Asaturov K., Teplova T., Sukhorukova K.

Higher School of Economics, Russia, Moscow

Volatility spillover effects on different equity markets

The aim of this work is to define links among international equity markets and local regions (Europe, Asia, America). In this study bivariate DCC-GARCH model (Dynamic Conditional Correlation – Generalized Autoregressive Conditional Heteroskedasticity) is used to estimate volatility spillover effects, cross volatility shocks and dynamic conditional correlation. Volatility interrelationships among the South and North America (the USA, Brazil), European markets (the UK, Germany, France, Poland, Slovakia, Russia, Netherlands, Austria, Sweden, the Czech Republic, Greece, Switzerland, Ukraine, Romania, Hungary, Bulgaria, Lithuania, Latvia, Estonia) and Asian markets (Japan, Hong-Kong, South Korea, the Republic of India and Taiwan) are tested by analyzing closing prices of representative market indices during the period from 1995 to 2012.

Keywords: *volatility spillover effects; time-varying correlation; international equity markets*; *DCC-GARCH*

The interaction between financial markets has increased with the integration of national economies through international trade and finance. The process of integration has involved both emerging and developed capital markets, which has formed strong connections in global economy. The Financial Crisis of 2007 – 2008 proved the existence of markets interrelationships, which makes the researchers in this field draw meticulous attention to this problem. The object of our study is markets interdependencies. A good understanding of the origins and drivers of markets interaction help investors, consumers and regulators, it contributes to securities pricing, portfolio optimization, developing hedging and regulatory strategies, etc. In many studies the degree of market integration plays a crucial role.

In order to estimate the degree of integration between international markets a number of measures has been introduced: cross-correlations analysis[1], cointegration analysis[2] and other econometric methods. Most researchers in this area examined the influence of some financial indicators on one another and estimated the degree of these impacts. However, few studies have been devoted to

[1] Longin, F. and B. Solnik, "Is the Correlation in International Equity Returns Constant: 1960 -1990?" Journal of International Money and Finance 14 (1995): 3-26.
[2] Richards, A., "Comovement in National Stock Market Returns: Evidence of Predicability, Not Cointegration," Journal of Monetary Economics 36 (1995): 455-79.

volatility spillovers and time-varying correlation analysis of international markets. Yet, studying volatility interrelationships it is possible to define how fluctuations of one market influence other markets, whereas dynamic correlation analysis contributes to better understanding of time-varying links in global economy.

The data include daily closing prices of representative indices of the USA (S&P500), Russia (RTSI), the UK (FTSE100), Japan (Nikkei225 and Topix), Germany (DAX), Hong-Kong (Hang Seng), Poland (WIG), France (CAC40), Brasil (Bovespa), Netherlands (AEX), Austria (ATX), the Czech Republic (PX Index), Slovakia (Slovak Share Index), Switzerland (Swiss Market Index), Sweden (OMX), South Korea (KOSPI), the Republic of India (BSE100), Greece (Athens Stock Exchange General Index), Taiwan (Taiwan Stock Exchange Weighted Index), Ukraine (PFTS), Romania (BET), Bulgaria (SOFIX), Estonia (TALSE), Poland (WIG), Hungary (BUX), Lithuania (VILSE), Latvia (RIGSE) and index of emerging markets (MSCI emerging markets), which is estimated by Morgan Stanley. The time period is from January 1995 to December 2012.

The methodology used in this study is based on the DCC-GARCH model (Dynamic Conditional Correlation – Generalized Autoregressive Conditional Heteroskedasticity), which was introduced by Engle n 2002[3]. The DCC-GARCH model implies that the correlation is varying during the time, which makes this model very tractable in assessing volatility interrelationships between markets, links of which are very changeable (Kang et al. (2009)[4], Agnolucci (2009)[5]). The equation of returns is defined by ARMA (p,q) (the order of *p* and *q* was defined by Box-Jenkins methodology[6]) :

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

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

$$H_t = D_t R_t D_t$$

[3] Engle, R., (2002) “Dynamic Conditional Correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models,” Journal of Business and Economic Statistics, 20, 339 – 350.

[4] Kang, S.H., S.M. Kang, S.M. Yoon, (2009) “Forecasting volatility of crude oil markets,” Energy Economics 31, 119-125.

[5] Agnolucci, P., (2009) “Volatility in crude oil futures: a comparison of the predictive ability of GARCH and implied volatility models,” Energy conimics 31, 316-321.

[6] Mills, T., (1999) “The econometric modeling of financial time series (2nd edition),” Cambridge, UK: Cambridge University Press.

Where r_{it} is returns of asset i at time t; ε_{it} is the innovation term in equation of returns at time t; R_t is the time-varying correlation matrix; H_t is the variance-covariance matrix; Ω_{t-1} is the matrix of conditional previous information set; D_t is the diagonal matrix of conditional variances.

The elements of D_t are computed as:

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

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

Thus, the diagonal elements a_{11} and a_{22} capture the own volatility shocks, which reflect the impacts of the past squared innovations on the current volatility, while non-diagonal elements a_{12} and a_{21} represent the cross-volatility shocks, which determine the effect of the lagged innovations of index 2 on the current volatility of index 1 and vice versa. Similarly, the diagonal elements g_{11} and g_{22} define the own volatility spillover, which can be considered as the influence of the past volatilities on the current volatility. Finally, the non-diagonal elements g_{12} and g_{21} measure the cross-volatility spillovers, which reflect impacts of the past volatility of index 2 on the current volatility of index 1 and vice versa. Thus, volatility influence will be acknowledged only in case of statistical significance of the parameter, which reflects corresponding volatility spillover effect.

Several hypotheses are put forward for testing in this paper:

1) Interdependence between the US and the international equity markets:

- The US stock market is a source of volatility for international and local capital markets.
- Only developed markets demonstrate an impact on the American market.
- Developed capital markets are less susceptible to the volatility of the US economy, rather than emerging.

Table 1. Volatility spillover effects (interdependence between the US and the international equity markets).

The estimators with one asterisk are significant at 1% significance level, with two asterisks – at 5% significance level, with 3 asterisks - at 10% significance level.

Spillover direction	Volatility spillover	P-value	Spillover direction	Volatility spillover	P-value
S&P500 → WIG	55,51%*	0,0000	**WIG → S&P500**	21,55%	0,4605

S&P500 → MSCI emerging markets	50,2%*	0,0000	**MSCI emerging markets → S&P500**	2,36%	0,9090
S&P500 → Bovespa	46,02%*	0,0000	**Bovespa → S&P500**	6,97%	0,9684
S&P500 → Slovak Share Index	45,93%*	0,0000	**Slovak Share Index → S&P500**	0,68%	0,9583
S&P500 → RTSI	44,05%*	0,0000	**RTSI → S&P500**	6,86%	0,9061
S&P500 → KOSPI	43,55%*	0,0000	**KOSPI → S&P500**	25,37%	0,5525
S&P500 → BSE100	42,85%*	0,0000	**BSE100 → S&P500**	20,29%	0,7531
S&P500 → Taiwan Stock Exhange Weighted Index	41,75%*	0,0000	**Taiwan Stock Exhange Weighted Index → S&P500**	10,39%	0,4548
S&P500 → ATX	40,6%*	0,0000	**ATX → S&P500**	3,98%	0,8715
S&P500 → AEX	38,61%*	0,0000	**AEX → S&P500**	5,24%	0,6417
S&P500 → Hang Seng	37,92%*	0,0000	**Hang Seng → S&P500**	15,02%	0,7444
S&P500 → OMX	36,75%*	0,0000	**OMX → S&P500**	39,54%	0,1921
S&P500 → PX index	33,6%*	0,0000	**PX index → S&P500**	16,63%	0,5666
S&P500 → Athens Stock Exchange General Index	30,72%*	0,0000	**Athens Stock Exchange General Index → S&P500**	0,02%	0,9992
S&P500 → Swiss Market Index	27,53%*	0,0000	**Swiss Market Index → S&P500**	4,83%	0,8056
S&P500 → TOPIX	26,7%*	0,0000	**TOPIX → S&P500**	12,42%	0,1143
S&P500 → FTSE100	25,78%*	0,0000	**FTSE100 → S&P500**	21,23%**	0,0384
S&P500 → Nikkei225	23,98%*	0,0000	**Nikkei225 → S&P500**	24,72%**	0,0296
S&P500 → CAC40	22,3%*	0,0000	**CAC40 → S&P500**	12,23%***	0,0548
S&P500 → DAX	18,4%*	0,0000	**DAX → S&P500**	7,02%	0,8516

The first two hypotheses were fully confirmed; the last one was partially confimed. The greatest volatility spillover effect from the US market is on Poland (55,51%), and the lowest - on Germany (18,4%). Among European countries, Russia is demonstrating one of the largest dependence on the US equity market in the region (44,05%), second only to Poland (55,51%) and Slovakia (45.93%). In the Asian region the Korean KOSPI is the most vulnerable to the volatility of S&P500 (43,55%). The opposite volatility spillovers to the USA are revealed only from the UK, Japanese and French stock markets. Among developed markets, the most dependent on the S&P500 index is the Korean KOSPI, and the least - the German DAX. Regarding the emerging markets the Czech PX index should be indicated as the least dependent on S&P500, while the Polish WIG, the Brazilian Bovespa index and the MSCI emerging markets, on the contrary, as the most susceptible to the volatility of the US index.

2) Interdependence between the German and the other European equity markets:

- All the European markets are exposed to the German DAX volatility.
- The volatility spillovers from Germany to the Eastern Europe markets are greater than to the other European markets.
- There are two-sided volatility spillovers effects between the German and the developed European capital markets.

Table 2. Volatility spillover effects (interdependence between the German and the other European equity markets).

The estimators with one asterisk are significant at 1% significance level, with two asterisks – at 5% significance level, with 3 asterisks - at 10% significance level.

Spillover direction	Volatility spillover	P-value	Spillover direction	Volatility spillover	P-value
DAX →Slovak Share Index	34,76%*	0,0000	**Slovak Share Index→ DAX**	1,08%	0,9593
DAX → RTSI	33,43%*	0,0000	**RTSI→ DAX**	0,78%	0,9201
DAX → OMX	30,25%*	0,0000	**OMX → DAX**	6,24%	0,3055
DAX → Athens Stock Exchange General Index	30%*	0,0000	**Athens Stock Exchange General Index→ DAX**	8,29%	0,4739
DAX → AEX	22,77%*	0,0000	**AEX→ DAX**	9,79%	0,4610
DAX → WIG	22,35%*	0,0000	**WIG→ DAX**	0,20%	0,9734

DAX → PX Index	21,22%*	0,0000	**PX Index → DAX**	2,59%	0,7932
DAX → ATX	19,14%*	0,0000	**ATX → DAX**	4,81%	0,3298
DAX → Swiss Market Index	16,89%*	0,0000	**Swiss Market Index → DAX**	11,77%**	0,0423
DAX → CAC40	15,77%*	0,0000	**CAC40 → DAX**	15,55%*	0,0007
DAX → FTSE100	14,09%*	0,0000	**FTSE100→ DAX**	20,58%**	0,0206

The first hypothesis was fully confirmed; the last two were partially confirmed. The least volatility spillover effect from the German market is on the UK (14,09%) and the greatest – on Slovakia (34,76%). The Russian as well as the Slovakian stock market is strongly influenced by the German DAX (33,43%), but Poland, another country of Eastern Europe, demonstrates approximately the same dependence on the German market as the countries of Central Europe (22,35%). In its turn the German stock market is exposed to the volatility of the UK, Swiss and French equity markets.

3) Influence of Russia and Poland on the Eastern and Northern European equity markets:

- There are statistically significant volatility spillovers from Russia and Poland to the equity markets of Eastern and Northern Europe.
- The Russian influence on the Eastern and Northern European countries is stronger than the Polish.

Table 3. Volatility spillover effects (Influence of Russia and Poland on the Eastern and Northern European equity markets). The estimators with one asterisk are significant at 1% significance level, with two asterisks – at 5% significance level, with 3 asterisks - at 10% significance level.

Spillover direction	Volatility spillover	P-value	Spillover direction	Volatility spillover	P-value
RTSI → PFTS	20,45%*	0,0021	**PFTS → RTSI**	1,77%	0,8760
RTSI → PX Index	17,94%*	0,0050	**PX Index → RTSI**	13,13%**	0,0172
RTSI → BET	14,87%**	0,0294	**BET → RTSI**	13,22%	0,3024
RTSI → SOFIX	13,91%**	0,0171	**SOFIX→ RTSI**	6,68%	0,9118
RTSI → TALSE	13,51%*	0,0004	**TALSE → RTSI**	6,83%	0,5427
RTSI → WIG	13,44%*	0,0000	**WIG → RTSI**	6,09%	0,2011
RTSI → BUX	12,47%*	0,0000	**BUX → RTSI**	6,05%	0,6023
RTSI → VILSE	12,4%**	0,0406	**VILSE → RTSI**	0,90%	0,8739

RTSI → Slovak Share Index	11,61%*	0,0056	**Slovak Share Index→ RTSI**	0,07%	0,9973
RTSI → RIGSE	9,22%**	0,0132	**RIGSE→ RTSI**	0,07%	0,9940
WIG → PFTS	17,14%**	0,0452	**PFTS → WIG**	3,97%	0,8794
WIG → BET	13,97%*	0,0046	**BET → WIG**	5,89%	0,7104
WIG → BUX	10,13%*	0,0000	**BUX → WIG**	4,04%	0,7005
WIG → TALSE	10,03%	0,1403	**TALSE → WIG**	3,42%	0,5715
WIG → SOFIX	9,94%	0,3212	**SOFIX → WIG**	2,56%	0,9240
WIG → Slovak Share Index	9,1%*	0,0055	**Slovak Share Index → WIG**	2,11%	0,9692
WIG → PX Index	8,42%**	0,0106	**PX Index → WIG**	2,62%	0,7450
WIG → RIGSE	8,41%**	0,0189	**RIGSE → WIG**	4,48%	0,9369
WIG → VILSE	7,83%	0,2830	**VILSE → WIG**	4,85%	0,8758
WIG → RTSI	6,09%	0,2011	**RTSI → WIG**	13,44%*	0,0000

The first hypothesis was partially confirmed; the last one was fully confirmed. According to the results, the most significant influence Russian RTSI has on the Ukrainian stock market (20,45%), and the least – on the Latvian (9,22%). The Czech market is the only one, which affects the Russian market (13,33%). The least volatility spillover effect from Poland is on the Latvian market (8,41%) and the greatest – on the Ukrainian (17,14%). Poland has no influence on Hungary, Estonia, Bulgaria, Slovakia, Lithuania and Russia, whereas the Polish stock market is exposed to the volatility of the Russian RTSI (13,44%). Volatility spillovers from the Russian equity market exceed the ones from the Polish in all the analyzed directions.