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Value-at-Risk with Application of DCC-GARCH Model

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Abstract

The article concentrates on modelling of volatility of capital markets and estimation of Value-at-Risk. The aim of the article is the description of volatility and interdependencies among three indices: WIG (Poland), DAX (Germany) and DJIA (United States). In order to measure the volatility and strength of interdependencies DCC-GARCH-In model was used, where an impact of the volatility of other markets is additionally taken into consideration during construction of the model. The conducted research for the years 2000-2012 confirmed the presence of interactions among selected capital markets. Next, the model DCC-GARCH-In was applied for evaluation of Value-at-Risk and the obtained measure was assessed with application of backtesting procedure. The results confirm that including volatility in the variance in DCC-GARCH-In model enables better assessment of VaR measure.

Key words

capital market, value-at-risk, backtesting, DCC-GARCH model, conditional variance

JEL Classification: G15, C58

1. Introduction

A research into the interdependences among capital markets should be treated as crucial scientific problem, since in current globalised economy a crisis situation in one country can spread geographically very quickly. Additionally, the disturbances occurring in the financial sphere can strongly affect the real economy. These factors can destabilise macroeconomic and institutional stability of countries (Balcerzak, 2009, 2015; Balcerzak & Pietrzak, 2015a, 2015b, 2016a, 2016b, 2016c; Pietrzak & Balcerzak, 2016; Balcerzak *et al*., 2016; Balcerzak & Rogalska, 2016) and threaten the sources of their international competitiveness (Balcerzak, 2016a, 2016b; Balcerzak & Pietrzak, 2016d, 2016e; Łapińska 2015; Pietrzak & Łapińska, 2015; Vitunskiene & Serva, 2015). Thus, identification of interrelations among markets is an essential problem in the risk management related to the functioning of capital markets (Bekaert & Wu, 2000; Pritsker, 2001; Forbes & Rigobon, 2002; Baur, 2003; Pericoli & Sbracia, 2003; Corsetti *et al*., 2005; Billio & Caporin, 2010; Heryán & Ziegelbauer, 2016; Fałdziński *et al*., 2016; Zineker *et al*., 2016; Pietrzak *et al*., 2017).

The objective of the research is to incorporate interdependence among markets for Value-at-Risk estimation. In the article the DCC-GARCH-In (In for interdependence) model is applied. The design of the model takes into account the impact of the volatility of other markets. The proposed model is an extended specification of the DCC-GARCH model. The extension refers to the determination of the level of interdependence between markets in volatility. In the article DCC-GARCH-In model was used for estimation of Value-at-Risk.

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Then, the measure was evaluated with application of backtesting procedure. The model was chosen due to its main advantages, which are the relatively easy parameters estimation and simple interpretation of results. The research was conducted for three indices DAX, DJIA, WIG for the years 2000-2012.

2. The DCC-GARCH-In model

GARCH class models enable the modelling of the conditional variance for individual indices. However, in the globalised economy modelling of individual indices disregarding potential influence form other markets can result in significant cognitive mistakes. In this regard one can use DCC-GARCH models that allows analysing interdependence among many markets by estimating the time-varying conditional correlation.

Fałdziński and Pietrzak (2015) proposed the DCC-GARCH-In model by taking into account the volatility of other markets in the conditional variance equation. This procedure allows to capture the interdependence between markets in volatility. The estimation of the DCC-GARCH-In model parameters can be carried out using the maximum likelihood method. Similar to the case of DCC-GARCH model, it is possible to use the two-stage estimation method proposed by Engle (2002, 2009). The application of DCC-GARCH-In model allows to capture the interdependencies in conditional variance, which is similar to the BEKK model. However, the main advantage of DCC-GARCH-In model is much easier procedure of estimation of the model parameters and the possibility to use the model for high number of processes (see more details in Fałdziński & Pietrzak, 2015).

The application of DCC-GARCH-In model to modelling volatility in the capital markets can be used for further analysis in the form of estimation of Value-at-Risk. The VaR measure is a key part of quantitative risk management. An important element of the analysis on the basis of VaR is the application of backtesting. This procedure allows to check correctness of calculating the value of measurement and simultaneously to choose the most precise method for their estimation. For most of the tests, the hit variable associated to the ex-post observation of α-VaR at the time t, denoted $I_t(\alpha)$, is defined as:

$$I_t(\alpha) = \begin{cases} 1 & r_t \leq -VaR_{t|t-1}(\alpha) \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

Therefore VaR can be tested using the violation sequence of $I_t(\alpha)$. As a part of the backtesting the three assumptions of process violations are tested:

1. Unconditional coverage (UC) (Kupiec, 1995)
   $P[I_t(\alpha) = 1] = \mathrm{E}[I_t(\alpha)] = \alpha$
2. Independence property (IND) (Christoffersen, 1998, Candelon *et al*., 2011)
   $I_t(\alpha)$ has to be independent i.e. $I_{t-k}(\alpha), \forall k \neq 0$
3. Conditional coverage (CC) (Christoffersen, 1998, Candelon *et al*., 2011)
   $I_t(\alpha) \overset{i.i.d.}{\sim} Bern(\alpha), \forall t$

Beside testing of process violations, additionally loss function can be used (Lopez, 1998). For backtesting binominal tests: the tests LRuc, LRind, LRcc (Christoffersen, 1998), tests Juc, Jcc (Candelon *et al*., 2011), and loss functions: QPS I (Lopez, 1998), QPS BI (Blanco & Ihle, 1998), LF (Angelidis & Degiannakis, 2006) and OLF can be used (Fałdziński, 2011).

3. Empirical research

In the empirical research we used time series for the three selected stock market indices - DAX, DJIA, WIG[6] for setting weight matrix adequate capitalization of stock markets. The weight matrix is used for estimation of parameters of DCC-GARCH-In model. We applied daily observations covering the period from 3 January 2000 to 3 January 2012, which gave a total of 3000 observations. The period allowed the consideration of two crisis episodes: a) the 2000-2002 dot-com bubble, b) the 2007-2009 global financial crisis. In the research the logarithmic returns were used.

In the estimation the maximum likelihood method with a conditional normal distribution was applied for both DCC-GARCH and DCC-GARCH-In models. Next the 2000 VaRs were estimated for last observations. We estimated risk measures forms for one day horizon as: $VaR_q^t = \mu_{t+1} + \delta_{t+1} Z_q$ where μ_{t+1} is one-day ahead prediction of conditional mean, δ_{t+1} is one-day ahead prediction of conditional volatility and Z_q is q-quantile of conditional distribution. We estimated Value-at-Risk for losses i.e. for coverage levels equal 99%, 95% and 90%.

Table 1. The assumed weight matrix based on the capitalization of stock markets for

Variable	$w_{i,1}$	$w_{i,2}$	$w_{i,3}$
WIG	0	0.0755	0.9244
DAX	0.0066	0	0.9933
DJIA	0.0758	0.9241	0

Source: own calculations.

Table 1 presents the weights matrix **W** determined by the capitalization of the stock markets. The procedure for setting the matrix **W** is presented by Fałdziński and Pietrzak (2015). The diagonal elements of the weights matrix equals zero. Due to the weight matrix **W** applied the GARCH part of the DCC-GARCH-In can be given as follow:

$$\begin{aligned} H_{WIG,t} &= \varpi_1 + \alpha_1 \eta_{t-1}^2 + \beta_1 H_{WIG,t-1} + \gamma_1 (0.0755 H_{DAX,t-1} + 0.9244 H_{DJIA,t-1}) \\ H_{DAX,t} &= \varpi_2 + \alpha_2 \eta_{t-1}^2 + \beta_2 H_{DAX,t-1} + \gamma_2 (0.066 H_{WIG,t-1} + 0.9933 H_{DJIA,t-1}) \\ H_{DJIA,t} &= \varpi_3 + \alpha_3 \eta_{t-1}^2 + \beta_3 H_{DJIA,t-1} + \gamma_3 (0.0758 H_{WIG,t-1} + 0.9241 H_{DAX,t-1}) \end{aligned} \quad (2)$$

where the remaining part of the DCC-GARCH-In model is the same as in the case of DCC-GARCH model.

Tables 2 contains the results of the estimation of the DCC-GARCH-In models parameters[7]. In the case of the three stock market indices used in the research, the constant was not taken into account in the conditional mean equation, since for each equation the constant was found to be statistically insignificant.

All the parameters both for the conditional variance equations, and for the conditional correlation equation were statistically significant. The sums of the parameters (α, β), (α_1, β_1), (α_2, β_2), (α_3, β_3) are lower than 1. Statistical significance of the parameters γ_i indicates the presence of interdependence in volatility among the markets. Additionally, we compared the DCC-GARCH model with the DCC-GARCH-In model using standard Lagrange Ratio test, but applying it only to the conditional variance equations. The obtained test statistic

[6] The data was downloaded from http://www.finance.yahoo.com.

[7] We use the two-stage estimation maximum likelihood method with a conditional normal distribution for both the DCC-GARCH and the DCC-GARCH-In models.

(LR=31.31 with *p*-value less than 0.001) means that the DCC-GARCH-In fits the data better than the standard DCC-GARCH model.

Table 2. The results of the estimation of the multivariate DCC-GARCH-In model parameters

The conditional variance equations			
Parameter	**Estimate**	**Std. error**	**p-value**
ω_1 (WIG)	0.017957	0.004676	0.0001
α_1 (WIG)	0.066567	0.006557	0.000
β_1 (WIG)	0.920289	0.007958	0.000
γ_1 (WIG)	0.00584	0.002468	0.018
ω_2 (DAX)	0.01974	0.010178	0.0525
α_2 (DAX)	0.102436	0.012405	0.000
β_2 (DAX)	0.839848	0.018576	0.000
γ_2 (DAX)	0.088134	0.020468	0.000
ω_3 (DJIA)	0.012442	0.003793	0.001
α_3 (DJIA)	0.088238	0.009006	0.000
β_3 (DJIA)	0.869189	0.014189	0.000
γ_3 (DJIA)	0.020493	0.004482	0.000
The conditional correlation equation			
Parameter	**Estimate**	**Std. error**	**p-value**
α	0.010785	0.002018	0.000
β	0.981799	0.003451	0.000

Source: own calculations.

Table 3. Backtesting results part I

Model	Time series	LRuc			LRind			LRcc		
		99%	95%	90%	99%	95%	90%	99%	95%	90%
DCC-GARCH-In	WIG	**18.546**	0.700	**6.814**	1.101	**8.576**	**3.984**	**19.647**	**9.276**	**10.798**
	p-value	**0.000**	0.403	**0.009**	0.294	**0.003**	**0.046**	**0.000**	**0.010**	**0.005**
	DAX	**6.141**	1.220	0.007	0.378	0.123	0.293	**6.519**	1.344	0.300
	p-value	**0.013**	0.269	0.935	0.539	0.725	0.588	**0.038**	0.511	0.861
	DJIA	**18.546**	1.220	**36.695**	0.016	0.568	0.243	**18.562**	1.789	**36.937**
	p-value	**0.000**	0.269	**0.000**	0.900	0.451	0.622	**0.000**	0.409	**0.000**
DCC-GARCH	WIG	**18.546**	0.273	**6.814**	1.101	**5.636**	**3.984**	**19.647**	5.908	**10.798**
	p-value	**0.000**	0.602	**0.009**	0.294	**0.018**	**0.046**	**0.000**	0.052	**0.005**
	DAX	**9.272**	1.010	0.020	0.214	1.423	1.214	**9.486**	2.433	1.234
	p-value	**0.002**	0.315	0.888	0.643	0.233	0.271	**0.009**	0.296	0.540
	DJIA	**14.254**	1.010	**36.695**	0.072	0.216	0.014	**14.326**	1.226	**36.709**
	p-value	**0.000**	0.315	**0.000**	0.789	0.642	0.905	**0.001**	0.542	**0.000**

Source: own calculations.

The estimation of parameters of the DCC-GARCH and the DCC-GARCH-In model enabled to assess VaR. For the obtained values the backtests LRuc, Lrind, LRcc, Juc, Jcc were applied. The results of the tests are given in table 3 and 4. With the coverage level 95% and

90% LRuc, Lrind, LRcc tests indicate that violations fulfil both assumptions, for the number of violations, and independence. The situation is different in the case of coverage level 99%, where the number of violations is not equal to the assumed one, but it was established that the violations are independent.

In the research also Juc, Jcc test were applied that are characterised with the higher power of the test and more appropriate test size. The results of the Juc and Jcc tests presented in table 4 are different form the once presented in table 3. In this case the number of violations is the same as assumed one. However, the assumption on the independence of violations is not fulfilled.

Table 4. Backtesting results part II

Model	**Test**	**Statistic**	**Simulated p-value (Dufour, 2006)**	**Test**	**Statistic**	**Simulated p-value (Dufour, 2006)**
DCC-GARCH	Juc(p=1)	3.176	0.078	Jind(p=1)	0.009	0.881
	Jcc(p=2)	12.760	0.010	Jind(p=2)	15.526	0.002
	Jcc(p=3)	19.448	0.010	Jind(p=3)	19.684	0.005
	Jcc(p=4)	20.905	0.010	Jind(p=4)	19.687	0.006
	Jcc(p=5)	21.043	0.014	Jind(p=5)	19.703	0.008
	Jcc(p=6)	21.079	0.016	Jind(p=6)	19.803	0.008
DCC-GARCH-In	Juc(p=1)	2.874	0.083	Jind(p=1)	0.009	0.874
	Jcc(p=2)	12.005	0.011	Jind(p=2)	14.488	0.003
	Jcc(p=3)	18.374	0.012	Jind(p=3)	18.613	0.006
	Jcc(p=4)	19.713	0.013	Jind(p=4)	18.618	0.007
	Jcc(p=5)	19.826	0.017	Jind(p=5)	18.637	0.009
	Jcc(p=6)	19.858	0.018	Jind(p=6)	18.730	0.010

Note: p denotes order of the orthonormal polynomials used in test statistics (see Candelon *et al*., 2011).
Source: own calculations.

Therefore, based on the backtests it can be concluded that both models (GARCH-DCC and GARCH-DCC-In) enabled to assess VaR with similar properties. Only taking into account the results of loss function leads to the conclusion on the advantage of GARCH-DCC-In model. This advantage is all the more visible, when the parameter γ_i is larger in absolute value, which is presented in table 5.

Table 5. Loss functions

Model	**Time series**	**QPS I**	**QPS BI**	**LF**	**OLF**
DCC-GARCH-In	WIG	**0.1102**	**0.0279**	**0.1279**	9.4680
	DAX	**0.1040**	**0.0327**	**0.1094**	10.3157
	DJIA	**0.1040**	**0.0395**	0.0901	**7.5089**
DCC-GARCH	WIG	0.1111	0.0286	0.1328	**9.4363**
	DAX	0.1049	0.0333	0.1116	**10.1884**
	DJIA	0.1049	0.0410	**0.0900**	7.5784

Note: Minimal values are made bold.
Source: own calculations.

4. Conclusions

In the globalised economy the identification of the interdependence among markets is an important research problem for risk management both from the macro and micro perspective. It is necessary for preparing strategies and scenarios for potential crisis situations.

In the current paper the application potential of DCC-GARCH-In model in multidimensional modelling of interdependencies among capital markets is presented. In current paper the application of DCC-GARCH-In model enabled to estimate Value-at-Risk with comparable statistical properties of the violations sequence, but with lower underestimation based on loss functions. The obtained results allow to conclude that taking into account of interdependencies in variances in DCC-GARCH-In model leads to better assessment of VaR measures.

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