6. INTERRELATIONSHIP BETWEEN DAX INDEX AND FOUR LARGEST EASTERN EUROPEAN STOCK MARKETS

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Abstract

This paper examines the interrelationship between German stock index and four indices of Emerging European markets (EEM). For the research purposes, we utilize asymmetric BEKK-GARCH models with and without structural breaks insertion. The dynamic correlations show that high level of integration exists between German stock market and selected EEMs, which undermines diversification opportunities. The shocks from the Czech market have unidirectional shock spillover impact on German stock market, while Polish and Romanian indices suffer shock impact that occur in the German stock market but it does not happen vice-versa. Spillover results can be used to forecast future dynamics of receiving variable. Utilizing dummy variables in the A-BEKK-GARCH framework, this paper raises awareness that proper model assessment is necessary, in order to get more reliable estimates that can be used in decision-making process.

Keywords: stocks, A-BEKK-GARCH, structural breaks, spillover, dynamic correlation
JEL Classification: C51, C58, G15

1. Introduction

Emerging European Markets (EEMs) have been widely recognized by the international investors as an attractive investment opportunity in the past few decades. Various recent papers, such as Fedorova and Vaihekoski, (2009), Durčáková (2011), Tee *et al.* (2014), Lupu (2015) and Cevik et al. (2016) asserted that significant growth rates of emerging European markets were directly caused by vast foreign investment inflows, an overall financial development and improvements of international competition. Due to the new diversification possibilities and risk reduction opportunities these markets became appealing to the various market participants and long-term portfolio investors around the world. In the process of accelerated development, emerging European economies started to become more and more integrated with developed European financial markets in recent decades. However, the

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growing interconnection of these markets with the developed financial markets makes them vulnerable and susceptible to the various events, news and shocks, which originate from the well-established equity markets. Therefore, a better understanding of the interconnection between developed and EEMs in terms of their mutual correlation as well as bidirectional shock spillover effects presents one of the most important tasks for portfolio managers and international investors who take part in EEMs. According to Černy-Cerge-El and Koblas (2008), Kizys and Pierdzioch (2011) and Stoica *et al.* (2015), there is a growing attention of global investors to the emerging capital markets, but generally the number of empirical papers that investigate interrelationship between emerging East European markets and mature markets remains relatively low, so we believe that further insight would be useful.

According to aforementioned, this study strives to determine the strength of the interrelationship between German stock market and four largest stock markets of EEMs. In particular, we determine the level of dynamic correlation and gauge the magnitude of bidirectional spillover effect between German DAX index and the four largest EEMs – the Czech Republic, Poland, Hungary and Romania. Some stylized facts about selected East European stock markets are presented in Table 1. As can be seen, these stock markets are the largest in East Europe according to market capitalization and their world's rank is not to be underestimated. In addition, their daily trading volumes are significant and they annual growth rates are relatively high, which represents an alluring opportunity for international investors.

Table 1

Some Characteristics of Selected East European Stock Markets

	Czech Rep.	Poland	Hungary	Romania
SMC♦ in millions of US$ in 2016	40,912	138,691	22,553	14,024
World's rank of SMC♦	50	36	61	64
Average daily trading volume in 2016	3,622,200	48,812,316	2,529,433	28,605,327
Annual stock market growth rate♣	4.032	6.804	9.072	17.388

Note: SMC stands for stock market capitalization.

♣ Averaged annual stock market growth rates are calculated for the full sample.

♦Source: https://www.indexmundi.com/facts/indicators/CM.MKT.LCAP.CD/rankings

In the research process, we utilize full asymmetric BEKK (A-BEKK) of Kroner and Ng (1998). Having in mind that our study comprises relatively long time-span, which was permeated with various crisis events and shocks, we assume that our time-series were most likely susceptible to multiple structural changes, which could generate various specification biases in GARCH models and eventually affect the assessment of their interconnection. It is well known in the literature that structural breaks presence in the GARCH processes could cause various problems. Firstly, as asserted by Kramer and Azamo (2007), volatility persistence might be overestimated and heavily inclined towards one if deterministic regime shifts are ignored in GARCH models. Secondly, Huang (2012) and Jung and Maderitsch (2014) contended that spillovers effect could be wrongly estimated if structural shifts are not recognized in the models. Thirdly, Miralles-Marcelo *et al.* (2008) found that asymmetric effect in GARCH framework could be biased if structural breaks are not considered.

In order to detect the presence of multiple structural shifts, we utilize the modified Iterative Cumulative Sum of Squares (ICSS) algorithm by Sansó *et al.* (2004) in the unconditional variance. Consequently, we embed dummy variables into the bivariate GARCH-BEKK model in order to improve its fitting performances. In that manner, we are in position to test all previously stated contentions regarding the issues of structural breaks in GARCH models. Also, we are able to measure the level of integration between selected markets and assess whether and in which magnitude shocks from German markets spillover to EEMs. The motivation behind this study lies in an effort to offer more in-depth analysis for decision-making stakeholders, regarding both dynamic conditional correlation and spillover effects between the East European stock indices and the German stock index. At the same time, we take into account possible estimation biases that could arise due to the presence of multiple structural breaks. To the best of our knowledge, this paper differs from other related studies in a way that it comprehensively investigates the interrelationship between major EEMs and the German market via bivariate A-BEKK-GARCH model, whereby we pay particular attention on specification biases that might obscure estimation results.

The remainder of the paper is structured as follows. Brief literature review is presented in Section 2. Methodological approach is described in Section 3, and Section 4 is reserved for data description and structural breaks explanation. Section 5 presents the results and last Section concludes.

2. Literature Review and Related Studies

Some recent papers, such as Chiang *et al.* (2007), Hu and Hsuen (2013) and Chang *et al.* (2015) analysed the nexus between the emerging and developed stock markets, mostly focusing on emerging markets in Asia and Latin America. Regarding the particular interrelationship between East European stock markets and developed stock markets, Syriopoulos (2007) investigated the short- and long-run behaviour of major emerging Central European (Poland, the Czech Republic, Hungary, Slovakia), and developed (Germany, US) stock markets. He concluded that Central European markets tend to display stronger linkages with their mature counterparts, whereas the US market holds a world leading influential role. The study of Lucey and Voronkova (2008) examined Russian equity market connections with several developed stock markets, but also with the equity markets of Hungary, the Czech Republic and Poland before and after the 1998 crisis. Their results suggested that Russian market does not show strong evidence of increased long-run convergence, either with regional or developed markets. But the evidence of short-run nexus assessed via DCC-GARCH model showed that conditional bivariate correlations have increased in the post-crisis period as compared to the pre-crisis period. Dajčman and Festić (2012) examined the interdependence of Slovenia, the Czech Republic and Hungary with some developed European stock markets. They divided the total observation period into three sub-periods: the period before the three EEM countries joined the EU, the period from EU membership until the start of the global financial crisis (GFC), and the period after GFC began. They found a small degree of co-movement with EEM and developed European stock markets, but they asserted that GFC have strengthened the interdependence of EEM and developed stock markets.

Anghelache *et al.* (2014) examined the relationship between a set of macro financial variables, the main stock indices of Western Europe and the stock indices of four EEM. They concluded that the stock market co-movements between EEM that have recently joined the European Union and the developed European capital markets, has significantly increased after joining the European Union. Also, their conditional correlations indicated that the financial shocks had simultaneously hit all the regional Stock Exchanges during GFC. Syllignakis and Kouretas (2010) examined the long-term linkages between seven Central and Eastern European (CEE) emerging stock markets and two developed stock markets – German and the US markets. They showed that the financial linkages between the CEE markets and the world markets increased with the beginning of the EU accession process. Also, they explained that they share a significant common permanent component which drives the system of these stock exchanges in the long-run, while the Estonian market appeared to be segmented. The manuscript of Wang and Moore (2008) found the evidence of a higher level of stock market correlation between three emerging CEE markets and the aggregate Eurozone market during the period after the Asian and Russian crises and also during the post-entry period to the European Union. The study of Voronkova (2004) revealed the existence of long-run links between the UK, the German, the French and three Central European stock markets (Hungary, Poland, and the Czech Republic), using daily data for the period 1993–2002. She claimed that the Central European markets display equilibrium relations with their mature counterparts, which persist after controlling for structural changes. Syllignakis and Kouretas (2011) utilized the DCC-GARCH model to capture potential contagion effects among the US, German and Russian stock markets and the seven CEE stock markets. They found statistically significant increase in conditional correlations between the US and the German stock returns and the CEE stock returns, especially during the 2007– 2009 world crises, showing that these emerging markets are exposed to external shocks with a substantial regime shift in conditional correlation.

3. Methodology

3.1. Multivariate A-BEKK-GARCH Model

This section presents brief theoretical review of full asymmetric BEKK-GARCH. For multivariate GARCH model we consider AR(1) specification in the mean equation, while the conditional variance equation follows GARCH(1,1) process in asymmetric BEKK models. In order to deal with possible specification biases, we incorporate several dummy variables in every BEKK-GARCH model, which account for the presence of structural breaks. Specifically, referring to Miralles-Marcelo ***et al.*** (2013), dummy variables are constituent part of the conditional variance-covariance matrix (H_t) of the disturbance term ε in the asymmetric BEKK models. The mean equation and the conditional variance equation with incorporated dummy variables have the following form:

$$y_{i,t} = c_i + \Phi_{i,n} y_{i,t-n} + \varepsilon_{i,t}; \qquad \varepsilon_{i,t} \sim iid \ , \tag{1}$$

$$h_{i,t} = C_i + \beta h_{i,t-1} + \alpha \varepsilon_{i,t-1}^2 \tag{2}$$

where: $y_{i,t} = [r_{DAX,t}, r_{EEM,t}]'$ and all stock returns are calculated as $r_{i,t} = 100 \cdot \log(\frac{P_{i,t}}{P_{i,t-1}})$, in which $P_{i,t}$ is the closing price for the particular stock (i) at time (t). Label Φ is parameter of AR(1) term. Symbol ε_t stands for independently and identically distributed error terms of selected stock indices, for which it is assumed to follow standard Student-t distribution, due to the fact that residual distributions of selected daily frequent asset returns commonly tend to report asymmetry and leptokurtosis. In the equation (2), parameter *α* measures the level-effect of shocks, and *β* parameter gauges the degree of volatility persistence.

As for the multivariate specification, we use the asymmetric full BEKK-GARCH model of Kroner and Ng (1998), where the variance–covariance matrix depends not only on the magnitude of past squared return innovations and variance–covariance matrix, but also on the sign of the past squared return innovations. This model is also capable of detecting dynamic correlation as well as volatility spillovers across asset markets. In addition, this model has an attractive property that the conditional covariance matrices are positive definite. A-BEKK model is a multivariate transposition of univariate GJR–GARCH model (see e.g. Fedorova and Saleem, 2010). In order to evade possible specification bias, our procedure considers recognition of sudden changes in the conditional variance-covariance matrix (H_t) of A-BEKK-GARCH model by introducing a set of dichotomous dummy variables. Accordingly, the conditional variance-covariance matrix of A-BEKK-GARCH model can be presented as:

$$H_{t+1} = \Omega'\Omega + B'H_tB + A'\varepsilon_t\varepsilon_t'A + C'\eta_{t-1}\eta_{t-1}'C + \sum_{i=1}^{k} D_i'X_i'X_iD_i\,, \quad (3)$$

where: Ω is a 2 × 2 lower triangular matrix with three parameters, while A and B are 2 × 2 square matrices of parameters. The B matrix depicts to which extent the current levels of conditional variances are related to the past conditional variances. The A matrix measures to which extent the conditional variances are correlated to past squared errors (i.e., deviations from the mean). Diagonal parameters a_{11} and a_{22} in matrix A capture their own ARCH effect indicating that conditional variances are affected by past squared errors, while diagonal elements b_{11} and b_{22} in matrix B measure their own GARCH effect, suggesting that current conditional variance is affected by their own past conditional volatility. The off-diagonal parameters (a_{12}, a_{21} and b_{12}, b_{21}) in matrices A and B reveal the manner in which shock and volatility are transmitted over time and across the selected financial markets. C is a 2 × 2 matrix that measures asymmetric ARCH effects, implying that negative shock (bad news) has higher effect on conditional variance than positive shock (good news), where $\eta_{t-1} = \varepsilon_{t-1}I;\ I = 0\left|\varepsilon_t > 0 \vee I = 1\right|\varepsilon_t \le 0$. Diagonal coefficients c_{11} and c_{22} of the matrix C assess the responses of its own negative shocks of return series on its current conditional volatility, whereas off-diagonal elements c_{12} and c_{21} of the matrix gauge the shock and volatility spillovers between return series. Symbol D_i stands for a 2 × 2 square diagonal matrix of parameters, X_i is a 1 × 2 row vector of volatility regime control variables, and k is the number of sudden change points found in variance.

All BGARCH models were estimated by quasi-maximum likelihood (QMLE) technique. This procedure allows for asymptotically consistent parameter estimates, even if the underlying distribution is not normal, as contended by Bollerslev and Wooldridge (1992).

3.2 Test of Multiple Structural Break Detection in the Variance

The basic ICSS algorithm of Inclan and Tiao (1994) – IT hereafter, assumes that variance of a time series is stationary over an initial period of time, until a sudden jump occurs. The variance then recurs to stationary until another market shock happens. This process is reiterated over time, generating a time series of observations with an unknown number of breaks in the variance. However, underlying ICSS procedure only yields reliable results under the assumption of *i.i.d.* process, which is highly unlikely characteristic for financial series in which dependent GARCH process is present. Addressing this problem, the study of Sans´o *et al*. (2004) showed that IT process can be significantly oversized due to the presence of heavy-tails, where extreme values are recognized as points of sudden jumps, even though they should be classified as outliers. Therefore, our approach refers to Sansó *et al.* (2004), who suggested a new test, modified Inclan and Tiao (MIT) test, which explicitly takes into account the fourth moment properties of the time series. Following Sansó *et al.* (2004) and some recent papers, such as Mensi *et al.* (2014) and Živkov *et al.* (2015) who used this procedure in empirical log-returns series, we applied a non-parametric IT adjustment based on the Bartlett kernel, which is set as:

$$MIT = \sup_k \left|T^{-0.5}G_k\right|, \quad (4)$$

where: $G_k = \hat{\lambda}^{-0.5}\left[C_k - (k/T)C_T\right]; \hat{\lambda} = \hat{\gamma}_0 + 2\sum_{l=1}^{m}\left[1 - l(m+1)^{-1}\right]\hat{\gamma}_l; \hat{\gamma}_l = T^{-1}\sum_{t=l+1}^{T}(\tau_t^2 - \hat{\sigma}^2)(\tau_{t-1}^2 - \hat{\sigma}^2);$ $\hat{\sigma}^2 = T^{-1}C_T$. Referring to the procedure of Newey and West (1994), we set the lag truncation parameter to $m = 0.75T^{1/3}$. With usage of modified ICSS algorithm, we were in position to detect multiple sudden changes in the conditional variances, and to implement them into BGARCH models via dummy variables. Each dummy variable is constructed as unity from structural break onwards and zero otherwise.

4. Dataset and Detection of Multiple Structural Breaks

The dataset used in this study comprises the daily closing log returns of four emerging Eastern European equity indices, namely: PX (the Czech Republic), WIG (Poland), BUX (Hungary) and BET (Romania). Each of these indices is combined with German DAX equity index into the bivariate A-BEKK-GARCH models. We observe period from January 2001 to December 2016 and all series were collected from Datastream. Due to the fact that some data are unavailable because of the national holidays and non-working days in national stock markets, all pairs of stock indices were synchronized according to the existing observations. The succinct descriptive statistics in Table 2 presents first four moments, Jarque-Bera coefficients of normality, Ljung-Box Q-statistics and unit root tests of assets' unconditional distributions.

Table 2 shows non-normal behaviour for all selected equity returns, which is substantiated by the notably negative features and leptokurtosis. High values of JB test verify non-normal characteristics, which justifies the use of standard t-distribution in all A-BEKK-GARCH models. LB(Q) statistics for level returns suggests that AR(1) mean specification might be suitable. Also, LB(Q^2) test indicates the presence of time varying-variance with an ARCH pattern in all series, implying that GARCH parameterization might be adequate. In order to dismiss the possibility of spurious regressions we performed DF-GLS test and KPSS test, which set a different hypothesis. Particularly, DF-GLS test sets a hypothesis that time series contain unit roots, while KPSS test examines the null hypothesis of stationarity and it is found to be more appropriate in the case of near unit root processes. The results of both tests shown in Table 2 strongly refute that selected series contain unit root and therefore they are all convenient for the further examination.

Table 2

Descriptive Statistics and Unit Root Tests of Underlying Stock Indices

	Mean	St. dev.	Skew.	Kurt.	JB	LB(Q)	LB(Q^2)	DF-GLS	KPSS
PX	0.016	1.405	-0.504	16.475	30386	0.000	0.000	-5.163	0.313
WIG	0.027	1.239	-0.347	6.235	1821	0.003	0.000	-6.796	0.138
BUX	0.036	1.523	-0.107	9.578	7227	0.000	0.000	-6.141	0.111
BET	0.069	1.541	-0.448	10.809	10026	0.000	0.000	-3.094	0.421
DAX	0.014	1.527	-0.005	7.375	3194	0.000	0.000	-3.536	0.180

Notes: Mean is multiplied by 100. JB stands for value of Jarque-Bera test for normality, LB(Q) and LB(Q^2) label p-values of Ljung-Box Q-statistics for level and squared residuals for 20 lags. Assuming the absence of the trend, the 1% and 5% critical values for the DF-GLS test (modified Dickey-Fuller test) with ten lags are -2.566 and -1.941, respectively. 1% and 5% critical values for KPSS test are 0.739 and 0.463, respectively.

Source: Authors' calculation.

In Table 3, we present the exact time points when structural breaks occurred. Also, we offer a concise explanation what might be a cause of their appearance. Selected time series encompass world crisis outbreak (2008-2009), so it may be expected that each examined series contains at least two breaks – at the beginning and at the end of the crisis. Generally, structural breaks originate as a consequence of various global and domestic events, and in our observed time frame several major global events occurred. Particularly, these events were September 11, 2001 terrorist attack, which was followed by the Afghanistan and Iraq invasions in 2002 and 2003. The global economy was hit by the GFC at the end of 2008, and soon after this crisis, the European sovereign debt crisis (ESDC) emerged in 2010.

Table 3

Detected Break Points in the Unconditional Volatility by the Modified ICSS Algorithm

PX		BUX		WIG	
Time period	s.d.	Time period	s.d.	Time period	s.d.
1/1/01 – 9/4/08	1.222	1/1/01 – 9/4/08	1.338	1/1/01 – 7/25/07	1.167
9/5/08 – 6/10/10	2.697	9/5/08 – 1/20/12	2.253	7/26/07 – 5/26/10	1.777
6/11/10 – 3/6/12	1.287	1/21/12 – 12/31/16	1.091	5/27/10 – 6/29/12	1.181
3/7/12 – 12/31/16	0.952			6/30/10 – 12/31/16	0.915

BET		DAX	
Time period	s.d.	Time period	s.d.
1/1/01 – 1/13/03	1.523	1/1/01 – 4/18/01	1.722
1/14/03 – 12/24/04	0.989	4/19/01 – 6/13/02	1.671
12/25/04 – 12/20/07	1.608	6/14/02 – 6/16/03	2.906
12/21/07 – 7/2/10	2.633	6/17/03 – 1/14/08	0.989
7/3/10 – 8/2/12	1.258	1/15/08 – 7/15/09	2.302
8/3/12 – 12/8/14	0.727	7/16/09 – 8/3/12	1.461
12/9/14 – 12/31/16	0.895	8/4/12 – 10/9/14	0.925
		10/10/14 – 12/31/16	1.399

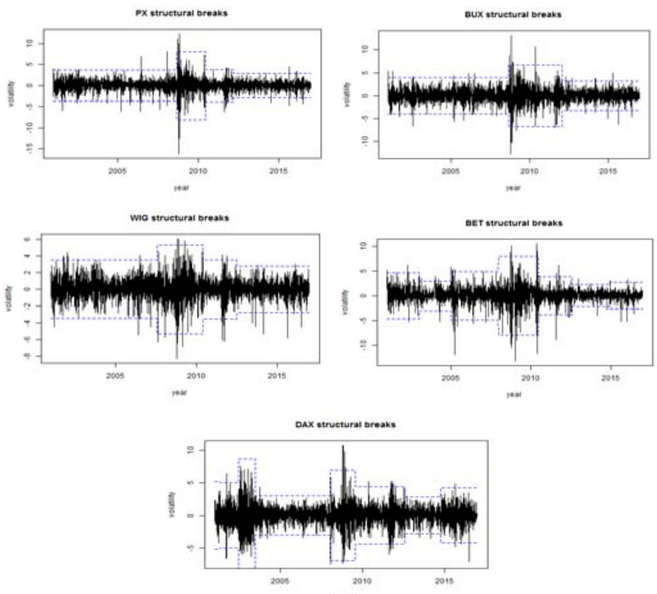
Note: Time periods were determined by the modified ICSS algorithm. s.d. stands for standard deviation.

Source: Authors' calculation.

Figure 1 depicts the log-returns series and their reaction on these events and Table 3 gives time spots when breaks happened, with ±3 standard deviation band for each period. The number of detected sudden changes varies between two and seven. It can be noted that global events are best illustrated on German stock market, as largest, most developed and most liquid market. German stock market is the only one that vividly has volatility increase during the Iraqi war, which is recognized by the modified ICSS algorithm with two breaks. Also, German index has clear reaction on the GFC and later ESDC. Regarding Eastern European stock markets, as it is assumed, modified ICSS algorithm found structural breaks around GFC on all markets, but it is evident that impact of GFC on selected stock markets was heterogeneous. According to the standard deviation values, Czech PX index suffered the biggest impact during the GFC, and Romanian BET index follows. As can be noticed, all Eastern European stock markets had higher volatility during ESDC, which is recognized as point of sudden shift in Czech, Polish and Romanian markets.

Figure 1

Logarithmic Stock Returns and Detected Structural Breaks



Note: Doted lines denote bands of ±3 standard deviations, where change points are estimated by the modified ICSS algorithm.
Source: Authors' calculation.

For every structural break detected by the modified ICSS, we created a dichotomous dummy variable defined as unity from structural break onwards and zero otherwise. By inserting multiple dummy variables in the various BGARCH models, we are able to see how structural breaks presence affects A-BEKK-GARCH performances.

5. Results of Bivariate A-BEKK-GARCH Models

This section presents the results of asymmetric full BEKK-GARCH models estimated with and without structural breaks insertion. These results disclose the nature of interrelationship between German and EEMs stock markets and Table 5 contains estimated parameters of the conditional variance-covariance matrix (H) as well as diagnostic tests and information criteria. It can be seen that all LB(Q) tests for level and squared residuals reveal that models have no problem with autocorrelation and heteroscedasticity. Also, in Panel C of Table 5 we present three information criteria and LL values. According to three information criteria and calculated LL values, in three out of four cases, A-BEKK-GARCH model with structural breaks has better performances in comparison to the no break counterpart, i.e. only in case of Poland model with no breaks had an upper hand. Referring to these findings, we plot dynamic correlations from the optimal A-BEKK-GARCH models and the results are presented in Figure 2. As can be seen, all EEMs indices have relatively high correlation with

German DAX index, which is an indication that all EEMs have very strong connections with the strongest European economy. Table 4 contains their average rho values. High level of integration is somewhat expected since Germany is the main trading partner for all selected EEMs, taking into account the volumes of export as well as import. Table 4 presents the amounts of export and import with Germany relatively to the GDP and it can be seen that in cases of Czech Republic and Hungary export level exceeds 20%, which is very high percent for the bilateral trading partner. Romania has the lowest export (import) and one of the reasons could lie in greater geographical distance from Germany in comparison with other three EEMs.

However, from the portfolio perspective, relatively high correlation between DAX index and other EEM indices is not good for diversification purposes, whatsoever. More specifically, Table 4 suggests that global investors cannot achieve significant diversification benefits if they couple DAX index with three Visegrad group indices, because their average correlations are around 50%. In case of Romania, it is somewhat better, since correlation between DAX and BET is around 25%, and BET index might be considered as an auxiliary asset in a two-asset portfolio, whereby DAX is a primary investment.

Table 4

Level of Trade Volume between EEMs and Germany in Billions of Dollars in 2015 and Average Rho Estimates from an Optimal A-BEKK-GARCH Model

	CZH	HUN	POL	ROM
Average rho*	0.497	0.459	0.528	0.242
Export in % of GDP**	23.95	20.66	9.43	7.36
Import in % of GDP**	20.05	18.18	9.62	7.92

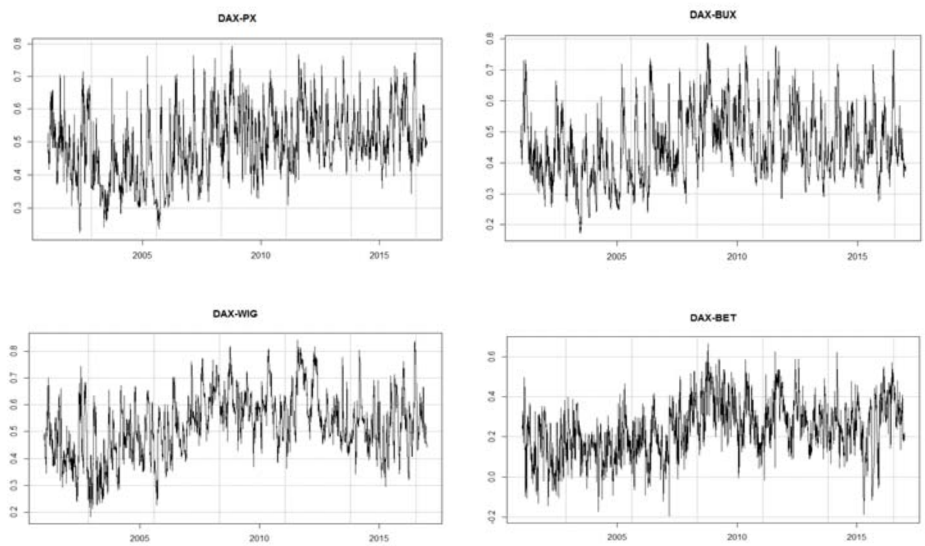
**Source: Authors' calculations.*

***Source: Observatory of economic complexity;* http://atlas.media.mit.edu/en/.

In addition, it should be mentioned that an interesting pattern can be viewed around GFC and ESDC periods, when most of dynamic correlations reached an astonishing level of nearly 80%. These findings are in line with Lin (2012), who asserted that stock prices nexus strengthens during turmoil periods. Also, according to Boyer et al. (2006), the stronger interconnection between asset markets, particularly between developed and emerging markets, might be induced by so-called contagion effect caused by the portfolio rebalancing. In the behavioural finance theory, this is described as herding effect, which happens when investors pursue actions of other investors, taking trading positions in the same direction over a period of time. Particularly, this scenario happened in recent GFC crisis as international stock owners urgently liquidated their portfolio investments in emerging markets and transferred their intentions towards the safer assets, e.g. gold, which was the typical flight to quality behaviour. In other words, all selected EEM indices have very poor risk-reduction possibilities when they are combined with DAX index in turbulent times, which indicates that investors in crisis periods should abandon, without hesitation, these indices and/or transfer their capital funds to some other assets, which preferably have rising prices in crisis (e.g. government bonds or precious metals).

Figure 2

Plotted Dynamic Correlations from the Optimal A-BEKK-GARCH Model



Source: Authors' calculation.

Looking at Table 5, the majority of estimated parameters 5 are statistically significant and some of the parameters have negative sign. However, since the parameters in BEKK model are shown in quadratic form, it should be mentioned that the signs of the coefficients are irrelevant. The diagonal elements of the matrix A, B and C measure the effect of own past shocks (a_{11}, a_{22}), its own lagged conditional variance (b_{11}, b_{22}) and its own asymmetric shocks (c_{11}, c_{22}). It can be noticed that the shocks of EEMs have the greater effect on its own conditional variance in comparison to this effect in the German stock market. The results are in line with the findings of Li and Giles (2015) who analysed six emerging economies in Asia and two developed economies and found similar results. They concluded that past shocks have a greater role in the volatility of the emerging markets comparing to the shocks on the developed markets. They explained that the more mature markets are less affected by their own past shocks.

Diagonal coefficients of the matrix B gauge the influence of past volatility of a market on its conditional variance, and all estimated diagonal parameters are significantly different from zero at the 1% level. All parameters b_{22}, which measure the effect of past volatility on conditional variance in EEMs, are mitigated in models with breaks in comparison to the models without breaks, which confirms that volatility persistence might be overestimated in models without breaks. The asymmetric response of volatility is measured via diagonal elements of the matrix C and they capture asymmetric response of a market to its own past negative shocks or 'bad news'. The asymmetric responses are highly significant in Table 5 and they have a more evident response to negative shocks on developed German stock market than on emerging European markets. All c_{22} parameters, which measure asymmetric shocks in EEMs, are lower in models without breaks and these results stands in line with the argumentation of Marcelo et al. (2008) who asserted that asymmetric effect in GARCH framework might be biased if sudden shifts were not taken into account.

Table 5

Estimated Parameters of Full A-BEKK-GARCH Models without and with Structural Breaks

	DAX – PX		DAX – BUX		DAX – WIG		DAX – BET	
	NB	**WB**	**NB**	**WB**	**NB**	**WB**	**NB**	**WB**
Panel A. Estimated parameters of conditional variance in full BEKK-GARCH models								
ω_{11}	0.002*	0.002*	0.002*	0.001*	0.002*	0.002*	0.002*	0.001*
ω_{21}	0.001*	0.001*	0.001*	0.001*	0.001*	0.001*	0.000	0.000
ω_{22}	0.002*	0.002*	0.002*	0.002*	0.001*	0.002*	0.002*	0.004*
a_{11}	0.063*	0.025*	0.058**	0.035	0.076*	0.025*	0.109*	0.099*
a_{12}	-0.006	0.011	0.028***	0.041*	-0.047*	0.011	0.019**	0.041*
a_{21}	0.037	0.049*	0.029***	0.039*	0.001	0.049*	0.009	0.019
a_{22}	0.286*	0.265*	0.214*	0.203*	0.223*	0.265*	0.422*	0.407*
b_{11}	0.959*	0.961*	0.958*	0.959*	0.953*	0.961*	0.948*	0.950*
b_{12}	0.002	0.007	-0.005	-0.002	-0.006***	0.007	0.010*	0.013*
b_{21}	-0.011	-0.015*	-0.006	-0.009	0.001	-0.015***	-0.000	-0.009
b_{22}	0.924*	0.914*	0.946*	0.941*	0.967*	0.915*	0.887	0.867*
c_{11}	-0.335*	-0.340*	-0.357*	0.362*	0.364*	-0.340*	0.376*	0.374*
c_{12}	-0.019	-0.009	-0.029	0.032	0.053*	-0.009	-0.046*	-0.049*
c_{21}	-0.058*	-0.059*	-0.023	0.022	0.019	-0.059*	0.018	0.033**
c_{22}	-0.252*	-0.283*	-0.242*	0.250*	0.173*	-0.284*	0.239*	0.284*
v_1	9.149		8.748		8.980		8.795	
v_2	7.473		8.859		7.302		5.581	
Panel B. Diagnostic tests								
$LB_1(Q)$	0.783		0.537		0.154		0.374	
$LB_1(Q^2)$	0.460		0.431		0.650		0.772	
$LB_2(Q)$	0.289		0.300		0.460		0.102	
$LB_2(Q^2)$	0.359		0.991		0.341		0.125	
Panel C. Information criteria								
LL	24570	24584	23964	23973	24778	24584	23246	23277
AIC	-12.305	-12.311	-11.969	-11.972	-12.413	-12.312	-11.941	-11.956
SIC	-12.281	-12.284	-11.945	-11.946	-12.389	-12.284	-11.917	-11.928
HQIC	-12.297	-12.302	-11.961	-11.963	-12.404	-12.302	-11.933	-11.946

*Notes: WB and NB labels signify the models with and without breaks, respectively. Symbol v stands for Student's tail parameter. LL, AIC, SIC and HQIC are Log Likelihood, Akaike, Schwarz and Hannan–Quinn information criteria, respectively. LB(Q) and LB(Q^2) are Ljung-Box Q-statistics for level and squared residuals with 20 degrees of freedom. *, **, *** indicate significance levels at the 1%, 5% and 10%, respectively.*

Source: Authors' calculation.

However, from the investors' point of view, the off-diagonal coefficients are more important for them, since they bear information about spillovers between markets. Knowing from which market spillovers originate, investors could use this information for asset reallocation, since if one variable transmits shocks to other one, then its realizations may be used to forecast the future dynamics of receiving variable (see Dajčman, 2013). The off-diagonal elements of the matrices A, B and C gauge the transmission effect of past shocks (a_{12}, a_{21}), lagged conditional variance (b_{12}, b_{21}) and asymmetric shocks (c_{12}, c_{21}) that come from the other market. The findings in Table 5 are heterogeneous, and it is obvious that cross market shock transmissions are higher than cross market volatility transmissions between EEMs markets and German market in all cases. For instance, in case of DAX-PX, it seems that shocks from Czech market have unidirectional shock spillover impact on German stock market, but only in model with breaks, which is better performing model. This finding indicates that shocks on the Czech market happen before the shocks on the German market, which might suggest investors how they should pursue their position in the DAX index.

On the other hand, Table 5 reports that bidirectional spillover effect exist in case of DAX-BUX in both models with and without breaks. Corresponding values of a_{12} and a_{21} parameters suggest that shock spillover effect between these markets are relatively equable, which does not leave much room for the predictions, which variable is leading and which one is lagging. Looking at the better model in the case of Poland, i.e. in model without breaks, it seems that Polish stock market suffers shock impact that occur in the German stock market but it does not happen other way around. In case of Romania, the situation is similar as in Poland, i.e. the unidirectional shock spillover effect exist from German toward Romanian stock market. The magnitude of this effect is relatively the same as in the case of DAX-WIG. Results from DAX-WIG and DAX-BET pairs indicate that Polish and Romanian stock markets are shock receivers, which means that investors could foresee future dynamics of these indices if they track DAX movements. Generally, our findings coincide with the paper of Gencer and Hurata (2017) who via BEKK-GARCH model found bidirectional spillover effect between developed U.S. stock market and those of the G20 countries, along with some selected European equity exchanges.

Asymmetric transmission of ‘bad news’ is also heterogeneous and it seems that asymmetric spillover from Czech market to the German market is higher than the opposite effect, while in case of Hungary, it does not exist in any direction. In case of Poland, WIG index suffers asymmetric shock transmission from DAX index, whereas in case of Romania this effect is bidirectional.

By inserting dummy variables in our A-BEKK-GARCH models, we can witness that shock spillover effect diverges between the models with and without breaks, and in some cases, it also induces the difference in a way whether some parameters are estimated as statistically significant or not. Knowing exactly from which stock market shock spillover effect originate could produce effective portfolio-rebalancing decisions for international investors. To this end, proper model assessment is necessary, that is, an inclusion of structural breaks in the GARCH models, which will produce the best estimation results, eventually.

6. Spillover Effects between the Selected EEM and Other Developed Stock Markets – Additional Analysis

This section tries to uncover how selected EEM are connected with other developed stock markets, such as American and British. In other words, we calculate bidirectional spillover effects via A-BEKK-GARCH model between both S&P500 and FTSE250 indices and the EEM indices, and Table 6 contains these results. In order to be concise as much as possible, we comment only the off-diagonal parameters, which contain an information how shocks are transmitted across the markets.

For instance, observing the S&P500 index vs EEM indices, it can be seen that shocks are transmitted only from the American stock market, but no other way around, whereby the biggest impact endures Hungarian index, while Polish index follows. This is different from the Table 5 results, in which we have seen that German index also suffer shock impacts from the East European markets.

Table 6

Spillover Effects between Developed Stock Markets and the Selected East European Stock Markets

	S&P500 vs PX	S&P500 vs BUX	S&P500 vs WIG	S&P500 vs BET	FTSE vs PX	FTSE vs BUX	FTSE vs WIG	FTSE vs BET
Panel A. Estimated parameters of conditional variance in full BEKK-GARCH models								
ω_{11}	0.140^{***}	0.145^{***}	0.146^{***}	0.144^{***}	0.184^{***}	0.184^{***}	0.183^{***}	0.194^{***}
ω_{21}	0.019	0.007	0.046^{***}	-0.037	0.113^{***}	0.099^{***}	0.052^{***}	0.035^{*}
ω_{22}	0.249^{***}	0.204^{***}	0.117^{***}	0.211^{***}	0.198^{***}	0.236^{***}	0.105^{***}	0.211^{***}
a_{11}	0.058^{**}	-0.008	-0.056^{*}	0.013	0.189^{***}	0.211^{***}	0.206^{***}	0.153^{***}
a_{12}	0.096^{***}	-0.203^{***}	-0.134^{***}	0.059^{***}	0.085^{***}	-0.056^{**}	0.059^{***}	0.053^{***}
a_{21}	-0.023	0.003	0.058^{***}	-0.014	-0.013	0.035^{**}	-0.070^{***}	0.007
a_{22}	0.242^{***}	0.221^{***}	0.230^{***}	0.430^{***}	0.258^{***}	0.158^{***}	0.175^{***}	0.427^{***}
b_{11}	0.945^{***}	0.945^{***}	0.944^{***}	0.943^{***}	0.916^{***}	0.917^{***}	0.893^{***}	0.914^{***}
b_{12}	0.018^{**}	0.012^{*}	0.001	0.023^{***}	-0.024^{**}	-0.021^{*}	-0.050^{***}	-0.011
b_{21}	-0.001	-0.003	-0.009^{**}	0.003	0.003	-0.002	0.032^{***}	-0.003
b_{22}	0.914^{***}	0.945^{***}	0.961^{***}	0.888^{***}	0.931^{***}	0.949^{***}	0.983^{***}	0.894^{***}
c_{11}	-0.392^{***}	0.423^{***}	0.440^{***}	0.429^{***}	0.347^{***}	0.354^{***}	0.397^{***}	0.394^{***}
c_{12}	0.056^{**}	-0.010	0.028	-0.017	0.096^{***}	0.169^{***}	0.162^{***}	0.129^{***}
c_{21}	-0.064^{***}	0.033^{***}	0.017	0.031^{**}	0.056^{***}	-0.002	0.029	0.040^{***}
c_{22}	-0.304^{***}	0.260^{***}	0.137^{**}	0.209^{***}	0.174^{***}	0.239^{***}	0.109^{***}	0.080^{*}
v_1	6.458^{***}	6.124^{***}	6.389^{***}	6.365^{***}	8.426^{***}	8.123^{***}	8.375^{***}	8.599^{***}
v_2	7.541^{***}	9.302^{***}	6.913^{***}	4.902^{***}	7.477^{***}	9.602^{***}	7.153^{***}	4.963^{***}
Panel B. Diagnostic tests								
$LB_1(Q)$	0.392	0.786	0.466	0.282	0.908	0.824	0.387	0.751
$LB_1(Q^2)$	0.314	0.426	0.192	0.353	0.633	0.634	0.938	0.964
$LB_2(Q)$	0.359	0.460	0.784	0.116	0.144	0.129	0.486	0.094
$LB_2(Q^2)$	0.723	0.989	0.496	0.435	0.752	0.989	0.583	0.543

*Notes: LB(Q) and $LB(Q^2)$ are Ljung-Box Q-statistics for level and squared residuals with 20 degrees of freedom. *, **, *** indicate significance levels at the 1%, 5% and 10%, respectively.*
Source: Authors' calculation.

Rationale lies in a fact that American stock market is globally the biggest market, and as such it affects stock markets around the world, while East European stock markets are not big enough to transmit any effect on the American market. On the other hand, "neighbouring" British stock market endures spillover effects from the EEM stock markets, but these effects are lower in comparison with the shocks that go from British stock markets towards EEM stock markets.

As for volatility spillover effect, it can be seen that this impact is significantly lower in comparison to shock spillover counterpart and sometimes it is almost negligible in size, which is similar to Table 5 results. Volatility spillovers go for most of the time from developed towards the East European stock markets, as b_{12} and b_{21} parameters indicate.

Off-diagonal c_{12} and c_{21} parameters point to asymmetric transmission of 'bad news', and it can be seen that bidirectional spillover effect exists between S&P500 and PX index as well as between FTSE and PX and BET indices.

Comparing all developed markets, we find that the strongest spillover shocks come from the American stock market, which is expected, since the American stock market is the biggest one.

7. Conclusion

This paper tries to thoroughly explore the interconnectedness between developed German stock market and four Eastern European emerging stock markets (the Czech Republic, Poland, Hungary and Romania), which remains unaddressed thus far. Results from this study may serve well for decision-making stakeholders who are interested in these markets. In addition, we uncover how structural breaks inclusion in A-BEKK-GARCH models affects their fitting performances and whether it benefits to the more precisely parameter estimation. All models couple German DAX index with one of four Eastern European indices: Czech PX, Polish WIG, Hungarian BUX and Romanian BET index.

All estimated BEKK-GARCH models prove to have very good fitting performances, and in all cases the majority of information criteria give the advantage to the models with breaks. The results of dynamic correlations show that high level of integration exists between German stock market and the selected EEMs, which speaks against efficient diversification possibilities. Also, all conditional correlations exhibit significant variability over the observed time-span, where recognizable pattern emerges in the sense that conditional correlations were higher during the World financial crisis and the European sovereign debt crisis.

As for spillover effects, the shocks from Czech market have unidirectional shock spillover impact on German stock market, while bidirectional spillover effect exists in the case of DAX-BUX in both models with and without breaks. In the case of Poland, the results indicate that Polish stock market suffers shock impact that occur in the German stock market but it does not happen other way around. In case of Romania, the situation is similar as in Poland. Including two more developed markets into our analysis *and comparing the size of shock spillover effects that come from them, we find that the strongest spillover shocks come from the American stock market, which is expected since the American stock market is the biggest one with the biggest influence on other stock markets around the world.*

Implications of this paper is that spillover results can be used effectively by international investors for asset reallocation, since realizations of variable that transmits shocks to other one, may be used to forecast the future dynamics of the receiving variable. By inserting dummy variables in the A-BEKK-GARCH model, this paper raises awareness that proper model assessment is necessary, since it yields more reliable estimates, which can be used for efficient decision making.

There is a room for future studies to assess which variables mostly affect dynamic conditional correlations, which would contribute to better understand what are the main driving factors of the dynamic correlations.

We believe that these findings could help various global investors, portfolio managers and market analysts to have clearer picture about the interconnection between these stock markets. Also, the results could significantly contribute to the process of decision making and portfolio construction.

References

Anghelache, G.V. Kralik, L.I. Acatrinei, M. and Pete, S., 2014. Influence of the EU accession process of the global crisis on the CEE stock markets: A multivariate correlation analysis. *Romanian Journal of Economic Forecasting*, 17(2), pp.35-52.

Bollerslev, T. and Wooldridge, J.M., 1992. Quasi-maximum likelihood estimation and inference in dynamic models with time-varying covariances. *Econometric Reviews*, 11(2), pp.143–172.

Boyer, B. Kumagai, T. and Yuan, K., 2006. How do crises spread? Evidence from accessible and inaccessible stock indices. *Journal of Finance,* 61(2), pp.957−1003.

Cevik, N.K. Dibooglu, S. and Kutan, A.M., 2016. Real and Financial Sector Studies in Central and Eastern Europe: A Review. *Finance a Uver: Czech Journal of Economics and Finance,* 66(1), pp.2-31

Chang, T-Y. Fang, H. and Lee, Y-H., 2015. Nonlinear adjustment to the long-run equilibrium between he REIT and the stock markets in Japan and Singapore. *Romanian Journal of Economic Forecasting*, 18(3), pp.27-38.

Chiang, T.C. Jeon, B.N. and Li, H., 2007. Dynamic correlation analysis of financial contagion: Evidence from Asian markets. *Journal of International Money and Finance*, 26(7), pp.1206−1228.

Černy-Cerge-El, A. and Koblas, M., 2008. Stock market integration and the sped of information transmission. *Finance a uver - Czech Journal of Economics and Finance*, 58(1-2), pp.2-20.

Dajčman, S. and Festić, M., 2012. The interdependence of the stock markets of Slovenia, the Czech Republic and Hungary with some developed European stock markets – The effects of joining the European Union and the Global financial crisis. *Romanian Journal of Economic Forecasting*, 15(4), pp.163-180.

Dajčman S., 2013. Interdependence between some major European stock markets – A wavelet led/lag analysis. *Prague economic papers*, 22(1), pp.28-49.

Durčáková, J., 2011. Foreign Exchange Rate Regimes and Foreign Exchange Markets in Transitive Economies. Prague Economic Papers, 20(4), pp.309-328.

Fedorova, E. and Vaihekoski, M. 2009. Global and Local Sources of Risk in Eastern European Emerging Stock Markets. *Finance a Uver: Czech Journal of Economics and Finance,* 59(1), pp.2-19.

Fedorova, E. and Saleem, K., 2010. Volatility spillovers between stock and currency markets: Evidence from emerging Eastern Europe. *Finance a uver - Czech Journal of Economics and Finance*, 60(6), pp.519-533.

Gencer, H.G. and Hurata, M.Y., 2017. Risk transmission and contagion in the equity markets: International evidence from the global financial crisis. *Romanian Journal of Economic Forecasting*, 20(3), pp.110-129.

Huang, P.K., 2012. Volatility transmission across stock index futures when there are structural changes in return variance. *Applied Financial Economics*, 22(19), pp.1603–1613.

Hu, Y-H. and Hsuen, S-J., 2013. A study of the nonlinear relationship among the U.S. and Asian stock markets during financial crisis. *Romanian Journal of Economic Forecasting*, 16(4), pp.134-147.

Inclan, C. and Tiao, G.C., 1994. Use of cumulative sums of squares for retrospective detection of changes of variance. *Journal of the American Statistical Association,* 89(427), pp.913-923.

Jung, R.C. and Maderitsch, R., 2014. Structural breaks in volatility spillovers between international financial markets: Contagion or mere interdependence?. *Journal of Banking and Finance,* 47, pp.331–342.

Kramer, W. and Azamo, B.T., 2007. Structural change and estimated persistence in the GARCH(1,1)-model. *Economics Letters*, 97(1), pp.17–23.

Kizys, R. and Pierdzioch, C., 2011. The financial crisis and the stock markets of the CEE countries. *Finance a uver - Czech Journal of Economics and Finance*, 61(2), pp.153-172.

Li, Y. and Giles, D.E., 2015. Modelling volatility spillover effect between developed stock markets and Asian emerging stock markets. *International Journal of Finance and Economics*, 20(2), pp.155–177.

Lin, C.H., 2012. The co-movement between exchange rates and stock prices in the Asian emerging markets. *International Review of Economics and Finance,* 22(1), pp.161–172.

Lucey, B.M. and Voronkova, S., 2008. Russian equity market linkages before and after the 1998 crisis: Evidence from stochastic and regime-switching cointegration tests. *Journal of International Money and Finance*, 27(8), pp.1303−1324.

Lupu, I., 2015. European Stock Markets Correlations in a Markov Switching Framework. *Romanian Journal of Economic Forecasting,* 18(3), pp.103-119.

Miralles-Marcelo, J.L. Quiros-Miralles, J.L.M. and Miralles-Quiros, M.M., 2008. Asymmetric variance and spillover effects Regime shifts in the Spanish stock market. *Journal of International Financial Markets, Institutions and Money*, 18(1), pp.1–15.

Miralles-Marcelo, J.L. Quiros-Miralles, J.L.M. and Miralles-Quiros, M.M., 2013. Multivariate GARCH models and risk minimizing portfolios: The importance of medium and small firms. *Spanish Review of Financial Economics,* 11(1), pp.29–38.

Mensi, W. Hammoudeh, S. and Kang, S.H., 2015. Precious metals, cereal, oil and stock market linkages and portfolio risk management: Evidence from Saudi Arabia. *Economic Modelling,* 51, pp.340–358.

Newey, W.K. and West, K.D., 1994. Automatic lag selection in covariance matrix estimation. *Review of Economic Studies,* 61(4), pp.631–654.

Sansó, A. Aragó, V. and Carrion-i-Silvestre, J., 2004. Testing for changes in the unconditional variance of financial time series. *Revista de Economia Financiera,* 4, 32–53.

Stoica, O. Perry, M.J. and Mehdian, S., 2015. An empirical Analysis of the diffusion of information across stock markets of Central and Easter Europe. *Prague Economic Papers*, 24(2), pp.192-210.

Syllignakis, M.N. and Kouretas, G.P., 2010. German, US and Central and Eastern European stock market integration. *Open Economies Review,* 21(4), pp.607−628.

Syllignakis, M.N. and Kouretas, G.P., 2011. Dynamic correlation analysis of financial contagion: Evidence from the Central and Eastern European markets. *International Review of Economics and Finance*, 20(4), pp.717–732.

Syriopoulos, T., 2007. Dynamic linkages between emerging European and developed stock markets: Has the EMU any impact? *International Review of Financial Analysis,* 16(1), pp.41-60.

Tee, L.T. Low, S.W. Kew, S.R. and Ghazali, N.A., 2014. Financial development and innovation activity: evidence from selected East Asian countries. *Prague Economic Papers,* 23(2), pp.162-180.

Wang, P. and Moore, T., 2008. Stock market integration for the transition economies: Time-varying conditional correlation approach. *Manchester School,* 76, pp.116-133.

Živkov, D. Njegić, J. and Milenković, I., 2015. Bidirectional volatility spillover effect between the exchange rate and stocks in the presence of structural breaks in the selected Eastern European economies. *Finance a Uver: Czech Journal of Economics and Finance*, 65(6), pp.477-498.