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Volatility Spillovers and Contagion in Emerging Europe

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Abstract:

What is the relationship between the two largest emerging financial markets of Eastern Europe, Russia and Poland, and how do they impact the region's stock markets? The purpose of this paper is to examine the role of these two countries in regional volatility by examining their effect on two separate phenomena: financial volatility, defined here as long-term interrelations, and contagion, a more short-term phenomenon. Utilizing bivariate DCC-GARCH modeling, this paper estimates long-term volatility spillover effects and short-term contagion effects and their origins during several periods of financial crisis in the Central and Eastern European region. Our results show that the long-term impact of volatility in the Russian market is much more substantial than that of Poland in Central and Eastern Europe, with this disparate impact corresponding to each country's level of market capitalization. Additionally, our results show that Russia served as a source of short-term contagion for neighboring countries during its banking crisis in 2004 and during the Russian stock market fall in 2008. Poland had comparatively less effect on the region during the Global Financial Crisis. Moreover, the entrance of Poland into the European Union in May 2004 had no impact on stock markets in the region in terms of enhancing contagion.

Keywords: DCC- GARCH, volatility spillovers, contagion, Poland, Russia.

JEL Classification: C58, E44, G01, G15

1. Introduction

Long-term interaction amongst, and short-term contagion between, global financial markets appears to have increased in recent years, mainly due to the greater integration of real economies via international trade and labor and capital market liberalization. Early research on financial volatility showed the existence of these interrelationships between international and local equity markets (including King and Wadhwani 1990; Hamao, Masulis and Ng 1990; Neumark, Tinsley and Tosini 1991; Von Furstenberg and Jeon 1989) using techniques such as cross-correlations analysis (Lin, Engle and Ito 1994) or cointegration analysis (Richards 1995). Later extensions to this work utilized more sophisticated volatility modeling techniques including vector autoregression (VAR) or generalized autoregressive conditional heteroskedasticity (GARCH) models, as well as focusing on the integration of developed country markets or discrete groupings of countries. In particular, work such as Liao and Williams (2004) and Booth and Ciner (2005) found that German markets are a key source of volatility for European financial markets, while US volatility affected nearly all global stock markets, including the UK (Tanizaki and Hamori 2009) and the rest of Europe (Dhesi and Xiao 2010).

However, much of the attention paid to the issue of market integration has focused exclusively on volatility spillover effects in-between developed markets (Liao and Williams 2004, Syriopoulos 2007, Theodossiou and Lee 1993, Karolyiet and Stulz 1996) with a comparatively less (but still robust) emphasis on the transmission of volatility from developed to developing economies (recent work includes Chiang, Jeon and Li (2007) for a comprehensive analysis of spillover from mature to emerging markets, Booth and Ciner (2005) and Martinez and Ramirez (2011) for research focused on Latin America).

To our knowledge, there are far fewer pieces that apply the same econometric rigor to testing volatility and contagion between emerging markets (Cho and Parhizgari (2008) and Barassi, Dickinson and Le (2012) are notable exceptions that touch on this issue, while Syllignakis and Kouretas (2011) is of special interest to us). Noting this hole in the literature, this paper aims to expand our knowledge of financial markets linkages to examine the integration between emerging markets that display similar attributes to the developed-developing dynamic proven elsewhere. In particular, we examine the financial linkages created by the two largest emerging markets in Eastern Europe, Poland and Russia, and their effects on the financial space in Central and Eastern Europe. Our main hypothesis is that Russia and Poland, as the markets with the biggest capitalization in this geographic region, should behave in the same manner as large and distant developed markets, acting as a source of volatility and contagion for other, smaller markets in the area. This hypothesis has been somewhat tested before in the extant literature for Russia (Syllignakis and Kouretas 2011), but work incorporating Poland is non-existent.

A second key contribution of this paper builds on Hamao *et al.* (1990) and Kaminsky and Reinhart (2008) to model volatility spillover effects and contagion as two separate phenomena with very different time-frames. In our estimation, volatility spillover effects reflect *long-term* stable links between various markets, or the reflection of interconnections that already have been built over time. Conversely, contagion effects are symptomatic of *short-term* effects, induced by exogenous economic shocks and possibly unrelated to prior interactions. Our analysis will thus focus on the identification of the two separate effects based on their time component, and provide a deeper understanding of the effects of Poland and Russia in the region. Moreover, the data we employ here stretches throughout several crisis periods, allowing us to examine after-crisis links, expanding previous research results regarding volatility transmission. Here as well, we are not aware of any prior research that explores these two separate phenomena in the context of Russia and Poland.

For this exercise, we follow from a wealth of prior literature devoted to contagion effects, including those on stock markets (Forbes and Rigobon 2002), currency markets (Nagayasu 2001), bonds and derivatives markets (Gravelle, Kichian and Morley 2006; Tai 2003) and different types of markets, particularly, among stock and currency markets within one country and on a global scale (Dungey, Fry, Gonzalez-Hermosillo and Martin 2006; Ito and Hashimoto 2005). However, in trying to evaluate contagion effects, researchers find difficulties in specifying the correct test for identification of these effects; this is mainly due to the fact that market correlations are strongly linked to volatility correlations, which can intensify due to increasing market variance during turmoil periods, but do not indicate a real reinforcement of the underlying links between markets. Methods of identifying contagion effects proposed in the previous literature are diverse, with the most popular being cross-correlation analysis (Longin and Solnik 1995), univariate GARCH and volatility interconnections analysis (Theodossiou and Lee 1993: Karolyi and Stulz 1996), probit and logit models (Eichengreen, Rose and Wyplosz 1996), conditional correlation calculation (Forbes and Rigobon 2002, Corsetti, Pericoli and Sbracia 2005), and Markov regime-switching models (Fratzscher 2003, Mandilaras and Graham 2010). Another econometric stumbling block encountered is that, even having quantitatively estimated contagion effects, previous work has been hampered by an inability to define which market is a source of contagion and which has its own internal sources of volatility.

Our own work (Asaturov and Teplova 2014) has already touched upon volatility spillover effects among key international markets, including in emerging Europe. In this previous work, we estimated the key sources of volatility of globally, which allowed for understanding the transmission mechanisms of shocks via both volatility spillover channels. In distinction to this earlier work, this current paper focuses exclusively on emerging Europe to identify particular events which may have significant effect on the markets in the region. Thus, the paper builds on our previous work to further examine the financial interrelationships in the region.

In particular, this paper will tackle the issues of volatility and contagion in a manner similar to Barassi *et al.* (2012) and Cho and Parhizgari (2008), through utilization of an ARMA-DCC-GARCH model on daily stock market data from Poland, Russia and the countries of Central and Eastern Europe. The nature of stock market data creates difficulties in normal econometric estimation, due to pervasive serial correlation issues and conditional heteroscedasticity (Chiang *et al.* 2007) and the GARCH family of models can account for these difficulties. In terms of our research question, the ARMA-DCC-GARCH model is able to simultaneously identify volatility spillover effects and contagion effects due to dynamic conditional correlation analysis; its main advantage is that it takes into account conditional information, which is essential for calculating volatility and correlations (Baillie and Myers 1991).

Given that we would expect to see these two effects at their strongest during times of turmoil in either stock market, this paper will accordingly examine the existence of financial contagion between the two large markets of Poland and Russia and other financial markets by separating out particularly tumultuous times and relatively "tranquil" periods. For the crisis times, we will concentrate on the periods of the Russian banking crisis of 2004, the entrance of Poland into the European Union in May of 2004, the global financial crisis of 2007-2009, and the specific financial crisis in Russia from 2008-2010; specifically, we test whether the Russian market was a source of contagion for the countries of Central and Eastern Europe during the Russian banking crisis of 2004 and the global financial crisis, and whether the Polish market had volatility or contagion effects during global financial crisis and after the accession of Poland into the European Union in May 2004.

Our paper is structured in the following manner: the next section will offer a brief review of the literature on financial market connections, while Section 3 will lay out our hypotheses and Section 4 will explore the DCC-GARCH model and tests for contagion. Section 5 will explore the results of the influence of Russia and Poland on the Central and Eastern European equity markets, while Section 6 concludes.

2. Literature review

Even as the relationships between developed markets have been well-documented, work between emerging markets has been relatively less frequent, with the Russian market in particular making only a few notable appearances and Poland remaining nearly unexplored. Ramaprasad and Nikolova (2009) analyzed connections between the BRIC countries writ large and several markets, including the world, Asian markets, the US, and European indices. Using a bivariate EGARCH model to account for leverage effects, Ramaprasad and Nikolova (2009) found that the Russian market was heavily influenced by European markets, with additional causality running from global markets (as proxied by Morgan Stanley's All Countries World Index) to Russia. In a similar article more focused on Russia by itself, Achsani and Strohe (2004) examined interrelationships between Russia and other European, Japanese, and US markets over 1994 to 2001, with an eye on understanding the impact of the Russian Financial Crisis of 1998. Based on a VAR model and correlation analysis, they concluded that the Russian financial crisis had a demonstrable impact on each of the other global markets they considered; however, they were unable to indicate if the transmission channels of these shocks from Russia were direct or indirect.

While these papers have documented somewhat the influence of Russia, the set of research grows even smaller when considering what factors influence emerging stock markets, including the influence of emerging markets themselves on others of their ilk. Syriopoulos (2007) was one of the first to explicitly focus on interconnections between emerging markets of Central Europe and major developed exchanges, using daily close prices of stock indices (WIG (Poland), PX50 (Czech Republic), BUX (Hungary), SAX (Slovakia), DAX (Germany), S&P500 (US)) between January 1997 and September 2003 to examine the influence of the US and Germany on these markets. His results showed that emerging markets appear to be connected with developed markets much more strongly than they are with each other, an intuitive conclusion that acknowledges the importance and size of developed country financial markets. But Syriopoulos' (2007) analysis left out the "bear in the room," Russia, one of the most important emerging markets, especially in relation to Central and Eastern Europe. In an important step forward, and closer to the research question we are interested in here, Saleem (2009) studied the interdependencies between Russia and the US, European, Asian, and emerging European countries, using GARCH-BEKK modelling. He concluded that, before the 1998 crisis, there were two-sided effects among Russia, the US, and emerging European markets, with one-sided volatility spillover effects also occurring from the European markets to Russia. Recently, Syllignakis and Kouretas (2011) also studied the relationships within Central Europe and between Central European markets and US, Germany, and Russia, showing that the global financial crisis led to a substantial regime shift in correlations; however, their work did not examine spillover effects, focusing on contagion. Caporale and Spagnolo (2011) used a VAR-GARCH model to analyze weekly data of stock exchanges in Russia, the UK, the Czech Republic, Hungary, and Poland over December 1996 to December 2008, their work showed significant spillover effect from the Russian and UK markets to the markets of Central and Eastern Europe (Czech Republic, Hungary, and Poland), but no volatility transmission in the opposite direction. Finally, the direct precursor to this paper, Asaturov and Teplova (2014), employed DCC-GARCH model to estimate volatility spillover effects between stock markets in South and North America, the US, and European markets. They found that the US market (as proxied by the S&P500 index) is the key source of volatility globally, while the UK, German, and French stock markets are major volatility transmitters in the European region.

Only in the past 15 years have researchers turned to the topic of dynamic correlation analysis in order to estimate contagion (short-term) effects among local and international markets (Chiang *et al.* 2007 and Barassi *et al.* 2012), as distinct from longer-term volatility spillovers. These studies have been clustered on specific financial crises, including the internet crash in the early 2000s, the global financial crisis of 2007-09, and the Eurozone crisis, and they have focused on contagion from developed to developing markets. The advent of the Global Financial Crisis brought with it a renewed interest in contagion effects within and between various markets (stocks, bonds, and derivatives), with a focus on the reality that the US stock market was a prime source of contagion for emerging markets (Sharkasi, Ruskin and Crane 2005). Other recent papers have scrutinized the impact of the Eurozone Crisis on stock market integration, with Samitas & Tsakalos (2013) employing ADCC and Copula models to data of 8 stock markets to measure contagion emanating from Greece. Their results show that Greece was not the only source of contagion during the crisis, but was a trigger affecting greater economies in the region, which in their turn spread a negative economic shock.

3. Hypotheses

In a sense, there is thus quite a large body of research on the financial linkages of developed markets to emerging markets. However, we believe that there is time for breaking new ground through examining the emerging markets of Central and Eastern Europe and their relations to each other. Thus, our study concentrates on three specific and related research questions (RQs):

RQ1. What is the long-term impact of Russia and Poland on the volatility of Central and Eastern European stock exchanges?

We hypothesize that:

- Statistically significant volatility spillovers were directed from Russian and Polish equity markets to the countries of Central and Eastern Europe.
- The long-term impact of the Russian stock market on the Central and Eastern Europe exceeds that of the Polish stock market, due to their differential sizes.

RQ2. What are the short-term contagion effects between Russia and the countries of Central and Eastern Europe?

Our beliefs in regard to this RQ are:

- Contagion occurred from Russia to the countries of Central and Eastern Europe during the Russian banking crisis in 2004.
- Contagion effects were observed between Russia and countries of Central and Eastern Europe during the decline in the Russian stock market index (RTSI) beginning in 2008.

RQ3. What are the short-term contagion effects between Poland and countries of Central and Eastern Europe?

Finally, we hold that:

- Contagion did occur from Poland to countries of Central and Eastern Europe after the accession of Poland into the European Union in May of 2004.
- Contagion effects were observed between Poland and the countries of Central and Eastern Europe during the Financial Crisis of 2007-2009.

4. Data and methodology

Our data includes the daily closing prices of 11 indices in local currencies (as in Karolyi and Stulz 1996, Koutmos and Booth 1995, Theodossiou and Lee 1993) we examine returns isolated from exchange rate dynamics) from European emerging markets: Russia (RTSI), Poland (WIG), Bulgaria (SOFIX), Estonia (TALSE), Slovakia (SAX), Latvia (RIGSE), Lithuania (VILSE), Ukraine (PFTS), Hungary (BUX), the Czech Republic (PXI) and Romania (BET). The sample we analyze includes data from January 2001 to December 2012. In order to justify employed methodology we carried tests for stationarity (Augmented Dickey-Fuller and Phillips-Perron), the Ljung-Box test for autocorrelation, and an LM test to determine the presence of ARCH errors.

Although the stock exchanges of the markets shown here operate in different time zones, the gap between trading hours does not exceed 24 hours, which we believe makes it possible to use daily closing prices without any adjustment. Additionally, this approach is heavily utilized in the literature in countries within a region (Dhesi and Xiao 2010, Hassan and Malik 2007, Saleem 2009), where daily closing prices are used to identify markets interrelationships (that is, the information embodied in closing prices is enough to understand market influences on each other). This approach of course has its drawbacks, but on the other hand, the use of weekly or monthly data reduces the sample size, which can be crucial for model estimation. But reverting to the method of synchronized prices (for example, the closing price of one market and a price of another at particular moment of time) while testing several volatility centers does not allow us to test our central thesis, which is the presence of volatility spillover effects from different regions. Finally, the closing price is considered to be a more reliable indicator of a market's dynamics and its mood, with Jondeau and Rockinger (2006) showing that non-synchronized trading hours makes little difference in practice to the interconnectedness of different markets.

For contagion estimation during the Russian banking crisis of 2004, the global financial crisis of 2007-2009, the fall of the RTSI index in 2008, and the accession of Poland into the European Union in 2004, differences in the dynamic conditional correlations between "turmoil" and "tranquil" periods are tested. As the starting point of turmoil period is taken a date, when a stock market index of the country is assumed to be a source of contagion began to drop. It is done to analyze whether the fall of the index caused a collapse of the other markets. A stable period represents the time before the crisis, when a market was not exposed to any significant shock. Turmoil period is assumed to last two years as it was assumed in the previous research to define contagion period longitude.

For the purpose of delineating the "turmoil" from the "tranquil," the reference points of the Russian banking crisis is marked in our data as 1 June 2004, which ended 5 years of stability pre-crisis (the tranquil period). The fall of the RTSI index it is coded as starting on 19 May 2008, the date when the index started a sharp decline as the global financial crisis reached the Russian market. This turmoil is contrasted with the 2-year period of (relative) tranquility that existed prior to the crash.

Concerning Poland, two events were tested for contagion: the accession of Poland to the EU in 2004 and the Global Financial Crisis. For the accession to the EU, a one year period was considered as the turmoil period, as we believe that the dislocation centered on accession would have dissipated within a years' time (if not much sooner). In regards to the financial crisis, we date the start of the crisis in Poland from July 6, 2007, the date of peak in the Polish WIG index. Unlike EU accession, the turmoil period for the Financial Crisis was much longer, dated as the 2-year period from mid-2007 to 2009. The tranquil periods for both the Polish accession to the EU and the global financial crisis were the preceding 5-year and 2-year time periods respectively, reflecting the periods of relative calm in the Polish markets.

We employed the DCC-GARCH model, introduced by Engle (2002), to detect linkage in each pair of market indices separately. The DCC-GARCH model has the advantage of being able to capture not only volatility interconnections between different financial markets, but also time-varying correlations among them. It makes the model very useful for aims of our research. The index returns equation is determined by an ARMA (p,q) process:

$$r_{it} = \alpha + \sum_{j=1}^{p} \beta_j r_{i,t-j} + \sum_{j=1}^{q} \gamma_j \varepsilon_{i,t-j} + \varepsilon_{it} \quad (1)$$

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

$$H_t = D_t R_t D_t$$

where: r_{it} is returns of index i at time t; ε_{it} are residuals at time t; H_t is the variance-covariance matrix; R_t is a time-varying correlation matrix; Ω_{t-1} is a conditional information set; and D_t is a diagonal matrix of conditional variances. The return of each asset is calculated as:

$$r_t = (\ln P_t - \ln P_{t-1}) \times 100\%$$

In case there is no data for certain date, this date was removed from the analysis for this particular pair of indices, an approach that is standard in the literature (see, for example, Koutmos and Booth 1995).

The order of p and q was determined by Box-Jenkins method based on the minimization of the Akaike information criterion (AIC).

As the target of this paper is volatility spillover within regions (as well as due to the length of the time period examined here) we do not include the US or other world market returns in the ARMA equation (as was done by Lee (2009) as part of the examination of volatility transmission in Asian markets). This omission is mainly because we are looking at the Russian and Polish economies as part of their own closed system; we are not concerned with how volatility is generated within the Polish or Russian market, but rather on how this radiates outward in the region. Put another way, we are examining Poland and Russia as two points in a pond after a rock is thrown into it. We are not concerned about the shape and size of the rock or where it came from, but what ripple effect it causes. This holds true in our paper, as we aim to define long-terms volatility links of local markets, even if they are just transmitting the volatility of the stronger economies. Moreover, the benefit of our model below is that it can isolate short-term contagion effects that originate from external factors, thus separating out the external economies from those of Poland and Russia. Thus, in the case of no volatility transmission, the model will show no statistical significance of the volatility spillover parameters (if the markets actually are affected by US or global markets). However, the model allows for estimation of any contagion effects, which can be generated from a third party outside of the system.

A correlation matrix R_t is computed as:

$$R_t = (diag(Q_t))^{-\frac{1}{2}} Q_t (diag(Q_t))^{-\frac{1}{2}} \tag{2}$$

where: Q_t is a variance-covariance matrix of standardized residuals ($z_t = \varepsilon_t / \sigma_t$), which takes the following form:

$$Q_t = (1 - \omega_1 - \omega_2)\overline{Q} + \omega_1 z_{t-1} z_{t-1}^{'} + \omega_2 Q_{t-1} \tag{3}$$

$$\overline{Q} = \frac{1}{T}\sum_{t=1}^{T} z_t z_t^{'}$$

$$\omega_1 + \omega_2 < 1 \; \omega_1, \omega_2 > 0$$

where: $\overline{Q}$ is an unconditional variance-covariance matrix of standardized residuals and z_t is a standardized residual at the time *t*.

Note that the number of parameters to be estimated for the conditional correlation matrix is not related to the number of variables in the DCC-GARCH model. On the one hand, this property of the model makes the optimization process easier, but on the other hand, such a model structure would force all of the correlation processes to have the same dynamic behaviour. This explains why we use the bivariate DCC-GARCH model.

The elements of D_t are estimated as:

$$\begin{pmatrix} h_{11,t} \\ h_{22,t} \end{pmatrix} = \begin{pmatrix} c_1 \\ c_2 \end{pmatrix} + \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} * \begin{pmatrix} \varepsilon_{1,t-1}^2 \\ \varepsilon_{2,t-1}^2 \end{pmatrix} + \begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix} * \begin{pmatrix} h_{11,t-1} \\ h_{22,t-1} \end{pmatrix} \tag{4}$$

where $h_{11,t}$ and $h_{22,t}$ are conditional variances.

The diagonal elements a_{11} and a_{22} reflect volatility shocks, which define the impacts of the past squared innovations on the current volatility. Non-diagonal elements a_{12} and a_{21} capture the cross-volatility shocks, which represent the influence of the lagged innovations of index 2 on the current volatility of index 1 and vice versa. In a similar way, the diagonal elements g_{11} and g_{22} measure the own volatility spillover, which should be considered as the impact of the past volatilities on the current volatility. Eventually, the non-diagonal elements g_{11} and g_{22} reflect the cross-volatility spillovers, which denote influence of the past volatility of index 2 on the current volatility of index 1 and vice versa. Note that the volatility effect will be confirmed only in case of statistical significance of the parameter, which represent appropriate volatility spillover. As the elements capturing the volatility spillover effect cannot exceed 1 according to a stationary condition, they are presented in a percent format.

A log-likelihood function utilized to estimate all the coefficients takes the following form:

$$L(\theta) = -\frac{1}{2}\sum_{t=1}^{T}(n\ln(2\pi) + \ln|D_t R_t D_t| + \varepsilon_t'(D_t R_t D_t)^{-1}\varepsilon_t) \tag{5}$$

where: T is the number of observations; n is the number of variables; θ is a vector of unknown parameters.

In the DCC-GARCH model, as dynamic conditional correlation is based on standardized residuals, it is not affected by heteroscedasticity. It then allows us to estimate contagion effects based on links adjusted to volatility of analyzed series. Thus, dynamic conditional correlation is the perfect basis for contagion recognition. The distinction of dynamic conditional correlation between the tranquil and turmoil periods is examined with a

Student's t-test for mean differences, the Mann-Whitney-Wilxocon test for median differences, and the Smirnov (or Kolmogorov-Smirnov) test for empirical distribution differences.

Student's t-test is used to define if difference in mean is significant or not. If the difference in mean is statistically insignificant, absence of contagion effect is confirmed. In our case Student's t-test examine the following hypotheses:

$$H_0 : \overline{p}_{stable} = \overline{p}_{turmoil}$$
$$H_1 : \overline{p}_{stable} < \overline{p}_{turmoil}$$

where $\overline{p}_{stable}$ and $\overline{p}_{turmoil}$ are conditional correlation mean values during stable and turmoil periods respectively.

The second criterion for contagion, the Mann-Whitney-Wilxocon test, examines whether the median values of two samples are statistically different. If the difference in median is statistically insignificant, we can infer that there is no contagion effect present. The null and alternative hypotheses are presented as:

$$H_0 : \tilde{p}_{stable} = \tilde{p}_{turmoil}$$
$$H_1 : \tilde{p}_{stable} < \tilde{p}_{turmoil}$$

where: $\tilde{p}_{stable}$ and $\tilde{p}_{turmoil}$ are median values of conditional correlation during stable and turmoil periods respectively.

The last criterion is the Smirnov test. This test is applied to dynamic conditional correlation to define whether its empirical distribution differs for stable and turmoil periods. If there is no difference in empirical distribution, no contagion effect is confirmed. The Smirnov criterion tests the following hypotheses:

$$H_0 : F_{stable} = F_{turmoil}$$
$$H_1 : F_{stable} \neq F_{turmoil}$$

where: F_{stable} and $F_{turmoil}$ are empirical cumulative distribution functions of conditional correlation during stable and turmoil periods.

We define a contagion effect as existing only the basis of the significance of all three tests jointly. While the first two tests define whether conditional correlation changes in absolute values, the third one tell us whether its empirical distribution differs during stable and turmoil periods. In our view stable and turmoil periods are characterized by not only increased conditional correlation but also various distribution moments (such as variance, skewness, and kurtosis). Otherwise a simple trend can be identified as contagion effect. Therefore, the contagion effect is confirmed to take place only if all three tests support its presence and the parameter reflecting volatility spillover effect is statistically significant.

In mathematical terms the latter condition is justified by the fact that conditional correlation analysis can only tell us whether contagion in a particular period takes place. However, without a volatility spillovers examination, it is indeterminate which market in each pair is a source of contagion. In the case of mutual volatility spillover effects, the contagion effect is also considered to be mutual. If volatility spillover effects for a pair of indices are not revealed, contagion effects are regarded as indirect. In the other words, it means that both analyzed markets were affected by other third party or factors, which caused a correspondingly greater correlation between them. We believe that this criteria for testing contagion effects avoids identification of a simple leap in markets interconnections as contagion (Forbes and Rigobon 2002), while also allowing us to define the source of contagion in each pair of indices.

5. Results

RQ1. What is the long-term impact of Russia and Poland on the volatility of Central and Eastern European stock exchanges?

Table 1 - Volatility spillover effects from Russia and Poland to Central and Eastern European stock exchanges

Spillover direction	Volatility spillover	P-value	Spillover direction	Volatility spillover	P-value
RTSI → PFTS	20,45%***	0,00	PFTS → RTSI	1,77%	0,88
RTSI → PXI	17,94%**	0,01	PXI → RTSI	13,13%**	0,02
RTSI → BET	14,87%**	0,03	BET → RTSI	13,22%	0,30
RTSI → SOFIX	13,91%**	0,02	SOFIX→ RTSI	6,68%	0,91
RTSI → TALSE	13,51%***	0,00	TALSE → RTSI	6,83%	0,54
RTSI → WIG	13,44%***	0,00	WIG → RTSI	6,09%	0,20
RTSI → BUX	12,47%***	0,00	BUX → RTSI	6,05%	0,60
RTSI → VILSE	12,4%**	0,04	VILSE → RTSI	0,90%	0,87
RTSI → SAX	11,61%**	0,01	SAX→ RTSI	0,07%	1,00
RTSI → RIGSE	9,22%**	0,01	RIGSE→ RTSI	0,07%	0,99
Spillover direction	Volatility spillover	P-value	Spillover direction	Volatility spillover	P-value
WIG → PFTS	17,14%*	0,05	PFTS → WIG	3,97%	0,88
WIG → BET	13,97%***	0,00	BET → WIG	5,89%	0,71
WIG → BUX	10,13%***	0,00	BUX → WIG	4,04%	0,70
WIG → TALSE	10,03%	0,14	TALSE → WIG	3,42%	0,57
WIG → SOFIX	9,94%	0,32	SOFIX → WIG	2,56%	0,92
WIG → SAX	9,1%**	0,01	SAX → WIG	2,11%	0,97
WIG → PXI	8,42%**	0,01	PXI→ WIG	2,62%	0,74
WIG → RIGSE	8,41%**	0,02	RIGSE → WIG	4,48%	0,94
WIG → VILSE	7,83%	0,28	VILSE → WIG	4,85%	0,88

*Note: *** shows significance at the 1% level, ** is at the 5% level, and * at the 10% level.*

- Statistically significant volatility spillovers were directed from Russian and Polish equity markets to the countries of Central and Eastern Europe. *Partially confirmed.*

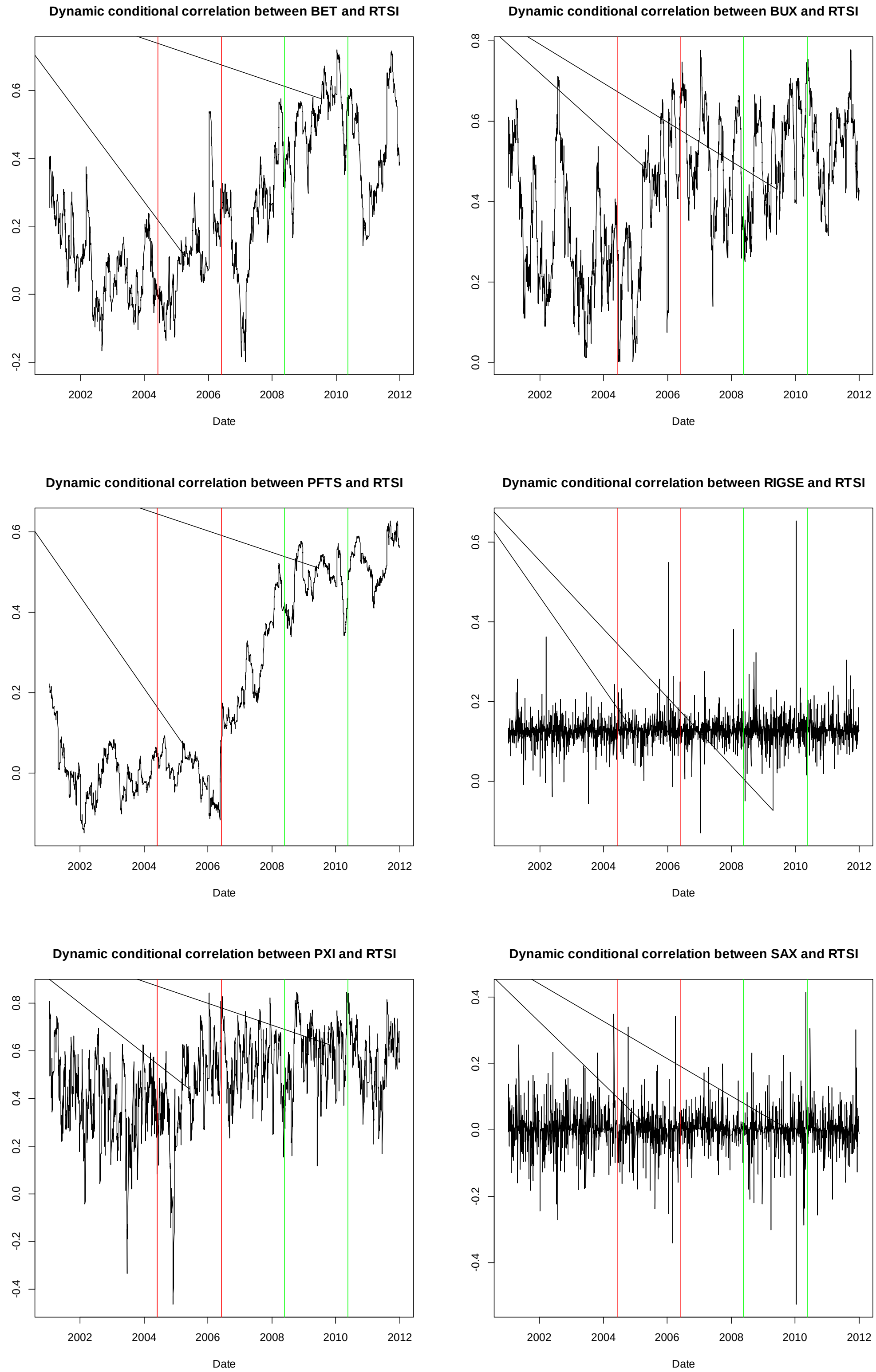
The volatility spillover effects from Russia and Poland to the emerging European stock markets are presented in Table 1. The results show a significant impact of the Russian market on each of the stock indices of Central and Eastern Europe markets (a result distinct from Syllignakis and Kouretas (2011), whereas the Polish WIG has no influence on Hungary, Estonia, Bulgaria, Slovakia, Lithuania and Russia. The Russian RTSI has its strongest effects on Ukrainian equity markets (with spillovers estimated at 20.5%), while it has the least impact on the Latvian RIGSE (9.2%). In terms of the causality running towards Russia from other emerging European markets, only the Czech market appears to influence the Russian market (13.3%). These relationships between Russia and other markets seem to be replicated in regards to Poland, with Latvia displaying a fierce independence streak and the smallest spillover effect from Poland (8.4%), while Poland influences Ukraine the most of all country pairings (17.1%).

- The long-term impact of the Russian stock market on the Central and Eastern Europe exceeds that of the Polish stock market, due to their differential sizes. *Fully confirmed.*

When considered on a pairwise basis, the volatility spillovers from Russia are of greater magnitude and significance than the same spillovers from Poland, showing the greater significance of Russian equity markets in the region. Moreover, the Polish market is almost wholly insignificant in regards to some countries of Central and Eastern Europe (including Hungary and, somewhat surprisingly, Lithuania). At the same time, the Polish stock market has a notable exposure to the volatility of the Russian market (13.44%). This demonstrates that Russia, which possesses the largest capitalization in the region, has a stronger impact within emerging Europe.

RQ2. What are the short-term contagion effects between Russia and the countries of Central and Eastern Europe?

The Figure 1 shows the dynamic conditional correlations between RTSI and the market indices of Central and Eastern Europe. The 2-year period of Russian banking crisis starting from June 2004 is indicated with red vertical lines and the 2-year period of the Financial Crisis in Russia is shown with green vertical lines. Dynamic conditional correlation increased sharply after the Russian banking crisis in the following pairs: BET-RTSI, BUX-RTSI and WIG-RTSI. In the rest of pairs, the rise in correlation was not as dramatic, as their links were too unstable. During Financial Crisis in Russia, dynamic correlations mainly had an upward trend. Only in the pairs of BUX-RTSI, RIGSE-RTSI, SAX-RTSI and TALSE-RTSI correlation was stable during the crisis period. Of note is the fact that dynamic correlation was notably higher after 2008 in most of the pairings.



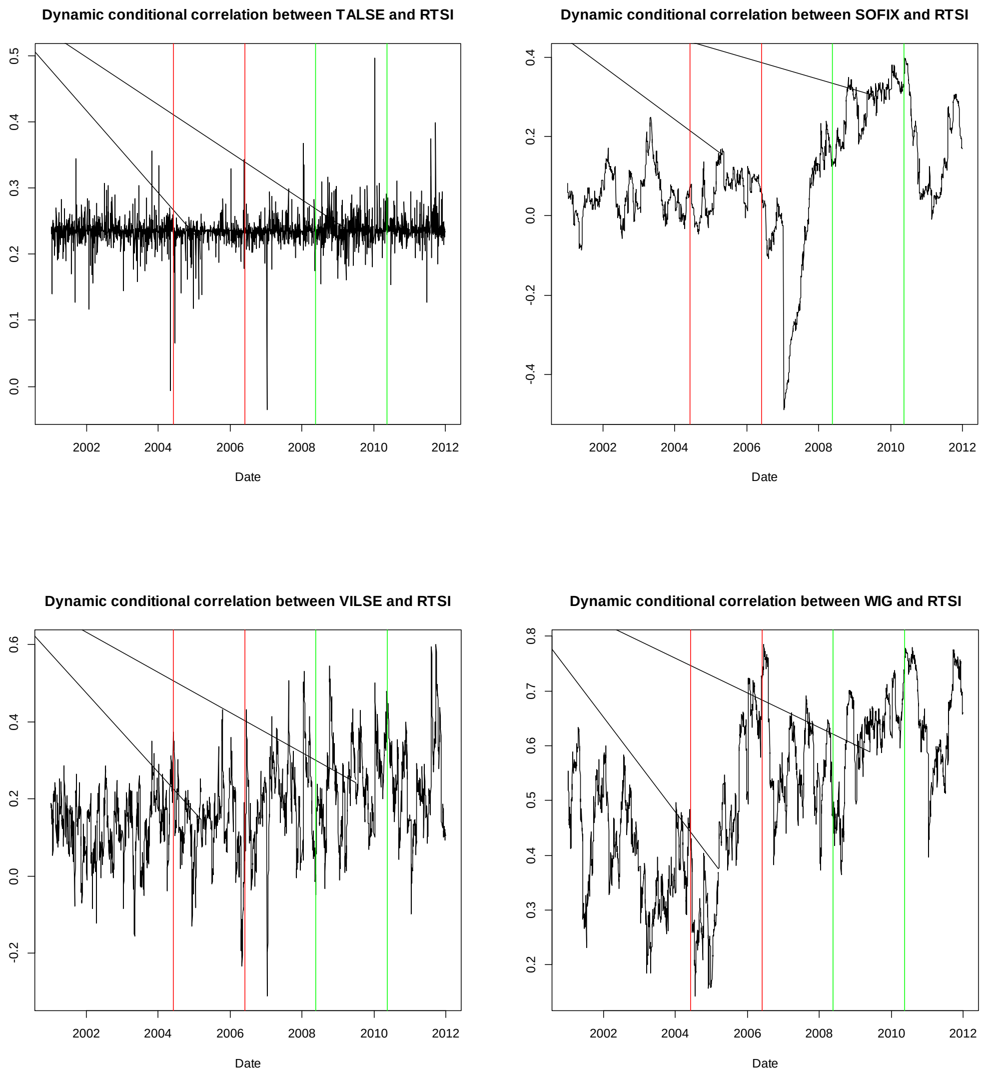


Figure 1 - Dynamic conditional correlation between RTSI and market indices of Central and Eastern Europe.

Table 2 presents results of Student's test, a Wilxocon test, and Smirnov tests for contagion effect estimation between Russia and countries of Central and Eastern Europe during Russian banking crisis in 2004.

Table 2 - Contagion effects between Russian and the countries of Central and Eastern Europe during Russian Banking Crisis (01.06.2004–01.06.2006).

Pair of indices	Dynamic conditional correlation (turmoil period)		Dynamic conditional correlation (turmoil period)		Student's t-test	Mann-Whitney-Wilxocon test	Smirnov test	Contagion effect?
	Mean	Median	Mean	Median	P-value	P-value	P-value	
BET and RTSI	0,093	0,110	0,091	0,103	0,01***	0,05**	0,01***	Yes
BUX and RTSI	0,314	0,381	0,271	0,421	0,00***	0,00***	0,00***	Yes
PFTS and RTSI	0,003	0,000	-0,005	0,012	0,79	0,038**	0,00***	No
PXI and RTSI	0,399	0,430	0,406	0,441	0,00***	0,00***	0,00***	Yes
RIGSE and RTSI	0,126	0,128	0,128	0,128	0,06*	0,11	0,55	No
SAX and RTSI	0,005	-0,001	0,004	0,002	0,97	0,96	0,05*	No
SOFIX and RTSI	0,054	0,066	0,042	0,077	0,00***	0,00***	0,00***	Yes
TALSE and RTSI	0,234	0,232	0,235	0,235	0,98	0,99	0,00***	No

VILSE and RTSI	0,130	0,135	0,141	0,144	0,16	0,16	0,2	No
WIG and RTSI	0,410	0,447	0,407	0,436	0,00***	0,00***	0,00***	Yes

*Note: *** shows significance at the 1% level, ** is at the 5% level, and * at the 10% level.*

- Contagion occurred from Russia to the countries of Central and Eastern Europe during the Russian banking crisis in 2004. *Partially confirmed.*

Contagion effects during the Russian banking crisis are confirmed to take place in the pairs of BET-RTSI, BUX-RTSI, PXI-RTSI, SOFIX-RTSI, and WIG-RTSI. Among countries not affected by contagion are the three Baltic countries, namely, Estonia, Lithuania and Latvia, with which Russia has much less economic and political links rather than the other countries of Central and Eastern Europe. It is worth mentioning that Russian interrelationships with Ukraine and Slovakia also did not change during the crisis. Contagion between Russia and the Czech Republic was mutual, while there were also volatility spillover effects evidenced between the two countries.

Table 3 shows results of Student's t, Mann-Whitney-Wilcoxon, and Smirnov tests for contagion effect estimation between Russia and countries of Central and Eastern Europe during the Financial Crisis in Russia.

Table 3 - Contagion effects between Russia and the countries of Central and Eastern Europe during Financial Crisis 2008-2010 in Russia (19.05.2008 – 19.05.2010).

Pair of indices	Dynamic conditional correlation (turmoil period)		Dynamic conditional correlation (turmoil period)		Student's t-test	Mann-Whitney-Wilxocon test	Smirnov test	Contagion effect?
	Mean	Median	Mean	Median	P-value	P-value	P-value	
BET and RTSI	0,229	0,507	0,253	0,533	0,00***	0,00***	0,00***	Yes
BUX and RTSI	0,507	0,515	0,514	0,546	0,15	0,14	0,02**	No
PFTS and RTSI	0,262	0,477	0,240	0,487	0,00***	0,00***	0,00***	Yes
PXI and RTSI	0,555	0,593	0,564	0,619	0,00***	0,00***	0,00***	Yes
RIGSE and RTSI	0,128	0,129	0,128	0,128	0,31	0,55	0,23	No
SAX and RTSI	0,006	0,002	0,004	0,004	0,89	0,6	0,8	No
SOFIX and RTSI	-0,050	0,278	-0,025	0,305	0,00***	0,00***	0,00***	Yes
TALSE and RTSI	0,235	0,238	0,235	0,235	0,02**	0,12	0,01**	No
VILSE and RTSI	0,191	0,238	0,198	0,239	0,00***	0,00***	0,00***	Yes
WIG and RTSI	0,574	0,613	0,554	0,637	0,00***	0,00***	0,00***	Yes

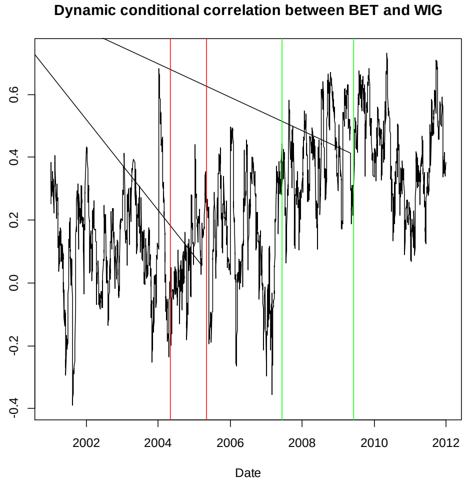
*Note: *** shows significance at the 1% level, ** is at the 5% level, and * at the 10% level.*

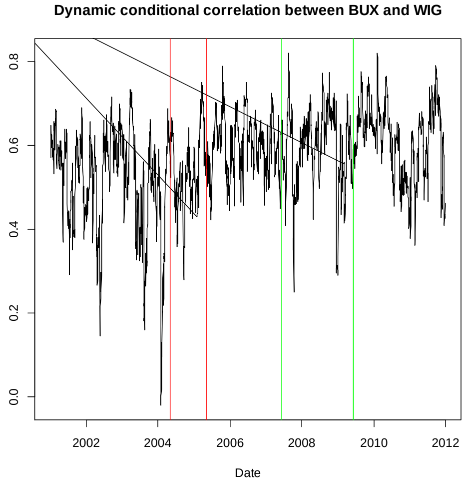
- Contagion effects were observed between Russia and countries of Central and Eastern Europe during the decline in the Russian stock market index (RTSI) beginning in 2008. *Partially confirmed.*

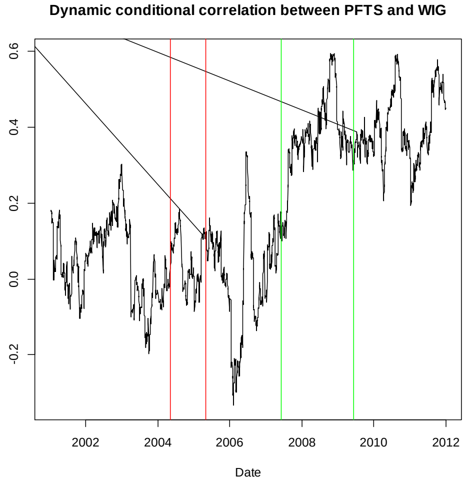
Contagion was confirmed to exist for all the pairs shown, with the exception of BUX-RTSI, RIGSE-RTSI, SAX-RTSI and TALSE-RTSI. The majority of Russia's neighboring countries were exposed to contagion from Russian markets, apart from two Baltic countries (Estonia and Latvia), Slovakia, and Hungary. In case of the Czech Republic contagion was two-sided as volatility spillover effects between the countries were also mutual (as well as during the Russian banking crisis).

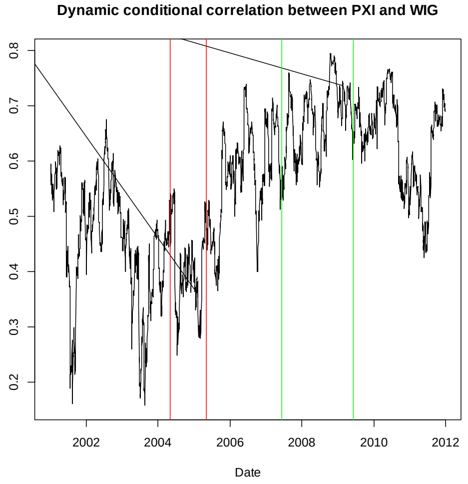
RQ3. What are the short-term contagion effects between Poland and countries of Central and Eastern Europe?

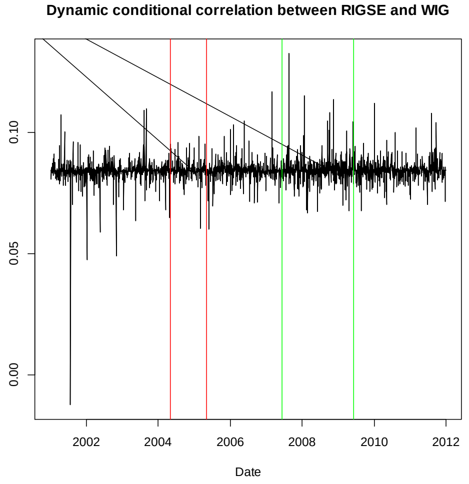
In the Figure 2 the dynamic conditional correlations between the Polish WIG and the market indices of Central and Eastern Europe are shown. The one-year period beginning with Poland's accession to the EU is indicated with red vertical lines, and the two-year period of the global financial crisis is shown with green vertical lines, representing both of the turmoil periods. The one-year period after Poland's accession to the EU showed no evidence of increased correlation with any other exchange apart from Bulgaria. On the contrary, the unexpected exogenous shock of the global financial crisis greatly affected the links of Polish stock market with the ones of Romania, Ukraine, Bulgaria, and Lithuania. Correlations in these pairs sharply grew during the turmoil period.

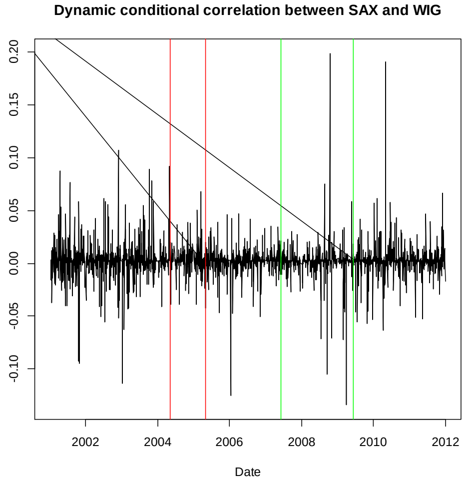












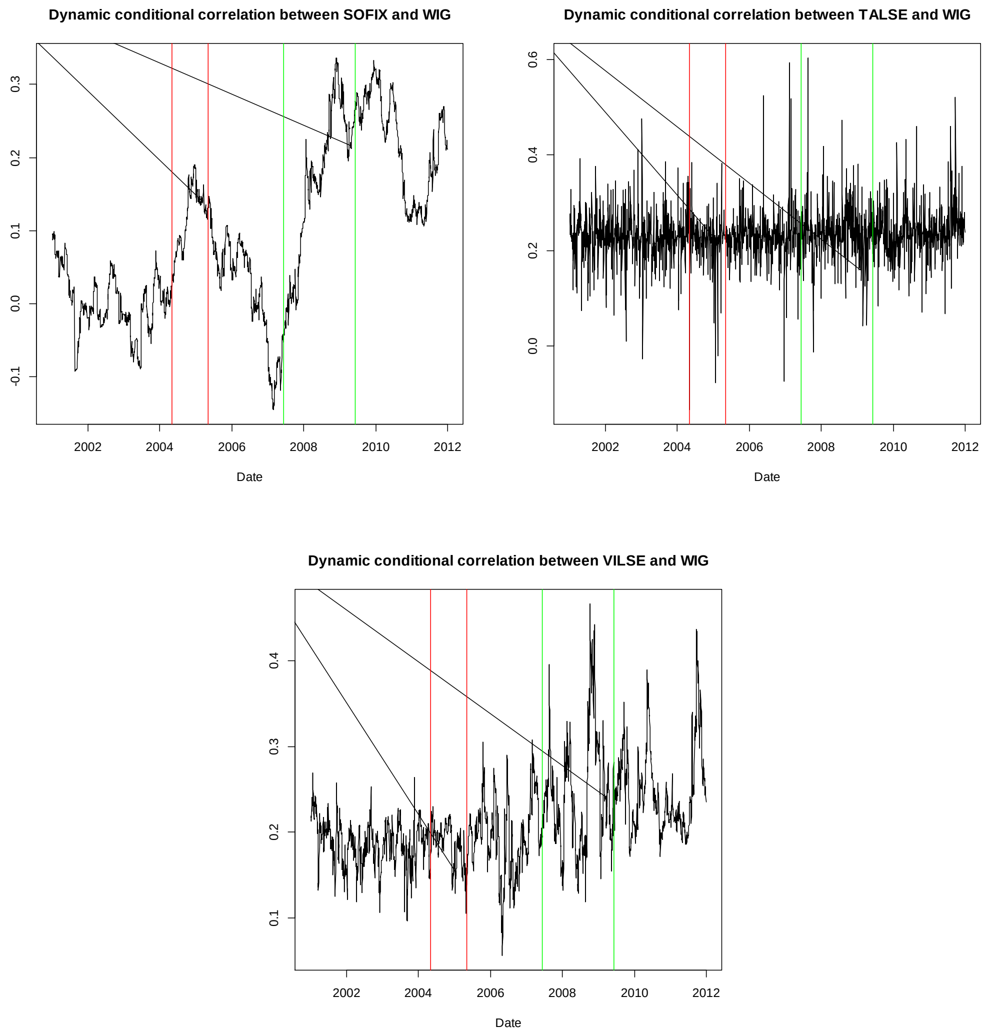


Figure 2 - Dynamic conditional correlation between WIG and market indices of Central and Eastern Europe.

Table 4 shows results of Student's t-test, Mann-Whitney-Wilcoxon test and Smirnov test for contagion effect estimation between Poland and countries of Central and Eastern Europe after Poland's accession to the European Union.

Table 4 - Contagion effects between Poland and the countries of Central and Eastern Europe after entering of Poland into EU (01.05.2004 – 01.05.2005).

Pair of indices	Dynamic conditional correlation (turmoil period)		Dynamic conditional correlation (turmoil period)		Student's t-test	Mann-Whitney-Wilcoxon test	Smirnov test	Contagion effect?
	Mean	Median	Mean	Median	P-value	P-value	P-value	
BET and WIG	0,127	0,082	0,129	0,070	1,00	1,00	0,00***	No
BUX and WIG	0,518	0,531	0,548	0,522	0,04**	0,64	0,00***	No
PFTS and WIG	0,043	0,046	0,039	0,028	0,29	0,34	0,00***	No
PXI and WIG	0,456	0,399	0,470	0,390	1,00	1,00	0,00***	No
RIGSE and	0,084	0,084	0,084	0,084	0,14	0,54	0,95	No

WIG								
SAX and WIG	0,003	0,003	0,002	0,003	0,55	0,44	0,93	No
SOFIX and WIG	0,001	0,118	0,000	0,127	0,00***	0,00***	0,00***	No****
TALSE and WIG	0,229	0,223	0,230	0,229	0,95	0,94	0,02**	No
VILSE and WIG	0,187	0,186	0,189	0,191	0,70	0,54	0,24	No

Note: *****Absence of statistically significant volatility spillover effect supporting the existence of a contagion source; *** shows significance at the 1% level, ** is at the 5% level, and * at the 10% level.*

- Contagion did occur from Poland to countries of Central and Eastern Europe after the accession of Poland into the European Union in May of 2004. *Rejected.*

According to Table 4, it can be inferred that the entrance of Poland into the EU did not influenced the correlation with the markets of Central and Eastern Europe (apart from the case of Bulgaria, which is confirmed but is shown to be indirect, as there is no volatility spillover effect observed between two countries). This is most likely due to the fact that the EU accession was long expected, and markets had already priced in the effects the event would have on the equity markets of each respective country.

Table 5 shows results of tests for contagion effect estimation between Poland and countries of Central and Eastern Europe during Financial Crisis 2007-2009.

Table 5 - Contagion effects between Poland and the countries of Central and Eastern Europe during Financial Crisis 2007-2009 (07.06.2007 – 07.06.2009).

Pair of indices	Dynamic conditional correlation (turmoil period)		Dynamic conditional correlation (turmoil period)		Student's t-test	Mann-Whitney-Wilxocon test	Smirnov test	Contagion effect?
	Mean	Median	Mean	Median	P-value	P-value	P-value	
BET and WIG	0,146	0,405	0,166	0,407	0,00***	0,00***	0,00***	Yes
BUX and WIG	0,600	0,597	0,607	0,617	0,68	0,13	0,00***	No
PFTS and WIG	0,014	0,375	0,044	0,371	0,00***	0,00***	0,00***	Yes
PXI and WIG	0,573	0,677	0,582	0,688	0,00***	0,00***	0,00***	Yes
RIGSE and WIG	0,084	0,085	0,084	0,084	0,21	0,30	0,05**	No
SAX and WIG	0,002	0,002	0,002	0,002	0,69	0,91	0,01***	No
SOFIX and WIG	0,018	0,164	0,041	0,180	0,00***	0,00***	0,00***	No****
TALSE and WIG	0,229	0,237	0,229	0,236	0,01***	0,00***	0,00***	No****
VILSE and WIG	0,195	0,245	0,194	0,237	0,00***	0,00***	0,00***	No****

Note: *****Absence of statistically significant volatility spillover effect supporting the existence of a contagion source; *** shows significance at the 1% level, ** is at the 5% level, and * at the 10% level.*

- Contagion effects were observed between Poland and the countries of Central and Eastern Europe during the Financial Crisis of 2007-2009. *Partially confirmed.*

The global financial crisis of 2007-2009 led to conditional correlation reinforcement between Poland and certain countries in Central and Eastern European regions (Romania, Ukraine, the Czech Republic, Bulgaria, Estonia and Lithuania). However, in case of Estonia, Bulgaria, and Lithuania contagion effects are unable to be accepted as statistically significant volatility spillover effect supporting its existence are not observed. It means that contagion of these countries and Poland were indirect, or in the other words, caused by another trigger. It is proved by the fact that correlation between Poland and these countries strongly increased during the turmoil period. Thus, contagion effects are confirmed only in the pairs BET-WIG, PFTS-WIG and PXI-WIG.

Conclusion

This paper examined the transmission of volatility and contagion among equity markets of Central and Eastern European region with Russia and Poland assumed to be a volatility and contagion source in the area. Using a bivariate DCC-GARCH model, we estimated volatility spillover effects and dynamic conditional correlation among European emerging markets from January 2001 to December 2012, with a focus on the effects among the countries of Central and Eastern Europe. Our results show that the influence of Russian market volatility appears to exceed the influence of the Polish market in the Central and Eastern European region, which corresponds to the level of their market capitalization. This also appears to prove the results of Ramaprasad and Nikolova (2009) and Saleem (2009) about the influence of the Russian market in Europe, as well as the conclusions of Syriopoulos (2007) concerning the presence of volatility interconnections among the emerging markets.

Moreover, in a first for the literature, our analysis also revealed contagion effects from the Russian and Polish stock markets for the Central and Eastern European countries during the Russian stock market crash of 2008 and the global financial crisis. However, the accession of Poland to the EU had no effect on the other markets.

In our view, the results of this study contribute to a deeper understanding of the stock market interrelationships in the global economy. In particular, they shed light on the volatility and contagion transmission linkages in the Central and Eastern Europe. Our findings can help investors, asset management companies, international banks, and investment funds who are seeking portfolio diversification in the region, in regards to the extent of interconnections among key stock indices and emerging markets. We think further research can continue this analysis as regional shocks (such as Ukraine) continue to develop our knowledge about both volatility spillovers and contagion. Thus, a full comprehension of the formation of links in the global economy and particularly in Central and Eastern European region may help to reduce investment risks, as well as allows financial regulators to carry out appropriate politics.

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