cointegrated. A common example is where the individual series are first-order integrated I(1) but some cointegrating vector of coefficients exists to form a stationary linear combination of them. If such a combination has a low order of integration — in particular if it is I(0), this can signify an equilibrium relationship between the original series, which are said to be cointegrated. Cointegrated time series follow mutual trend and their relationship follows the equilibrium in long term.

Time series is stationary in its weak or covariance form if following assumptions are hold:

a) mean value of variable $E(Y_t)$ is a constant for all *t* periods,

b) variance $var(Y_t)$ is also a constant and doesn´t change for all *t* periods,

c) covariance $cov(Y_{t1}, Y_{t2}) = cov(Y_{t1+h}, Y_{t2+h})$ doesn´t change when shifting in time for any *h*.

In the case of non-stationary time series parameters φ_p of regression model *AR*(*p*) that is given by:

$$Y_t = \varphi_1 Y_{t-1} + ...+, \varphi_p Y_{t-p} + \varepsilon_t, \tag{3}$$

are equal to one.

In order to evaluate if a time series is a stationary process it will be used Augmented Dickey-Fuller (ADF) test, see Dickey-Fuller (1979). If a time series has a unit root it may occur a problem of false regression among particular time series. Potential existence of cointegration vector is in case of non-stationary time series evaluated by Engle-Granger methodology. According to Engle and Granger (1987), the process of testing the cointegration should have three steps as follows:

a) it should be tested a stacionarity of respective time series,

b) a regression model should be estimated,

c) a stacionarity of residuals from previous step should be evaluated.

If residuals are stationary then used time series are cointegrated. In order to test stacionarity of residuals the Engle-Granger test in the form of the null hypothesis will be used as follows:

$$H_0 : \Delta\varepsilon_{t-1} = \omega\varepsilon_t + u_t, \qquad \text{for } \omega = 0, \tag{4}$$

in other words, it will be tested a hypothesis that the estimation of residual ε from regression model of original times series has a unit root. If the null hypothesis of unit root of residuals is rejected it is possible to say that two time series are cointegrated.

2.3 VAR model and Granger causality

Vector autoregression model (VAR) represents some kind of generalized univariate autoregression process, see Lütkepohl (2005). The VAR model is commonly used for forecasting systems of interrelated time series and for analysis of dynamic impact of random disturbances on the system of variables. The VAR approach sidesteps the need for structural modeling by treating every endogenous variable in the system as a function of the lagged values of all endogenous variables included in the system. The VAR(1) model for two variables is given by:

$$\begin{aligned} Y_{c1,t} &= \alpha_1 + \beta_1 Y_{c1,t-1} + \gamma_1 Y_{c2,t-1} + \varepsilon_{1t}, \\ Y_{c2,t} &= \alpha_2 + \beta_2 Y_{c2,t-1} + \gamma_1 Y_{c1,t-1} + \varepsilon_{2t}, \end{aligned} \tag{5}$$

where $Y_{c1,t}$ represents returns of country *c1* at time *t* while $Y_{c2,t}$ denotes returns of country *c2* at time *t*. When estimating VAR model it is necessary to identify order of respective model. For this purpose it may be used information criteria, see Cipra (2008). As a next step, VAR model should be estimated with a help of OLS method. Regarding diagnostic control it is important to evaluate especially stacionarity.

The VAR model allows in relatively easy way to explore causality among stationary variables with a help of Granger test, see Granger (1969). If a variable X_{t-1} is statistically significant independent variable in relation to variable Y_t then variable X_{t-1} affects causally on variable Y_t in Granger sense. Any lagged values of one of variables is hold in the regression model if it is significant according to *t*-test and the other lagged values of the variable jointly add explanatory power to the model according to *F*-test. Then the null hypothesis of no Granger causality is not rejected if and only if no lagged values of an explanatory variable have been hold in the regression, see Arlt (1999).

2.4 Data sample

In this paper, an empirical analysis is performed on daily data of stock indexes in Czech Republic, Poland, Hungary, USA and Germany in the period from 2004 till 2012. It includes total of 2225 observations. This period was chosen purposely, to investigate changes of equity markets relationships during time with a special emphasis to compare mutual relationships in the time before, during and after the global financial crisis of 2008-2009 years. We have more than 8 years long time series of the closing rates of respective stock indexes.

The basic testing period of 2004-2012 years was divided into three testing periods. The pre-crisis period characterized by economic growth was defined from January 2004 to the end of June 2007. The crisis period of financial instability started at the beginning of July 2007 and finished by March 2009, and finally the post-crisis period which is typical by economic stagnation and debt crisis was defined from April 2009 to the middle of March 2012.

As an approximation of events on national markets we used major stock indexes of respective countries, namely PX for Czech Republic, WIG20 for Poland and BUX in the case of Hungary. As a benchmark portfolio for the euro area was selected German index DAX30 as a representative of the biggest economy in the Eurozone region. Development of the S&P 500 index was chosen as an approximation of events in global stock market as global market is primarily influenced by changes in the U.S. stock market. In this paper, we worked with daily closing rates of indices, respectively with their logarithmic returns. We worked just with those days when trading was open on all analyzed markets. Table 1 shows several descriptive statistics for all stock returns. Symbol ** indicates values that are significant at 5% significance level.

Table 1: Descriptive statistics of returns

Index	Mean	Stand. dev.	Skewness	Kurtosis	*J-B* test	*L-B Q*(12)
CZ	0.00019	0.01621	-0.56017	16.5685	16489.34**	58.199**
POL	0.00018	0.01606	-0.28645	5.91220	783.65**	19.045
HUN	0.00032	0.01759	-0.10175	9.16751	3387.49**	67.190**
USA	0.00009	0.01352	-0.31052	13.49942	9840.88**	56.401**
GER	0.00026	0.01432	0.05246	10.17004	4574.28**	21.346**

Source: author´s calculations in Eviews

The means of all sample returns are quite small while the standard deviations are significantly higher. Based on the values of skewness, increased values of kurtosis and *J-B* test of normality, the daily return series show mostly leptokurtic distribution which has a higher peak and heavy tail, instead of normal distribution. The Ljung-Box statistics Q_n for the squared return series are high which indicate rejection of the null hypothesis of no correlation.

3. Empirical results

In this chapter estimation results will be presented. The studies will be summarized as described in the Introduction section. In other words, all the methods defined in previous section will be used for estimations.

3.1 Regression and correlation analysis

Before we applied regression model as defined in subsection 2.1, it had been estimated values of correlation coefficients for each pair of analyzed return series taking into consideration also all time periods. Therefore, Table 2 shows values of correlation coefficients of respective stock markets for pre-crisis period (Pre), period of the global financial crisis (Cris) and post-crisis period (Post) as well.

Table 2: Correlation coefficients for pre-crisis period, global financial crisis period and post-crisis period

POL			*HUN*			*USA*			*GER*			
Pre	Cris	Post	Pre	Cris	Post	Pre	Cris	Post	Pre	Cris	Post	
0.50	0.71	0.66	0.54	0.64	0.35	0.17	0.33	0.44	0.43	0.61	0.60	*CZ*
			0.58	0.59	0.31	0.20	0.37	0.50	0.43	0.63	0.70	*POL*
						0.12	0.42	0.34	0.38	0.62	0.60	*HUN*
									0.46	0.62	0.71	*USA*

Source: author´s calculations in Eviews

It can be seen from Table 2 that highest values of linear correlation in the pre-crisis period were achieved among European countries including Germany while correlations between US and European markets was significantly lower. During the period of the global financial crisis overall relationships dramatically changed. Paired values of all correlation coefficients significantly increased. Direct linear dependences among respective time series became higher than in previous period. In the post-crisis period values of paired correlation coefficients remained on similar values like in the period of financial instability of 2008-2009 years with an exception of the U.S. stock market. A degree of linear dependence between European stock markets and the U.S. stock market increased significantly again. It seems that rate of integration among analyzed stock markets increased significantly after 2007 year.

As a next step it will be provided the regression analysis using a model applied by CNB, as described in subsection 2.1. As a benchmark it was selected German stock index DAX30. Due to potential existence of heteroscedasticity and autocorrelation of residual components all the models were estimated using a HAC estimator (heteroscedasticity and autocorrelation consistent estimator) to estimate residual components to be robust to heteroscedasticity and autocorrelation. Table 3 shows OLS regression for daily returns of respective indexes. In order to make some valuable conclusion regarding degree of integration of respective stock markets with Eurozone it is necessary to evaluate statistical significance of gamma coefficients, *F*-tests and values of coefficients of determination. Symbols ***, ** and * indicates values that are significant at 1%, 5% and 10% significance level.

Table 3: Results of OLS regressions in the period of 2004-2012 years

		Pre-crisis period	Crisis period	Post-crisis period
CZ	Intercept	0.0007**	-0.0011*	0.0001
	Gamma	0.5118***	0.6439***	0.6076***
	Adj. R^2	0.1884	0.3719	0.3624
	F-statist.	213.6063	252.8368	444.5271
POL	Intercept	0.0005	0.0008	0.0002
	Gamma	0.5968***	0.6679***	0.7295***
	Adj. R^2	0.1824	0.3997	0.4827
	F-statist.	205.2475	284.3191	729.6580
HUN	Intercept	0.0008	-0.0013	0.0002
	Gamma	0.5454***	0.6969***	0.7394***
	Adj. R^2	0.1421	0.3609	0.3857
	F-statist.	152.3699	262.8016	450.9160

Source: author´s calculations in Eviews

Before estimation results will be interpreted, it is necessary to test whether estimated model meet expected assumptions of the classical linear regression model, thus homoscedasticity, no autocorrelation to its delay values and normality of distribution of residual components will be tested. First, heteroscedasticity in residuals of estimated regression models was tested using Breusch-Pagan-Godfrey (BPG) test. Next, potential autocorrelation of residuals was evaluated with a help of Breusch-Godfrey (BG) test, and finally normality of residuals was tested by Jarque-Bera (JB) test. Table 4 shows results of testing the residuals estimated by regression analysis.

The null hypothesis of homoscedasticity wasn´t rejected at 5% significance level in the pre-crisis period for all markets. Also the BP tests of autocorrelation denote that statistically significant autocorrelation was not observed in any market. In the period of the global financial crisis and subsequent economic stagnation according the BPG test the null hypothesis of homoscedasticity cannot be rejected again with an exception of Hungarian stock market in the period of 2010-2012 years. Residuals are robust to autocorrelation in post-crisis period for all indexes while in the period of financial instability of 2008-2009 years a statistically significant autocorrelation was observed in Czech and Hungarian market. Since test statistics of JB tests lie in all cases in critical interval the null hypothesis of normality of residual component can be clearly rejected at 5% significance level.

Table 4: Results of testing of residual components from regression analysis

		Pre-crisis period	Crisis period	Post-crisis period
CZ	*BPG* test	3.6529	0.6769	0.1431
	p-value	0.0561	0.4111	0.7053
	BG test	1.5581	2.1750	0.9091
	p-value	0.0560	*0.0026*	0.7960
	J-B test	580.2479	2647.4591	95.6046
	p-value	*0.0000*	*0.0000*	*0.0000*
POL	*BPG* test	3.2305	0.4306	0.3139
	p-value	0.0726	0.5120	0.5754
	BG test	0.7698	1.1379	0.7311
	p-value	0.7520	0.1739	0.9966
	J-B test	84.3552	203.3326	126.1703
	p-value	*0.0000*	*0.0000*	*0.0000*
HUN	*BPG* test	1.4497	0.8969	4.4042
	p-value	0.2289	0.3441	0.0362
	BG test	1.1624	1.9412	0.7996
	p-value	0.0783	*0.0000*	0.9740
	J-B test	51.2333	2280.8661	93.8067
	p-value	*0.0000*	*0.0000*	*0.0000*

Source: author´s calculations in Eviews

In the pre-crisis period values of gamma coefficients were relatively low with the highest value achieved on Polish stock market. This period was characterized by economic growth in all Central European countries which was higher than in Eurozone countries. Relatively low values gamma coefficients can be explained by fact that returns on CEE markets were growing faster than returns in Eurozone.

In the global financial crisis period situation changed significantly. Values of all gamma coefficients increased while the biggest increment was observed in the case of Czech stock market. Quickly growing values of gamma coefficients denote strong convergence of CEE stock markets towards Eurozone. Alternative explanation of high sensitivity on events in Eurozone can be used in case of Hungary which received relatively huge financial aid by International Monetary Fund and therefore become more risky in eyes of investors.

In post-crisis period, gamma coefficients followed a trend which was set up in previous period. Moreover, in case of Poland and Hungary values of gamma coefficients increased again. The same can be said about coefficients of determination in all CEE markets. In the period of global financial crisis and subsequent debt crisis one can observe significant growth of their values.

Nevertheless, estimated models are able to explain less than 50% variability in data sample. Our findings indicate that this model is not proper tool for modeling mutual interrelations of particular markets with Eurozone market. Since we used the German index DAX30 in terms of independent variable as approximation of common information we cannot distinguish between innovations which are mutual for global financial market and those are important for Eurozone market only. It is fully possible that Central European stock markets and Eurozone react on innovations coming from the U.S. stock market in the same way without having any significant mutual integration. Because of these reasons it may be necessary to include into regression a variable which is able to approximate development of US stock market and, moreover to add lagged values of other CEE indexes.

3.2 Cointegration analysis

In order to evaluate whether a time series is a stationary process it will be used ADF test. Table 5 shows values of ADF statistics for closing values and logarithmic returns of respective indexes in the period of 2004-2012 years. In the case of closing values we cannot reject hypothesis of the unit root at 5% significance level. Time series therefore follow a non-stationary process. It can lead to "false regression" problem. On the other hand, in the case of logarithmic returns we clearly rejected the null hypothesis of unit root so that all investigated time series are I(1).

Table 5: ADF statistics for values and returns of respective indexes

		CZ	*POL*	*HUN*	*USA*	*GER*
ADF statistic	Pre-crisis	-0.07	-0.48	-0.13	-0.32	-0.27
	Crisis	-0.64	-0.03	-0,74	-0.53	-0.71
	Post-crisis	-0.34	-0.74	-0.63	-0.43	-0.66
		difCZ	*difPOL*	*difHUN*	*difUSA*	*difGER*
ADF statistic	Pre-crisis	-27.86***	-29,17***	-28.03***	-31.15***	-31.04***
	Crisis	-18.81***	-19.89***	-16.14***	-18.56***	-21.82***
	Post-crisis	-20.89***	-21.79***	-28.26***	-17.71***	-26.24***

Source: author´s calculations in Eviews

As a next step, we explored potential existence of a common trend between particular pairs of indexes. For this purpose we applied cointegration analysis using the daily closing rates of indices, thus their level values. Results of Engle-Granger (EG) test as described in subsection 2.2 are reported in cross-table for all three investigated periods, see Table 6. In first row of each cell there are reported values of EG test while in second row there are given appropriate *p*-values. Statistically significant values of EG test at 5% significance level are written in italics.

Table 6: Results of Engle-Granger (EG) tests of cointegration for pre-crisis period, global financial crisis period and post-crisis period

POL			*HUN*			*USA*			*GER*			
Pre	Cris	Post	Pre	Cris	Post	Pre	Cris	Post	Pre	Cris	Post	
-3.21 0.07	-2.59 0.25	-1.98 0.54	*-4.09* *0.02*	*-3,98* *0.03*	-3.73 0.07	-2.39 0.33	*-5.72* *0.00*	-1.34 0.87	-3.26 0.06	*-4.55* *0.01*	*-4.05* *0.00*	*CZ*
			-2.45 0.41	-3.04 0.21	-3.95 0.12	-3.05 0.09	-1.73 0.66	-1.20 0.85	*-4.92* *0.01*	*-5.69* *0.00*	*-6.36* *0.00*	*POL*
						-2.47 0.30	-2.23 0.53	-2.82 0.74	-3.54 0.26	*-3.78* *0.04*	*-3.91* *0.02*	*HUN*
									-2.48 0.55	-3.12 0.21	-3.52 0.17	*USA*

Source: author´s calculations in Eviews

Results we achieved show that for the period of 2004-2007 the null hypothesis of a unit root in residuals was rejected only for two pairs of indices at 5% significance level. For the period of the global financial crisis we can reject the null hypothesis of unit root for both of these pairs and also for additional 3 pairs. In the post-crisis period from April 2009 one can talk about cointegration relationship in a total of 3 pairs of indices. All these pairs include relationships between German stock index and particular CEE indexes. It seems that in the period from the middle of 2007 it was established a balanced relationship between more stock markets than in the pre-crisis period. More markets thus follow joint trend in times of economic turmoil and stagnation comparing with the period of economic growth. This would support the hypothesis that in times of crisis markets are more affected by common events while during the period of economic growth local information are more important for the development of the individual national markets. This effect may be also explained by herd behavior of investors in times of crisis and their higher sensitivity to new information.

3.3 VAR model and Granger causality

Since we failed to confirm the existence of cointegration among the majority of indices it will be used the VAR model as described in subsection 2.3. The VAR model can be used for stationary time series only. As closing rates of indexes time series are not stationary, it was necessary to use the logarithmic differences which follow stationary process, see Table 5.

Results of estimated VAR(5) model for the period of 2004-2007 years are presented in Table 7, VAR(10) model for the crisis period is shown in Table 8, and VAR(8) model for the post-crisis period of 2010-2012 years is presented in Table 9. Order of delay was determined using the Akaike information criterion (AIC) and all three models were estimated with a help of Huber-White estimator (HC1) so that standard errors have to be robust to heteroscedasticity.

Table 7: Estimation of VAR(5) model for the pre-crisis period

	CZ		*POL*		*HUN*		*USA*	
Regres.	const.	0.001**	const.	0.001*	const.	0.001*	const.	0.001*
	CZ_2	0.087**	CZ_2	0.119**	CZ_5	0.093*	USA_1	-0.072*
	CZ_4	0,054**	CZ_4	0.086*	POL_2	0.093**	USA_2	-0.128*
	USA_1	0.541***	POL_2	0.096**	HUN_2	-0.093*	GER_1	0.065**
	GER_1	-0.109**	POL_3	-0.086*	USA_1	0.679***	GER_5	-0.01**
			USA_1	0.576***	USA_2	0.240**		
			USA_2	0.203**	USA_3	0.181**		
Adj. R^2	0.088		0.081		0.103		0.015	
F-stat.	2.766		2.609		3.091		1.281	
p-value	*0.000*		*0.000*		*0.000*		0.125	

Source: author´s calculations in Eviews

In the pre-crisis period, the most important independent variables were their own lagged values together with lagged values of the U.S. stock market index for all CEE indices. This result is consistent with an assumption that development of stock markets in the U.S. affects also development of other stock markets. One day lagged U.S. returns are always statistically significant. Moreover, estimated coefficients are relatively high. In case of the U.S. and Eurozone market situation differs significantly. It seems that those markets are not influenced by CEE stock markets. If we focus on values of adjusted R^2 it can be said that estimated VAR models are able to explain only a small share of variability. For development of those indexes are probably more important other factors.

After 2007 year, more CEE indexes are included in all equations of estimated VAR model in terms of independent variables. It indicates a greater coherence of CEE markets during the global financial crisis period and subsequent economic stagnation. German stock index belongs to significant independent variables in only a few cases. It would confirm the hypothesis that Central European stock markets are more integrated with the U.S. market than the Eurozone market. It seems that CEE markets are more integrated with other CEE markets and the U.S. market than the Eurozone market. Notable is also a fact that level of adjusted R^2 increased significantly in the period of global financial crisis comparing with previous period. In the post-crisis period, we can still confirm relatively high coherence of CEE markets even though values of adjusted R^2 decreased towards to pre-crisis values.

Table 8: Estimation of VAR(10) model for the crisis period

	CZ		*POL*		*HUN*		*USA*	
Regres.	const.	-0.001	const.	-0.001*	const.	-0.002**	const.	-0.002**
	CZ_1	-0.203**	CZ_2	-0.148**	CZ_2	-0.172**	CZ_1	-0.194**
	CZ_2	-0.274**	POL_5	-0.131*	POL_2	0.271***	HUN_4	0.2001**
	CZ_3	-0.207**	POL_7	-0.137*	HUN_4	0.169**	HUN_6	-0.165**
	CZ_4	-0.230**	HUN_1	0.039**	HUN_6	-0.281**	HUN_7	0.203**
	POL_2	0.183**	HUN_2	0.129**	HUN_9	-0.249**	HUN_10	0.131*
	POL_3	0.200**	HUN_4	0.237***	USA_1	0.373***	USA_1	-0.213**
	HUN_1	0.048**	HUN_6	-0.152**	USA_3	0.171*	USA_4	-0.213**
	HUN_2	0.283***	HUN_7	0.168**	USA_9	0.197**	USA_8	0.289***
	HUN_4	0.272***	HUN_9	-0.172**	USA_10	0.239**	USA_9	0.197**
	HUN_6	-0.181**	USA_1	0.364***	GER_6	0.274**	GER_1	0.209**
	HUN_10	-0.137*	USA_9	0.277***			GER_4	0.191*
	USA_1	0.589***	USA_10	0.228**			GER_5	-0.211**
	USA_9	0.247***					GER_6	0.289**
	USA_10	0.137*					GER_8	-0.358**
Adj. R^2	0.348		0.199		0.362		0.189	
F-stat.	5.465		3.076		3.961		2.958	
p-value	*0.000*		*0.000*		*0.000*		*0.000*	

Source: author´s calculations in Eviews

It can be seen that Hungarian market plays an important role for most of analyzed indexes, especially in the period of financial instability and following period of economic stagnation. After an outbreak of the financial crisis, the role of Hungarian index in terms of independent variable increased since lagged values of this index influenced developments of other indices, even in USA and Eurozone. We can say that the Hungarian index affects other indexes in Granger sense. One can also assume that investors' decisions to invest in CEE markets were significantly influenced by events in Hungarian market. A possible explanation for this phenomenon may be partly a fact that investors tend to perceive groups of countries in a particular region as a whole, and also a fact that investors tend to perceive negative messages more strongly than positive ones. Since Hungarian economy was heavily hit by the financial crisis already in 2007, Hungary was forced to ask for help the International Monetary Fund and the EU.

Table 9: Estimation of VAR(8) model for the post-crisis period

	CZ		*POL*		*HUN*		*USA*	
Regres.	const.	-0.001	const.	-0.000	const.	0.001	const.	0.001*
	CZ_1	-0.166**	CZ_1	-0.134**	HUN_1	-0.098*	USA_1	-0.176**
	POL_2	-0.119**	POL_2	-0.195**	HUN_7	-0.156**	USA_4	0.147**
	HUN_2	0.078*	POL_5	-0.201**	USA_1	0.277***	GER_4	-0.149**
	HUN_6	-0.079*	POL_8	-0.101*	USA_2	0.238**		
	USA_1	0.372***	HUN_2	0.077*	USA_5	-0.156*		
	USA_2	0.238***	HUN_5	0.126**				
	GER_2	-0.192**	USA_1	0.337***				
			USA_2	0.284***				
			USA_4	0.148**				
			GER_5	-0.147*				
Adj. R^2	0.115		0.063		0.038		0.023	
F-stat.	3.005		2.139		1.959		1.134	
p-value	*0.000*		*0.000*		*0.000*		0.105	

Source: author´s calculations in Eviews

When estimating VAR models we used in terms of independent variables also lagged values of other indices. Due to the limited extent of this paper there are given just those values of lagged indexes that are significant at least at the 5% significance level. Although we used HC1 estimator it is necessary to test residuals for autocorrelation, normality and stacionarity. Results are presented in Table 10.

In order to test autocorrelation it was used standard Ljung-Box test which is able to test significance of *k*-th comprehensive autocorrelations. The null hypothesis of no autocorrelation of residual component cannot be rejected in any VAR model estimated. For testing a normality of residual components we used again Jarque-Bera test. Since test statistics almost in all cases falls into the critical field and corresponding *p*-value is low, the null hypothesis of normality of the distribution of residual can be rejected in all periods. The only exception is Polish market in the crisis period.

Table 10: Results of autocorrelation, heteroscedasticity and normality tests of residuals from VAR models for pre-crisis period, global financial crisis period and post-crisis period

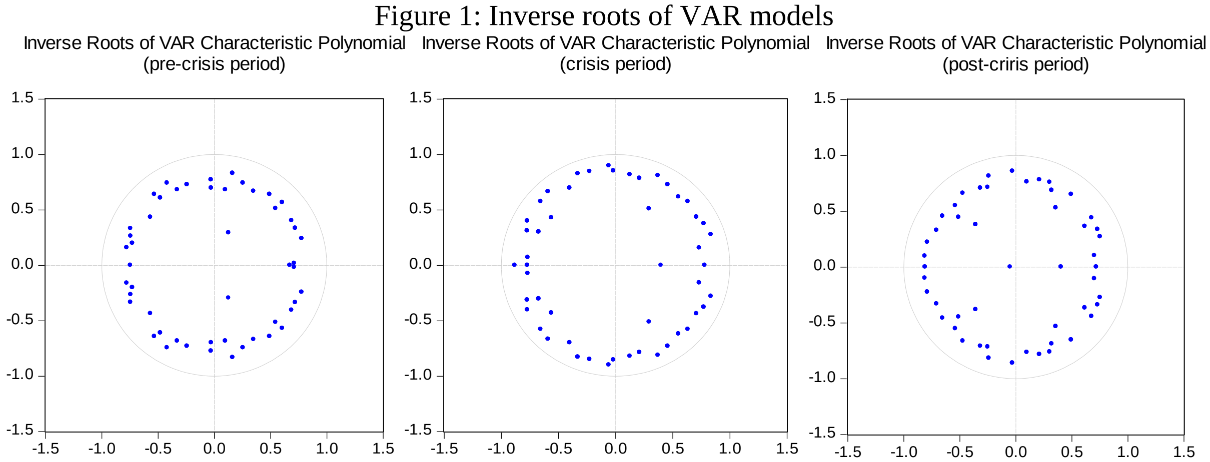
	Ljung-Box test					
	Pre-crisis period		Crisis period		Post-crisis period	
	Q-statistic	*p*-value	*Q*-statistic	*p*-value	*Q*-statistic	*p*-value
CZ	29.418	0.773	32.895	0.617	25.255	0.910
POL	28.209	0.820	35.881	0.474	13.528	0.991
HUN	18.648	0.993	27.487	0.845	35.753	0.480
USA	20.376	0.983	39.977	0.298	32.377	0.642
	Jarque-Bera test					
	Pre-crisis period		Crisis period		Post-crisis period	
	J-B statistic	*p*-value	*J-B* statistic	*p*-value	*J-B* statistic	*p*-value
CZ	884.433	*0.000*	213.157	*0.000*	397.462	*0.000*
POL	46.719	*0.000*	4.542	0.103	114.722	*0.000*
HUN	37.297	*0.000*	24.522	*0.000*	217.381	*0.000*
USA	51.078	*0.000*	54.228	*0.000*	218.001	*0.000*

Source: author´s calculations in Eviews

It is also clear that the estimated VAR models are stationary, since all inverse roots of autoregressive polynomials in all periods lie within the unit circle in the complex plane, see Figure 1.

As it has been already mentioned in subsection 2.3, estimated VAR models can be used to test the Granger causality when using the overall *F*-test and partial *t*-tests. Tables 7-9 show that according overall values of *F*-test of estimated VAR models the null hypothesis of absence of Granger causality can be rejected at the 1% significance level for all countries except USA in pre-crisis and post-crisis period.

Figure 1: Inverse roots of VAR models



Source: author´s calculations in Eviews

4. Discussion

Analysis provided in this paper suggests that CEE stock markets were less affected by events in other markets before July 2007 while developments of CEE stock markets became more synchronized in following periods of financial instability and economic stagnation.

Prior to July 2007, a linear correlation among CEE markets was relatively low which would indicate low consistency in developments of individual markets. Also estimated VAR models confirmed that values of returns of other CEE markets were not decisive for development of individual CEE markets. Therefore, it cannot be said that markets followed a common trend. This period was mostly characterized by economic growth in all markets and relative economic stability which reflected in the relatively low values of standard deviations comparing with following periods. We can say that in times of economic growth CEE markets are affected mainly by domestic factors.

After July 2007, in the period of the financial crisis and subsequent economic stagnation, linear correlations between paired returns increased significantly. Although an existence of cointegration relationship has been proven between some markets and indexes, stock markets did not follow a common trend in most cases. Based on the estimation of the VAR models one can say that developments in other markets became more important for the development of domestic returns since nearly 40% of the variability in returns (Czech Republic and Hungary) can be explained by events on foreign markets.

Regarding the development of the U.S. market and the Eurozone area, their importance for the development of CEE equity markets during the global financial crisis increased significantly. However, innovations coming from USA were more important than innovations coming from the Eurozone. It seems that CEE stock markets are rather influenced by events in the U.S. stock market. This result is not surprising since USA is the strongest economy in the world and their financial market is the largest one. It can therefore be assumed that negative events as a result of globalization of the world economy will be easily transferred to other economies.

Our results also show that in the period after an outbreak of the global financial crisis, there was a greater spillover of shocks across CEE markets. This would correspond to assumption of high sensitivity of investors to new information in times of crisis which can lead to their herd behavior. Relatively remarkable is also a fact that development of Hungarian stock market was significant for development of other CEE stock markets comparing with other CEE markets, especially in the period of financial instability and subsequent debt crisis.

In the case of Hungary delayed values of returns became statistically significant independent variable for other CEE markets. This result is and relatively low correlation between Hungarian index and other indices suggest that the development of Hungarian market anticipates developments of other CEE markets. The events in Hungary are an important factor for the change in returns in CEE markets.

As a possible extension of this paper it can be used an impulse response function which traces the effect of a one-time shock to one of the innovations on current and future values of the endogenous variables. Moreover, it seems that another useful tool could be a variance decomposition that separates the variation in an endogenous variable into the component shocks to the VAR model. Thus, the variance decomposition provides information about the relative importance of each random innovation in affecting the variables in the VAR model.

5. Conclusion

Previous research dealing with interrelations between stock markets concludes that the degree of interdependence of new EU countries with the global market is gradually growing. However, local effects remain still the most determinative. This paper contributes to discussion concerning mentioned topic. The aim of this paper was to describe and analyze interrelations among CEE stock market and developed stock markets represented by the U.S. stock market and Germany as biggest stock market in Eurozone, and to evaluate potential impact of global financial crisis on those relationships.

Results we achieved indicate that recent period of the global financial crisis and subsequent debt crisis changed a system of mutual relationships among stock markets in Central Europe and Eurozone, respectively in USA significantly. In the period of economic growth, stock markets were less synchronized, and one can consider that most important factors were probably mainly domestic factors, while in the period of global financial crisis, developments of respective stock markets became more synchronized since events on global markets started to play more significant role on national markets. In the post crisis period, it can be said that interrelations among respective stock markets basically follow status quo which was set up in the global financial crisis period.

Regarding mutual interrelations of CEE stock markets with global stock markets and Eurozone markets it can be summed up that these markets are rather influenced by the U.S. stock market than Eurozone instead. CEE stock markets are probably considered by investors as Eastern Europe area. In the period of the global financial crisis CEE behave as one region since negative innovation from one market influence other CEE markets significantly.

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