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CONTAGION IN INTERNATIONAL STOCK MARKETS DURING THE EUROZONE CRISIS: ANALYSIS WITH THE USE OF GRANGER CAUSALITY TEST

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Abstract: *The aim of the paper is the analysis of contagion effect in international stock markets during the period of Eurozone crisis. Research was performed with the use of logarithmic rates of return for stock indexes of 26 countries. Analysis concerns the second phase of Eurozone crisis, when stock market quotations became highly turbulent due to increasing uncertainty connected with endless debt problems of some European entities. Many German banks faced intense difficulties due to Greek debt crisis. Apart from that, on the 5th of August, 2011 Standard and Poor's decreased U.S. credit rating from the level AAA to AA+. It was the first time in the history the U.S. credit rating was downgraded. As a result on the next working day (August 8, 2011), described as Black Monday 2011, many international stock markets crashed. This paper tries to assess the shock transmission in the second phase of Eurozone crisis (before and after August 2011 stock markets fall) stemming from U.S. and German stock market indexes (S&P500 and DAX). In order to examine the contagion effect in international stock markets Granger causality test and variance decomposition was utilized. Results confirmed contagion effect during the Eurozone crisis between the U.S. stock market and developed as well as emerging markets considered in the analysis. It was also noted that the influence of DAX index on another national stock market indexes increased considerably in the turmoil period.*

Key words: *stock market, contagion effect, financial crisis, shock transmission*

JEL codes: *C10, F30, G10, G15*

1. Introduction

Globalization and increased integration of national economies cause, that modern financial markets are characterized by rapid transfer of information. A crash on a given market influences the course of events on markets not only in neighbouring countries but also affects market situation in countries thousand kilometers away from the distressed market. As a result financial market connections constitute significant channel of shock transmission and spread of crises between countries.

This paper analyses particular case of shock transmission in financial markets defined as contagion effect. Research on contagion effect was performed with use of Granger causality test and variance decomposition. The aim of the research is the analysis of contagion effect in international stock markets during the period of Eurozone crisis.

In the analysis daily logarithmic rates of return for stock indexes from the period 01.07.2010 to 28.09.2012 from 26 countries were considered. During this turbulent period situation on financial markets was influenced not only by debt problems of some European countries and financial institutions but also dependent on U.S. credit rating downgrade on the 5th August 2011. Due to multifaceted origin of stock indexes volatility in this period it was assumed in the research, that the U.S. as well as German stock market indexes (as Germany was the most involved country in financial rescue packages for Greece, what caused intense difficulties faced by many German banks) can constitute the source of contagion in international stock markets and the influence of the above mentioned stock markets on another stock markets considered in the analysis was examined independently. According to the results during the period of Eurozone crisis contagion effect stemming from U.S. stock market was observed for developed and emerging markets (the null hypothesis of no causality of

S&P500 index was rejected for 16 markets before and for 22 markets after August 2011 stock market fall, whereas the hypothesis for reverse no causality was rejected for 6 markets before and for 4 markets after the begin of stock market turmoil). In case of shock transmission stemming from German stock market, the influence of DAX index quotations on another stock market indexes considered in the analysis increased considerably after the August 2011 stock market fall but according to Granger causality test was still weaker than the influence of S&P500 on international stock market indexes (the null hypothesis of no causality of DAX index was rejected for 9 markets before and for 19 markets after August 2011 stock market fall, whereas the hypothesis for reverse no causality was rejected for 2 markets before and for 9 markets after the begin of stock market turmoil).

2. Review of selected methods applied to analysis of contagion effect in financial markets

Contagion effect constitutes topic, which is widely discussed within research on financial markets. According to the very restrictive definition of World Bank (www1) contagion effect in financial markets occurs, if the correlation between assets quoted in different countries is considerably stronger in the crisis period than in the tranquil period.

Analysis of contagion in financial markets according to the above mentioned definition was performed by many researchers. Forbes and Rigobon (2002) analyzed the impact of the October 1997 Hong Kong stock market crisis on international equity markets. Forbes and Rigobon (2002) emphasized, that the increase in correlation coefficient between assets in different financial markets in turmoil periods often is not connected with contagion effect, but may arise due to higher degree of interdependence between markets. Pearson's correlation coefficient is increasing function of volatility and may lead to overestimation of connection's strength between rates of return from analyzed assets in the crisis period. In order to solve the problem of correct identification of contagion effect Forbes and Rigobon proposed application of adjusted correlation coefficient, which was cleansed of variance heteroskedasticity in the market, which initiates the crisis.

Forbes and Rigobon (2002) define contagion as a significant increase in linkages between markets as a result of shock – such effect occurs, if the adjusted correlation coefficient from the crisis period is significantly higher than the unadjusted correlation coefficient from the tranquil period. According to the results based on methodology developed by Forbes and Rigobon during the 1997 Hong Kong stock market crisis there was no contagion, but only strong interdependence in international equity markets.

Alternative approach to the problem of contagion in financial markets was presented by Corsetti et al. (2005). They define contagion as a structural break in the transmission mechanism of financial shocks. In other words contagion takes place, if the pattern of comovements in asset prices after a shock occurrence is to strong compared with the transmission mechanism observed before the period of turbulence.

Corsetti et al. (2005) pointed out that Forbes and Rigobon made in their methodology regarding contagion analysis some unrealistic assumption that the variance of stock returns in the country initiating international crisis constitutes a proxy for the volatility of the common factor affecting all markets. Corsetti et al. (2005) suggest that the contagion test introduced by Forbes and Rigobon (2002) does not distinguish between common and country-specific components of market returns and therefore is biased toward accepting the null hypothesis of no contagion. Being aware of this misspecification, Corsetti et al. (2005) proposed an improved model describing transmission of financial shocks from market initiating contagion to another markets, taking into consideration the influence of global factor on asset return on a specified market. Focusing on 1997 Hong Kong crisis Corsetti et al. (2005) found evidence of contagion effect for 8 of 17 analyzed countries, whereas Forbes and Rigobon (2002) detected such effect for only 1 of 27 countries for the same crisis period.

Besides the approach based on correlation coefficient, alternative techniques are also utilized to study contagion effect in international stock markets. Correlation approach allows assessment of the strength of comovement between stock markets, but does not give the information about the causal links between particular markets. Sander and Kleimer (2003) extended the conventional measurement of contagion based on increase of cross-market correlation and identified contagion by an increasing number of cointegrating relationships between the tranquil and crisis period. They also examined causal relationships between financial markets using the Granger causality test. Sander and Kleimer (2003) analyzed financial market connections during the Asian crisis in 1997 and Russian ruble crisis in 1998 and found evidence of new and changed causality patterns during these crisis periods. According to the authors, amplified causality between financial markets following a shock points to global financial contagion. Boubaker et al. (2016) analyzed contagion between the U.S. equity market and selected developed and emerging market during the subprime crisis of September 2008. They found evidence regarding contagion effect between the U.S. stock market and the considered equity markets. Boubaker et al. (2016) pointed out that contagion effect in financial markets occurs if the impulse response function changes abruptly in the crisis period compared to tranquil period or when the contribution of own innovations in the forecast error variance decomposition decreases while contribution of innovations from the market initiating crisis increases. Gómez-Puig and Sosvilla-Rivero (2016) analyzed contagion effect in European Monetary Union during the euro debt crisis using 10-year bond yields. Gomez-Puig and Sosvilla-Rivero (2016) define contagion as an abnormal increase in the number or in the intensity of causal relationships in the crisis period compared with that of tranquil period, triggered by an endogenously detected shock. They found many new causality patterns as well as intensification of causality during the crisis period, which provide evidence of contagion in the aftermath of Eurozone debt crisis.

Granger (1969) causality test is a widely used method to test the connection between two variables. A variable *Y* is said to Granger-cause another variable *X* if past values of *Y* help predict the current level of *X* better than past values of *X* alone, indicating that past values of *Y* have some informational content that is not present in past values of *X*. It can be said that knowledge of the evolution of the variable *Y* reduces the forecast errors of the variable *X*, suggesting that *X* does not evolve independently of *Y*. The concept of Granger causality depends on the nature of the considered variables with regard to the integration order and cointegration between them. If the variables *X* and *Y* are stationary, that is $I(0)$, the Granger causality can be tested according to bivariate VAR model of order *k* described by equations (1) and (2). The optimal lag length *k* can be selected using one of information criteria – e.g. Akaike, Schwarz-Bayesian or Hannan-Quinn information criterion. MacDonald et al. (2015) emphasized that Akaike information criterion is usually the most tolerant, because provides evidence for higher lag order, whereas Schwarz-Bayesian criterion chooses the shorter lag order.

$$X_t = \alpha_X + \sum_{i=1}^{k} \beta_{X,i} X_{t-i} + \sum_{i=1}^{k} \gamma_{X,i} Y_{t-i} + \varepsilon_{X,t}, \tag{1}$$

$$Y_t = \alpha_Y + \sum_{i=1}^{k} \beta_{Y,i} Y_{t-i} + \sum_{i=1}^{k} \gamma_{Y,i} X_{t-i} + \varepsilon_{Y,t}. \tag{2}$$

If the null hypothesis that all coefficients γ_i are equal to zero cannot be rejected in both equations using standard *F*-test, then variable *Y* (*X*) does not Granger-cause the variable *X* (*Y*).

If variables *X* and *Y* are non-stationary, that is $I(1)$, and not cointegrated, the Granger causality tests have to be utilized in the VAR framework based on first-differenced time-series:

$$X_t = \alpha_X + \sum_{i=1}^{k} \beta_{X,i} \Delta X_{t-i} + \sum_{i=1}^{k} \gamma_{X,i} \Delta Y_{t-i} + \varepsilon_{X,t}, \tag{3}$$

$$Y_t = \alpha_Y + \sum_{i=1}^{k} \beta_{Y,i} \Delta Y_{t-i} + \sum_{i=1}^{k} \gamma_{Y,i} \Delta X_{t-i} + \varepsilon_{Y,t}. \tag{4}$$

If variables *X* and *Y* are non-stationary, that is $I(1)$, and cointegrated, then to the VAR framework based on first-differenced time-series the error correction term obtained from the cointegrating equation between variables *X* and *Y* have to be added. In this case Granger causality test is based on the following equations:

$$X_t = \alpha_X + \sum_{i=1}^{k} \beta_{X,i} \Delta X_{t-i} + \sum_{i=1}^{k} \gamma_{X,i} \Delta Y_{t-i} + \varphi_X ECT_{X,t-1} + \varepsilon_{X,t}, \tag{5}$$

$$Y_t = \alpha_Y + \sum_{i=1}^{k} \beta_{Y,i} \Delta Y_{t-i} + \sum_{i=1}^{k} \gamma_{Y,i} \Delta X_{t-i} + \varphi_Y ECT_{Y,t-1} + \varepsilon_{Y,t}, \tag{6}$$

where ECT_{t-1} is the one-period lagged error correction term. It should be noted that two types of causality can be distinguished. Short-term Granger causality is based on the dynamics of the VAR process with the use of standard *F*-test. Long-term Granger causality is based on the long-term equilibrium relationship by applying *t*-test of the estimated error correction term coefficient.

Forecast error variance decomposition constitute a method which enables the split of the forecast error variances of particular variable into parts attributable to own shocks and shocks originating from another variables in the system. This method can be based on Cholesky factorization, where the variance decompositions depend on the ordering of the variables. The second method is based on the generalized approach proposed by Pesaran and Shin (1998), which provides variance decompositions which are invariant to the variables ordering.

3. Empirical analysis of contagion effect in international stock markets

The aim of the research is the analysis of contagion effect in international stock markets during the period of Eurozone crisis. The analysis covers the period from 01.07.2010 to 28.09.2012, so it concerns the second phase of Eurozone crisis, when stock market quotations became highly turbulent due to increasing uncertainty connected with endless debt problems of some European entities. During this period many German banks faced intense difficulties due to Greek debt crisis. Apart from that, on the 5th August 2011 Standard and Poor's decreased U.S. credit rating from the level AAA to AA+. It was the first time in the history the U.S. credit rating was downgraded. As a result on the next working day (8th August 2011), described as Black Monday 2011, many international stock markets crashed.

Due to multifaceted origin of stock indexes volatility in this period it was assumed in the research, that the U.S. as well as German stock market indexes (as Germany was the most involved country in financial rescue packages for Greece, what caused intense difficulties faced by many German banks) can constitute the source of contagion in international stock markets and the influence of the above mentioned stock markets on another stock markets considered in the analysis was examined independently.

Research concerning contagion effect in financial markets requires division of the whole period into tranquil period and turmoil period, which is characterized by high degree of returns volatility. On account of the sharp decrease of many international stock markets quotations in August 2011, 1st August 2011 was assumed in the analysis as the start date of the crisis period.

In the analysis of contagion effect in international stock markets daily logarithmic rates of return of stock indexes from 26 countries were considered – the list of countries is presented in table 1. All stock indexes quotations were expressed in local currencies.

Tab. 1 List of stock market indexes utilized in the analysis

Region	Country	Index	Market	Region	Country	Index	Market
North America	United States	S&P500	Devel.	Western Europe	Great Britain	FTSE100	Devel.
	Canada	TSX	Devel.		Ireland	ISEQ	Devel.
Middle and South America	Mexico	IPX	Emerg.		Netherlands	AEX	Devel.
	Brazil	BVP	Emerg.		Belgium	BEL20	Devel.
Asia and Australia	China	SHC	Emerg.		Italy	FTSE MIB	Devel.
	Region: Hongkong	HSI	Devel.		Spain	IBEX35	Devel.
	Japan	NKX	Devel.		Portugal	PSI20	Devel.
	South Korea	KOSPI	Emerg.		Greece	ATH	Emerg.
	Philippines	PSEI	Emerg.	Middle and Eastern Europe	Poland	WIG	Emerg.
	Singapore	STI	Devel.		Czech Republic	PX	Emerg.
	Australia	S&P/ASX 200	Devel.		Hungary	BUX	Emerg.
Western Europe	Germany	DAX	Devel.		Romania	BET	Emerg.
	France	CAC40	Devel.		Russia	RTSI	Emerg.

The division on developed ("Devel.") and emerging ("Emerg.") market was performed according to market classification used by Morgan Stanley Capital International (www2).
Source: Own elaboration

Before conducting Granger causality analysis, stationarity of logarithmic rates of return for stock indexes has to be tested. The level of integration of time series was examined using Augmented Dickey Fuller (ADF) test, Phillips Perron (PP) test and Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test. Since according to the results of the tests (due to limited size of the paper the results are not shown here but are available from the author upon request) all time series are stationary, that is $I(0)$, Granger causality tests were carried out with use of equations (1) and (2). The number of lags for particular equations of Granger causality tests was determined in accordance with Schwarz-Bayesian information criterion.

Results of Granger causality analysis for the significance level $\alpha = 0.05$ for S&P500 (DAX) index were presented in table 2 (table 3). In the last columns of tables 2 and 3 causality changes were analyzed taking into consideration p-values in the tranquil and crisis period. According to the results, 5 types of causality changes can be distinguished ("New" – no causality in the tranquil period, statistically significant causality in the crisis period; "Intensif." – statistically significant causality in both periods, but in the crisis period p-value lower than in the tranquil period; "Constant" – statistically significant causality in both periods, constant p-value in both periods; "Weaken." – statistically significant causality in both periods, but in the crisis period p-value higher than in the tranquil period; "Reduct." – statistically significant causality in the tranquil period, no causality in the crisis period).

Tab. 2 Granger causality test for S&P500 index

Direction			Tranquil period			Crisis period			Causality changes
			F-test	p-value	Causality	F-test	p-value	Causality	
S&P500	→	TSX	0.100	0.752	No	3.966	0.008	Yes	New
TSX	→	S&P500	0.215	0.643	No	0.700	0.552	No	-
S&P500	→	IPC	1.853	0.174	No	0.106	0.744	No	-
IPC	→	S&P500	0.137	0.711	No	0.238	0.626	No	-
S&P500	→	BVP	4.286	0.039	Yes	3.042	0.010	Yes	Intensif.
BVP	→	S&P500	1.320	0.251	No	0.424	0.832	No	-
S&P500	→	SHC	9.221	0.003	Yes	16.849	4.59E-05	Yes	Intensif.
SHC	→	S&P500	0.565	0.453	No	0.114	0.736	No	-
S&P500	→	HSI	68.331	9.99E-16	Yes	73.069	< 2.2e-16	Yes	Intensif.
HSI	→	S&P500	0.131	0.717	No	2.361	0.070	No	-
S&P500	→	NKX	75.355	< 2.2e-16	Yes	55.534	< 2.2e-16	Yes	Constant
NKX	→	S&P500	0.333	0.564	No	2.134	0.095	No	-
S&P500	→	KOSPI	57.631	1.32E-16	Yes	23.938	< 2.2e-16	Yes	Intensif.
KOSPI	→	S&P500	1.306	0.254	No	2.954	0.002	Yes	New
S&P500	→	PSEI	48.483	9.33E-12	Yes	34.341	< 2.2e-16	Yes	Intensif.
PSEI	→	S&P500	0.086	0.770	No	0.351	0.788	No	-
S&P500	→	STI	44.908	5.03E-11	Yes	66.531	< 2.2e-16	Yes	Intensif.
STI	→	S&P500	0.150	0.699	No	4.166	0.016	Yes	New
S&P500	→	S&P/ASX 200	156.560	< 2.2e-16	Yes	35.804	< 2.2e-16	Yes	Constant
S&P/ASX 200	→	S&P500	2.354	0.126	No	0.585	0.712	No	-
S&P500	→	DAX	5.210	0.023	Yes	5.895	0.001	Yes	Intensif.
DAX	→	S&P500	3.117	0.078	No	3.309	0.020	Yes	New
S&P500	→	CAC40	2.676	0.102	No	6.045	4.65E-04	Yes	New
CAC40	→	S&P500	7.715	0.006	Yes	1.068	0.362	No	Reduct.
S&P500	→	FTSE100	7.277	0.007	Yes	11.056	4.49E-07	Yes	Intensif.
FTSE100	→	S&P500	5.682	0.017	Yes	0.735	0.532	No	Reduct.
S&P500	→	ISEQ	7.715	0.006	Yes	11.742	1.74E-07	Yes	Intensif.
ISEQ	→	S&P500	7.255	0.007	Yes	0.229	0.876	No	Reduct.
S&P500	→	AEX	3.557	0.060	No	7.030	1.19E-04	Yes	New
AEX	→	S&P500	7.959	0.005	Yes	1.447	0.228	No	Reduct.
S&P500	→	BEL20	9.113	0.003	Yes	6.246	3.52E-04	Yes	Intensif.
BEL20	→	S&P500	1.982	0.160	No	1.135	0.334	No	-
S&P500	→	FTSE MIB	0.161	0.688	No	3.579	0.059	No	-
FTSE MIB	→	S&P500	4.822	0.029	Yes	0.566	0.452	No	Reduct.
S&P500	→	IBEX35	0.281	0.597	No	1.833	0.176	No	-
IBEX35	→	S&P500	3.263	0.071	No	0.968	0.326	No	-
S&P500	→	PSI20	0.023	0.880	No	5.765	3.3E-05	Yes	New
PSI20	→	S&P500	0.320	0.572	No	0.338	0.890	No	-
S&P500	→	ATH	9.902	0.002	Yes	6.141	4.07E-04	Yes	Intensif.
ATH	→	S&P500	0.003	0.958	No	0.578	0.629	No	-
S&P500	→	WIG	2.083	0.150	No	11.077	4.37E-07	Yes	New
WIG	→	S&P500	0.063	0.802	No	1.690	0.168	No	-
S&P500	→	PX	20.750	6.42E-06	Yes	9.572	8.52E-09	Yes	Intensif.
PX	→	S&P500	1.696	0.193	No	0.440	0.821	No	-
S&P500	→	BUX	0.726	0.395	No	5.517	5.64E-05	Yes	New
BUX	→	S&P500	0.758	0.384	No	1.050	0.387	No	-
S&P500	→	BET	15.380	9.88E-05	Yes	51.016	2.6E-12	Yes	Intensif.
BET	→	S&P500	1.041	0.308	No	4.382	0.037	Yes	New
S&P500	→	RTSI	6.502	0.011	Yes	23.449	1.55E-10	Yes	Intensif.
RTSI	→	S&P500	4.519	0.034	Yes	2.335	0.098	No	Reduct.

Source: Own elaboration

Tab. 3 Granger causality test for DAX index

Direction			Tranquil period			Crisis period			Causality changes
			F-test	p-value	Causality	F-test	p-value	Causality	
DAX	→	S&P500	3.117	0.078	No	3.309	0.020	Yes	New
S&P500	→	DAX	5.210	0.023	Yes	5.895	0.001	Yes	Intensif.
DAX	→	TSX	0.033	0.857	No	0.704	0.402	No	-
TSX	→	DAX	5.325	0.021	Yes	2.115	0.146	No	Reduct.
DAX	→	IPC	0.239	0.625	No	2.479	0.116	No	-
IPC	→	DAX	1.107	0.293	No	2.283	0.131	No	-
DAX	→	BVP	0.610	0.435	No	9.775	0.002	Yes	New
BVP	→	DAX	2.791	0.095	No	1.087	0.298	No	-
DAX	→	SHC	5.628	0.018	Yes	20.559	6.95E-6	Yes	Intensif.
SHC	→	DAX	0.330	0.566	No	0.186	0.667	No	-
DAX	→	HSI	28.885	1.13E-7	Yes	38.305	< 2.2e-16	Yes	Intensif.
HSI	→	DAX	0.118	0.732	No	4.391	0.005	Yes	New
DAX	→	NKX	28.646	1.44E-12	Yes	55.534	< 2.2e-16	Yes	Intensif.
NKX	→	DAX	2.440	0.088	No	2.134	0.095	No	-
DAX	→	KOSPI	25.121	7.22E-7	Yes	45.976	< 2.2e-16	Yes	Intensif.
KOSPI	→	DAX	0.093	0.761	No	1.853	0.136	No	-
DAX	→	PSEI	33.347	1.28E-8	Yes	78.369	< 2.2e-16	Yes	Intensif.
PSEI	→	DAX	1.148	0.285	No	0.055	0.814	No	-
DAX	→	STI	18.731	1.78E-5	Yes	25.892	8.88E-16	Yes	Intensif.
STI	→	DAX	0.321	0.571	No	3.405	0.017	Yes	New
DAX	→	S&P/ASX 200	41.400	< 2.2e-16	Yes	146.010	< 2.2e-16	Yes	Constant
S&P/ASX 200	→	DAX	2.794	0.062	No	0.140	0.708	No	-
DAX	→	CAC40	1.591	0.208	No	9.589	0.002	Yes	New
CAC40	→	DAX	0.296	0.587	No	8.085	0.005	Yes	New
DAX	→	FTSE100	0.251	0.617	No	3.538	0.060	No	-
FTSE100	→	DAX	0.075	0.784	No	0.492	0.483	No	-
DAX	→	ISEQ	0.069	0.793	No	6.310	3.22E-4	Yes	New
ISEQ	→	DAX	0.250	0.617	No	3.489	0.016	Yes	New
DAX	→	AEX	2.494	0.115	No	10.915	0.001	Yes	New
AEX	→	DAX	1.058	0.304	No	9.352	0.002	Yes	New
DAX	→	BEL20	1.080	0.299	No	7.820	3.98E-4	Yes	New
BEL20	→	DAX	1.093	0.296	No	4.822	0.003	Yes	New
DAX	→	FTSE MIB	0.549	0.459	No	4.842	0.028	Yes	New
FTSE MIB	→	DAX	0.016	0.900	No	6.797	0.009	Yes	New
DAX	→	IBEX35	1.971	0.161	No	0.645	0.422	No	-
IBEX35	→	DAX	0.085	0.771	No	0.535	0.465	No	-
DAX	→	PSI20	0.416	0.519	No	8.764	0.003	Yes	New
PSI20	→	DAX	0.503	0.478	No	4.658	0.031	Yes	New
DAX	→	ATH	1.339	0.248	No	6.641	0.010	Yes	New
ATH	→	DAX	1.645	0.200	No	0.001	0.980	No	-
DAX	→	WIG	0.181	0.671	No	1.999	0.113	No	-
WIG	→	DAX	0.115	0.735	No	1.271	0.283	No	-
DAX	→	PX	9.430	0.002	Yes	25.469	5.93E-7	Yes	Intensif.
PX	→	DAX	0.037	0.847	No	1.068	0.302	No	-
DAX	→	BUX	4.318	0.038	Yes	1.756	0.186	No	Reduct.
BUX	→	DAX	1.056	0.305	No	0.293	0.589	No	-
DAX	→	BET	3.654	0.056	No	20.807	6.13E-6	Yes	New
BET	→	DAX	2.735	0.099	No	0.959	0.328	No	-
DAX	→	RTSI	0.024	0.876	No	9.830	0.002	Yes	New
RTSI	→	DAX	1.947	0.163	No	0.851	0.357	No	-

Source: Own elaboration

According to the results in table 2. it can be said that in the crisis period the number and the intensity of the causal relationship stemming from U.S. equity market increased considerably. In the tranquil period 16 out of 25 causal relationships stemming from S&P500 index was statistically significant, whereas in the crisis period the number of statistically significant causal relationship increased to 22, so there was 6 new causal relationships stemming from U.S. equity market. Moreover in 14 cases there was an intensification of causal relationships stemming from S&P500 index. Taking into account the reverse causality (from international stock markets to US equity market) there were 6 statistically significant causal relationships in the tranquil period and only 4 causal relationships in the crisis period, so it can be said that the increase in number and intensity of the causal relationships in the crisis period was unidirectional: from U.S. equity market to international stock markets.

Taking into consideration Granger causality concerning DAX index (presented in table 3) it can be observed that the number and intensity of statistically significant causal relationships increased in the crisis period in comparison to the tranquil period. There were 9 causal relationships in the tranquil period and 19 causal relationships in the crisis period. In the crisis period there were 11 new causal relationships, in 7 cases the intensity of the causal relationship increased, in 1 case remained constant and in 1 case there was a reduction of causal relationship. As opposed to the results from the previous analysis dedicated to S&P500 index for DAX index there was observed an increase in reverse causality (from international stock markets to German equity market): there were 2 statistically significant causal relationships in the tranquil period and 9 causal relationships in the crisis period. According to the results it can be noted that for the case of DAX index the increase in causal relationships in the crisis period was partially bidirectional.

The analysis was complemented by examining generalized forecast error variance decomposition within the VAR framework, taking into consideration influence of S&P500 and DAX indexes separately. It enables the measurement of the effect of U.S. and German innovations on the extent of innovations in particular markets over a given time horizon. Due to limited size of this article, results are provided only for selected markets. The influence of S&P500 index on generalized forecast error variance decomposition (expressed in percent shares) for selected markets was presented in table 4 whereas table 5 concerns generalized forecast error variance decomposition for selected markets taking into account influence of DAX index (due to limited size of the paper the results are presented only for selected markets; for the remaining markets results concerning generalized forecast error variance decomposition are available from the author upon request).

According to the results presented in tables 4 and 5 it can be observed that the percent share of S&P500 index (table 4) and DAX index (table 5) in generalized forecast error variance decomposition of particular stock indexes increased in all cases in the crisis period. This increase is especially noticeable for stock indexes from European emerging markets (WIG, BET and RTSI), whereas for some developed markets indexes (CAC40, FTSE100 and AEX) the increase of S&P500 or DAX percent share in generalized forecast error variance decomposition is quite small. According to the results based on generalized forecast error variance decomposition it can be said that the contagion effect, recognized as the increase of the contribution of the innovations from the market initiating crisis in the generalized forecast error variance decomposition of particular market in the crisis period compared to tranquil period, is especially evident for stock indexes belonging to emerging markets, whereas for indexes from developed markets the increase in cross-market linkages with the market being the source of shock is quite limited.

Tab. 4 Variance decomposition (percent shares) for selected markets – influence of S&P500 index

Index (*i*)	Horizon (days)	Variance decomposition of the *i*th index in the tranquil period		Variance decomposition of the *i*th index in the crisis period	
		S&P500	*i*th index	S&P500	*i*th index
TSX	1	33.166	66.834	40.600	59.400
	5	33.166	66.834	41.634	58.366
	10	33.166	66.834	41.678	58.322
IPC	1	32.221	67.779	37.442	62.558
	5	32.218	67.782	37.442	62.558
	10	32.218	67.782	37.442	62.558
BVP	1	29.755	70.245	35.722	64.278
	5	29.757	70.243	36.689	63.311
	10	29.757	70.243	36.773	63.227
HSI	1	25.065	74.935	39.812	60.188
	5	25.155	74.845	39.945	60.055
	10	25.155	74.845	39.974	60.026
NKX	1	22.713	77.287	38.772	61.228
	5	22.834	77.166	39.048	60.952
	10	22.834	77.166	39.048	60.952
KOSPI	1	21.002	78.998	28.390	71.610
	5	21.229	78.771	29.707	70.293
	10	21.229	78.771	31.198	68.802
S&P/ASX200	1	37.005	62.995	38.038	61.962
	5	37.801	62.199	40.125	59.875
	10	37.801	62.199	40.436	59.564
DAX	1	35.752	64.248	39.719	60.281
	5	35.753	64.247	40.190	59.810
	10	35.753	64.247	40.220	59.780
CAC40	1	37.718	62.282	37.753	62.247
	5	37.713	62.287	38.075	61.925
	10	37.713	62.287	38.093	61.907
FTSE 100	1	35.677	64.323	38.715	61.285
	5	35.682	64.318	39.574	60.426
	10	35.682	64.318	39.608	60.392
AEX	1	36.650	63.350	38.711	61.289
	5	36.644	63.356	39.180	60.820
	10	36.644	63.356	39.180	60.820
FTSE MIB	1	29.161	70.839	32.606	67.394
	5	29.162	70.838	32.629	67.371
	10	29.162	70.838	32.629	67.371
WIG	1	19.101	80.899	30.492	69.508
	5	19.102	80.898	32.150	67.850
	10	19.102	80.898	32.155	67.845
BET	1	6.010	93.990	25.724	74.276
	5	6.105	93.895	25.752	74.248
	10	6.105	93.895	25.752	74.248
RTSI	1	11.789	88.211	23.055	76.945
	5	11.796	88.204	26.181	73.819
	10	11.796	88.204	26.181	73.819

Source: Own elaboration

Tab. 5 Variance decomposition (percent shares) for selected markets – influence of DAX index

		Variance decomposition of the *i*th index in the tranquil period		Variance decomposition of the *i*th index in the crisis period	
Index (*i*)	k	DAX	*i*th index	DAX	*i*th index
S&P500	1	35.177	64.823	38.394	61.606
	5	35.166	64.834	37.419	62.581
	10	35.166	64.834	37.325	62.675
TSX	1	22.226	77.774	31.508	68.492
	5	22.226	77.774	31.511	68.489
	10	22.226	77.774	31.511	68.489
IPC	1	20.714	79.286	28.593	71.407
	5	20.714	79.286	28.588	71.412
	10	20.714	79.286	28.588	71.412
BVP	1	16.651	83.349	28.769	71.231
	5	16.651	83.349	28.755	71.245
	10	16.651	83.349	28.755	71.245
HSI	1	19.723	80.277	30.921	69.079
	5	19.723	80.277	30.625	69.375
	10	19.723	80.277	30.627	69.373
NKX	1	20.829	79.171	35.193	64.807
	5	21.129	78.871	35.074	64.926
	10	21.129	78.871	35.078	64.922
KOSPI	1	15.388	84.612	28.778	71.222
	5	15.396	84.604	31.028	68.972
	10	15.396	84.604	31.054	68.946
S&P/ASX200	1	27.330	72.670	36.251	63.749
	5	27.445	72.555	36.260	63.740
	10	27.446	72.554	36.260	63.740
CAC40	1	45.934	54.066	47.457	52.543
	5	45.930	54.070	47.466	52.534
	10	45.930	54.070	47.466	52.534
FTSE 100	1	41.730	58.270	44.193	55.807
	5	41.730	58.270	44.196	55.804
	10	41.730	58.270	44.196	55.804
AEX	1	44.657	55.343	46.910	53.090
	5	44.649	55.351	46.916	53.084
	10	44.649	55.351	46.916	53.084
FTSE MIB	1	38.485	61.515	43.771	56.229
	5	38.479	61.521	43.780	56.220
	10	38.479	61.521	43.780	56.220
WIG	1	28.075	78.158	29.648	70.352
	5	28.075	78.158	29.665	70.335
	10	28.075	78.158	29.665	70.335
BET	1	8.212	91.788	24.168	75.832
	5	8.211	91.789	24.305	75.695
	10	8.211	91.789	24.305	75.695
RTSI	1	21.842	78.158	29.648	70.352
	5	21.842	78.158	29.665	70.335
	10	21.842	78.158	29.665	70.335

Source: Own elaboration

4. Conclusions

The aim of the paper was the examination of contagion effect in international stock markets during the period of Eurozone crisis. The analysis was performed with the use Granger causality test and generalized forecast error variance decomposition. It was assumed, that contagion effect refers to significant increase in the number or in the intensity of causal relationships in the crisis period compared with causal relationships identified in the tranquil period. Contagion effect can be also identified as significant increase in the contribution of the innovations from the market initiating crisis in the generalized forecast error variance decomposition of particular market in the crisis period compared to the tranquil period.

Due to multifaceted origin of stock indexes volatility in the analyzed period (on the one hand caused by intense difficulties faced by many German banks and on the other hand by U.S. credit rating downgrade on the 5th August 2011) German as well as U.S. equity markets were assumed as the origin of possible shocks and contagion effect in international stock markets initiated by quotations of DAX and S&P500 indexes was examined independently.

According to the results from the Granger causality tests significant increase in the number and intensity of causal relationships stemming from S&P500 index in the crisis period compared to the tranquil period was observed. In the crisis period there were identified 6 cases on new causal relationships and 14 cases of intensification of causal relationships stemming from S&P500 index. It has to be noticed that this increase in the number and intensity of causal relationships was unidirectional (from U.S. equity market to another stock markets); the number of reverse causal relationships decreased in the crisis period. These results constitute evidence of contagion effect stemming from S&P500 index.

Analyzing the influence of DAX index on another international stock market indexes significant increase in the number and intensity of causal relationships for the German national index in the crisis period compared to the tranquil period was also observed (11 new and 7 intensified causal relationships in the crisis period), however this increase as opposed to S&P500 index was partially bidirectional (due to increase of reverse causal relationships from 2 cases in the tranquil period to 9 cases in the crisis period).

According to the results of generalized forecast error variance decomposition it was observed that contribution of the innovations from S&P500 as well as DAX index in the generalized forecast error variance decomposition of particular indexes increased in all cases in the crisis period compared to tranquil period. This increase was especially evident for emerging markets and quite limited for some developed markets.

Comparing the total number of causal relationships in the crisis period between S&P500 and DAX index (for S&P500: 22 causal relationships, 4 reverse causal relationships; for DAX: 19 causal relationships, 9 reverse causal relationships) it can be said that the U.S. equity market was in the analyzed period more globally influential market than the German equity market. The results of the paper give evidence of dominant role of U.S. equity market in shock transmission on international stock markets in the second phase of the Eurozone crisis, however the increased significance of German equity market on the global stock indexes was also noticed. The results confirm also increased integration of financial markets, which is especially enhanced in the aftermath of crisis events, when the number and intensity of market connections rises considerably.

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