

DYNAMICS OF VOLATILITY SPILLOVER BETWEEN STOCK AND FOREIGN EXCHANGE MARKET: EMPIRICAL EVIDENCE FROM CENTRAL AND EASTERN EUROPEAN COUNTRIES

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KEYWORDS

Volatility spillover, Central and Eastern European Countries, ARCH, GARCH, EGARCH, Exchange rate, Stock market.

ABSTRACT

We use an Exponential Generalised Autoregressive Conditional Heteroskedasticity (EGARCH) model to investigate the asymmetric volatility spillover effects between the stock market and foreign exchange market in Hungary, Poland, the Czech Republic, Romania and Croatia for the pre- and post- financial crisis periods. The whole of the study period covers from 1st April 2000 to 29th September 2017. The results reveal bidirectional volatility spillover between stock and foreign exchange market of Hungary in all periods and Poland in the post-crisis period, unidirectional volatility spillover in Croatia in the pre-crisis period and from the stock market to exchange market in the Czech Republic during two periods. In the post-crisis period, the two financial markets show the non-presence of the volatility spillover between them in Croatia. Furthermore, empirical results from our analysis provide valuable insights to investors, multinational companies and economic policymakers regarding financial decision making.

INTRODUCTION

The interlinkage between the stock and foreign exchange markets has attracted the attention from academic researchers and practitioners alike for a long time and offers meaningful insight into them. It is widely acknowledged that rapid growth in international financial markets has become substantially more integrated in recent years. The drastic increasing trend in financial assets has been followed by increasing in high demand and supply of foreign currencies. The interdependency has been generated by both the high demand of currencies and equity flows, leading to some degree of interdependency in both securities and currencies. According to (Kanas 2000), the huge increases in interdependency has also increased the volatility spillovers between stock and foreign exchange markets, positive and significant spillovers of volatility transmission may increase the nonsystematic residual international portfolio risk faced by global investors, this might reduce the gains from international portfolio

diversification. In reality, volatility analysis helps us to understand the information mechanism in both financial markets including price and volatility spillovers across markets, shock propagation across foreign exchange and stock markets and hedging strategy problems (Chaker Aloui 2007).

In recent finance literature, there is a lot of interest in the financial press on the relationship between returns in the stock and foreign exchange markets because the financial roles of both variables play in prominent portfolio decisions and economic development. Theory suggests two broad channels which link return in stock and exchange markets. The first approach known as the flow-oriented models of exchange rates (Dornbusch and Fischer 1980), this approach posits that there exists a positive linkage between exchange rates and stock prices, and specifically centering on the current account and trade balance. The second approach known as the stock-oriented models of exchange rates (Frankel 1983), these models suggest that the exchange rate is determined by the demand and supply of financial assets such as equities and bonds. More recently, the information of volatility spillovers between the two financial markets has been studied by many researchers for different countries. However, this paper distinguished itself from the previous studies in the following ground. A lot of studies exist in the developed and emerging markets, but for developing markets such as Hungary, Poland, Czech Republic, Romania and Croatia, there are only two investigations of (Lucia Morales 2008) and (Fedorava and Saleem 2010) regarding volatility spillover effect between stock and foreign exchange markets. (Lucia Morales 2008) undertook his study on pre-and post-europe periods in Hungary, Poland, Czech Republic and Slovakia, while (Fedorava and Saleem 2010) focused on the questions of volatility spillover effects of Poland, Hungary, Russia, and the Czech Republic. However, in this research, we studied in the Hungarian, Polish, the Czech Republic, Romanian and Croatian financial markets on subprime financial crisis period, and the methodology adopted is not the same with that of our purposed study.

In this paper, we employ the EGARCH model to address some critical research questions. First, the persistence and asymmetric effects in the conditional volatility of daily returns on stock and exchange indices in Central and Eastern European countries in the pre-and post-crisis periods. Second, whether there is a relationship between the two financial markets or not in these

countries. Besides, making comparisons between different countries and various time periods has been performed.

The organization of the paper is as follow. The next section gives the relevant literature review. Section 3 discusses the EGARCH model. Section 4 presents and discusses the estimation results of EGARCH model. Section 5 summarizes the study and concludes with some implications.

LITERATURE REVIEW

There is a rich empirical literature which exists on the investigation of the volatility transmission mechanism of the dynamic linkage between the exchange rates and the stock market. Many of these studies are based on the Generalized ARCH(GARCH) framework to examine volatility spillovers between two financial markets in different countries. It is clear that in the context of the literature of the volatility spillover can be divided into three key points: first, a bidirectional volatility spillover between two markets; second, an unidirectional flow of volatility from stock market to exchange market and vice versa; third, non-persistence of the volatility spillover between two financial markets.

The first study of analyzing volatility spillovers was conducted by (Kanas 2000), he used daily data for the period from January 1st, 1986 to February 28th, 1998 and investigated six industrialised countries, namely the US, the UK, Japan, Germany, France and Canada by employing the bivariate EGARCH model for conditional variances. He found evidence of spillovers from stock returns to exchange rate returns for all countries except Germany, the non-persistence of spillovers from exchange to the stock market.

Yang and Doong (2004) applied the bivariate EGARCH model on weekly data from May 1st, 1979 to January 1st, 1999 to examine the nature of the mean and volatility spillover between stock and foreign exchange markets for the G-7 countries. Their empirical evidence supports the asymmetric volatility spillover effect from the stock market to the foreign exchange market in France, Italy, Japan and the US.

Chaker Aloui (2007) explored the nature of the mean, volatility and causality transmission mechanism between stock and foreign exchange markets for the US and some major European markets (France, Germany, Belgium, Spain, Italy). The dataset consisted of daily closing exchange rates and stock indexes for these countries. The asymmetric volatility transmission was illustrated by EGARCH model. He found the asymmetric and long-range persistence volatility spillover effect and evidence of causality in mean and variance in the two markets for both pre and post-europe periods. Additionally, the author confirmed that the stock returns had a more significant effect on the foreign exchange rate for the two subsamples.

Volatility spillovers between stock returns and foreign exchange rates in four Central and Eastern European countries (Hungary, Czech Republic, Poland and

Slovakia) was studied by (Lucia Morales 2008). The author applied daily data for the 1999-2006 period that was divided into two sub-periods, pre- Europe and post-Europe. The analyses were carried out on EGARCH model in which apparently confirmed that there was non-existence of significant volatility spillover from stock to foreign exchange markets in these countries. However, the overall results were the lack of significant spillovers from exchange rates to stock returns and volatility in both markets tended to decrease after the countries joined the European Union.

Fedorava and Saleem (2010) investigated the dynamic volatility spillover between stock and currency markets in emerging Central and Eastern European markets of Poland, Hungary, Russia, and the Czech Republic. By estimating a bivariate GARCH-BEKK model using weekly returns. The findings showed strong evidence of direct linkages between the equity markets in term of both returns and volatility and currency markets. The unidirectional volatility spillovers from currency to stock markets had been highlighted for all countries except the Czech Republic in this research.

Natalia and Helena (2014) used a multivariate asymmetric GARCH model to examine volatility spillovers between stock and currency markets in Asian economies, consisted of 2893 observations daily indices, in the period 2003 to 2014. Their results presented evidence of bidirectional volatility spillovers between both markets, independently of the individual country's level of development.

Mozumder et al. (2015) examines the volatility spillover between stock prices and exchange rates in three developed and three emerging countries including Ireland, Netherlands, Spain, Brazil, South Africa and Turkey, across the recent pre-financial-crisis, crisis and post-crisis periods, using weekly data and employing a bivariate EGARCH model. The study concluded that there are the asymmetric volatility spillover effects between both markets in both developed and emerging economies during the financial crisis. Namely, the findings indicated that there is a unidirectional volatility spillover effect running from stock returns to exchange rate returns in developed countries. Volatility spillover direction between the two markets is opposite in the emerging countries, but there is a bidirectional volatility spillover both financial markets in Brazil.

Dynamics of volatility spillover between the stock market and foreign exchange market in Asian countries (China, Hong Kong, India, Japan, Pakistan and Sri Lanka) was empirically investigated by (Jebran and Iqbal 2016) by using EGARCH model. This study considered daily data from January 4th, 1999 to January 1st, 2014. Their research pointed out bidirectional asymmetric volatility spillover between the stock market and foreign exchange market of Pakistan, China, Hong Kong and Sri Lanka. For India, the findings shown unidirectional transmission of volatility from stock to exchange markets. Nevertheless, the analysis also

confirmed no evidence of volatility spillover in both markets in case of Japan.

It is clear from the above review of relevant literature that there are mixed results on volatility spillover effects from various periods as well as different countries. This study aims at contributing to the existing literature by filling the gap of exploring knowledge about the volatility transmission mechanism of the dynamic linkage between the exchange rates and the stock market in the selected countries by adopting an empirical approach based on a multivariate EGARCH model. Also from EGARCH model, examining the relationship between stock and exchange rate movements has been estimated, the questions of the previous researches have centered only on the first moments of the joint stock and exchange rate distributions. Another contribution of our study is considering daily data for the pre-crisis period of 9 years and the post-crisis period of 10 years to research in the long run because daily data capture more information than weekly and monthly data and so as to ascertain the extent to which the recent financial crisis affected the link in question. Furthermore, empirical results from our analysis are of great interest to investors, multinational companies and economic policymakers regarding financial decision making.

METHODOLOGY

Data

The data set consists of daily closing stock and exchange rate prices for five Central and Eastern European countries, we took daily data covering the period from 1st April 2000 to 29th September 2017. The entire investigation period is subdivided into two sub-periods: Pre-crisis period: 1st April 2000 to 29th August 2008. Post-crisis period: 1st September 2008 to 29th September 2017. The whole period in present study divides into pre and post financial crisis period on the basis of certain justifications. The reason for collecting daily data is to capture more the precise information content of changes in stock prices and exchange rates than doing with weekly or monthly data (Jebran and Iqbal 2016), and better able to capture the dynamics between variables (Agrawal et al. 2010). The sample five European countries includes Hungary, Poland, Czech Republic, Romania and Croatia and their stock indexes are: Budapest Stock Exchange BUX, Warsaw Stock Exchange WIG, Prague Stock Exchange PX, Bucharest Stock Exchange BET and Zagreb Stock Exchange respectively. The national currencies of these countries are Hungarian Forint HUF, Polish Zloty PLN, Czech Koruna CZK, Romanian Leu RON and Croatian Kuna HRK respectively. The exchange rate series are from the European countries are stated in US dollars per local currency (note that value of the dollar). Because stock markets operate for five trading days from Monday to Friday and foreign exchange markets operate six trading days (excluding weekends and holidays), this research makes a common data series by adjusting the

dates of both the stock and exchange rate indices. The data for our empirical investigation is obtained from Bloomberg, accounted by the Department of Finance, Corvinus University of Budapest. The daily return data series are calculated as $R_{i,t} = 100 \times \ln(P_{i,t}/P_{i,t-1})$, where $P_{i,t}$ is the price level of market i ($i = 1$ for the stock market and $i = 2$ for the foreign exchange rate) at time t . The plots of stock prices and exchange rate series for five countries in sample illustrate the volatility that occurs in bursts. (not reported to conserve space).

Model Specification

Unit root test

The stationary of the series is considered by commonly checking through Phillips and Perron PP (1988) and Dickey and Fuller ADF (1979) methods to ensure that the results of the analysis are not spurious. These tests have been implemented to confirm that the data were stationary at level.

EGARCH model

The empirical study for examining whether the volatility of stock returns affects and is affected by the volatility of exchange rate returns is aimed to be captured by employing Exponential Generalized Autoregressive Conditional Heteroskedasticity (EGARCH) model developed by (Nelson 1991). The EGARCH specification is applied to test whether the volatility spillover effects are asymmetric. The simple GARCH model enforces a symmetric effect of volatility (positive shocks) and is not able to capture asymmetric shocks (negative shocks) because of the conditional variance being a function of lagged residuals and not their signs. There is no such restriction in EGARCH model on the parameters, the EGARCH model is able to capture both symmetric and asymmetric shocks. Therefore, numerous empirical studies based on the EGARCH framework to specify volatility spillovers between different financial assets in different countries. For instance, except for foregoing mentioned scholars, (Mishra et al. 2007; Choi et al. 2010; Adiasi et al. 2008; Qayyum and Kamal 2006; Okpara and Odionye 2012; Beer and Hebein 2011). In this study, we applied EGARCH(1,1) model to examine the transmission mechanism of volatility separately for each selected country.

EGARCH model for volatility spillover from foreign exchange market to stock market

$$R_t = \alpha_0 + \alpha_1 R_{t-1} + \alpha_2 R_{t-1(ER)} + \varepsilon_t \quad (1)$$

$$h_{t(SP)} = \beta_0 + \beta_1 h_{t-1} + \beta_2 \left| \frac{\varepsilon_t - 1}{\sqrt{h_{t-1}}} \right| + \phi \frac{\varepsilon_t - 1}{\sqrt{h_{t-1}}} + \delta_{(resid(ER))} \quad (2)$$

The equation (1) and (2) represent the EGARCH(1,1), which is applied for examining volatility spillover from foreign exchange market to stock market in each country.

EGARCH model for volatility spillover from stock market to foreign exchange market

$$K_t = a_0 + a_1 K_{t-1} + a_2 K_{t-1(SP)} + \varepsilon_t \quad (3)$$

$$h_{t(ER)} = \gamma_0 + \gamma_1 h_{t-1} + \gamma_2 \left| \frac{\varepsilon_t - 1}{\sqrt{h_{t-1}}} \right| + \phi \frac{\varepsilon_t - 1}{\sqrt{h_{t-1}}} + \Psi_{(resid(SP))} \quad (4)$$

Table 1: Description of Parameters Equations (1)-(4)

Explanation	S	E
The conditional mean equation	(1)	(3)
The conditional variance equation	(2)	(4)
Return	R_t	K_t
Intercept	α_0	a_0
Measuring the effects of previous day's return on today's return	α_1	a_1
Measuring the effects of exchange rates changes on stock returns	α_2	
Measuring the effects of stock returns on exchange rate returns		a_2
Error term	ε_t	ε_t
Log of conditional variance	$h_{t(SP)}$	$h_{t(ER)}$
Volatility constant	β_0	γ_0
Function of volatility (consistency)	β_1	γ_1
Volatility reaction to change in news	β_2	γ_2
Measuring asymmetric effect of volatility	ϕ	ϕ
Volatility spillover	δ	ψ

Note: S is stock return, E is exchange rate return

The procedure for measuring volatility spillover of this study is implemented in the following stages. An initial step we provide descriptive statistics for stock and exchange rate returns to summarize the statistical characteristics of our sample. We then carry out the stationary test including ADF and PP test on each of the concerned variables. Next step, identifying and estimating an autoregressive and moving average (ARMA) model for the mean equation, using the residuals of the mean equation to test for ARCH effect (the significant value of chi-square depicts ARCH effect in the underlying variable). EGARCH model shall be employed on data in which ARCH effect exists. After making sure that there exists ARCH effect, we have specified and estimated the volatility spillover between stock market and foreign exchange rate market. Finally, residual diagnostics have been performed.

RESULTS

Descriptive statistics for stock and foreign exchange returns as well as unit root are reported in Table 2 and Table 3. The analyses reveal that sample means of stock return are positive and significantly different from zero for five countries except for the Czech Republic and Croatia in the post-crisis period. The sample variances range from 0.69% for Croatia to 1.62% for Hungary. Similarly, Hungarian and Polish exchange markets have the highest daily average return over the study period. Skewness and Kurtosis coefficients indicate that return

series are far from the normal distribution, this is formally confirmed by The Jarque-Bera test statistics. Finally, all exchange rate changes and stock returns series are found to be stationary at level (e.i I(0)) at the 1% significance level according to the PP & ADF statistics.

Table 4 represents the results of the purpose of ARCH effect for the underlying variables (stock prices and exchange rate) over the study periods. The ARCH effect illustrates the presence of autocorrelation and heteroskedasticity issues in data. The result shows that there is the strong evidence of the existence of ARCH effect in all concerned series. EGARCH (1,1) can be employed on data having ARCH effect in data.

Examining volatility spillover between stock and exchange market by using EGARCH (1,1) model is the final step. We have studied on each market information spillover separately for each country. First, we have conducted analyses by examining volatility spillover from the foreign exchange market to the stock market, after that we have continued to examine volatility spillover from the stock market to the exchange market. For selecting the appropriate lag length of each model, the basis of Akaike's information criterion has been selected.

Table 5 presents the EGARCH estimations for both the mean and conditional variance equations. The mean equation results show that the changes in the exchange rate have a significant negative impact on stock returns of Hungary, Poland over the study period and the Czech Republic, Romania, Croatia in the post-crisis period, nevertheless, insignificant for the Czech Republic, Romania and Croatia in the pre-crisis period. The significant negative impact of foreign exchange market on stock market reveals that changes in exchange market could reduce stock returns of these countries, this decreases the profitability and stock prices of the firms. The negative effect of exchange market would create fluctuation in trade balance and the competitiveness of the country. As a result, it would decrease real income and economic growth (Jebran and Iqbal 2016). The results of the negative impact of the foreign exchange rate market on the stock return are similar to those of (Aloui 2007; Yang and Doong 2011; Jebran and Iqbal 2016). The findings support the theoretical prediction of stock-oriented models in which reported that there is a negative relationship between foreign exchange rate and stock price. In case of the Czech Republic, Romania and Croatia, there is an insignificant effect of exchange rate on stock returns in the pre-crisis period may postulate the effective hedging strategies against the currency risk in these countries. The results of our empirical analysis indicate that there is also an insignificant linkage between stock market changes and foreign exchange rate dynamics for all countries over study period except Romania in the post-crisis period. The mean equation reveals that stock market fluctuations have a significant negative effect on exchange rate returns in Romania recent years, it supports the theoretical prediction of

portfolio balance model which points that exchange rates respond to the demand for and supply of stock market. Consequently, an increase in domestic stock prices will lead investors to sell foreign assets in the market for the purpose of purchasing domestic assets. This result is in line with a study like (Jebran and Iqbal 2016). Additionally, as regards to other countries, the weak or no impact of stock prices on exchange rate supports the theoretical prediction of monetary approach which presumes that there is no linkage between exchange rate and stock prices. These results are consistent with (Ngo Thai Hung 2017).

Turning to the second moment interdependencies, the variance equation results indicate coefficient δ which measures volatility spillover from exchange market to stock market and indicates whether this spillover is asymmetric, is statistically significant for Hungary, Poland in all the periods, Romania and Croatia in the pre-crisis period. For the pre-crisis period, the coefficient is positive in case of Hungary, Poland and Croatia, while negative in case of Romania. For the post-crisis period, the coefficient is positive for Hungary and Poland, while negative in case of Croatia. The positive coefficient illustrates that foreign exchange market volatility is increasing the volatility of the stock market, on the other hand, negative coefficient shows that foreign exchange market volatility is decreasing the volatility of the stock market. In case of Hungary, Poland and the Czech Republic, the findings are consistent with (Lucia Morales 2008; Chaker Aloui 2007; Natalia and Helena 2014). ψ measures volatility spillover from stock prices to exchange rates. The coefficient is statistically significant for Hungary and the Czech Republic in all periods, however, insignificant in case of Poland and Romania in the pre-crisis period and Croatia in the post-crisis period. The coefficient is negative in all cases. This negative coefficient describes that stock market volatility is decreasing the volatility of foreign exchange market. It is important to note that we find no volatility spillover from exchange market to stock market in case of Czech Republic in both periods and Romania and Croatia in the post-crisis period, and no volatility spillover from the stock market to the exchange market in case of Poland and Romania in the pre-crisis period and Croatia the post-crisis period. These results are in line with (Fedorava and Saleem 2010) and inconsistent with (Lucia Morales 2008).

Briefly, the results are mixed when we compare the volatility spillover with different countries and during two periods because changes in volatility spillover between stock returns and foreign exchange market have changed over time, in particular, have increased in post-crisis period, it is consistent with the notion that financial market integration has increased after crisis period. The results show that there is a bidirectional volatility spillover between stock and foreign exchange market in Hungary in all period and Poland in the post-crisis period that represents the information inefficiency of these stock markets, while unidirectional volatility

spillover in Croatia in pre-crisis period and from the stock market to the exchange market in the Czech Republic during two periods. However, no volatility spillover for Croatia in the post-crisis period, this implies that effective strategies against the stock market and exchange rate fluctuations. The absence of volatility spillover from exchange market to stock market in case of the Czech Republic (two periods), Romania and Croatia (post-crisis period) could indicate the effective hedging strategies against currency risk. Finally, the asymmetric spillovers from stock returns to exchange rates have all the positive signs, they are interpreted as follows: good news has a greater impact on volatility than unexpected bad news. On the other hand, the asymmetric spillovers from exchange rates to stock returns have all the negative signs implies that negative shocks generate more volatility than positive shocks of the same magnitude.

In order to evaluate the robustness of the estimation results, we examined the ARCH effect on the residuals of each model to determine whether the ARCH effect still exists in model. The null hypothesis is that there is ARCH effect. It can be seen in Table 5, the results of ARCH test illustrate that we find strong evidence that there is no ARCH effect for all series considered except only for Romania when we estimate the volatility spillover from the stock market to the foreign exchange market in the pre-crisis period. It is similar to the study of (Melik Kamisly et al. 2015) and also a limitation of this investigation. Hence, modeling the EGARCH model can successfully capture the price volatility interaction between stock and exchange markets.

CONCLUSION

In this study, we have investigated the empirical dynamics of volatility spillover effects between the stock market and foreign exchange market in Central and Eastern European countries i.e... Hungary, Poland, the Czech Republic, Romania and Croatia across the pre-crisis and post-crisis periods using EGARCH model. Our empirical evidence shows that there is a bidirectional volatility spillover between stock and foreign exchange markets in Hungary in all periods and Poland in the post-crisis period. The results also reveal unidirectional volatility spillover in Croatia in the pre-crisis period and from the stock market to the exchange market in the Czech Republic during two periods. In the post-crisis period, the two financial markets show the non-presence of the volatility spillover between them in Croatia. The spillovers are asymmetric in nature in all financial markets. Volatility spillover from stock returns to exchange rates have decreased after the crisis period. The volatility persistence indicates that there was volatility persistence in all series in all periods, in general, the persistence of exchange market volatility was found greater than stock market volatility.

Our findings have several important economic and finance implications for economic policymakers and investors. First, international portfolio managers and

hedgers may be better able to understand how the two financial markets interrelated overtime, they might provide them benefit in forecasting the behavior of one market by capturing the other market information. Second, the information concerning the nature of volatility transmission across stock and exchange markets in the country would be important for policymakers and decision makers from an economic stability perspective as financial markets integration through exchange rates imply financial sector integration. Third, for investors, this should be particularly important when they want to make an efficient portfolio, can apply these results in reducing their risk, increase their returns and make decisions in the selected markets.

REFERENCES

- Agrawal G., Srivastav A.K. and Srivastava A. 2010. "A Study of Exchange Rates Movement and Stock Market Volatility". *International Journal of Business and Management* 5, No. 12 (Dec), 62-73.
- Beer. F and Hebein. F. 2011. "An Assessment of The Stock Market and Exchange Rate Dynamics in Industrialized and Emerging Markets". *International Business Economic Research Journal* 7, No.8, 59–70.
- Chaker Aloui. 2007. "Price and Volatility Spillovers Between Exchange Rates and Stock indexes for the pre-and post-Euro period". *Quantitative Finance* 7, No. 6(Dec), 669-685.
- Choi DF, Fang V, Fu TY. 2010. "Volatility Spillovers Between New Zealand Stock Market Returns and Exchange Rate Changes Before and After the 1997 Asian Financial Crisis". *Asian Journal of Finance & Accounting* 1, No. 2, 106–117.
- Dornbusch. R and Fischer S.1980. "Exchange Rates and The Current Account". *American Economic Review* 70, No. 5, 960-971.
- Dickey, David A., and Wayne A. Fuller. 1979. "Distribution of the estimators for autoregressive time series with a unit root." *Journal of the American statistical association* 74 No. 366a , 427-431.
- Frankel J. A. 1983. "Monetary and Portfolio-Balance Models of Exchange Rate Determination' in Bhandari J S and Putnam B H (eds) *Economic Interdependence and Flexible Exchange Rates*", Cambridge: MIT Press.
- Fedorova E. and Saleem K. 2009. "Volatility Spillovers Between Stock and Currency Markets: Evidence from Emerging Eastern Europe". *Czech Journal of Economics and Finance* 60, No. 6, 519-533.
- Jerban K. and Iqbal A. 2016. "Dynamics of Volatility Spillover Between Stock Market and Exchange Market: Evidence from Asian Countries". *Financial Innovation* 2, No. 3, 1-20.
- Kanas A. 2000. "Volatility Spillovers Between Stock Return and Exchange Rate Changes: International Evidence". *Journal of Business Finance and Accounting* 27, No. 3, 447-467.
- Lucia Morales. 2008. "Volatility Spillovers Between Stock Returns and Foreign Exchange Rates: Evidence from Four Eastern European Countries". *In the conference proceedings of the Financial management Association (FMA) European Conference*, 4-6 June 2008, Prague, the Czech Republic.
- Mishra A. K, Swain N. and Malhotra D. K. 2007. "Volatility Spillover Between Stock and Foreign Exchange Markets: Indian Evidence". *International Journal of Business* 12, No. 3, 343-359.
- Mozumder N., Vita G., Kyaw K. S. and Larkin C. 2015. "Volatility Spillover Between Stock Prices and Exchange Rates: New Evidence Across the Recent Financial Crisis Period". *Economic Issues* 20, No. 1, 43-64.
- Melik Kamisli, Serap Kamisli and Mustafa Ozer. 2015. "Are Volatility Transmissions Between Stock Market Returns of Central and Eastern European Countries constant or dynamic? Evidence from MGARCH Models". *In the conference proceedings of 10th MIBES Conference*, 15-17 October 2015, Larisa, Greece, 190-203.
- Natalia V. and Helena C. 2014. "Volatility Transmission Between the Stock and Currency Markets in Emerging Asia: the Impact of the Global Financial Crisis". *Research Institute of Applied Economics* 31, 1-26.
- Nelson D. B. 1991. "Conditional Heteroskedasticity in Asset Returns: A New Approach". *Econometrica* 59, No. 2, 347-370.
- Ngo Thai Hung. 2017. "An Empirical Test on Linkage between Foreign Exchange Market And Stock Market: Evidence From Hungary, Czech Republic, Poland And Romania". *European Scientific Journal* 13, No. 31, 25-38.
- Okpara G.C. and Odionye J.C. 2012. "The Direction of Volatility Spillover between Stock Prices and Exchange Rate: Evidence From Nigeria. *Elixir Finance* 42, 6410–6414.
- Qayyum A. and Kamal A. 2006. "Volatility Spillover Between the Stock Market and the Foreign Market in Pakistan". *Pakistan Institute of Development Economics Working Papers* 7.
- Phillips, Peter CB, and Pierre Perron. 1988. "Testing for a unit root in time series regression." *Biometrika* 75, No. 2 , 335-346.
- Yang S. and Doong S. 2004. "Price and Volatility Spillovers Between Stock Prices and Exchange Rates: Empirical Evidence from The G-7 Countries". *International Journal of Business and Economics*, 3 No. 2, 139-153.

Table 2: Descriptive statistics of daily return of stock indices

Countries	Hungary	Poland	Czech	Romania	Croatia
Panel A. Pre- crisis period					
Mean (%)	0.04	0.03	0.05	0.11	0.07
SD (%)	1.39	1.30	1.26	1.78	1.39
Skewness	-0.0883	-0.2559	-0.1862	-0.1390	0.5367
Kurtosis	4.3107	5.1726	5.4575	21.9218	16.726
Jarque-Bera	157.88**	449.76**	559.39**	313320**	16342.68**
PP test	-44.47*	-44.92*	-44.96*	-43.33*	-44.93*
ADF test	-44.49*	-44.79*	-44.96*	-43.36*	-44.92*
N	2166	2166	2173	2099	2069
Panel B. Post- crisis period					
Mean (%)	0.02	0.02	-0.01	0.01	-0.02
SD (%)	1.62	1.22	1.4927	1.52	1.18
Skewness	-0.1033	-0.5254	-0.6210	-0.7250	0.0734
Kurtosis	11.4429	7.9297	20.3306	15.5740	27.2175
Jarque-Bera	6746.18**	2407.276	28642.34**	15240**	55425.20
PP test	-45.07*	-34.53*	-39.97*	-44.89*	-44.53*
ADF test	-35.42*	-42.73*	-44.53*	-44.93*	-25.32*
N	2270	2274	2277	2283	2268

Table 3: Descriptive statistics of daily changes in exchange rate return

Countries	Hungary	Poland	Czech	Romania	Croatia
Panel A. Pre- crisis period					
Mean (%)	-0.0196	-0.026	-0.033	0.0129	-0.02
SD (%)	0.78	0.6937	0.7049	0.6516	0.69
Skewness	0.4141	0.2921	0.0008	0.9338	-0.0863
Kurtosis	6.1554	5.3131	4.2452	20.066	5.0085
Jarque-Bera	960.48**	513.65**	140.39**	25778.4**	350.36*
PP test	-46.89*	-43.80*	-47.20*	-48.94*	-50.02*
ADF test	-46.89*	-43.80*	-47.19*	-48.80*	-49.99*
N	2166	2166	2173	2099	2069
Panel B. Post- crisis period					
Mean (%)	0.02	0.02	0.01	0.02	0.01
SD (%)	1.0559	1.04	0.85	0.77	0.69
Skewness	0.1971	0.2039	-0.1349	0.2228	-0.0347
Kurtosis	6.0054	6.6307	8.3099	6.6083	5.6903
Jarque-Bera	869.04**	1264.76**	2681.99**	1257.42**	684.43**
PP test	-47.65*	-47.85*	-48.39*	-45.12*	-47.68*
ADF test	-47.61*	-47.71*	-48.38*	-34.59*	-47.68*
N	2270	2274	2277	2283	2268

Note (Table 2&3): SD represents standard deviation. N: Observations. ** denotes the level of significance at 5%, * indicates $p < 1\%$. Critical value at 1%, 5% and 10% are -3.43, -2.86 and -2.56 respectively.

Table 4. ARCH test

Countries	Hungary	Poland	Czech	Romania	Croatia
Panel A: Pre-crisis period (Stock indices)					
Constant	1.254*	1.021*	0.892*	1.525*	1.137*
AR(1)	0.061*	0.042**	0.071*	0.390*	0.271*
ARCH test	80.09*	110.57*	141.74*	362.65*	240.30*
Panel B: Post-crisis period (Stock indices)					
Constant	1.137*	0.579*	0.659*	0.942*	0.544*
AR(1)	0.290*	0.020	0.228*	0.306*	0.297*
ARCH test	363.55*	309.09*	559.10*	411.67*	550.14*
Panel A: Pre-crisis period (Exchange rates)					
Constant	0.515*	0.331*	0.402*	0.2085*	0.335*
AR(1)	0.097*	0.137*	0.012	0.567*	0.108*
ARCH test	25.01*	72.17*	21.37*	576.77*	59.96*
Panel B: Post-crisis period (Exchange rates)					
Constant	0.498*	0.408*	0.291*	0.256*	0.276*
AR(1)	0.042**	0.158*	0.084*	0.038	0.173*
ARCH test	251.82*	403.89*	325.83*	291.60*	151.88*

Note: ARCH test is the arch effect test

Table 5: Volatility spillover between stock and foreign exchange market

Countries	Hungary	Poland	Czech	Romania	Croatia
Volatility spillover from foreign exchange market to stock market					
Panel A: Pre-crisis period					
α_0	0.041	0.053**	0.074*	0.075*	0.099*
α_1	0.033	0.061*	0.049**	0.143*	0.037
α_2	-0.083**	-0.116*	-0.022	0.021	-0.014
β_0	-0.082*	-0.080*	-0.133*	-0.221*	-0.167*
β_1	0.943*	0.979*	0.939*	0.916*	0.924*
β_2	0.147*	0.112*	0.192*	0.406*	0.285*
ϕ	-0.052*	-0.028*	-0.095*	-0.033*	-0.008
δ	0.055*	0.014*	-0.0006	0.134*	-0.092*
ARCH LM(1)	0.019(0.89)	3.21(0.07)	4.48(0.03)	0.39(0.53)	2.14(0.14)
Panel B: Post-crisis period					
α_0	0.031	0.033	0.005	0.027	0.015
α_1	-0.016	0.052**	0.024	0.067*	0.055*
α_2	-0.11*	-0.102*	-0.111*	-0.049**	-0.066*
β_0	-0.110*	-0.094*	-0.159*	-0.285*	-0.156*
β_1	0.986*	0.986*	0.980*	0.957*	0.987*
β_2	0.152*	0.123*	0.209*	0.393*	0.200*
ϕ	-0.063*	-0.045*	-0.067*	-0.062*	-0.036*
δ	0.016**	0.027*	0.004	0.011	-0.001
ARCH LM(1)	0.63(0.42)	0.76(0.37)	0.61(0.43)	2.38(0.12)	0.06(0.79)
Volatility spillover from the stock market to foreign exchange market					
Panel A: Pre-crisis period					
a_0	-0.017	-0.033**	-0.031**	0.078*	-0.036*
a_1	0.010	0.072*	-0.013	0.0004	-0.072*
a_2	-0.018	-0.004	-0.016	-0.002	0.0002
γ_0	-0.130*	-0.216*	-1.025**	-0.100*	-0.057*
γ_1	0.864*	0.901*	-0.367**	0.993*	0.995*
γ_2	0.080*	0.181*	0.073**	0.123*	0.069*
φ	0.078*	0.074*	0.073*	-0.038*	-0.001
ψ	-0.046*	-0.010	-0.051**	-0.004	-0.015*
ARCH LM(1)	0.48(0.48)	0.60(0.43)	0.01(0.90)	80.7(0.00)	0.02(0.86)
Panel B: Post-crisis period					
a_0	0.011	0.016	0.017	0.011	0.014
a_1	-0.026	-0.04**	-0.005	-0.008	-0.032
a_2	-0.001	-0.025	0.015	-0.023**	-0.018
γ_0	-0.046*	-0.062	-0.077*	-0.050*	-0.047
γ_1	0.996*	0.994*	0.992*	0.993*	0.996*
γ_2	0.058*	0.078*	0.091*	0.057*	0.047*
φ	0.025*	0.028*	0.019*	0.0211*	0.029*
ψ	-0.016*	-0.022*	-0.021*	-0.012*	-0.007
ARCH LM(1)	0.08(0.76)	1.25(0.26)	0.34(0.55)	0.14(0.70)	4.49(0.03)

Note: ** denotes the level of significance at 5%, * indicates $p < 1\%$. Numbers in parentheses are probability.