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## **LINKAGES OF NATURAL GAS AND OIL FUTURES PRICES ON THE AMERICAN AND EUROPEAN DERIVATIVES MARKET**

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### **POWIĄZANIA POMIĘDZY CENAMI GAZU ZIEMNEGO I ROPY NAFTOWEJ NA AMERYKAŃSKIM I EUROPEJSKIM RYNKU TERMINOWYM**

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**Summary:** In recent years, the world natural gas market is changing mainly due to the wider access to LNG (Liquefied Natural Gas). This technology allows to trade between the market participants all over the world. The natural gas prices on the American and European market are benchmarked to Henry Hub and National Balancing Point (NBP) natural gas. The goal of this paper is to investigate whether the listings of natural gas in the derivatives markets are linked and to analyse the relationship between natural gas and crude oil prices. We show that the probability distribution of returns is not normal and that there is a strong ARCH effect. We use multivariate GARCH model to describe the linkages between several series. We take into account two return series of natural gas futures contracts (Henry Hub and National Balancing Point) and two returns series of crude oil futures contracts (West Texas Intermediate and Brent) to measure the strength of linkages across two commodity markets of the most important fossil fuels.

**Keywords:** natural gas, crude oil, derivative market, constant conditional correlation model.

**Streszczenie:** Światowy rynek gazu ziemnego zmienia się w ostatnich latach. Przyczyną tych zmian jest coraz szerszy dostęp do skroplonego gazu LNG (Liquefied Natural Gas). Większa liczba terminali LNG umożliwia zawieranie transakcji pomiędzy uczestnikami rynku z całego świata. Benchmarkiem cenowym dla rozpatrywanego surowca w Stanach Zjednoczonych i w Europie jest gaz ziemny Henry Hub oraz gaz National Balancing Point (NBP). Celem artykułu jest zweryfikowanie, czy ceny gazu ziemnego dla USA oraz Europy na rynku terminowym są ze sobą powiązane oraz zbadanie siły zależności pomiędzy cenami terminowymi gazu ziemnego i ropy naftowej. Na podstawie analizy szeregów czasowych stwierdzamy, że rozkład badanych zwrotów nie jest normalny, oraz że występuje silny efekt ARCH. Do opisu dynamiki badanych szeregów wykorzystujemy wielowymiarowy model

GARCH, pozwalający na oszacowanie siły zależności warunkowych. Oprócz szeregów zwrotów z notowań gazu Henry Hub i NBP uwzględniamy w badaniu szeregi zwrotów z notowań ropy naftowej West Texas Intermediate oraz Brent, by zmierzyć siłę powiązań pomiędzy dwoma najważniejszymi surowcami energetycznymi.

**Słowa kluczowe:** gaz ziemny, ropa naftowa, rynek terminowy, model stałych korelacji warunkowych.

## 1. Introduction

Natural gas is one of the most traded commodities in the world, but historically the world trading markets were regionalized. The world natural gas market is changing mainly due to the wider access to LNG (Liquefied Natural Gas). A conversion of a natural gas to a liquid form allows to simplify storage and transport of this commodity and to trade between the partners from different parts of the globe. Yet the price difference between the United States, Europe and Asia is still large due to the region-specific factors affecting supply and demand and because of the high liquefaction, shipping and regasification costs.

Natural gas market attracts investors looking for opportunities to earn money. There are many ways to invest in the natural gas market. Two of the widely used instruments are Henry Hub and National Balancing Point futures contracts.

Henry Hub (HH) Natural Gas Futures is one of the largest physical commodity futures contracts in the world by volume and allows the investors to manage risk resulting from very volatile natural gas prices. The delivery point is at Henry Hub in Louisiana. It is traded via open outcry and electronically using CME-Globex. The contract size is 10 000 mm Btu and is priced in USD. The price of Henry Hub natural gas is commonly regarded as the benchmark for the United States.

National Balancing Point (NBP) Natural Gas Futures is another physical commodity futures contract. The delivery point is at the NBP Virtual Trading Point. The contract size is 1000 therms per day per delivery period and is priced in GBP.

Historically the price of natural gas and the crude oil prices have moved together. Schofield [2007] enumerates several reasons for this situation. Early natural gas finds in Europe were valued based on fuels like crude oil, which commercial and domestic consumers had used prior. Also, today some end users (such as electricity generators and iron, steel, and paper mills) can switch between natural gas and petroleum, depending on the cost of each fuel, so relative pricing seems to be important.

The results of previous works support the presence of a cointegrating relationship between the crude oil and natural gas price time series, providing evidence that WTI crude oil and Henry Hub natural gas prices have a long-run relationship [Villar, Joutz 2006]. Marzo and Zagaglia [2008] modelled the joint movements of daily returns on one-month futures for crude oil, heating oil and natural gas with a multivariate GARCH with dynamic conditional correlations using data between November 1,

1990 and November 22, 2005. They found that at daily frequency the conditional correlation between the futures prices of natural gas and crude oil was weak on average over two thirds of the sample, but it was rising over the last 5 years of the examined period. They concluded that futures markets have no established tradition of pricing natural gas as a function of the developments in oil markets at a daily frequency. Efimova and Serletis [2014] investigated the empirical properties of oil, natural gas and electricity wholesale price volatilities using a range of univariate and multivariate GARCH models and daily data for the period from 2001 to 2013. They found that price spill-overs are rather unidirectional, suggesting the existence of a hierarchy of influence from oil to gas and electricity markets. They showed the oil-gas correlations decreased during times of recession or slow economic growth, specifically, 2003-2005 and 2009-2010 and the decrease in the correlation between oil and gas since 2011.

Another aspect of our analysis is the issue of the relations between the natural gas prices in different parts of the world. Some of the previous studies of the natural gas markets have shown the lack of cointegration between the prices in United States and Europe. Siliverstovs et al. [2005] investigated the degree of integration of natural gas markets in Europe, North America and Japan. The relationship between international gas market prices and their relation to the oil price were explored through principal component analysis and Johansen likelihood-based cointegration procedure. Obtained results suggest that the European and the North American markets were not integrated in the time period between the early 1990s and 2004. Neumann [2009] investigated price dynamics covering the period from 1999 until 2008 using daily spot prices for natural gas in North America and Europe. Results of the analysis using Kalman Filter technique suggest an increasing convergence of natural gas spot prices. Brown and Yücel [2009] used bivariate causality tests between the weekly Henry Hub and NBP prices of natural gas and showed bidirectional causality, indicating coordinated movement in natural gas prices across the Atlantic. They concluded that the possibility that the coordination of natural gas prices across the Atlantic could be facilitated through co-movements with crude oil prices.

Li, Joyeux and Ripple [2014] examined the relationships between the North American, European and Asian natural gas markets for evidence of convergence and integration for the January 1997 through May 2011 period. The analyses were conducted under a multivariate framework. They found evidence of convergence among the Asian and UK prices. The North American gas price displays distinctive behaviour. They concluded that there is not a fully integrated international natural gas market and that the integration between Europe and Asia appears to be due mechanisms linking natural gas prices to oil prices rather than the result of market supply and demand interactions. Geman and Liu [2015] investigated whether the US and UK gas markets are moving towards integration. Using the cointegration of the Henry Hub and National Balancing Point indexes for the period January 2005 to April 2014 they concluded that there is no convergence between the two markets.

Following the question by Neumann [2009] of whether LNG is playing its part in integrating international gas market, in our study we undertake to check what is the current situation on the two natural gas markets and to investigate whether the daily listings of natural gas in the derivatives markets are linked to each other. We also examine whether the strength of linkages with oil market is significant after the 2013 year, ending the period analysed by Efimova and Serletis [2014]. For this purpose, we use multivariate GARCH framework to describe the linkages between daily returns series.

Our results are significant for several reasons. Correlations are important for many of the tasks of financial management. Engle [2002] enumerates some examples of correlation applications: estimates of the correlation between the returns are required by hedges, a forecast of future correlations and volatilities is the basis of pricing formula, asset allocation and risk assessment rely on correlations, construction of an optimal portfolio requires a forecast of the covariance matrix of the returns.

The structure of the article is as follows. First, we describe the methodology: a multivariate CCC-GARCH model and the two constant conditional correlation tests. Then we examine basic properties of selected series and present the estimation results. Finally, Section 4 concludes our findings.

## 2. Constant conditional correlation model

Let  $\mathbf{r}_t = (r_{1,t}, r_{2,t}, \dots, r_{n,t})'$  denote a multivariate time series of returns with the following decomposition:

$$\mathbf{r}_t = \boldsymbol{\mu}_t + \mathbf{y}_t,$$

where  $\boldsymbol{\mu}_t = E(\mathbf{r}_t | \mathcal{F}_{t-1})$  is a conditional mean,  $\mathcal{F}_{t-1}$  is the information set available at time  $t - 1$ . Conditional expected value  $\boldsymbol{\mu}_t = (\mu_{1t}, \mu_{2t}, \dots, \mu_{nt})'$  can be modelled simply by using univariate ARMA( $p, q$ ) model for each conditional mean  $\mu_{it}$ :

$$\mu_{i,t} = a_{i,0} + \sum_{j=1}^p a_{i,j} r_{i,t-j} - \sum_{j=1}^q b_{i,j} y_{i,t-j}.$$

A general multivariate GARCH model for  $\mathbf{y}_t$  is given by equation:

$$\mathbf{y}_t = \mathbf{H}_t^{\frac{1}{2}} \boldsymbol{\varepsilon}_t,$$

where  $\boldsymbol{\varepsilon}_t$  is an  $n$ -dimensional i.i.d. process with zero mean and identity covariance matrix and  $\boldsymbol{\varepsilon}_t \sim iid(\mathbf{0}, \mathbf{I}_n)$ ,  $\mathbf{H}_t^{\frac{1}{2}}$  is a  $n \times n$  matrix satisfying  $\mathbf{H}_t^{\frac{1}{2}} \cdot \mathbf{H}_t^{\frac{1}{2}} = \mathbf{H}_t$ ,  $E(\mathbf{y}_t | \mathcal{F}_{t-1}) = \mathbf{0}$  and  $E(\mathbf{y}_t \mathbf{y}_t' | \mathcal{F}_{t-1}) = \mathbf{H}_t$ .

Specific multivariate GARCH model is specified by parametrization of positive definite covariance matrix  $\mathbf{H}_t$ . The Constant Conditional Correlation CCC-GARCH model was proposed by Bollerslev [1990]. It is the class of multivariate time series models with time varying conditional variances and covariances, but constant conditional correlations. The following equation defines the CCC model:

$$\mathbf{H}_t = \mathbf{D}_t \mathbf{R} \mathbf{D}_t = (\rho_{ij} \sqrt{h_{ii,t} h_{jj,t}}),$$

where  $\mathbf{D}_t = \text{diag}(\sqrt{h_{11,t}}, \dots, \sqrt{h_{nn,t}})$ ,  $\mathbf{R} = (\rho_{ij})$  is an  $n \times n$  time invariant, positive definite matrix containing the constant conditional correlations. The model has a GARCH(1,1) specification for each conditional variance in  $\mathbf{D}_t$ :

$$h_{ii,t} = \omega_{i,t} + \alpha_i y_{i,t-1} + \beta_i h_{i,t-1}.$$

More general is a Dynamic Conditional Correlation (DCC) GARCH model proposed by Tse and Tsui [2002] and Engle [2002]. The model introduced by Engle [2002] and corrected by Aielli [2013] has the following specification:

$$\begin{aligned} \mathbf{H}_t &= \mathbf{D}_t \mathbf{R}_t \mathbf{D}_t, \\ \mathbf{Q}_t &= (1 - \alpha - \beta) \bar{\mathbf{Q}} + \alpha \mathbf{u}_{t-1}^* \mathbf{u}_{t-1}' + \beta \mathbf{Q}_{t-1}, \\ \mathbf{R}_t &= (\text{diag}(\mathbf{Q}_t))^{-1/2} \mathbf{Q}_t (\text{diag}(\mathbf{Q}_t))^{-1/2}, \end{aligned}$$

where  $\bar{\mathbf{Q}}$  is the unconditional variance matrix of  $\mathbf{u}_t^* = \mathbf{P}_t \mathbf{u}_t$  and  $u_{it} = \frac{y_{it}}{\sqrt{h_{ii,t}}}$ .

The validity of the assumption that conditional correlations are constant remains an empirical question. Some tests that verify this assumption have been proposed in the literature. Tse's [2000] and Engle and Sheppard's [2001] test are a common choice with the constant conditional correlations null hypothesis.

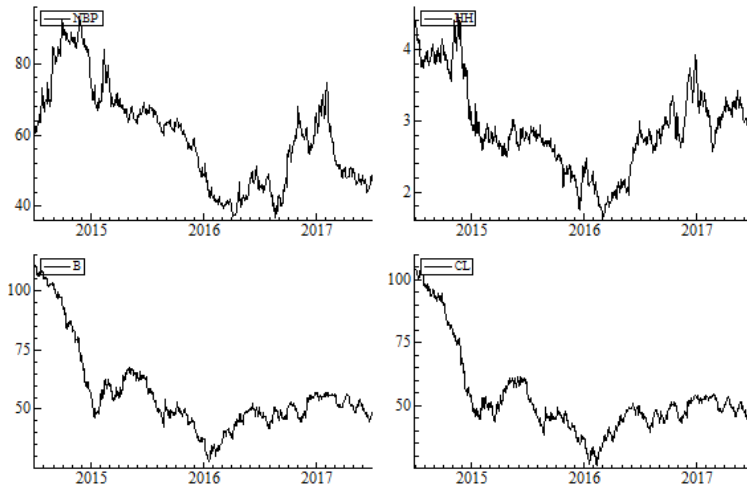
Tse [2000] proposes a test with null hypothesis  $h_{ij,t} = \rho_{ij} \sqrt{h_{ii,t} h_{jj,t}}$ , the alternative is  $h_{ij,t} = \rho_{ij,t} \sqrt{h_{ii,t} h_{jj,t}}$ . The distribution of the LM test statistic under the null hypothesis is  $\chi^2 \left( \frac{n(n-1)}{2} \right)$ .

Engle and Sheppard [2001] introduce a test with  $H_0: \mathbf{R}_t = \bar{\mathbf{R}}, t = 1, \dots, N$  and  $H_1: \text{vech}(\mathbf{R}_t) = \text{vech}(\bar{\mathbf{R}}) + \beta_1 \text{vech}(\mathbf{R}_{t-1}) + \dots + \beta_p \text{vech}(\mathbf{R}_{t-p})$ , where  $\text{vech}(\mathbf{R}_t)$  denotes half-vectorization of the matrix  $\mathbf{R}_t$ . Let  $\mathbf{Y}_t = \text{vech}^u \left( \left( \bar{\mathbf{R}}^{-\frac{1}{2}} \mathbf{D}_t^{-1} \mathbf{y}_t \right) \left( \bar{\mathbf{R}}^{-\frac{1}{2}} \mathbf{D}_t^{-1} \mathbf{y}_t \right)' - \mathbf{I}_n \right)$ , where  $\text{vech}^u$  denotes the operator that selects the elements above the main diagonal. The null hypothesis implies that coefficients in the regression  $\mathbf{Y}_t = \alpha + \beta_1 \mathbf{Y}_{t-1} + \dots + \beta_p \mathbf{Y}_{t-p} + \boldsymbol{\eta}_t$  are equal to zero. The test statistic  $\frac{\hat{\boldsymbol{\delta}}' \mathbf{X}' \mathbf{X} \hat{\boldsymbol{\delta}}}{\hat{\sigma}^2}$  is asymptotically  $\chi^2(p+1)$ , where  $\hat{\boldsymbol{\delta}}$  are the estimated regression  $\mathbf{Y} = \mathbf{X} \boldsymbol{\delta} + \mathbf{e}$  parameters and  $\mathbf{X}$  is a matrix consisting of the regressors.

### 3. Data summary and empirical results

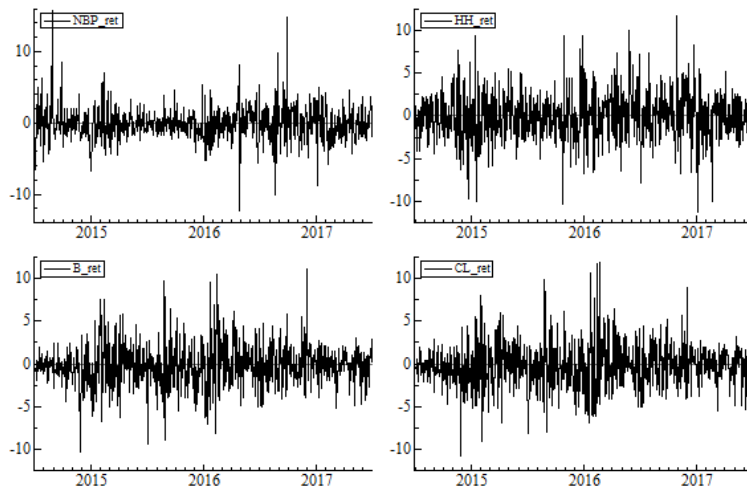
For the natural gas and crude oil futures contracts we take the daily prices in the period from July 1, 2014 to June 30, 2017. We use the data only from high volatility period, when oil and gas prices were falling and remained low, to avoid structural

breaks in the series. On the other hand, we use nearly 750 observations, so the length of the series is sufficient to apply a multivariate GARCH model.



**Fig. 1.** The price of two natural gas and two crude oil futures contracts

Source: own study.



**Fig. 2.** The returns of two natural gas and two crude oil futures contracts

Source: own study.

Figure 1 presents the prices of two natural gas and two crude oil futures contracts in selected period. Because the National Balancing Point (NBP) futures contract is

denominated in GBP, we convert the prices using historical USD/GBP exchange rates and due to this modification, all prices are denominated in USD. We examine the percentage logarithmic returns calculated by  $r_t = 100 \cdot \ln\left(\frac{p_t}{p_{t-1}}\right)$ , where  $p_t$  is the price of a contract at the time  $t$ . Figure 2 presents the returns series of selected futures contracts. The NBP and HH returns series have different dynamics. As we can see, the HH returns series is more volatile than NBP's.

We conduct the Box-Pierce tests to check whether there are some significant autocorrelations in returns series and to detect the ARCH (autoregressive conditional heteroscedasticity) effect. Table 1 contains the results of the Box-Pierce tests. The large  $p$ -values suggest that there is no significant autocorrelation in HH series. Using the results of similar tests for squared returns we conclude that there is an ARCH effect in all the series.

**Table 1.** The results of Box-Pierce test

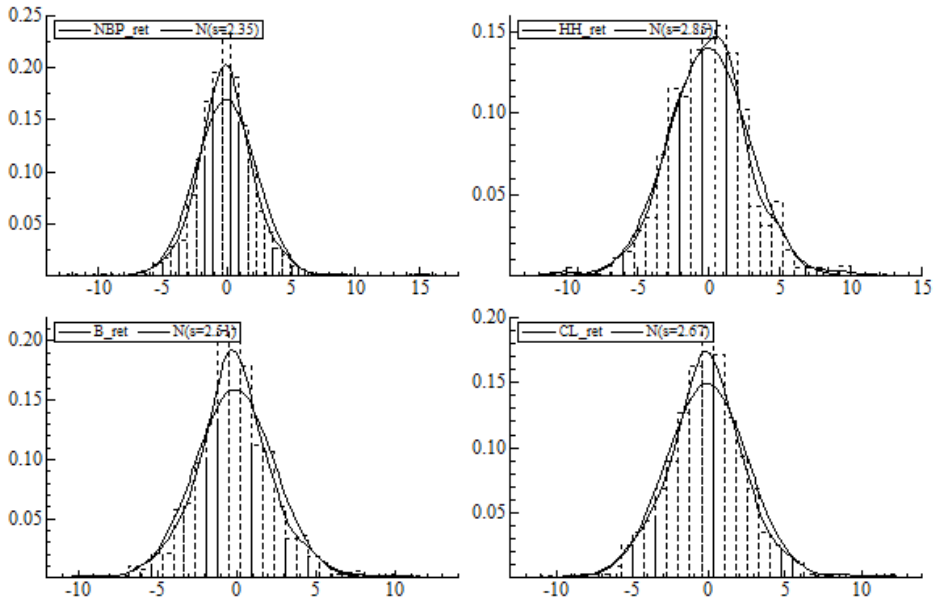
	NBP	HH	B	CL
	P-values from Box-Pierce tests H0: No autocorrelation in returns			
lag=5	0.2067	0.2067	0.2067	0.2067
lag=10	0.0146	0.0146	0.0146	0.0146
	P-values from Box-Pierce tests on squared returns H0: No autocorrelation in squared returns			
lag=5	0.0450	0.0450	0.0450	0.0450
lag=10	0.0760	0.0760	0.0760	0.0760

Source: own study.

Figure 3 presents the kernel estimators of the density of four daily returns series. The distribution of NBP is non-Gaussian, sharp peaked and heavy tailed. The visual inspection of the kernel estimator of density of the HH series suggests that the distribution is close to Normal, but the results of the formal Jarque-Bera [1987] test, reported in Table 2, indicate that the HH and other returns are not normally distributed.

We estimate the multivariate AR(1)-CCC-GARCH(1,1) model with Student's  $t$ -distribution. The value of the parameter  $\rho_{NBP,HH}$  between the daily returns for two natural gas markets is statistically insignificant. Our results suggest that the daily natural gas returns on the two markets in the analysed period are not correlated. The impact of using LNG on the integration of international gas market is rather limited.

A more interesting result is that NBP and HH natural gas futures contract are both correlated with the listings of crude oil CL and B. The estimates of the correlation parameters  $\rho_{NBP,CL}$ ,  $\rho_{NBP,B}$  and  $\rho_{HH,CL}$ ,  $\rho_{HH,B}$  are significant. This suggests that the natural gas derivatives market investors ascribe some importance to the situation on the crude oil futures markets. We find that conditional correlation coefficient between crude oil and natural gas daily returns in Europe and USA is significant and



**Fig. 3.** The empirical distribution of returns of two natural gas and two crude oil futures contracts with normal reference

Source: own study.

**Table 2.** The results of Jarque-Bera normality test

Series	NBP	HH	B	CL
Skewness	0.5941	0.0564	0.2655	0.3279
Excess Kurtosis	6.2206	1.3133	2.0745	1.9562
Jarque-Bera test statistic	1260.0000	54.5860	144.0600	133.7300

Source: own study.

equals nearly 0,2 in examined period. The level of the linkages at the daily frequency seems to be low, confirming the results of earlier studies (compare [Marzo, Zagaglia 2008] and [Efimova, Serletis 2014]).

The results of the Box-Pierce tests posted in Table 3 suggest that our model describes most of the existing dependencies. Only for the CL returns series we still observe an ARCH effect in the standardized residuals.

We also check the validity of the assumption, that conditional correlations are constant in the selected period. Using the results of Tse [2000] and Engle and Shephard [2001] tests posted in Table 4 we conclude that correlations are in fact time-invariant in the period from July 2014 to June 2017. There is no need to use a more



sophisticated and parameterized dynamic conditional correlation DCC model developed by Engle [2002] or Tse and Tsui [2002]. We check the estimation of DCC-GARCH model and the indications of information criteria (not reported here). The optimal model is CCC-GARCH.

**Table 3.** The estimation results of AR(1) – CCC-GARCH(1,1) model and the results of Box-Pierce tests on standardized residuals

Parameter	NBP	HH	B	CL
$\alpha_1$	0.0831** (0.0373)	-0.0481 (0.0331)	-0.0476* (0.0280)	-0.0494* (0.0280)
$\omega$	0.0983 (0.0718)	0.2449 (0.1251)	0.1113 (0.0558)	0.1428 (0.0579)
$\alpha$	0.0756 ** (0.0307)	0.0422*** (0.0122)	0.0646*** (0.0184)	0.0673*** (0.0170)
$\beta$	0.9081 *** (0.0369)	0.9319 *** (0.0202)	0.9225*** (0.0218)	0.9162*** (0.0196)
DF	6.8277 (0.7710)			
	Correlations $\rho_{i,j}$			
	HH	B	CL	
NBP	0.0504 (0.0402)	0.1603*** (0.0361)	0.1869*** (0.0355)	
HH		0.1736*** (0.0356)	0.1767*** (0.0367)	
B			0.9354*** (0.0061)	
	P-values from Box-Pierce tests H0: No autocorrelation in standardized residuals			
	NBP	HH	B	CL
lag=5	0.9503	0.4430	0.0825	0.7109
lag=10	0.3807	0.1629	0.1938	0.8460
	P-values from Box-Pierce tests H0: No autocorrelation in squared standardized residuals			
lag=5	0.7662	0.3505	0.9763	0.0138
lag=10	0.9757	0.4324	0.9606	0.0607

\* The significance of the parameters  $\alpha$  and  $\beta$  estimates and correlations  $\rho_{i,j}$  is tested, \*\*\* denotes the level of significance at 1%, \*\* denotes the level of significance at 5%, \* denotes the level of significance at 10%.

Source: own study.

**Table 4.** The results of constant conditional correlation tests

Name of the test	Tse	Engle and Sheppard	
		$p = 5$	$p = 10$
p-value	0.2892	0.7892	0.4510

Source: own study.

## 4. Conclusion

The goal of the paper was to investigate whether the listings of natural gas and crude oil in the derivatives markets are linked. We checked that the probability distribution of returns was not normal and that there was a strong ARCH effect. Using the multi-variate CCC-GARCH model we described the linkages between several series. We took into account two returns series of natural gas futures contracts (Henry Hub and National Balancing Point) and two returns series of crude oil futures contracts (West Texas Intermediate and Brent) to measure the strength of the linkages across the two most important fossil fuels. We show that the conditional correlation between the daily returns on NBP and HH is insignificant. Instead, we affirmed the existence of a significant, but rather low linkages among the natural gas and crude oil daily returns for the European and American market.

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