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SPILLOVER OF VOLATILITY ON THE FINANCIAL MARKETS; M-GARCH INSIGHTS FROM PRE- AND POST-CRISIS PERIODS IN EU COUNTRIES

Petra Palić | Assistant Professor, Department of Sociology, Catholic University of Croatia, Zagreb, Croatia, petra.palic@unicath.hr; ORCID ID: 0000-0001-5181-6657

Abstract: *This research aims to investigate whether increased volatility occurs within the government bond market, stock market, and foreign exchange market during periods of crisis, using European Union countries as a case study. Additionally, this paper explores whether there are variations in the strength and dynamics of correlations among these three markets before and after the onset of the global economic crisis. Recognizing the global significance of the Lehman Brothers' collapse as the official commencement of the crisis, this analysis is divided into two distinct periods. The first period scrutinizes the volatility within these three markets from January 1, 2005, to September 14, 2008. The second period covers the period from September 15, 2008, to December 31, 2016. To conduct this investigation, it is employed Engel's Dynamic Conditional Correlation (DCC) Multivariate Generalized Autoregressive Conditional Heteroskedasticity (MGARCH) model. This model is instrumental in examining the relationships between volatilities originating from multiple markets concurrently, enabling the estimation of conditional and time-varying correlations and covariances among different markets. Using an appropriate MGARCH (1,1) model, it is assessed the intensity and direction of the conditional correlation between the government bond market, stock market, and foreign exchange markets for European Union countries before and after the official commencement of the global economic crisis.*

Keywords: *volatility, financial markets, MGARCH (1,1) model, global economic crisis*

JEL classifacation: *C32, E44, F30, G01*

INTRODUCTION

The aim of this research is to investigate whether there is increased volatility between government bond markets, stock markets, and foreign exchange markets during periods of crisis, using EU member countries as a case study. Additionally, it examines whether there are differences in the strength and dynamics of correlations among these three markets before and after the onset of the global economic crisis. Given that the turning point on the global stage was the collapse of Lehman Brothers, which is considered the official beginning of the crisis, the analysis is divided into two periods. The first period examines the volatility of these markets from January 1, 2005, to September 14, 2008. The second period spans from September 15, 2008, to December 31, 2016. Engel's Dynamic Conditional Correlation (DCC) Multivariate Generalized Autoregressive Conditional Heteroskedasticity (MGARCH) model is employed for this investigation, estimating the MGARCH model for each country in both the pre-crisis and post-crisis periods for the three markets of interest.

The formulation and examination of volatility propagation, or financial contagion, within different markets—specifically the government bond market, stock market, and foreign exchange market—and their interactions remain inadequately explored in both Croatian and global literature.

Financial contagion, broadly defined, refers to the spread of detrimental shocks that can trigger financial crises. Without a clear definition and understanding of financial contagion and its underlying mechanisms, it is challenging to effectively evaluate the problem or devise appropriate policy measures to mitigate it.

The concept of financial contagion is prevalent in both international and domestic literature and is often synonymous with adverse economic spillovers. Even in contemporary times, the term "contagion" carries negative connotations, suggesting unfavorable developments. According to the World Bank, much of the discourse over the past decade regarding reforms to the international financial architecture has focused on mitigating the risk of contagion. The World Bank defines financial contagion as a significant increase in connectivity between markets following a shock in a single country or a group of countries. This definition underscores the importance of various channels through which shocks are transmitted, including trade. In times of crisis, these transmission mechanisms differ markedly, and these distinctions are crucial as they define various interpretations of financial contagion. This research investigates the presence of increased volatility within the government bond market, stock market, and foreign exchange market during crisis periods, using EU countries as a case study.

The study also explores variations in the strength and dynamics of correlations among these markets before and after the onset of the global economic crisis, with a particular focus on the collapse of Lehman Brothers as the crisis's official commencement. By conducting a comprehensive analysis of the relevant literature, this research presents significant theoretical and empirical contributions related to the spillover effects of volatility between these markets for European Union member countries.

LITERATURE REVIEW

Despite its widespread use, the term "financial contagion" lacks a precise definition. Many economists employed it to comprehend and provide insights into the East Asian crisis and the Russian crisis, thus forming a consensus on which countries were genuinely affected (Forbes & Rigobon, 2001). A review of relevant articles published since 1997 revealed that the term "contagion" appeared in almost all of them when describing the transmission and upheavals in financial markets across different countries. It has become an integral part of the vocabulary of both international economists and policymakers worldwide (Claessens & Forbes, 2004).

Contagion elucidates the dissemination of disturbances within markets, often originating in a single country and then extending to others. It is a phenomenon observed through comparative movements and alterations in interest rates, stock prices, government bond yields, and capital flows. Conceptually, the causes of contagion can be categorized into two groups (Dornbusch, Park, & Claessens, 2000; Masson, 1998; Wolf, 1999; Forbes & Rigobon, 2001; Pritsker, 2001). The first group underscores spillovers resulting from the natural interdependence among market economies. This interdependence implies that shocks, whether micro or macro-level, can cross borders due to genuine financial interconnections. For example, Calvo & Reinhart refer to this type of contagion as "fundamentals-based contagion" (Calvo & Reinhart, 1996). Such comparative movements would not typically represent contagion under normal circumstances. However, during times of crisis, if these effects are unfavourable, they can be termed as contagion. Most empirical studies aim to elucidate the degree of comparative movements and the mechanisms responsible for transmitting shocks in financial markets.

As already has been mentioned, financial contagion, a phenomenon where disturbances in one sector or country spread to others, has been a significant area of study in the field of finance. This part of the review delves into relevant studies on contagion in the foreign exchange market, government bond market, and systemic risk models to provide insights into the transmission of crises and the importance of interconnectedness.

For example, Han et al. (2003) investigated the Mexican peso crisis, revealing a pivotal aspect of financial contagion in the foreign exchange market (Han, Lee, & Suk, 2003). Their research demonstrated that a currency crisis in one country could trigger contagion in other emerging market currencies. This finding underscores the intricate interconnections among currencies and the potential for crises in one nation to affect neighbouring economies. It emphasized the importance of understanding contagion dynamics in the foreign exchange market, especially within emerging markets. On the other side, Tai (2007) extended the exploration of contagion by studying its effects on various financial markets. This research provided empirical evidence of the pure contagion effects between stock and foreign exchange markets for each Asian country during the 1997-98 Asian crisis. Notably, it is found that these crises were not confined solely to the foreign exchange market; they also had spillover effects on stock markets. This study emphasized the complex web of connections among different segments of the financial system, highlighting the need for a comprehensive understanding of contagion phenomena in the global financial landscape (Tai, 2007). Also, Muratori (2014) furthered the exploration of contagion effects on government bond markets during the European sovereign debt crisis. Their research emphasized the intricate relationships among government bond markets within the European Monetary union. It highlighted the interconnectedness and vulnerability of these markets to contagion, prompting a closer examination of the European sovereign debt crisis's extensive implications. This study served as a reminder of the interwoven nature of global financial markets and the importance of understanding the dynamics of contagion (Muratori, 2014).

Silva et al. (2017) introduced a model that addressed systemic risk and contagion within the financial sector. Their model emphasized the critical role of interconnectedness between financial institutions in propagating systemic risk and contagion. It highlighted the importance of understanding the network structure within the financial sector to manage systemic risk effectively (Silva, da Silva, & Tabak, 2017).

In recent research, Leung et al. (2017) examined hourly volatility spillovers between the New York (DJI), London (FTSE 100), and Tokyo (N225) stock markets and their associated exchange rates (USD, EUR, GBP, and JPY) for the period 2001 to 2013. This period encompassed both crisis-free periods and significant crises like the global financial crisis and the euro debt crisis. The findings revealed a general increase in spillovers between stock and foreign exchange markets during crisis periods (Leung, Schiereck, & Schroeder, 2017). Similarly, Alexakis and Pappas (2018) employed the ADCC-GJR-GARCH model to investigate financial contagion in the European Union during the global financial crisis (GFC) of 2007-2009 and the European sovereign debt crisis (ESDC) that began in 2009. Their analysis included capital sector indices for 15 countries spanning 2004 to 2014, and the results indicated the presence of financial contagion in all sectors, with contagion spillovers to stock markets being particularly notable during crisis periods (Alexakis & Pappas, 2018).

Also, in more recent literature, Hung (2019) examined the short-term and long-term dynamics between China and four Southeast Asian countries (Vietnam, Thailand, Singapore, and Malaysia) during the period 2008–2018. His empirical research employed the Generalized Autoregressive Conditional Heteroskedasticity-Asymmetric Dynamic Conditional Correlation (MGARCH-ADCC) model and wavelet coherence technique to estimate time-varying correlations and co-movements in both time-frequency spaces of the stock markets of China and its neighboring countries. The study's findings indicate that the stock markets of China and its trading partners became relatively integrated after the global financial crisis of 2008, with frequency changes in co-movement patterns showing a positive linkage throughout the sample period (Hung N. T., 2019). Similarly, Hung (2022) empirically analyzes the dynamic relationship and volatility spillover effects between exchange rates and stock returns of five Central and Eastern European (CEE) countries; Hungary, Poland, the Czech Republic, Romania, and Croatia for the period 2000–2017. The analysis employs the bivariate Generalized Autoregressive Conditional Heteroskedasticity-Baba, Engle, Kraft, and Kroner (GARCH-BEKK) framework, as well as constant and dynamic conditional correlation (CCC and DCC) models (Hung N. T., 2022).

The existing literature, both globally and in Croatian scholarly work, has inadequately investigated the transmission of financial contagion across these three specific markets. Most prior research primarily concentrates on individual markets and the cross-border transmission of volatility through the chosen market (Hamao, Masulis, & Ng, 1990; Bekaert & Harvey, 1997; Bekaert, Harvey, & Lundblad, 2005; Baele, 2005; Jurun, Pivac, & Arnerić, 2007; Posedel Šimović, Tkalec, & Vizek, 2015; Palić, Posedel Šimović, & Vizek, 2017; Hung N. T., 2022). This research contributes to the field by being the first to comprehensively investigate the transmission and modelling of financial contagion across these three markets—namely, the government bond market, stock market, and foreign exchange market—over time. Specifically, the focus is on the period from 2005 to 2016, encompassing 27 European Union countries. This comprehensive analysis of volatility and shock transmission across the government bond, stock, and foreign exchange markets in European Union countries offers new insights into the phenomenon of financial contagion over time. This research is particularly valuable for economic policymakers and regulators striving to prevent the emergence of contagion.

METHODOLOGY

It has been established that correlations between volatilities across different markets vary over time, and in such cases, multivariate GARCH models have proven to be suitable. Moreover, Engel's Dynamic Conditional Correlation (DCC) multivariate GARCH model was employed to examine whether there is increased volatility between the government bond market, stock market, and foreign exchange market during crisis periods. The purpose of the multivariate GARCH (M-GARCH) model is to study the relationship between volatilities from several different markets simultaneously, enabling the estimation of conditional and time-varying correlations and covariances among these markets.

Multivariate GARCH models defined by a linear combination of univariate GARCH models are given by the expression (Arnerić, 2012);

$$\Sigma_t = WD_tW^t \tag{1.1}$$

if for each t the decomposition of the variance and covariance matrix of the standardized yields of k securities is valid. Here, W is the orthogonal matrix of factor constraints of order mxk, and D_t is the diagonal matrix of the variances of m main components. At the same time, in fact, the expression, that is, the decomposition of the matrices of the estimated coefficients C, A and B with Choleski factorization

$$\begin{bmatrix} \sigma_{1,t}^2 & 1 \\ \sigma_{21,t} & \sigma_{2,t}^2 \end{bmatrix} = \begin{bmatrix} c_1 & 0 \\ c_2 & c_3 \end{bmatrix} \cdot \begin{bmatrix} c_1 & c_2 \\ 0 & c_3 \end{bmatrix} + \begin{bmatrix} a_{11} & 0 \\ a_{21} & a_{22} \end{bmatrix} \cdot \begin{bmatrix} a_{11} & a_{21} \\ 0 & a_{22} \end{bmatrix} \odot \begin{bmatrix} \varepsilon_{1,t-1}^2 & 0 \\ \varepsilon_{2,t-1}\varepsilon_{1,t-1} & \varepsilon_{2,t-1}^2 \end{bmatrix}$$
$$+ \begin{bmatrix} b_{11} & 0 \\ b_{21} & b_{22} \end{bmatrix} \cdot \begin{bmatrix} b_{11} & b_{21} \\ 0 & b_{22} \end{bmatrix} \odot \begin{bmatrix} \sigma_{1,t-1}^2 & 0 \\ \sigma_{21,t-1} & \sigma_{2,t-1}^2 \end{bmatrix} \tag{1.2}$$

represents an orthogonal transformation of m univariate GARCH(p,q) models. The model $\Sigma_t = WD_tW^t$ is called an orthogonal GARCH model (OGARCH (1,1,m)). Given that in multivariate GARCH models with four or more than four values, the problem of too many parameters appears in empirical analyses, orthogonal GARCH models are used and $m \leq k$ must be satisfied. It can be concluded that this actually leads to a significant simplification of the model (Enders, 2008).

The correlation matrix of standardized yields of k securities can be defined as a linear combination of m main components that are mutually independent, i.e. orthogonal. At the same time, the main components P_j, j=1,2,3,…m are the diagonal elements of the matrix D_t and are generally explained with the help of the GARCH(1,1) model, where each main component is also a linear combination of the values of the standardized returns variables (Enders, 2008);

$$p_{1=}w_{11} \cdot z_1 + w_{12} \cdot z_2 + \ldots. + w_{ij}z_i \ldots. + w_{1k} \cdot z_k \tag{1.3}$$

$$p_{2=}w_{12} \cdot z_1 + w_{22} \cdot z_2 + \ldots... + w_{ij}z_i \ldots. + w_{2k} \cdot z_k \tag{1.4}$$

$$\vdots$$

$$p_{m=}m \cdot z_1 + w_{2m} \cdot z_2 + \ldots... + w_{ij}z_i \ldots. + w_{mk} \cdot z_k \tag{1.5}$$

Or matrix:

$$P_{i=} Zw_i \tag{1.6}$$

where w_j is the eigenvector of the matrix Z of order kx1. At the same time, each vector of the matrix of standardized returns of the entire system can be written in the form of a linear combination of the main components

$$Z=PW^t \tag{1.7}$$

given that $W^t = W^{-1}$ is valid. It can also be written as $WW^t=I$. Decomposition of matrix Σ_t for each t into m main components P_j, j=1,2,3,…m which are described by GARCH(1,1) models, is based on the eigenvalues and eigenvectors of the yield correlation matrix

$$RW = W\Lambda \tag{1.8}$$

where $R=Z^TZ$. In the expression above, the matrix Λ is a diagonal matrix of eigenvalues of order kxk with elements $\lambda_1>\lambda_2>\lambda_3>\ldots>\lambda_k$. In order to solve the problem of large dimensions, only those principal components that explain the largest part of the common variance of the standardized returns are included in the analyses.

The expression:

$$\frac{\lambda_i}{k} \qquad i=1,2\ldots k \tag{1.9}$$

represents the proportion with which each principal component explains part of the common variance. As for the labels, λ_i is the i-th eigenvalue of the correlation matrix, while k represents the number of principal components.

For the purpose of modeling Engel's DCC model is defined as

$$H_t=D_tRD_t \tag{1.10}$$

D_t is defined as

$$D_t = diag(h_{11t\ldots\ldots}^{1/2}h_{NNt}^{1/2}) \tag{1.11}$$

where h_{iit} is defined as a univariate GARCH model and R_t as

$$R_t=\text{diag}(q_{11,t\ldots\ldots}^{-1/2}q_{NN,t}^{1/2})Q_t\text{diag}(q_{11,t\ldots\ldots}^{-1/2}q_{NN,t}^{1/2}), \tag{1.12}$$

N x N is a symmetric positive definite matrix of the parameter $Q_t=(q_{ij,t})$ given as

$$Q_t = (1-\alpha-\beta)\bar{Q}+\alpha u_{t-1}u'_{t-1}+\beta Q_{t-1} \tag{1.13}$$

while u_t is defined as

$$u_t=(u_{1t}u_{2t}\ldots u_{Nt}), \tag{1.14}$$

$\bar{Q}$ is an N x N unconditional variance matrix u_t, α i β are non-negative scalar parameters satisfying the condition $\alpha+\beta<1$.

Engle's correlation coefficient in the DCC model is defined as:

$$\rho_{12t} = \frac{(1-\alpha-\beta)\bar{q}_{12}+\alpha u_{1,t-1}u_{2,t-1}+\beta q_{12,t-1}}{\sqrt{(1-\alpha-\beta)\bar{q}_{11}+\alpha u_{1,t-1}^2+\beta q_{11,t-1}((1-\alpha-\beta)\bar{q}_{22}+\alpha u_{2,t-1}^2+\beta q_{22,t-1})}} \quad (1.15)$$

Engle (2002) formulated conditional correlation as a weighted sum of past correlations. In fact, the matrix is written as a GARCH equation and then transformed into a correlation matrix. Also, for this model one can test $\theta_1 = \theta_2 = 0$ or $\alpha=\beta=0$ respectively to determine whether the implied constant of conditional correlations is empirically relevant (Engle R. , 2002).

RESULTS AND DISCUSSION

Engel's (DCC) MGARCH model was implemented, which was previously defined. Based on the adequate MGARCH (1,1) model, the intensity and direction of the conditional correlation between the government bond market, stock market and foreign exchange markets for the European Union countries in the period before and after the official start of the world economic crisis was estimated. For the purpose of the analyses, the econometric software OxMetrics was utilized.

Regarding data frequency, weekly data was used for all three markets of interest in this study. The variable used to explain the government bond market is the spread, which is defined as the difference in government bond yields representing the difference in the level of development, risk, expected returns and other important characteristics of the countries whose bond yields are being compared. Germany was taken as the benchmark country and the spreads were calculated in relation to the German government bond. Since these are financial time series, the data are differentiated for modelling purposes. The source of these data is Eurostat.

In the analysis, the nominal exchange rate was used for the foreign exchange market. In doing so, the EUR/USD exchange rate was used for eurozone countries, and for countries that were not members of the Eurozone at the time (for example, Croatia - HRK/EUR). Also, the source of these data is Eurostat. The variable used to explain the stock market is the stock market index, which measures the value of the stock market. It is usually calculated using the prices of selected stocks (most often in the form of a weighted average). It was used for the purpose of describing the market and for comparing the returns of individual investments. The data source is the Bloomberg database. Since these are financial time series, the data are differentiated for modelling purposes.

Using Engle's MGARCH (1,1) model, the existence of increased volatility between the government bond market, the stock market and the foreign exchange market in periods of crisis was examined. It can be said that it was actually examined whether there was a difference in the strength and dynamics of the correlation of these three markets before and after the beginning of the world economic crisis. Considering that the turning point on the global scene was the fall of Lehman Brothers, which is taken as the official beginning of the crisis, the analysis is divided into two periods. In the first period, the transfer between the government bond market, the stock market and the foreign exchange market was examined in the period from 1 January 2005. until

September 14, 2008. year, while for the second period, the analysis was carried out in the period from September 15, 2008. until 31.12.2016. years.

Tables 1 and 2 reveal that the coefficients α and β are higher in the second observed period, signifying a greater level of volatility following the crisis. Moreover, the parameters (γ_(2,1), γ_(3,1), γ_(2,3)) are predominantly statistically significant at the 1 percent level after the crisis began. This further validates that the volatility among these three markets was more pronounced in the period following the official commencement of the crisis (Table 2). In both periods, diagnostic tests for autocorrelation of the residual Q(5) and the autocorrelation of the squared residual Q2(5) (Tables 1, 2) confirm that the equations for conditional expectations and conditional variances and covariances are appropriately specified. This implies that autocorrelation and ARCH effects are no longer present in the estimated models. As such, the null hypothesis of no autocorrelation is accepted. It is crucial to note that Ljung-Box bivariate (group) portmanteau tests are conducted, specifically focusing on group tests of residuals' autocorrelation and autocorrelation of squared residuals over a 5-time shift.

Table 1: Results of estimations of the MGARCH (1,1) model for government bond markets, stock markets, and foreign exchange markets of EU countries in the period from January 1, 2005, until September 14, 2008

	Multivariate GARCH (1,1) model Dynamic Correlation Model (Engle)									
Country	**Correlation coefficient between the government bond market and the stock market**	**Correlation coefficient between the government bond market and the foreign exchange market**	**Correlation coefficient between the stock market and the foreign exchange market**	α	β	**Information criteria (Akaike)**	**Information criteria (Schwarz)**	**Jarque–Bera test**	**Hosking Q(5)**	**Hosking (5)**
AT	-0,15	-0,05	0,04	0,02	0,90***	0,65	1,04	31,93 [0,00]**	60,65 [0,04]	45,81 [0,36]
BE	-0,23***	0,03	-0,04	0,05	0,68***	-0,50	-0,11	58,92 [0,00]**	42,55 [0,49]	45,64 [0,36]
CY	-0,23***	-0,04	0,01	0,06	0,46	3,94	4,33	40,22 [0,00]**	27,92 [0,96]	42,53 [0,49]
CZ	-0,40**	0,41**	-0,34*	0,02**	0,98***	5,84	6,23	44,62 [0,00]**	46,98 [0,31]	26,64 [0,98]
DK	-0,09	0,03	0,15**	0,0000002	0,66	-7,70	-7,30	44,71[0,00]**	41,17 [0,55]	27,28 [0,97]
FI	-0,14	0,01	0,07	0,06	0,51	1,66	2,05	84,09 [0,00]**	43,33 [0,46]	170,89 [0,64]
FR	-0,10	0,06	0,06	0,02	0,62***	0,67	1,06	91,05 [0, 00]**	48,71 [0,25]	40,34 [0,59]
EL	-0,25***	0,05	0,05	0,04	0,36	0,86	1,25	64,50 [0,00]**	37,03 [0,73]	23,12 [0,99]
IE	-0,07	0,11	-0,01	0,00	0,63	3,00	3,39	76,92 [0,00]**	39,73 [0,61]	65,52 [0,02]
IT	-0,27***	0,03	-0,0004	0,09***	0,74***	4,31	4,70	51,93 [0,00]**	38,64 [0,66]	25,69 [0,98]
LV	0,12	-0,01	0,17*	0,05	0,60***	14,63	15,02	143,30 [0,00]**	43,19 [0,46]	73,50 [0,003]
LT	0,08	0,08	-0,03	0,07	0,50**	-0,51	-0,12	24,50 [0,04]**	36,25 [0,76]	33,76 [0,84]
LU	-0,14	-0,01	-0,01	0,03	0,76***	-0,05	0,34	164,83 [0,00]**	40,70 [0,57]	15,83 [1,00]
HU	-0,43***	0,58***	-0,36***	0,00	0,62	18,34	18,73	138,18 [0,00]**	55,83 [0,09]	49,76 [0,22]

MT	-0,13	-0,003	-0,16**	0,07	0,00	2,53	2,92	47,34 [0,00]**	44,27 [0,42]	54,47 [0,11]
NL	-0,07	-0,01	-0,02	0,02	0,62***	-4,04	-3,65	72,82 [0,00]**	49,90 [0,22]	44,78 [0,40]
DE	0,35***	0,03	-0,01	0,09*	0,46**	3,72	4,11	30,04 [0,00]**	40,18 [0,60]	35,42 [0,79]
PL	-0,33***	0,35***	-0,32***	0,02	0,91***	5,10	5,50	13,66 [0,03]*	36,61 [0,74]	38,78 [0,65]
PT	-0,05	0,07	-0,04	0,002	0,23	2,72	3,11	85,56 [0,00]**	61,67 [0,03]	20,65 [1,00]
RO	-0,002	-0,01	-0,36***	0,02	0,31	8,72	9,13	140,10 [0,00]**	37,81 [0,70]	28,43 [0,96]
SI	-0,22**	-0,09	0,12	0,14**	0,44***	1,88	2,27	106,70 [0,00]**	49,62 [0,23]	29,39 [0,94]
SK	-0,33***	-0,04	-0,01	0,09**	0,55***	-1,66	-1,27	71,89 [0,00]**	32,84 [0,87]	23,98 [0,99]
ES	-0,19**	0,05	0,04	0,04	0,84***	-2,51	-2,12	23,14 [0,08]**	42,82 [0,48]	27,91 [0,96]
SE	0,01	-0,16*	-0,25***	0,05	0,40**	1,06	1,45	29,22 [0,01]**	53,59 [0,13]	43,65 [0,44]
UK	-0,09	-0,27***	0,10	0,004	0,78***	0,55	0,95	42,11 [0,00]**	36,45 [0,75]	21,11 [1,00]

Notes: *** Significant at 1 percent significance level. ** Significant at 5 percent significance level. * Significant at 10 percent significance level.

Source: Authors' calculations.

Table 2: Results of estimations of the MGARCH (1,1) model for government bond markets, stock markets, and foreign exchange markets of EU countries in the period from September 15, 2008, until December 31, 2016

	Multivariate GARCH (1,1) model Dynamic Correlation Model (Engle)									
Country	**Correlation coefficient between the government bond market and the stock market**	**Correlation coefficient between the government bond market and the foreign exchange market**	**Correlation coefficient between the stock market and the foreign exchange market**	α	β	**Information criteria (Akaike)**	**Information criteria (Schwarz)**	**Jarque–Bera test**	**Hosking Q(5)**	**Hosking (5)**
AT	-0,27***	-0,10	0,25**	0,03***	0,96	2,35	2,56	125,35 [0,00]**	38,79 [0,65]	26,40 [0,98]
BE	-0,28*	-0,15	0,22	0,02***	0,97***	2,51	2,73	110,28 [0,00]**	41,21 [0,55]	42,48 [0,49]
BG	-0,17***	-0,02	0,01	0,000003	0,85	-1,39	-1,15	1848,1 [0,00]**	190,91 [0,00]	60,30 [0,04]
CY	-0,20***	-0,17**	0,24***	0,05**	0,58*	0,64	0,85	1041,0 [0,00]**	34,53 [0,82]	43,69 [0,44]
CZ	-0,20 ***	-0,17**	0,24***	0,05**	0,58*	0,64	0,85	1041,0 [0,00]**	34,53 [0,82]	43,69 [0,44]
DK	-0,06	-0,05	-0,01	0,08	0,0002	-6,08	-5,87	273,77 [0,00]**	51,9 [0,17]	62,35 [0,03]
FI	-0,17	-0,02	0,15	0,03*	0,95***	3,32	3,54	118,10 [0,00]**	40,14 [0,60]	32,86 [0,87]
FR	-0,13	-0,08	0,21**	0,03**	0,96***	2,92	3,13	50,48 [0,00]**	35,85 [0,77]	65,67 [0,01]
EL	-0,48***	-0,17**	0,34***	0,11***	0,65***	6,53	6,79	269,92 [0,00]**	36,40 [0,75]	29,45 [0,94]
HR	0,01	0,12**	-0,07	0,0000009	0,65	1,34	1,71	37,33 [0,00]**	46,34 [0,34]	61,71 [0,03]
IE	-0,31***	-0,15**	0,04	0,03	0,94***	5,08	5,30	68,35 [0,00]**	46,62 [0,33]	51,19 [0,18]
IT	-0,44	-0,10	0,24	0,03***	0,97	7,90	8,11	181,19 [0,00]**	28,39 [0,96]	75,64 [0,002]
LV	-0,05	-0,15**	0,10*	0,02	0,83***	0,63	0,85	403,73 [0,00]**	42,44 [0,50]	24,92 [0,99]

LT	-0,09	-0,09	0,08	0,00	0,97***	0,42	0,63	3105,0 [0,00]**	46,79 [0,32]	48,23 [0,27]
LU	-0,18***	-0,09*	0,10*	0,0000006	0,77***	0,74	0,95	239,38 [0,00]**	56,42 [0,08]	42,05 [0,51]
HU	-0,45***	0,56***	-0,45***	0,01**	0,98***	19,16	19,38	38,02 [0,00]**	49,26 [0,24]	37,32 [0,72]
MT	-0,04	-0,20**	0,01	0,02**	0,94***	1,55	1,77	102,98 [0,00]**	27,63 [0,97]	32,96 [0,87]
NL	-0,12	-0,04	0,19	0,02***	0,97***	-2,50	-2,28	69,06 [0,00]**	43,38 [0,46]	37,64 [0,70]
DE	0,31***	0,24**	0,18**	0,04*	0,93***	5,06	5,28	43,20 [0,00]**	25,32 [0,99]	56,89 [0,08]
PL	-0,44***	0,48***	-0,54***	0,024952	0,85	4,85	5,07	25,82 [0,00]**	36,57 [0,74]	45,01 [0,39]
PT	-0,45***	-0,09	0,29***	0,03	0,94***	6,96	7,17	139,39 [0,00]**	30,27 [0,93]	26,90 [0,97]
RO	-0,18***	0,11**	-0,25***	0,02	0,85***	7,63	7,84	432,53 [0,00]**	59,62 [0,05]	26,41 [0,98]
SI	-0,07	-0,17***	0,20***	0,06	0,59*	1,97	2,22	95,59 [0,00]**	47,99 [0,28]	37,11 [0,72]
SK	-0,14	-0,15	0,15	0,05	0,90	-0,36	-0,14	268,41 [0,00]**	31,49 [0,90]	27,09 [0,97]
ES	-0,40**	-0,12	0,29**	0,02**	0,98***	2,15	2,40	93,12 [0,00]**	30,54 [0,92]	78,56 [0,001]
SE	0,06	-0,27***	-0,30***	0,004	0,98	3,56	3,80	56,24 [0,00]**	46,23 [0,34]	61,18 [0,04]
UK	0,04	-0,34***	0,04	0,01	0,97***	2,75	2,96	180,64 [0,00]**	47,79 [0,28]	49,27 [0,24]

Notes: *** Significant at 1 percent significance level. ** Significant at 5 percent significance level. * Significant at 10 percent significance level.

Source: Authors' calculations.

Table 3: Average volatility spillovers between government bond markets, stock markets and foreign exchange markets of European Union countries

Country	The percentage of spillover between the government bond market and the stock market in the period from January 1, 2005, to September 14, 2008	The percentage of spillover between the government bond market and the stock market in the period from September 15, 2008, until December 31, 2016	The percentage of spillover between the government bond market and the foreign exchange market in the period from January 1, 2005, to September 14, 2008	The percentage of spillover between the government bond market and the foreign exchange market in the period from September 15, 2008, until December 31, 2016	The percentage of spillover between the stock market and the foreign exchange market in the period from January 1, 2005, to September 14, 2008	The percentage of spillover between the stock market and the foreign exchange market in the period from September 15, 2008, until December 31, 2016.
AT	2,80	8,37	0,33	3,38	0,41	9,12
BE	5,45	12,97	0,53	5,53	0,70	8,94
BG	-	2,73	-	0,04	-	0,00
CY	5,37	4,15	0,49	3,31	0,41	6,28
CZ	10,92	6,25	9,63	1,89	6,74	5,24
DK	0,86	0,87	0,10	0,70	2,30	0,47
FI	2,35	5,31	0,38	1,14	0,94	4,33
FR	1,16	5,84	0,46	3,98	0,47	8,72
EL	6,20	23,46	0,37	4,16	0,42	13,51
HR	-	0,01	-	1,42	-	0,49
IE	0,50	10,74	1,13	2,85	0,00	1,54
IT	7,84	33,81	1,19	8,08	1,99	12,86
LV	1,35	0,38	0,00	2,38	3,21	1,21
LT	1,21	1,01	1,10	1,13	0,64	1,08
LU	2,22	3,14	0,19	0,74	0,30	1,08
HU	18,07	20,97	33,35	34,34	12,85	22,44

MT	2,02	0,64	0,41	5,40	2,96	0,85
NL	0,52	4,53	0,06	1,82	0,08	6,50
DE	12,68	11,84	1,00	9,16	0,98	5,98
PL	11,12	19,43	13,07	23,44	10,50	29,59
PT	0,30	23,01	0,51	1,86	0,19	10,01
RO	0,05	3,23	0,06	1,41	12,70	6,25
SK	11,56	5,53	1,20	4,62	0,97	5,27
SI	5,71	0,75	2,20	3,28	2,88	4,62
ES	4,02	26,62	1,11	8,35	0,92	15,43
SE	0,21	0,36	2,88	7,06	6,47	9,49
UK	0,83	0,50	7,06	11,63	0,94	0,69

Source: Authors' calculations.

The empirically performed MGARCH analysis results indicate a higher intensity, or mutual correlation, among these three markets in the second observed period for all analyzed countries, corresponding to the period following the onset of the global economic crisis. To provide a comprehensive analysis, it is also presented the averages of spillovers between the government bond market and the stock market, the government bond market and the foreign exchange market, and the stock market and the foreign exchange market (Table 3). These averages further demonstrate that volatility is higher in the second observed period for the all analyzed countries, after the onset of the global economic crisis.

In light of these findings, it is evident that the onset of the crisis significantly impacted the transmission of volatility between the government bond market, the foreign exchange market, and the stock market for European Union countries. Consequently, the results suggest an increased transfer of volatility among these markets in the period following the crisis.

CONCLUSION

Globalization of financial markets imposed the need to measure and examine the spread of volatility and shocks, i.e. contagion in financial markets. The issue itself, and the spread of contagion in the government bond markets, stock markets and foreign exchange markets has been insufficiently researched both in the international and domestic literature. Through a thorough analysis, this paper presents and explains the most important theoretical and empirical research on the effect of financial contagion.

Also, a detailed econometric analysis of conditional covariances and correlations over time suggest that there is a significant transfer of volatility between the government bond market, the stock market and the foreign exchange markets of the European Union countries.

Considering that the turning point on the global scene was the fall of Lehman Brothers, which is considered the official beginning of the crisis, the analysis is divided into two periods. In the first period, the interaction between the government bond market, the stock market, and the foreign exchange market was examined from January 1, 2005, to September 14, 2008. For the second period, the analysis covered September 15, 2008, to December 31, 2016. Based on the implemented multivariate GARCH models for both periods for all analyzed EU Countries, differences were observed, particularly showing higher dynamics in the second period, which followed the crisis.

Additionally, for the purpose of examination, the average volatility spillovers between these three markets before and after the start of the global financial crisis and its spillover to the countries of the European Union are given. What is evident is that the intensity, that is, the mutual correlation of these three markets is greater in the second observed period, that is, after the onset of the global economic crisis. From all of the above, it can be concluded that periods of crisis significantly affect the transfer of volatility between the government bond market, the foreign exchange market and the stock market for members of the European Union.

The theoretical and empirical conclusions of this research are certainly useful for researchers in terms of new knowledge presented about the phenomenon of financial contagion itself, and economic policymakers and regulators who should make additional efforts to prevent the recurrence and spread of financial contagion.

It should be noted that in modeling with multivariate GARCH models, it is recommended to use two to three variables. For this reason, the MGARCH model was estimated for each country in both the pre-crisis and post-crisis periods for the three markets of interest. In the future, it would be interesting to model the transfer of volatility of an individual financial market and, for example, the real estate market or the oil market.

Apendix

Table 1: Descriptive statistics of government bond spreads for EU countries from 2005 to 2016.

Country	Variable	Mean	Median	Max	Min	Standard deviation	Skewness	Excess kurtosis	Jarque-Bera (p- value)
AT	DSpread-AT	0,000	-0,002	0,40	-0,39	0,06	0,94	17,09	5263,77 (0,00)
BE	DSpread-BE	0,001	-0,002	0,41	-0,65	0,08	-0,11	17,64	5585,44 (0,00)
BG	DSpread-BG	0,000	0,000	2,40	-0,67	0,18	3,79	54,75	21,98 (0,00)
CY	DSpread-CY	0,001	0,008	1,08	-1,59	0,14	-2,86	44,77	46298,22 (0,00)
CZ	DSpread-CZ	0,000	-0,002	0,61	-0,34	0,09	0,97	9,21	1102,32 (0,00)
DK	DSpread-DK	0,000	0,000	0,19	-0,22	0,04	0,07	12,39	2294,37 (0,00)
FI	DSpread-FI	0,000	0,000	0,16	-0,14	0,03	0,69	7,97	693,23 (0,00)
FR	DSpread-FR	0,001	0,000	0,32	-0,46	0,05	-0,27	16,58	4813,67 (0,00)
EL	DSpread-EL	0,011	0,002	5,52	-12,57	0,76	-6,04	131,07	430944,80 (0,00)
HR	DSpread-HR	-0,001	0,001	0,77	-0,59	0,13	0,72	10,49	504,42 (0,00)
IE	DSpread-IE	0,001	-0,002	1,74	-1,69	0,20	0,15	24,08	11574,44 (0,00)
IT	DSpread-IT	0,000	0,006	3,39	-5,09	0,33	-2,87	129,07	414744,90 (0,00)
LV	DSpread-LV	0,000	-0,002	1,39	-2,12	0,22	-0,81	29,58	18467,88 (0,00)

LT	DSpread-LT	0,000	0,006	3,39	-5,09	0,33	-2,87	129,07	414744,90 (0,00)
LU	DSpread-LU	0,000	-0,002	0,57	-0,29	0,05	2,24	28,97	18088,14 (0,00)
HU	DSpread-HU	-0,001	-0,004	1,66	-1,66	0,24	0,29	13,02	2620,77 (0,00)
MT	DSpread-MT	-0,001	-0,002	0,27	-0,21	0,06	0,14	4,55	64,31 (0,00)
NL	DSpread-NL	0,000	0,000	0,17	-0,20	0,04	0,22	8,14	692,59 (0,00)
DE	DYield-DE	-0,006	-0,008	0,29	-0,27	0,08	0,11	3,82	18,88 (0,00)
PL	DSpread-PL	0,002	-0,008	0,81	-0,44	0,11	0,72	7,58	598,42 (0,00)
PT	DSpread-PT	0,006	0,002	1,83	-2,21	0,28	-0,55	15,89	4359,97 (0,00)
RO	DSpread-RO	0,001	0,004	3,48	-2,59	0,36	1,84	35,35	26994,36 (0,00)
SK	DSpread-SK	0,000	0,000	0,88	-0,83	0,12	-0,05	18,58	6323,23 (0,00)
SI	DSpread-SI	0,001	0,002	1,09	-0,70	0,15	1,09	13,86	3192,87 (0,00)
ES	DSpread-ES	0,002	0,000	0,64	-1,01	0,14	-0,95	14,67	3643,57 (0,00)
SE	DSpread-SE	0,000	-0,002	0,25	-0,22	0,05	0,38	5,89	232,61 (0,00)
UK	DSpread-UK	0,000	0,000	0,35	-0,34	0,07	0,13	7,23	468,52 (0,00)

Source: Authors' calculations.

Table 2: Descriptive statistics of stock indicies for EU countries from 2005 to 2016.

Country	Variable	Mean	Median	Max	Min	Standard deviation	Skewness	Excess kurtosis	Jarque-Bera (p- value)
AT	DEquity-AT	0,28	10,58	262,46	-456,39	80,34	-1,14	6,49	453,54 (0,00)
BE	DEquity-BE	0,99	8,92	235,78	-342,34	65,45	-0,90	5,58	256,91 (0,00)
BG	DEquity-BG	-0,06	0,14	115,28	-161,27	22,98	-1,17	17,42	5559,80 (0,00)
CY	DEquity-CY	-1,51	-0,12	334,95	-462,48	78,04	-1,21	10,95	1799,24 (0,00)
CZ	DEquity-CZ	-0,23	2,46	113,44	-182,16	29,40	-1,16	8,40	899,12 (0,00)
DK	DEquity-DK	0,95	2,25	60,17	-80,18	13,00	-0,93	9,20	1092,32 (0,00)
FI	DEquity-FI	4,24	23,49	576,52	-770,39	181,18	-0,73	4,54	117,38 (0,00)
FR	DEquity-FR	1,59	12,53	341,64	-504,77	94,52	-0,70	5,19	176,50 (0,00)
EL	DEquity-EL	-3,35	2,04	237,27	-401,59	72,41	-1,19	7,45	656,46 (0,00)
HR	DEquity-HR	0,68	-0,71	261,57	-455,72	66,72	-1,14	12,57	2518,14 (0,00)
IE	DEquity-IE	0,31	19,72	560,05	-666,68	130,23	-1,06	6,87	508,04 (0,00)
IT	DEquity-IT	-18,84	47,91	2133,80	-3265,00	596,80	-0,69	5,03	156,55 (0,00)
LV	DEquity-LV	0,51	0,82	68,13	-52,77	10,41	-0,36	10,75	1578,36 (0,00)
LT	DEquity-LT	0,40	0,52	47,93	-58,72	8,19	-1,03	11,74	2099,91 (0,00)
LU	DEquity-LU	0,62	4,51	131,48	-220,14	36,55	-1,18	7,62	699,42 (0,00)
HU	DEquity-HU	27,40	62,11	1975,03	-2728,87	554,02	-0,71	5,39	201,08 (0,00)
MT	DEquity-MT	2,48	-1,22	337,51	-334,08	60,05	0,15	8,88	901,87 (0,00)
NL	DEquity-NL	0,21	0,77	29,60	-43,28	8,68	-0,78	5,10	179,05 (0,00)
DE	DEquity-DE	11,48	25,51	660,87	-772,20	177,16	-0,71	5,39	201,79 (0,00)

PL	DEquity-PL	0,02	4,22	188,71	-275,64	64,29	-0,67	5,36	191,06 (0,00)
PT	DEquity-PT	-4,84	10,64	625,43	-1212,47	180,01	-1,05	7,64	675,75 (0,00)
RO	DEquity-RO	3,38	14,22	693,31	-793,58	171,62	-0,68	5,97	277,39 (0,00)
SK	DEquity-SK	0,49	1,50	26,75	-31,65	7,58	-0,52	4,37	77,21 (0,00)
SI	DEquity-SI	-0,33	0,58	148,11	-172,02	30,38	-1,16	11,83	1942,47 (0,00)
ES	DEquity-ES	-0,03	2,36	100,18	-115,31	26,54	-0,45	4,13	54,43 (0,00)
SE	DEquity-SE	1,24	4,05	80,03	-95,47	23,67	-0,43	4,18	55,75 (0,00)
UK	DEquity-UK	3,62	12,85	324,05	-544,89	106,54	-0,65	4,79	126,51 (0,00)

Source: Authors' calculations.

Table 3: Descriptive statistics of exchange rates for EU countries from 2005 to 2016.

Country	Variable	Mean	Median	Max	Min	Standard deviation	Skewness	Excess kurtosis	Jarque-Bera (p- value)
BG	DEX-BG	-6.4E-08	0.0E+00	2.4E-03	-2.4E-03	1.5E-04	1.2E-01	2.0E+02	9.9E+05 (0,00)
CZ	DEX-CZ	-5.4E-03	-2.6E-03	8.5E-01	-1.0E+00	1.8E-01	7.4E-02	7.9E+00	6.4E+02 (0,00)
DK	DEX-DK	-6.1E-06	2.0E-05	1.7E-02	-1.0E-02	2.1E-03	4.8E-01	1.2E+01	2.2E+03 (0,00)
Eurozone	DEUR-US	-4.5E-04	-3.6E-04	9.3E-02	-6.1E-02	1.5E-02	5.3E-02	5.8E+00	2.1E+02 (0,00)
HR	DEX-HR	-5.4E-05	2.0E-04	8.2E-02	-6.8E-02	1.8E-02	1.9E-01	4.5E+00	6.2E+01 (0,00)
HU	DEX-HU	1.0E-01	-3.6E-02	1.6E+01	-1.4E+01	2.9E+00	3.1E-01	6.2E+00	2.9E+02 (0,00)
PL	DEX-PL	5.0E-04	-9.0E-04	2.2E-01	-1.3E-01	4.2E-02	8.9E-01	7.3E+00	5.7E+02 (0,00)
RO	DEX-RO	1.0E-03	-5.0E-04	1.6E-01	-1.4E-01	2.7E-02	4.8E-01	8.1E+00	7.0E+02 (0,00)
SE	DEX-SE	9.2E-04	-6.0E-05	4.2E-01	-3.4E-01	7.3E-02	6.4E-02	7.3E+00	4.9E+02 (0,00)
UK	DEX-UK	2.4E-04	-1.8E-04	5.4E-02	-5.5E-02	8.1E-03	4.2E-01	1.1E+01	1.7E+03 (0,00)

Source: Authors' calculations.

LITERATURE

Alexakis, C., & Pappas, V. (2018). Sectoral dynamics of financial contagion in Europe-The cases of the recent crises episodes. *Economic Modelling, 73*, 222-239.

Arnerić, J. (2012). Modeliranje volatilnosti na financijskim tržištima. U *Matematički modeli u analizi razvoja hrvatskog financijskog tržišta.* Split: Ekonomski fakultet Sveučilišta u Splitu.

Baele, L. (2005). Volatility spillover effects in European equity markets. *Journal of Financial and Quantitative Analysis, 40*(2), 373-401.

Bekaert, G., & Harvey, C. R. (1997). Emerging equity market volatility. *Journal of Financial economics, 43*(1), 29-77.

Bekaert, G., Harvey, C. R., & Lundblad, C. (2005). Does financial liberalization spur growth?. *Journal of Financial economics, 77*(1), 3-55.

Calvo, S. G., & Reinhart, C. (1996). Capital flows to Latin America: is there evidence of contagion effects? *Available at SSRN 636120.*

Claessens, S., & Forbes, K. (2004). International financial contagion: The theory, evidence and policy implications. *In Conference "The IMF's role in emerging market economies: Reassessing the adequacy of its resources".* Amsterdam.

Dornbusch, R., Park, Y. C., & Claessens, S. (2000). Contagion: Understanding how it spreads 15(2), . *The World Bank Research Observer*, 177-197.

Enders, W. (2008). *Applied econometric time series.* John Wiley & Sons.

Engle, R. (2002). Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models. *Journal of business & economic statistics, 20*(3), 339-350.

Forbes, K., & Rigobon, R. (2001). Measuring contagion: conceptual and empirical issues. *In International financial contagion Boston,* , 43-66.

Hamao, Y., Masulis, R. W., & Ng, V. (1990). Correlations in price changes and volatility across international stock markets. *The review of financial studies, 3*(2), 281-307.

Han, K. C., Lee, S. H., & Suk, D. (2003). Mexican peso crisis and its spillover effects to emerging market debt. *Emerging Markets Review, 4*(3), 310-326.

Hung, N. T. (2019). Equity market integration of China and Southeast Asian countries: further evidence from MGARCH-ADCC and wavelet coherence analysis. *Quantitative Finance and Economics, 3*(2), 201-220.

Hung, N. T. (2022). Spillover effects between stock prices and exchange rates for the central and eastern European countries. *Global Business Review, 23*(2), 259-286.

Jurun, E., Pivac, S., & Arnerić, J. (2007). Historical and prognostic risk measuring across stocks and markets. *Journal of WSEAS Transactions on Business and Economic, 4*, 126-134.

Leung, H., Schiereck, D., & Schroeder, F. (2017). Volatility spillovers and determinants of contagion: Exchange rate and equity markets during crises. *Economic Modelling, 61*, 169-180.

Masson, M. P. (1998). *Contagion: Monsoonal effects, spillovers, and jumps between multiple equilibria.* International Monetary Fund.

Muratori, U. (2014). Contagion in the Euro area sovereign bond market. *Social Sciences, 4*(1), 66-82.

Palić, P., Posedel Šimović, P., & Vizek, M. (2017). The determinants of country risk premium volatility: Evidence from a panel VAR model. *Croatian Economic Survey, 19*(1), 37-66.

Posedel Šimović, P., Tkalec, M., & Vizek, M. (2015). Time-varying integration in European post-transition sovereign bond market. *Radni materijali EIZ-a, 1*, 5-36.

Pritsker, M. (2001). The channels for financial contagion. *In International financial contagion*, 67-95.

Silva, T. C., da Silva, M. A., & Tabak, B. M. (2017). Systemic risk in financial systems: a feedback approach. *Journal of Economic Behavior & Organization, 144*, 97-120.

Tai, C. S. (2007). Market integration and contagion: Evidence from Asian emerging stock and foreign exchange markets. *Emerging markets review, 8*(4), 264-283.

Wolf, H. (1999). International asset price and capital flow comovements during crisis: the role of contagion, demonstration effects, and fundamentals . *In World Bank/IMF/WTO conference on "Capital Flows, Financial Crises, and Policies"* (str. 15-16). In World Bank/IMF/WTO conference.