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Changes in Stock Markets Interdependencies as a Result of the Global Financial Crisis: Empirical Investigation on the CEE Region

Summary: This paper investigates causal relationships and short-term interaction mechanisms among six Central and Eastern European stock markets and the USA stock exchange, while paying special consideration to the effects of the 2007-2009 global financial crisis. We employ daily observations for the six CEE stock indexes and also for the US market covering the period January 2006-March 2009, which is subsequently divided into two sub-periods corresponding to the pre-crisis and crisis period. The study reveals that the relationships among CEE stock markets are time varying. While before the crisis stock market linkages are limited, we find that during crisis these interactions become significantly stronger. Our results further suggest that the potential for diversifying risk by investing in different CEE markets is limited during financial turmoil. Other findings reveal the leading role of the Russian market in the CEE region before the crisis. Also, before the crisis CEE markets were significantly influenced by innovations in the USA market, thus explaining why they were affected heavily by the crisis, which has managed to spread immediately in the region.

Key words: VAR analysis, Granger causality, Impulse response, Crisis, CEE stock markets.

JEL: C32, F36, G15.

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The concept of financial market integration is central to the international finance literature and it is well accepted that integration of financial markets is fundamentally linked to economic growth through risk sharing benefits, improvements in allocation efficiency, and reductions in macroeconomic volatility (see Marco Pagano 1993).

International integration, which is supposed to produce benefits in terms of capital attraction, better allocation of funds, and higher reliability constitutes the next step of stock market development. However, the process of integration has mixed effects; on one hand determining a diminution of risk-premium resulting in lower cost of capital for the local businesses, evidenced by Rene Stulz (1999), but on the other hand increasing the vulnerability to international shocks due to higher levels of correlations with the foreign markets. The latter effect is evidenced by many research papers in the field of contagion, with methods that developed after the Asian crisis

and have reached their maturity after the sub-prime crisis. The increased correlation reduces the possible benefits of inclusion of these stocks in internationally diversified portfolios, as the integration sweeps away the possible hedging power of the less correlated assets.

The true process of financial market integration is dynamic and difficult to measure, and a wide range of empirical methods have been used to analyze the issue. First, the most basic technique has been the use of unconditional cross-country correlations on equity prices and returns. Later on, a theoretical vector autoregressions (VARs) were used by Cheol S. Eun and Sangdal Shim (1989), Mervyl King and Sushil Wadhwani (1990), among others. Further, higher frequency data led to the use of ARCH variants, with Yasushi Hamao, Ronald W. Masulis and Victor Ng (1990) examining linkages and spillovers using daily returns and Raul Susmel and Robert F. Engle (1994) using hourly data to analyze major stock markets in London, New York and Tokyo. However, it is now known that ARCH is less useful for the non-normal distributions exhibited by emerging market returns. Instead, semi-parametric ARCH (SPARCH) has been used by Geert Bekaert and Campbell R. Harvey (1997) to capture the fat tails and skewness in emerging market returns. On another front, both univariate and multivariate cointegration/error correction models have been used to model stock returns and prices for major and emerging markets. Finally, to address variations in stock market integration over time, researchers have performed regressions on different sub-periods to gain insight into long-term changes in stock market integration dynamics (see for example Francois Longin and Bruno Solnik 1995 or Vincent Bodart and Paul Reding 1999). In addition, rolling and recursive windows and time varying coefficients generated by instrumental variables have also been employed (see for example Marcel Fratzscher 2002).

Emerging markets from Central and Eastern Europe, now members of the European Union and subject of stronger economic links with the developed markets in the EU and between themselves have also drawn the attention of international researchers in more recent years. Expectations are that correlations of CEE markets with the developed markets in the EU would grow in time, as long as CEE countries enter into a gradual economic harmonization process requested by EU membership. As consequence, the capital markets of CEE countries would naturally see themselves in a permanent deregulation process, which, in turn, will lead to a higher integration with the EU capital markets.

Starting from this prior research, in this article we investigate and analyze the common long-run stochastic trends and the short-term interaction mechanisms among six Central and Eastern European stock markets and the USA. We pay special attention to the effects of the 2007-2009 global financial crisis. As VAR models, cointegration tests, and Granger causality tests are very sensitive to the number of lags included (e.g. Pin Chung and Donald Liu 1994; Reid Click and Michael G. Plummer 2005; Dumitru Miron and Cristiana Tudor 2010), we implement lag-length tests and choose the optimal number of lags based on Sims' likelihood-ratio test. As Nancy Huyghebaert and Lihong Wang (2010) show, including too few lags in the VAR models could make it impossible to capture any delayed responses of one market to shocks in another (or in its own market). Therefore, considering more lags is indeed

likely to be imperative, especially in an emerging-market context and, therefore, may allow us to obtain more robust conclusions.

The remainder of the study is organized as follows: Section 1 presents the related literature. Section 2 describes the data and Section 3 defines the methods to be used in the empirical investigation. In Section 4, we present and analyze the estimation results. Finally, Section 5 summarizes the main findings of the paper, draws conclusions and suggests future related research.

1. Literature Review

Many empirical studies in the financial literature report substantial evidence of interdependency among world financial markets both in the short and the long run.

Eun and Shim (1989) found a substantial amount of multi-lateral interaction among the nine largest stock markets in the world (Australia, Canada, France, Germany, Hong Kong, Japan, Switzerland, the United Kingdom and the United States). In particular, they documented that shocks in the US market have the most important impact on the other national markets included in the study. Hamao, Masulis, and Ng (1990) investigate the price and volatility spillovers in three major stock markets (New York, Tokyo, and London) and documented evidence for spillover effects from New York to Tokyo and London, and from London to Tokyo, but not from Tokyo to either to New York or London. Geoffrey G. Booth, Teppo Martikainen, and Yiuman Tse (1997) show that the Scandinavian stock markets exhibit interdependencies both in term of price and volatility transmission. Abul M. Masih and Rumi Masih (2001) study both Asian markets and developed countries of the OECD and find evidence of interdependency among the two categories of markets. They also attest that the markets of the USA and Britain have a dominant role both in the short and the long-run.

Francis In et al. (2001) examine dynamic interdependence, volatility transmission, and market integration across Asian stock markets during the Asian financial crisis periods 1997 and 1998. They employ a vector autoregressive–exponential generalized autoregressive conditional heteroskedasticity (VAR-EGARCH) model and report that reciprocal volatility transmission existed between Hong Kong and Korea, and unidirectional volatility transmission from Korea to Thailand.

Gaston R. Gelos and Ratna Sahay (2001) examine financial market comovements across European transition economies and observe that the pattern of high-frequency spillovers during the Russian crisis looks very similar to that observed in other regions during turbulent times. Caroline Van Rijckeghem and Beatrice Weder (2001) investigate whether is it bank lending or trade linkages and country characteristics that help explain contagion, and find evidence in favor of a common lender effect in the Mexican, Thai, and Russian crises, after controlling for the degree of trade competition and macroeconomic fundamentals. Elna Pretorius (2002) empirically estimates cross-section and time-series models to determine the fundamental factors that influence the correlation and evolution of the correlation between emerging stock markets. Chen Gong-meng, Michael Firth, and Oliver Meng Rui (2002) investigate stock market linkages in Latin America and report that there is cointegration among the analyzed markets (Brazil, Mexico, Chile, Argentina, Kolombia, and Venezuela) up to 1999, but the relationship is no longer significant thereafter.

David A. Bessler and Jian Yang (2003) investigate the dynamic structure of nine major stock markets using an error correction model and directed acyclic graphs (DAG) and report that the US market is highly influenced by its own historical innovations, but it is also influenced by market innovations from the UK, Switzerland, Hong Kong, France and Germany. They also show that US market is the only market that has a consistently strong impact on price movements in other major stock markets in the long run. Michalis Glezakos, Anna Merika, and Haralambos Kaligosfiris (2007) examine, through Cointegration tests, the short and long run relationships between major world financial markets, with particular attention to the Greek stock exchange, and confirm the dominance of the USA financial market and the strong influence of DAX and FTSE on all other markets of the sample.

Lillian Cheung, Laurence Fung, and Chi-Sang Tam (2008) employ the dynamic conditional correlation and the spillover index in order to assess the interdependence between equity markets in the EMEAP region and the US, and across the EMEAP markets. They show that equity market interdependence has increased steadily since early 2006, and rose sharply following the collapse of the Lehman Brothers in September 2008. Giorgio De Santis and Selahattin Imrohoroglu (1997) study the dynamics of expected stock returns and volatility in emerging financial markets and find clustering, predictability, and persistence in conditional volatility. Rakesh Kumar and Raj S. Dhankar (2010) analyzed correlations between South Asian stock markets (India, Sri Lanka, Pakistan, and Bangladesh) and reported weak interdependency between these markets and global stock markets.

Very recently, Sergey K. Aityan, Alexey K. Ivanov-Schitz, and Sergey S. Izotov (2010) used the time-shift asymmetric correlation analysis method for stock exchanges with different but non-overlapping trading hours to analyze the degree of global integration between stock markets of different countries and their influence on each other. They compute next-day correlation (NDC) and same-day correlation (SDC) coefficients and analyze interrelations between major U.S. and Asia-Pacific stock market indices. Results show that most NDCs are statistically significant while most SDCs are insignificant, that NDCs grow over time and the U.S. stock market plays a pace making role for the Asia-Pacific region. Huyghebaert and Wang (2010) examine the integration and causality of interdependencies among seven major East Asian stock exchanges before, during, and after the 1997–1998 Asian financial crisis and reveal that the relationships among East Asian stock markets are time varying and change as a result of the crisis, while the USA plays a determinant role in all periods.

As mentioned above, many authors have been particularly preoccupied with studying the interdependencies among Central and Eastern European markets. Patricia L. Chelley-Steeley (2008) investigates the extent to which the equity markets of Hungary, Poland, the Czech Republic, and Russia have become less segmented. It is found that in the cases of Poland and Hungary, a significant movement towards market integration has been achieved, with Hungary becoming integrated the most rapidly. Also, some reduction in market segmentation was experienced by the Czech Republic. Very little movement away from segmentation was exhibited by the Russian equity market overall, although it does appear to experience short bursts of increased

integration. Further, Cristiana Tudor (2009) studies the Romanian stock market over the period 2002–2008 and the results suggest that although firm-specific financial indicators are important risk factors and help explain time-variation in Romanian common stocks returns, global risks are also conditionally priced.

Finally, Kamal Smimou (2010) shows that, although the Euro market integration has increased inter-country correlations, it does not preclude gains from international diversification, which partially rely on the non-Eurozone countries for an optimal portfolio in a mean-variance framework.

In conclusion, the majority of empirical findings attest that over the last decades international stock markets have become increasingly interdependent. In addition, the role of the US market worldwide is dominant, and the evolution of US stock indices has an important impact on the majority of financial markets.

2. Data

The data for this study was retrieved from Morgan Stanley Capital Indices - Barra and consist of daily stock market index closing prices (dollar denominated) from six CEE stock markets; namely, the stock exchanges from the Czech Republic, Hungary, Bulgaria, Poland, Russia and Romania. We also collected data on the US stock market, given its proven determinant role at a global scale. Similar to Brian M. Lucey and Svitlana Voronkova (2008), we use MSCI indices as they are designed to be directly comparable across national exchanges, compiled on a value-weighted basis of freely investible shares. The MSCI Global Standard Indices include large and mid cap segments and provide exhaustive coverage of these size segments. The indices target a coverage range of around 85% of the free float-adjusted market capitalization in each market. MSCI defines the free float of a security as the proportion of shares outstanding that are deemed to be available for purchase in the public equity markets by international investors. As far as the US equity market is concerned, MSCI includes in the eligible US equity universe all listed equity securities of US incorporated companies listed on the NYSE, NYSE Arca, AMEX, and the NASDAQ, except investment trusts (other than REITs), preferred REITs, mutual funds (other than Business Development Companies), equity derivatives, limited partnerships, limited liability companies and business trusts that are structured to be taxed as limited partnerships, and royalty trusts.

The sample period extends from January 2, 2006 to March 31, 2009 and therefore includes 847 observations for each series. Similar to Mardi Dungey et al. (2007), we consider that the extension of the sample period to include a longer period before the 2007-2009 crisis years would complicate estimating the model as it would involve including additional regimes and could affect the results. We subsequently take the natural logarithm of the daily closing values and daily returns are computed as the first differences of the log-transformed series in the following manner:

$$R_{i,t} = \ln(P_t) - \ln(P_{t-1}) = \ln(\frac{P_t}{P_{t-1}})$$

Further, as different sample periods could result in contradictory findings, particularly when a crisis arises we split the sample into two sub-samples to capture possible time-variant stock market integration in the CEE area before and during the 2007–2009 global financial crisis. The choosing of the moment that delineated the starting point of the crisis on international stock markets must be conducted with care.

2.1 The Starting Point of Crisis Manifestations on International Stock Markets

The ongoing financial crisis has its roots in the US house bubble that peaked in 2006, when many lenders offered mortgages with low rates to borrowers that were not qualified to repay them or requesting very light fulfillment criteria (so-called *sub-prime* loans). Beginning in early 2007 and accentuating in the second half of 2007, these sub-prime lenders started to collapse, after their borrowers failed to meet their payment obligation. This situation immediately developed into the so-called "*Credit Crunch*" (defined as "a severe shortage of money or credit"), caused by the lack of trust of major banks to continue to provide funds amongst each other. The US real estate sector reached a peak in 2006 and the beginning of 2007, but the trend reversed violently after that point, a development that was closely linked to the unfolding of the financial crisis. Home mortgages decreased from the highest value of 1199.5 bn dollars in the first quarter of 2007, to 1166.7 bn dollars the following quarter (at the same time, in April 2007 New Century Financial, which specializes in sub-prime mortgages, files for Chapter 11 bankruptcy protection and cuts half of its workforce). The US home mortgages indicator continued with sharp decreases till year end (904 bn $ in Q3 of 2007 and 702 bn $ in Q4 of 2007), encountering a light recovery in the first half of 2008 to subsequently reach a negative value of -258.9 in the third quarter of 2008. Figure 1 gives a clear view of this evolution.

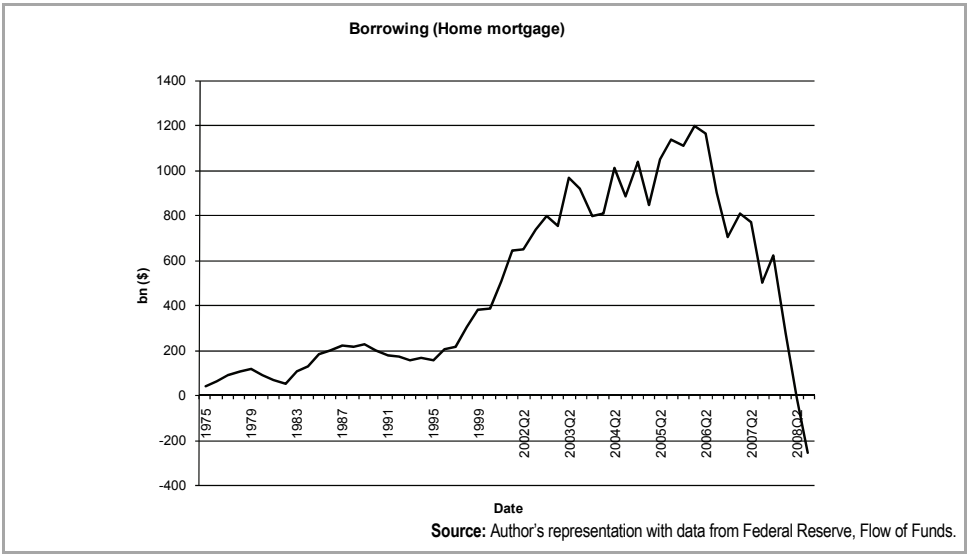
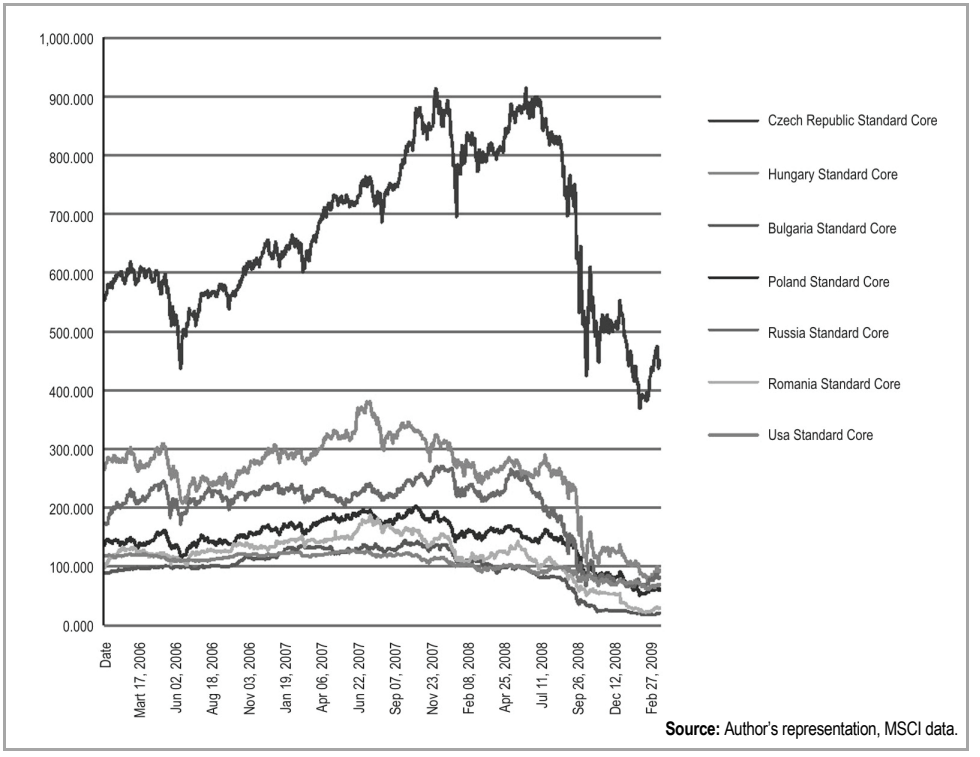


Figure 1 Evolution of Borrowing in the US Home Mortgage Sector

Hence, although many authors use the Lehman Brothers' collapse in September 2008 as the event which reflects the beginning of the crisis on international financial markets, we have seen that a more thorough investigation shows that the manifestations of the crisis started long before that moment. Figure 2 also reflects this reality: the decreasing trend of the stock indexes began in July 2007 for Hungary, Romania and USA, a few months later for Russia, Poland and Bulgaria. Only in the case of the Czech stock market the crisis showed its full manifestations only in the summer of 2008.



Source: Author's representation, MSCI data.

Figure 2 Evolution of CEE and US Stock Market Indexes: January 2006-March 2009

Following the above investigation, we chose the beginning of July 2007 as the moment when the global financial crisis began to show its full manifestations on international stock exchanges. The choice of the crisis dates is clearly partly subjective and is further complicated by the occurrence of many events over a relatively short period. In the event that the structural break is known, as is the case in the event of a global crisis, a standard approach is to sub-sample both sides of the break. Following this method, our first sub-sample covers the period from January 2, 2006 to June 30, 2007, or a total of 390 daily observations for each series and represents the pre-crisis period. The crisis period then starts at July 1, 2007 and ends after the first quarter of 2009 (March 31, 2009), a time window containing 457 daily observations for each series which should correspond to a genuine crisis period. Hsiao-Ching Sheng and

Anthony H. Tu (2000) also used this approach for examining stock market data before and during the Asian financial crisis. Their research suggested that stock markets were not cointegrated before the crisis of 1997, but that there was some degree of cointegration during the crisis. Like the case in our present study, Sheng and Tu (2000) prejudged the sampling break – a procedure that may have affected their results. Because failing to consider possible structural breaks in one or more series can affect the results and the dating of the regimes is important in identifying the parameters of each regime, a future research study could use a longer time span for the data series and could follow Pierre Perron (1989, 1994) for identifying potential break dates in the series and in this way investigating longer-term stock markets interrelations.

2.2 Descriptive Statistics

Table 1 confirms that there was indeed a structural break in our time series after the second trimester of 2007. The distributions of stock returns in the pre-crisis period (Panel A) are generally slightly leptokurtic (with the exception of Hungary and USA stock indexes) and present negative skewness, while during the crisis (Panel B) all distributions became strongly leptokurtic and positively skewed. As expected, mean returns decreased significantly during crisis, while volatility accentuated. The markets that were most affected by the crisis in terms of difference in mean returns between the two sub-samples are the Hungarian, Polish and Romanian stock markets, while the least affected were the Czech and the Russian markets. Market volatility, as represented by the standard deviation of returns, increased the most on the Bulgarian and Romanian stock exchanges.

Table 1 Descriptive Statistics of Daily Stock Return Series

PANEL A: Pre-Crisis (January 2, 2006 – June 29, 2007)							
	Czech Republic	Hungary	Bulgaria	Poland	Russia	Romania	USA
Mean	0.00072	0.00083	0.00095	0.00087	0.00066	0.00148	0.00013
Std Error	0.00068	0.00087	0.00050	0.00086	0.00102	0.00087	0.00039
Median	0.00113	0.00170	0.00013	0.00115	0.00124	0.00061	0.00018
Mode	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Std Deviation	0.01345	0.01710	0.00995	0.01692	0.02022	0.01725	0.00776
Variance	0.00018	0.00029	0.00010	0.00029	0.00041	0.00030	0.00006
Kurtosis	6.02230	0.40637	6.02489	0.60941	5.53077	5.52493	1.97276
Skewness	-0.08236	-0.12535	-0.59970	-0.21290	-0.72661	-0.05925	-0.46342
Range	0.14929	0.10425	0.09760	0.11537	0.20394	0.17822	0.06200
Minimum	-0.06205	-0.04880	-0.05965	-0.06133	-0.11276	-0.08634	-0.04050
Maximum	0.08724	0.05545	0.03795	0.05405	0.09118	0.09188	0.02150
Sum	0.27957	0.32402	0.37067	0.33738	0.25632	0.57626	0.05117
Count	390.00000	390.00000	390.00000	390.00000	390.00000	390.00000	390.00000

PANEL B: Crisis (July 2, 2007 – March 31, 2009)

	Czech Republic	Hungary	Bulgaria	Poland	Russia	Romania	USA
Mean	0.0004	0.0001	0.0002	0.0001	0.0004	0.0002	0.0001
Std Error	0.0020	0.0034	0.0045	0.0029	0.0031	0.0043	0.0017
Median	0.0000	-0.0022	-0.0007	-0.0007	-0.0006	-0.0029	0.0000
Mode	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Std Deviation	0.0425	0.0726	0.0966	0.0620	0.0672	0.0917	0.0371
Variance	0.0018	0.0053	0.0093	0.0038	0.0045	0.0084	0.0014
Kurtosis	171.1023	298.0424	392.1751	307.6535	218.7986	363.5036	170.2076
Skewness	10.1316	15.5068	19.0344	15.8751	12.2564	17.8922	10.2047
Range	0.8670	1.5931	2.1450	1.3119	1.4269	2.1842	0.7109
Minimum	-0.1569	-0.1998	-0.1605	-0.1123	-0.2334	-0.3360	-0.0914
Maximum	0.7101	1.3933	1.9845	1.1996	1.1936	1.8482	0.6195
Sum	0.2001	0.0305	0.0849	0.0503	0.1758	0.0860	0.0235
Count	457.0000	457.0000	457.0000	457.0000	457.0000	457.0000	457.0000

Source: Author's estimations, MSCI data.

2.3 Correlation Analysis

A simple investigation of the correlation matrix between index return series can provide important information for the subsequent Granger causality tests. The correlation coefficients of daily stock market returns for the two sub-sample periods are reported in Table 2. The correlation coefficients for the pre-crisis period are relatively low (Panel A), in particular in the cases of Romania, Bulgaria and USA, which do not seem to be correlated with other markets in the sample, or amongst each other. Some linkages appear to exist only among stock markets in Czech Republic, Hungary, Poland and Russia in the pre-crisis period. The situation changes dramatically during crisis times, when all correlation coefficient increase significantly and stock markets become strongly interconnected (see Panel B). Even the three markets which moved independently before the crisis (Romania, Bulgaria and USA) are now correlated with the others. For example, the correlation between stock exchanges from Bulgaria and Romania increased from 0.11 before crisis to a strong level of 0.94 during crisis. The correlation between the US market and the six CEE markets also increased significantly in the second sub-sample, while the four markets that showed important linkages before the crisis (i.e. Czech Republic, Hungary, Poland and Russia) seem to move almost identically during crisis time.

Table 2 Correlation Matrix for the Seven Stock Market Indexes

PANEL A: Pre-Crisis

	Czech Republic	Hungary	Bulgaria	Poland	Russia	Romania	USA
Czech Republic	1.00						
Hungary	**0.58**	1.00					
Bulgaria	-0.04	-0.07	1.00				
Poland	**0.58**	**0.71**	-0.06	1.00			
Russia	**0.61**	**0.54**	-0.02	**0.51**	1.00		
Romania	0.12	0.15	0.11	0.17	0.15	1.00	
USA	0.20	0.09	-0.12	0.14	0.20	0.04	1.00

PANEL B: Crisis

	Czech Republic	Hungary	Bulgaria	Poland	Russia	Romania	USA
Czech Republic	1.00						
Hungary	0.87	1.00					
Bulgaria	0.82	0.90	1.00				
Poland	0.89	0.94	0.91	1.00			
Russia	0.87	0.87	0.85	0.90	1.00		
Romania	0.84	0.91	0.94	0.92	0.86	1.00	
USA	0.69	0.79	0.75	0.77	0.75	0.77	1.00

Source: Author's estimations, MSCI data.

The above results provide insight that the correlations between the seven stock markets increased sharply during the crisis, information which should also be attested by Granger causality tests. Further, we implement unit root tests to examine whether the log-transformed stock market indices are stationary (not reported). Using a 0.05 significance level, the Augmented Dickey–Fuller (ADF) tests as well as the Phillips–Perron tests suggest that all series are integrated at level I(0). Finally, and most importantly, the ADF-test results for the two sub-periods (pre-crisis and crisis) also indicate that all indices in both sub-periods are stationary in the level, therefore we have no restrictions in conducting Granger causality tests on our dataset.

3. Method

3.1 Granger Causality Test

Testing causality, in the Granger sense, involves using *F*-tests to test whether lagged information on a variable *Y* provides any statistically significant information about a variable *X* in the presence of lagged *X*. If not, then "*Y* does not Granger-cause *X*." In other words, a variable *Y* is said not to Granger-cause a variable *X* if the distribution of *X*, conditional on past values of *X* alone, equals the distribution of *X*, conditional on past realizations of both *X* and *Y*. If this equality does not hold, *Y* is said to Granger-cause *X*. If Y can predict future X, over and above what lags of X itself can, then Y Granger causes X.

We test for Granger causality by estimating the following VAR models for each pair-wise combination of stock returns series (Clive W. J. Granger 1969):

$$X_t = \mu_1 + \sum_{i=1}^{p} \alpha_{1,i} Y_{t-i} + \sum_{i=1}^{p} \beta_{1,i} X_{t-i} + \varepsilon_{1,t}$$

If the null hypothesis: $H_0 : \sum_{i=1}^{p} \alpha_{1,i} = 0$ is rejected Y is said to Granger cause X.

$$Y_t = \mu_2 + \sum_{i=1}^{p} \alpha_{2,i} X_{t-i} + \sum_{i=1}^{p} \beta_{2,i} Y_{t-i} + \varepsilon_{2,t}$$

If the null hypothesis: $H_0 : \sum_{i=1}^{p} \alpha_{2,i} = 0$ is rejected X is said to Granger cause Y.

If the null hypothjesis is rejected from both cases, it is said that there is a feedback relationship between X and Y.

As Granger causality test results are very sensitive to the number of lags chosen, we first run the models with 20 days as maximum lag length and we further implement a lag-length test.

3.2 Impulse Response Analysis

Finally, we investigate the short-term causal relationships among the six CEE stock markets and the US stock market by implementing generalized impulse response analyses in the two sub-periods. As in Huyghebaert and Wang (2010), we explore the effects of a one unit shock rather than a one standard deviation shock, to account for the changing volatility of stock returns over time. By definition, an impulse response function traces the effect of a one-time shock to one of the innovations on current and future values of the endogenous variables. A shock to the i-th variable not only directly affects the i-th variable but is also transmitted to all of the other endogenous variables through the dynamic (lag) structure of the VAR.

If the innovations ε_t are contemporaneously uncorrelated, interpretation of the impulse response is straightforward. The i-th innovation $\varepsilon_{t,i}$ is simply a shock to the i-th endogenous variable $y_{t,i}$. Innovations, however, are usually correlated, and may be viewed as having a common component which cannot be associated with a specific variable. In order to interpret the impulses, it is common to apply a transformation P to the innovations so that they become uncorrelated:

$v_t = P\varepsilon_t - (o, D)$, where D is a diagonal covariance matrix.

4. Empirical Results

4.1 Causal Relationships among CEE and the US Stock Markets

For the pre-crisis period, the Granger causality test results suggest that the exchanges from USA and Russia are two interactive markets, as the US stock market Granger causes the Russian market while the Russian stock index also leads the US stock market index, and this bilateral causality is significant at 1% and 5%, respectively, being stronger from the American stock market to the Russian one. Other interactive pairs of stock exchanges in the pre-crisis period are Romania-Hungary and Russia-Hungary. When considering the overall role of the US market in the analyses, we observe that it leads the Bulgarian, Czech, Hungarian, Polish, and Romanian stock markets while only the Russian market has some marginally leading effect (as stated earlier) on the US market in the pre-crisis period, suggestion a leading role for the Russian market in the CEE region before the crisis.

For the crisis period, results reveal that causal relationships have increased during the 2007–2009 global financial crisis. Bilateral causality is now present between stock market in Hungary-Bulgaria, USA-Bulgaria, USA-Czech Republic, USA-Romania and USA-Russia, while strong unilateral causality is found from Romania to Bulgaria, from the Czech Republic to Hungary, from Romania to the Czech Republic, from Poland to Hungary, from Romania to Hungary, from Russia to Hungary, from Romania to Poland. In other words, results suggest that the linkages among CEE stock markets are generally larger during the crisis than before. Considering only the interactions between the CEE region and the USA, we find that during the crisis this linkages have become generally bi-directional, and the evolution of Central and Eastern European stock markets is more often reflected in the subsequent evolution of the US stock exchange. Table 3 reveals the Granger causality test results between each pair of markets in our dataset for the two sub-periods.

Table 3 Granger Causality Test Results

H_0: X does not Granger cause Y	Pre-Crisis	Crisis
Czech Republic → Bulgaria	0.25458	3.20367***
Bulgaria → Czech Republic	0.00055	0.32537
Hungary → Bulgaria	1.31778	4.67027**
Bulgaria → Hungary	0.37999	5.88830**
Poland → Bulgaria	0.42672	0.20182
Bulgaria → Poland	0.41187	6.67296**
Romania → Bulgaria	0.10938	45.4535*
Bulgaria → Romania	1.20872	0.76627
Russia → Bulgaria	0.05372	0.03185
Bulgaria → Russia	20.6093*	1.70694
USA → Bulgaria	20.4032*	6.52363**
Bulgaria → USA	0.22428	62.0235*
Hungary → Czech Republic	0.54750	1.73693
Czech Republic → Hungary	0.15498	21.7962*
Poland → Czech Republic	0.30035	0.33348
Czech Republic → Poland	0.37284	4.47299**
Romania → Czech Republic	0.69153	47.4041*
Czech Republic → Romania	6.66731**	1.30228
Russia → Czech Republic	1.83256	0.25430
Czech Republic → Russia	11.9293*	1.81421
USA → Czech Republic	30.3674*	15.4548*
Czech Republic → USA	1.71908	103.526*
Poland → Hungary	0.31966	11.9502*

Hungary → Poland	0.04731	0.08832
Romania → Hungary	2.81149***	68.4111*
Hungary → Romania	2.78696***	0.31084
Russia → Hungary	9.70624**	9.55204*
Hungary → Russia	2.92076***	2.08579
USA → Hungary	2.78000***	0.22444
Hungary → USA	1.25798	5.13534**
Romania → Poland	0.83449	14.5677*
Poland → Romania	3.56401***	0.81652
Russia → Poland	0.82116	0.15364
Poland → Russia	11.9656*	2.15235
USA → Poland	13.2372*	0.82947
Poland → USA	0.46815	63.1564*
Russia → Romania	1.51315	0.99028
Romania → Russia	25.0197*	33.1299*
USA → Romania	16.1896*	11.2758*
Romania → USA	0.55412	3.0E+18*
USA → Russia	10.4599*	4.80548**
Russia → USA	4.76270**	25.0383*

Note: * significant at 1%
** significant at 5%
*** significant at 10%

Source: Author's estimations, MSCI data.

To sum up, Granger causality tests, as well as the correlation analysis point out that the stock markets in the CEE region have become increasingly integrated in recent years, reflecting this geographical area's increased importance in the European and in the world economy. Also, before the crisis, CEE markets were significantly influenced by innovations in the USA market, thus explaining why they were affected heavily by the crisis, which managed to spread immediately in the region.

4.2 Short-term Interdependencies between CEE and the US Stock Markets

Finally, we investigate the short-term causal relationships among the seven stock exchanges in our data sample (six CEE and the US stock markets) by implementing a generalized impulse response analysis in the each of the two predefined sub-periods. As previously mentioned, we explore the effects of a one unit shock rather than a one standard deviation shock, to account for the changing volatility of stock returns over time. Table 4 presents the results.

Table 4 Results of the Impulse Response Analysis (Decomposition Method – One Unit)

Impulse response by stock market		Innovations in the stock market						
Panel A: Pre-Crisis								
		Czech Republic	**Bulgaria**	**Hungary**	**Poland**	**Romania**	**Russia**	**USA**
Czech Republic	1	1.000000	-0.019586	-0.054569	0.060855	-0.111862	0.094831	0.496958
	2	0.384395	0.141174	0.028636	0.097596	-0.089565	0.153156	0.016272
	3	0.513648	-0.010255	-0.014758	0.109088	-0.079544	0.048089	-0.01683
	4	0.498691	0.000801	-0.002304	0.062448	-0.094625	0.101065	0.284816
	5	0.464155	0.080441	-0.004226	0.067127	-0.069200	0.090638	0.093084
Bulgaria	1	-0.027389	1.000000	-0.071290	-0.04848	-0.040048	0.032422	0.352760
	2	-0.016270	0.490168	0.046824	0.037175	-0.061766	0.048439	0.058537
	3	-0.077363	0.593345	-0.022883	0.072721	-0.047670	0.048123	-0.06251
	4	-0.019078	0.503213	-0.014368	-0.00408	-0.053550	0.042095	0.216848
	5	-0.023532	0.534234	0.006830	0.007495	-0.035359	0.022364	0.087853

Hungary	1	0.004770	-0.041353	1.000000	-0.05363	0.070958	0.032180	0.132574
	2	0.089997	-0.008435	0.418673	-0.09947	0.084060	-0.09749	0.086508
	3	0.031551	-0.014662	0.539835	-0.06394	0.043693	-0.01678	0.111604
	4	0.026252	-0.017478	0.326282	-0.05360	0.063032	0.010430	0.098384
	5	0.050879	-0.013503	0.452050	-0.06855	0.061783	-0.06050	0.079912
Poland	1	0.065435	0.007747	-0.029711	1.000000	-0.029035	-0.14257	0.433952
	2	0.012579	0.179926	0.029052	0.331406	0.035272	-0.05934	0.156231
	3	0.043927	-0.022330	-0.058118	0.515695	0.054993	-0.07538	0.156910
	4	0.066371	0.040315	0.005373	0.399316	-0.025681	-0.08943	0.323537
	5	0.009714	0.101217	-0.001053	0.416573	0.033751	-0.07074	0.156232
Romania	1	0.079852	0.020824	-0.120817	0.099826	1.000000	0.272839	0.302217
	2	-0.128535	0.062003	0.088735	0.182798	0.310854	0.137622	-0.07327
	3	-0.116887	0.007456	-0.015169	0.207899	0.387096	0.169923	-0.19632
	4	0.017389	0.014564	-0.031082	0.101877	0.270921	0.114214	0.164146
	5	-0.075856	0.033139	0.028782	0.143263	0.352823	0.123438	-0.03383
Russia	1	0.073403	0.096061	-0.135131	-0.19160	0.233268	1.000000	0.448099
	2	0.187891	-0.095158	-0.059328	-0.24558	0.159010	0.257217	0.312979
	3	0.109558	0.068504	-0.055789	-0.19123	0.167292	0.442608	0.261093
	4	0.083657	0.022232	-0.111644	-0.15153	0.158217	0.305408	0.333904
	5	0.136683	-0.018635	-0.052486	-0.20408	0.154705	0.317586	0.307052
USA	1	-0.076340	0.032593	-0.004062	0.063990	-0.050523	0.022510	1.000000
	2	-0.095313	0.031791	0.025908	0.120223	-0.091527	0.071632	0.272912
	3	-0.051208	-0.006192	0.018338	0.063423	-0.043011	0.036072	0.508753
	4	-0.065854	0.026332	0.001076	0.062017	-0.047579	0.019766	0.335511
	5	-0.069221	0.020925	0.016964	0.082398	-0.063306	0.049274	0.368981

Panel B: Crisis

		Czech Republic	Bulgaria	Hungary	Poland	Romania	Russia	USA
Czech Republic	1	1.000000	-0.119161	0.040112	-0.02314	0.401732	-0.06365	0.063290
	2	0.356745	-0.019445	0.061428	0.015787	-0.062937	-0.01835	0.117766
	3	0.174558	-0.031984	0.166521	0.049851	0.044081	-0.00212	0.121228
	4	0.146371	-0.212434	-0.051790	-0.04815	0.015482	-0.05024	0.041287
	5	0.628039	-0.151352	-0.036275	-0.08633	0.019636	0.013600	0.095468
Bulgaria	1	0.119705	1.000000	0.033788	-0.12668	0.336229	0.000799	0.131406
	2	0.231493	0.036633	0.153342	-0.13476	-0.080457	-0.01165	0.077358
	3	0.136301	0.106179	0.159030	-0.12305	-0.051021	0.032491	0.184548
	4	0.321660	-0.063151	0.101688	-0.08892	-0.080836	0.002186	0.205553
	5	0.305045	0.016323	0.108865	-0.14743	0.079300	-0.00085	0.122987
Hungary	1	0.044591	0.007065	1.000000	0.023263	0.338054	0.022795	0.026228
	2	0.055421	-0.051940	0.302959	0.170851	-0.056400	-0.08317	-0.11859
	3	-0.223601	0.195361	0.269020	0.081480	0.015290	0.035788	-0.04631
	4	0.104369	0.041583	0.321816	0.010631	-0.041122	-0.00841	0.007919
	5	-0.008835	0.066486	0.101664	0.035747	0.047872	0.049819	-0.07494
Poland	1	0.149942	-0.004025	0.253142	1.000000	0.288911	-0.08930	0.143777
	2	0.190598	-0.051482	0.189558	0.046833	-0.023930	-0.05531	0.315507
	3	0.049772	-0.023029	0.099260	0.092236	-0.067029	-0.02393	0.147644
	4	0.423767	-0.106766	0.047697	-0.01844	-0.126038	-0.07398	0.158097
	5	0.326828	-0.223775	0.143777	0.131406	0.026764	-0.03696	0.109142
Romania	1	0.042434	-0.046581	0.110279	0.019184	1.000000	0.447598	0.108865
	2	-0.021261	-0.008679	0.140640	-0.05720	0.107677	0.020412	0.159916
	3	0.023687	-0.087334	0.168038	-0.00541	0.305912	-0.01038	0.025016
	4	0.104143	-0.037687	-0.048445	-0.00118	0.185354	0.000541	0.135780
	5	-0.031685	0.026228	0.152347	-0.13061	0.314782	0.014587	0.077154
Russia	1	0.037169	-0.058907	-0.065518	0.028431	0.314999	1.000000	0.159628
	2	-0.031309	-0.288087	0.134930	0.059401	0.031223	0.244266	-0.04923
	3	-0.047094	-0.019251	0.054609	-0.02402	0.068332	0.255026	0.010389
	4	0.203688	-0.099723	0.000550	-0.04450	0.058485	0.284822	0.050063
	5	-0.012234	-0.065729	-0.046140	-0.00358	0.063290	0.376351	-0.01683
USA	1	0.088181	-0.490051	0.051507	0.077358	0.089867	0.004269	1.000000
	2	0.173878	-0.151966	0.147644	0.184548	0.009264	-0.07095	0.173878
	3	0.140844	-0.146806	0.158097	0.205553	0.012012	-0.07674	0.140844
	4	0.222120	-0.125996	0.109142	0.122987	0.007483	-0.05117	0.222120
	5	0.426003	-0.126127	0.037186	-0.02966	0.065459	-0.01040	0.009988

Source: Author's estimations, MSCI data.

It is found that before the crisis, the CEE markets that responded the most to innovations on the US stock markets were Bulgaria, Poland, Romania and Russia (in this order), while during crisis the countries remained the same, but the order of innovations intensity changed in the following manner: Poland, Russia, Bulgaria and Romania.

Further, regarding the six European stock markets, we observe that Russia and Romania are two interactive exchanges in the pre-crisis period as well as during the global financial crisis. The Bucharest stock market reacts to innovations in the Russian market by 0.27 and 0.44, respectively on the first day before and during the crisis. On the other hand, the stock market in Moscow responds by 0.23 and 0.31, respectively to a one unit shock in Bucharest. In addition, during the crisis, lagged responses of the stock markets from Bulgaria and Poland to shocks in the Czech Republic became stronger, as well as responses from Hungary and Poland to innovations from Romania. Responses in the CEE region to shocks on the US market are generally strong in the pre-crisis period, while they lose intensity during crisis. Overall, we find no other major interdependencies amongst stock returns in our data sample. While these results confirm some of the previous results of Granger causality tests, the other causal relationships encountered earlier are no longer valid, suggesting that long-term linkages are not visible when studying the short-term dynamics of stock exchanges.

5. Conclusions

This paper investigates interdependencies among six selected stock exchanges in the CEE region, while also considering their linkages with the USA market. As major economic events can influence the relationships among stock markets, we pay special attention to the effects of the 2007-2009 global financial crisis. Thus, we split the sample into two sub-samples to capture possible time-variant stock market integration in the CEE area before and during the crisis, while paying special consideration to finding the moment that delineated the starting point of the manifestations of the crisis on international stock markets. Descriptive statistics showed that the markets that were most affected by the crisis in terms of difference in mean returns between the two sub-samples are the Hungarian, Polish and Romanian stock markets, while the least affected were the Czech and the Russian markets. Also, market volatility, as represented by the standard deviation of returns, increased the most on the Bulgarian and Romanian stock exchanges. Further, in line with previous findings in the literature, a simple correlation analysis revealed that all stock markets move together during crisis, while in the pre-crisis period the markets were fragmented, some linkages appearing only among stock indexes from the Czech Republic, Hungary, Poland and Russia. Results of the Granger causality tests also confirm that the interdependencies among CEE stock markets are generally larger during the crisis than before, and also that the relationships between CEE markets and the US market became generally bidirectional. We also find that in the pre-crisis period the US stock market leads the Bulgarian, Czech, Hungarian, Polish, and Romanian stock markets while only the Russian market has some marginally leading effect on the US market, suggestion a

leading role for the Russian market in the CEE region before the crisis. This outcome was expected in view of the prominence of the Russian economy within the region.

In the end, a generalized impulse response analysis confirms the overall dominant role of the USA market on the CEE exchanges in the pre-crisis period, while its impact seams to have decreased during crisis. Also, before the crisis, CEE markets were significantly influenced by innovations in the USA market, thus explaining why they were affected heavily by the crisis, which managed to spread quickly in the region.

As expected, all conducted tests confirm the strong interrelations between the CEE stock markets during crisis, which in turn implies that the diversification benefit from investing across all six countries disappears during financial turmoil. Nevertheless, the strong interdependencies which are present during crisis do not necessary imply that CEE economies henceforth share the same long-run equilibrium relationship. Whether these crisis interdependencies also translate into increased stock market integration at a regional level in the long run remains to be seen, and could make the subject of a future research by introducing a post-crisis data sub-sample in the analysis. This extension of the study is particularly interesting given its possible implications for policy makers. As Bekaert and Harvey (1995) have noted and Jian Yang, James W. Kolari, and Insik Min (2003) have underlined, previous research assumes that stock markets are perfectly integrated, perfectly segmented, or partially integrated, where in the latter case the degree of integration is constant over time. Nevertheless, both Bekaert and Harvey (1995) and Yang, Kolari, and Min (2003) have empirically proved that this assumption does not hold and that stock market integration can be time variant. If indeed CEE stock markets prove that after crisis they are no longer isolated by national borders, this implies that financial market surveillance in the CEE area should not be confined at national level, which in turn will raise new challenges to the European Union as a whole.

References

Aityan, Sergey, Alexey K. Ivanov-Schitz, and Sergey S. Izotov. 2010. "Time-shift Asymmetric Correlation Analysis of Global Stock Markets." *Journal of International Financial Markets, Institutions and Money*, 20(5): 590-605.

Bekaert, Geert, and Campbell R. Harvey. 1995. "Time-Varying World Market Integration." *Journal of Finance*, 50(2): 403-444.

Bekaert, Geert, and Campbell R. Harvey. 1997. "Emerging Equity Market Volatility." *Journal of Financial Economics*, 43(1): 29–77.

Bekaert, Geert, and Campbell R. Harvey. 2003. "Emerging Markets Finance." *Journal of Empirical Finance*, 10(1-2): 3–55.

Bessler, David A., and Jian Yang. 2003. "The Structure of Interdependence in International Stock Markets." *Journal of International Money and Finance,* 22(2): 261-287.

Bodart, Vincent, and Paul Reding. 1999. "Exchange Rate Regime, Volatility and International Correlations on Bond and Stock Markets." *Journal of International Money and Finance,* 18(1): 133-151.

Booth, Geoffrey G., Teppo Martikainen, and Yiuman Tse. 1997. "Price and Volatility Spillovers in Scandinavian Stock Markets." *Journal of Banking & Finance,* 21(6): 811-823.

Chelley-Steeley, Patricia L. 2005. "Modeling Equity Market Integration Using Smooth Transition Analysis: A Study of Eastern European Stock Markets." *Journal of International Money and Finance,* 24(5): 818-831.

Chen, Gong-meng, Michael Firth, and Oliver Meng Rui. 2002. "Stock Market Linkages: Evidence from Latin America." *Journal of Banking and Finance,* 26(6): 1113-1141.

Cheung, Lillian, Laurence Fung, and Chi-Sang Tam. 2008. "Measuring Financial Market Interdependence and Assessing Possible Contagion Risk in the EMEAP Region." Hong Kong Monetary Authority Working Paper 0818.

Click, Reid, and Michael G. Plummer. 2005. "Stock Market Integration in ASEAN After the Asian Financial Crisis." *Journal of Asian Economics,* 16(1): 5-28.

Chung, Pin, and Donald Liu. 1994. "Common Stochastic Trends in Pacific-Rim Stock Markets." *Quarterly Review of Economics and Finance*, 34(5): 241−259.

De Santis, Giorgio, and Selahattin Imrohoroglu. 1997. "Stock Returns and Volatility in Emerging Financial Markets." *Journal of International Money and Finance,* 16(4): 561-579.

Dungey, Mardi, Renee Fry, Brenda Gonzalez-Hermosillo, and Vance Martin. 2007. "Contagion in Global Equity Markets in 1998: The Effects of the Russian and LTCM crises." *The North American Journal of Economics and Finance,* 18(2): 155-174.

Eun, Cheol S., and Sangdal Shim. 1989. "International Transmission of Stock Market Movements." *Journal of Financial and Quantitative Analysis,* 24(2): 241-256.

Fratzscher, Marcel. 2002. "Financial Market Integration in Europe: On the Effects of the EMU on Stock Markets." *International Journal of Finance and Economics,* 7(3): 165–193.

Gelos, Gaston R., and Ratna Sahay. 2001. "Financial Market Spillovers in Transition Economies." *Economics of Transitions,* 9(1): 53-86.

Glezakos, Michalis, Anna Merika, and Haralambos Kaligosfiris. 2007. "Interdependence of Major World Stock Exchanges: How is the Athens Stock Exchange Affected?" *International Research Journal of Finance and Economics,* 7: 24-39.

Granger, Clive W. J. 1969. "Investigating Causal Relations by Economic Models and Cross-spectral Methods." *Econometrica,* 37(3): 424–438.

Granger, Clive W. J., and Oskar Morgenstern. 1970. *Predictability of Stock Market Prices*. Lexington, MA: Lexington Books.

Hamao, Yasushi, Ronald W. Masulis, and Victor Ng. 1990. "Correlations in Price Changes and Volatility across International Stock Markets." *The Review of Financial Studies,* 3(2): 281-307.

Huyghebaert, Nancy, and Lihong Wang. 2010. "The Co-movement of Stock Markets in East Asia. Did the 1997–1998 Asian Financial Crisis Really Strengthen Stock Market Integration?" *China Economic Review,* 21(1): 98-112.

In, Francis, Sangbae Kim, Jai Hyung Yoon, and Cristopher Viney. 2001. "Dynamic Interdependence and Volatility Transmission of Asian Stock Markets: Evidence from the Asian Crisis." *International Review of Financial Analysis,* 10(1): 87-96.

King, Mervyl, and Sushil Wadhwani. 1990. "Transmission of Volatility between Stock Markets." *Review of Financial Studies,* 3(1): 5–33.

Kumar, Rakesh, and Raj S. Dhankar. 2010. "Empirical Analysis of Conditional Heteroskedasticity in Time Series of Stock Returns and Asymmetric Effect on Volatility." *Global Business Review,* 11(1): 21-33.

Longin, Francois, and Bruno Solnik. 1995. "Is the Correlation in International Equity Returns Constant: 1960–1990?" *Journal of International Money and Finance,* 14(1): 3–26.

Lucey, Brian M., and Svitlana Voronkova. 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): 1303-1324.

Masih, Abul M. M., and Rumi Masih. 1997. "Dynamic Linkages and the Propagation Mechanism Driving Major International Stock Markets." *Quarterly Review of Economics and Finance,* 37(4): 859-885.

Miron, Dumitru, and Cristiana Tudor. 2010. "Asymmetric Conditional Volatility Models: Empirical Estimation and Comparison of Forecasting Accuracy." *Romanian Journal for Economic Forecasting,* 13(3): 74-92.

Pagano, Marco. 1993. "Financial Markets and Growth: An Overview." *European Economic Review,* 37(2-3): 613–622.

Perron, Pierre. 1989. "The Great Crash, the Oil Price Shock, and the Unit Root Hypothesis." *Econometrica*, 57(6): 1361−1401.

Perron, Pierre. 1994. "Trend, Unit Root and Structural Change Macroeconomic Time Series." In *Co-Integration for the Applied Economist*, ed. Rao B. Bhaskara, 113−146. New York: St. Martin's Press.

Pretorius, Elna. 2002. "Economic Determinants of Emerging Stock Market Interdependence." *Emerging Markets Review,* 3(1): 84-105.

Sheng, Hsiao-Ching, and Anthony H. Tu. 2000. "A Study of Co-integration and Variance Decomposition among National Equity Indices before and during the Period of the Asian Financial Crisis." *Journal of Multinational Financial Management*, 10(3–4): 345−365.

Smimou, Kamal. 2011. "Transition to the Euro and Its Impact on Country Portfolio Diversification." *Research in International Business and Finance*, 25(1): 88-103.

Stulz, Rene M. 1999. "Globalization, Corporate Finance, and the Cost of Capital." *Journal of Applied Corporate Finance,* 12(3): 8-25.

Susmel, Raul, and Robert F. Engle. 1994. "Hourly Volatility Spillovers between International Equity Markets." *Journal of International Money and Finance,* 13(1): 3–25.

Tudor, Cristiana. 2009. "Price Ratios and the Cross-section of Common Stock Returns on Bucharest Stock Exchange: Empirical Evidence." *Romanian Journal for Economic Forecasting*, 10(2): 132-146.

Van Rijckeghem, Caroline, and Beatrice Weder. 2001. "Sources of Contagion: Is It Finance or Trade?" *Journal of International Economics,* 54(2): 293-308.

Yang, Jian, James W. Kolari, and Insik Min. 2003. "Stock Market Integration and Financial Crises: The Case of Asia." *Applied Financial Economics,* 13(7): 477-486.

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