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AN ANALYSIS OF COAL AND OIL PRICE TRANSMISSION TO NATURAL GAS PRICE VOLATILITY

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Abstract

This study aims to analyze the causes of price volatility transmission between natural gas and substitute energy commodities in different markets after accounting the natural gas price interdependency. Besides, it is intended to contribute to the understanding of natural gas price volatility and transmission of price volatility in energy markets and present empirical findings by applying DCC-GARCH model to the system of recent natural gas, oil, and coal price data that would be of use to academic literature as well as energy market participants, international trade parties, and policymakers. The oil and coal are substitutes for natural gas, so as the prices of the substitutes change, they affect the price and volatility of natural gas. Hence, the examination is carried out with National Balancing Point, Henry Hub, Title Transfer Facility, Zeebrugge Hub, and Japan Korean Marker prices as endogenous set of natural gas variables with prices of Brent Oil, West Texas Intermediate Oil, and Newcastle Coal as exogenous variables. Accordingly, coal prices are found to be more effective in terms of natural gas price volatility as a substitute, and the higher the coal prices, the higher the volatility of the natural gas prices. These findings are also compatible with the other exogenous variables of oil prices, but the relationship is more effective in coal prices because natural gas mainly replaces coal as a close substitute. This situation creates a source of perception in terms of pricing and price fluctuations concerning volatility in natural gas markets.

Keywords: *Energy Economics, DCC-GARCH Model, Natural Gas, Energy Commodity Substitutes, Price Volatility.*

KÖMÜR VE PETROL FİYATLARININ DOĞAL GAZ FİYAT OYNAKLIĞINA AKTARIMININ ANALİZİ

Öz

Bu çalışma, enerji emtia fiyatlarının karşılıklı bağımlılığının hesaba katılması ile farklı piyasalardaki doğal gaz ile ikame enerji ürünleri arasındaki fiyat oynaklığı aktarımının nedenlerini incelemeyi amaçlamaktadır. Ayrıca, akademik yazın, enerji piyasası aktörleri, uluslararası ticaret tarafları ve politika yapıcılar açısından enerji piyasalarındaki fiyat oynaklığı ve fiyat oynaklığının aktarımının anlaşılmasına katkıda bulunabilmek adına güncel doğal gaz, petrol ve kömür fiyatı verilerinden

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oluşan sisteme DCC-GARCH modeli uygulanarak ampirik bulgular sunulması amaçlanmıştır. Petrol ve kömürün doğal gaz ile yakın ikâmeler olması sebebiyle ilgili enerji emtialarının fiyatlarında meydana gelen değişimler, doğal gaz fiyatlarını ve oynaklığını etkilemektedir. Bu nedenle çalışmada, National Balancing Point, Henry Hub, Title Transfer Facility, Zeebrugge Hub ve Japan Korean Marker doğal gaz fiyatları içsel fiyat değişkenleri iken Brent Petrol, West Texas Intermediate Petrol ve Newcastle Coal Kömür fiyatları dışsal değişkenler olarak belirlenmiştir. Gerçekleştirilen ampirik analize göre, ikâme olarak kömür fiyatlarının doğal gaz fiyatlarındaki oynaklık açısından daha etkili olduğu ve kömür fiyatları yükseldikçe doğal gaz fiyatlarındaki oynaklığın da arttığı tespit edilmiştir. Ayrıca, ilgili bulguların diğer dışsal değişkenler olan petrol emtialarının fiyatları ile de uyumlu olduğu gözlemlenirken, doğal gazın esas olarak kömür ile yakın ikâme olması sebebiyle bu ilişkinin kömürde daha etkili olduğu sonucuna varılmıştır. Bu durum, doğal gaz piyasalarındaki fiyatlama ve oynaklığa ilişkin fiyat dalgalanmaları açısından bir bakış açısı kaynağı oluşturmaktadır.

Anahtar Kelimeler: *Enerji Ekonomisi, DCC-GARCH Modeli, Doğal Gaz, İkâme Enerji Emtiaları, Fiyat Oynaklığı.*

Introduction

Energy has always been a crucial need for humanity. Throughout history, one of the focal areas of many political conflicts has been generating energy from various sources such as crude oil, natural gas, coal, solar, wind, and water (U.S.D.E., n.d.). Since all these sources exist in nature, human activity is focused on generating energy from them. Similarly, obtaining a reliable and secure energy supply has changed countries' political and economic approaches. In terms of demand and supply for the main subject of the study, that is natural gas, there are two major areas of inquiry for the prices. Natural gas prices are perceived to be mainly associated with oil and coal prices from the supplier side. In contrast, from the consumer side, it is observed on the side of the demand of the industry, housing, and electricity production concerns. Actually, the global importance of natural gas energy commodity began to increase after the 1980s. Along with industrial utilization, several other uses of sectors have evolved, driving up natural gas demand even more. Nonetheless, the role of pipelines in transporting natural gas has increased in the scope of technological progress at the time, and the perception of natural gas has thus become an instrument for policy beyond borders. Eventually, this issue stimulated the transformation of international natural gas trade into a fact that is both an economic activity and a topic of international policy. Additionally, aspects such as natural gas pricing, contract types, duration, and terms of trade contracts have become more of a global political economy issue than a commercial one. Some producers have used this power as a policy instrument for importing countries with significant energy constraints, and consequently, these countries have pursued several strategies. One of the most effective outcomes of this effort was the idea of Liquefied Natural Gas (LNG). Therefore, a gas trading potential for reaching distant demanders and new markets has emerged with the arrival of LNG while importing economies maintained diverse resources. (Şahin, 2021)

Natural gas commodity contracts are indeed the outcome of market circumstances associated with the regional pricing mechanism that differs across the major international markets where natural gas prices are determined and traded. As a result, one must first grasp the natural gas pricing methodology before evaluating natural gas contracts. It differs between the major global marketplaces where natural gas is priced and traded. Moreover, as natural gas transforms into a more significant source of energy, natural gas pricing models are becoming increasingly important for demanders, suppliers, and policymakers. Therefore, examining the factors affecting the price and price volatility is of great importance for the whole global economy.

Regarding trade and natural gas pricing, hubs are essential for the industry. A hub is a geographic area where numerous trade parties exchange services. Correspondingly, the principal US gas hub is Henry Hub (NGO), the UK gas hub is National Balancing Point (NBP), and there are other gas hubs in North West Europe, such as Zeebrugge (ZEE) (Belgium), Title Transfer Facility (TTF) (Holland), NetConnect Germany (NCG) (Germany), PEGs (France) (Heather, 2012). A hub in natural gas trading can be either a physical hub where pipeline infrastructures are linked, such as NGO or ZEE, or a virtual hub where natural gas is exchanged as a balancing point inside the pipeline, such as NBP. NBP is the British Pounds benchmark for gas into British islands and LNG supplies, whereas TTF is the Euros standard for the North-Western European gas market. (Heather, 2019). On the other hand, NGO is the US Dollars benchmark for the US Market; ZEE is a transit hub linked to NBP and priced in British Pounds; Japan Korean Marker (JKM) is the benchmark price assessment for spot physical LNG cargoes in Northeast Asia and worldwide.

Moreover, oil (as Brent and WTI in the study) and coal are the primary substitute energy commodities for natural gas and are closely related in terms of pricing and volatility. Because natural gas and other energy sources are substitutable, the prices of associated energy sources impact each other. Across different markets, there is a significant difference in the price of natural gas that end-users are willing to pay. In discordance with the oil market, there are no price-setting cartels within the natural gas market. Specifically, the price of natural gas imports is determined by the structure and economics of trade between importing and exporting countries (Stern, 1984).

The price volatility transmission between natural gas and related energy sources is a particular field of study, as well as the effects of these energy sources on each other in terms of price. The concept of price volatility refers to the price fluctuations of a commodity, and the day-to-day percentage variation in a commodity's price is utilized to assess volatility. The so-called volatile market is expressed by the degree of deviation rather than the price level. While considering pricing as a consequence of the demand and supply mechanism, the volatility can be described as a consequence of the market's fundamental demand and supply dynamics. Accordingly, volatility with high degrees indicates unique demand and supply dynamics and gives a gauge of market price uncertainty. Energy commodities such as natural gas, crude oil, and coal are often more volatile than other commodities in terms of pricing. One of the rationales for the volatility of energy prices is that many users have limited opportunities to substitute alternative fuels. Actually, the impact of price volatility varies depending on the consumers' demand and patterns of purchase. As compared to industrial and commercial users, prices for residential consumers are considerably more consistent. On the other hand, electric power plants and other high-volume consumers extensively rely on contracts and market purchases for the short term without fixed pricing terms, and these consumers are ready to accept price swings in exchange for cost savings and the option to switch to alternative fuels if necessary (EIA, 2007).

Likewise, the focus of this study is the abovementioned volatility subject. The ability to accurately monitor the volatility of energy prices is crucial for decision-making by policymakers, hedging tactics used by production and refinery companies, and, eventually, short-term price movements of traders on financial markets. Energy price volatility substantially impacts economic indicators through production cost channels, making it a significant cost factor for strategic decisions.

Natural gas price is the primary driving factor behind natural gas economics and market contracts amongst suppliers and demanders. There is a substantial amount of literature and various approaches about natural gas pricing, variables influencing natural gas pricing, and the relation between the prices of substitutes (especially oil and coal) and the price of natural gas (see, for example, Egenhofer et al., 1998; Serletis and Herbert, 1999; Emery and Liu, 2002; Serletis and Rangel-Ruiz, 2004; Krichene, 2002; Serletis and Shahmoradi, 2005; Ghouri, 2006; Villar and Joutz, 2006; Panagiotidis and Rutledge, 2007; Brown and Yücel, 2008; Neumann, 2009; Mohammadi, 2011; Manzoor and Seiflou, 2011; Regnard and Zakoïan, 2011; Ramberg and Parsons, 2012; Erdös, 2012; Brigida, 2014; Atil et al., 2014; Ji et al., 2014; Hartley and Medlock, 2014; Giziene and Zalgiryte, 2015; Hulshof et al., 2016; Shi and Variam, 2016; Geng et al., 2016a; Batten et al., 2017; Caporin and Fontini, 2017; Asche et al., 2017; Jadidzadeh and Serletis, 2017; Ji et al., 2018; Zhang and Ji, 2018; Zhang et al., 2018, Şahin, 2021) while there is relatively less on the perspective of the volatility of natural gas prices and the substitutes (see, for example, Ewing, 2002; Pindyck, 2004; Mu, 2007; Lin and Wesseh, 2013; Lin and Li, 2015; Ergen and Rizvanoghlu, 2016; Jadidzadeh and Serletis, 2017; Batten et al., 2017; Wiggins and Etienne, 2017). Recent academic studies regarding natural gas pricing and the factors determining natural gas prices indicate that natural gas price volatility has significantly increased. Factors affecting demand and supply in natural gas markets, such as weather conditions, modern innovations, the shale gas revolution, political and financial occurrences, and issues regarding alternative energy commodities, all contribute to increased volatility in natural gas prices.

Moreover, there are not many papers investigating the causes of the volatility for the energy commodities, especially for different natural gas markets, benefiting the Dynamic Conditional Correlation Generalized Autoregressive Conditional Heteroskedasticity (DCC-GARCH) model operated in this study (see Pindyck, 2004; Mu, 2007; Creti et al., 2013; Nicola et al., 2016; Basher and Sadorsky, 2016; Perifanis and Dagoumas, 2018; Behmiri et al., 2019).

The importance of the study in terms of its contribution to the literature is that examining the volatility between the examined energy commodity variables is essential in explaining price changes and determining the relationship. In addition, to the best of our knowledge, the causes of the price volatility of natural gas prices in various markets via their close substitutes have not been examined in the literature with DCC-GARCH model benefited in the study.

In this study, while Brent and WTI are employed as exogenous variables and serve as benchmarks for oil and natural gas prices, the other exogenous variable, coal, comes out on one of the tops when it comes to products that are close alternatives for natural gas. Furthermore, TTF, NGO, NBP, ZEE (the specified natural gas hubs) and LNG (with the developing role of natural gas transportation) are taken as endogenous variables, and they are significant in terms of pricing the natural gas trade. The DCC-GARCH model is used to analyze the dynamics of the volatility of endogenous variables such as NBP, NGO, TTF, ZEE, JKM prices via exogenous variables such as Brent Oil (BRENT), West Texas Intermediate Oil (WTI), Newcastle Coal (COAL) prices. The relevant price data for the analysis is on a daily basis, and the joint time period is between June 2, 2014 and May 25, 2022. The main reason behind using the DCC-GARCH model in this research is that it assures the variance-covariance matrix of the return distribution is positive definite while also generating more robust conditional correlation estimations (Tse and Tsui, 2002). The consistency of multivariate and univariate volatility estimates is a desirable feature of DCC models in practice. When additional variables are introduced into the system, the volatility estimates for the initial assets will stay unchanged, and correlations also may remain intact, according to the way the model is adjusted. According to the empirical findings obtained as a result of the examination carried out with the DCC-GARCH model, it is understood that coal prices seem more critical in terms of natural gas pricing because natural gas mainly replaces coal. Based on the acquired results, the higher the coal prices, the higher the volatility. Moreover, this effect is also seen in Brent and WTI, but the relationship is more effective in coal. The importance of the outcomes is to contribute to the literature and energy markets in an empirical and concrete sense in order to investigate the causes of volatility in related natural gas prices via the substitutes.

An overview of the study is as follows: After an introduction to the topic, including a literature review, and concepts of the study, Section 1 discusses the data specifications. Afterward, the research methodology and the empirical findings are presented in Section 2, whereas a discussion is provided in Section 3, and the study concludes in the last section.

1. DATA

In this study, the DCC-GARCH model was used to analyze the volatility between endogenous variables taken as National Balancing Point (NBP), Henry Hub (NGO), Title Transfer Facility (TTF), Zeebrugge Hub (ZEE), Japan Korean Marker (JKM) futures prices and exogenous variables taken as Brent Oil (BRENT), West Texas Intermediate Oil (WTI), Newcastle Coal (COAL) futures prices. The main reason for determining these endogenous and exogenous variables was that the exogenous variables of BRENT, WTI, and COAL were close substitutes for natural gas. The overall time span of the data was January 7, 1997 and May 25, 2022 while the joint time span in the analysis was June 2, 2014 and May 25, 2022 on a daily basis, and the summary of the data is presented in Table 1.

Table 1. Data Summary

Variable (Price)	Abbreviation	Data Source	Unit
Henry Hub	NGO	Refinitiv Eikon Database	Dollars per Million Btu
National Balancing Point	NBP	Refinitiv Eikon Database	GBP per Therm
Title Transfer Facility	TTF	Refinitiv Eikon Database	Euros per MWh
Zeebrugge Hub	ZEE	Refinitiv Eikon Database	GBP per Therm
Japan Korean Marker LNG	LNG	Energy Market Price Database	Dollars per Million Btu
Brent Oil	BRENT	Refinitiv Eikon Database	Dollars per Gallon
West Texas Intermediate Oil	WTI	Refinitiv Eikon Database	Dollars per Gallon
Newcastle Coal	COAL	Energy Market Price Database	Dollars per Tonne

More information on the energy commodity variables used in the study can be given as follows:

Henry Hub (NGO) was established by The New York Mercantile Exchange (NYMEX) as the primary market hub for natural gas in the United States. It is located on the US natural gas pipeline system, which connects to four intra- and nine inter-state pipelines. A location differential regarding Henry Hub is used to price natural gas traded at another hub that varies based on local supply and demand as well as transportation costs (Heather, 2015).

National Balancing Point (NBP) is designated by The Network Code as a virtual trading point to support the mechanism of balance. It is, in effect, the entire NTS where shippers appoint their buys and sells, and National Grid Gas daily balances the system. The NBP also grew substantially as well as a natural gas trading point and hub. Because the NBP market has reached maturity, its potential for further growth may be limited. Nonetheless, the NBP has expanded in recent years, attracting even more new participants, including, for the first time, companies that have not previously traded as shippers (Heather, 2012).

The Title Transfer Facility (TTF) is a virtual trading hub where the Dutch TSO, Gas Trading Services (GTS), enables market players to transfer gas that is already existing in the GTS system, which is entry-paid gas, to another party. It can also be traded as futures contracts on the ICE-Index. TTF can function “as a virtual entrance point in the portfolio of a shipper or trader who buys or a virtual exit point in the portfolio of a shipper or trader who sells natural gas on it”. Despite functioning under an open and transparent framework, it appears that the TTF, which grew quickly at first but then looked to stagnate for four years or so, had reached its potential. (Heather, 2012).

Zeebrugge Hub (ZEE) is a transit hub, commonly known as a physical hub, located outside of the town of Zeebrugge and supplying natural gas from nearby countries, adjacent LNG facilities, or the Belgian market. The Zeebrugge region is amongst the major ports for the delivery of natural gas in the European Union (EU), with connections to a range of pipeline gas and LNG suppliers. The Interconnector Zeebrugge Terminal (IZT) links the Belgian grid to the underwater Interconnector pipeline, which routes to England. The LNG Terminal at Zeebrugge acts as the entry point for LNG deliveries to North West Europe. The ZEE hub trades in pence per Therm and is commonly referred to as the “NBP across the channel” since it is physically linked by the Interconnector UK Pipeline to NBP hub. The purely physical design provides benefits for large-scale natural gas transportation, and ZEE is truly geographically positioned to take advantage of natural gas flows to and from France, the United Kingdom, Norway, the Netherlands, Germany, and the neighboring LNG terminal and Belgian gas grid (Heather, 2012).

Japan Korean Marker LNG (JKM) is a benchmark price assessment for spot physical LNG shipments and was established by S&P in 2009. It is used in spot transactions, offers, and a wide range of maturity contracts in both Northeast Asia and throughout the World. Moreover, “the spot market value of cargoes Delivered Ex-Ship (DES) into Japan, South Korea, China and Taiwan” is reflected by JKM, and it indicates the spot LNG cargoes' day-to-day tradable value at the specified delivery location and date (SP, n.d.).

Brent Oil (BRENT) futures is the transaction reference price introduced in 1988 and referenced by about two-thirds of all petroleum contracts worldwide, making it the most commonly used marker of all. BRENT is used for pricing various crude oil grades “produced and traded not only in Europe, the Mediterranean, and Africa but also in Australia and some countries in Asia" (EIA, 2014).

West Texas Intermediate Oil (WTI) is a light and sweet oil grade produced in the US, which is priced in the trading hub of Cushing, Oklahoma. WTI is the primary oil benchmark in the United States and the Western Hemisphere (EIA, 2014).

Newcastle Coal (COAL) is thermal coal that is exported and delivered in terms of Free on Board (FOB) from Newcastle, New South Wales, Australia. It is the Asia-Pacific region's benchmark price for seaborne thermal coal (IM, n.d.; ICE, n.d.).

2. METHODOLOGY AND EMPIRICAL FINDINGS

2.1 Methodology

The methodology of the Dynamic Conditional Correlation Generalized Autoregressive Conditional Heteroskedasticity (DCC-GARCH) model conducted in the study for investigating the pricing and the causes of volatility in natural gas prices is given in the following. The parameters of the variance specification equation can be estimated by implementing the Autoregressive Conditional Heteroskedasticity (ARCH) model by Engle (1982). As a result, the data was able to determine the consistent estimates needed to model the variance equation using the model. Generalized Autoregressive Conditional Heteroskedasticity (GARCH) parameterizations of Bollerslev (1986) are a helpful generalization of this model. Furthermore, GARCH models can be used to investigate the efficiency of crude oil markets, investigate the impact of resource price uncertainty on economic growth rates, investigate the links between related products, test the presence of persistence and the leverage effect, analyze the consequences of price fluctuations and the introduction of futures trading, and forecast energy prices. The conditional variance in GARCH models is defined as a function of the squared residuals and the conditional variance in the past. Several multivariate GARCH models have been proposed and developed to investigate the co-movement of various financial and economic variables. The Constant Conditional Correlation (CCC) specifications were offered by Bollerslev (1990) for modeling the time-invariant conditional correlation matrix. The primary issue in the CCC technique is the constant conditional correlation assumption over time, which is impractical for empirical application (Engle, 2002; Tse and Tsui, 2002). As a result, the CCC model was generalized to the DCC-GARCH model in discrete and independent studies. Moreover, the DCC-GARCH model was favored because it endorses the positive definiteness of the return distribution's variance-covariance matrix while simultaneously providing more robust conditional correlation estimates (Tse and Tsui, 2002). It is also worth noting that multivariate and univariate volatility assessments are consistent with one another, which is a useful and practical feature of DCC models. The volatility projections for the initial assets will remain unchanged when new variables are introduced to the system, and correlations may even remain unchanged depending on how the model is amended.

Therefore, Engle's (2002) DCC-GARCH model is utilized in this study to explain the volatility dynamics and conditional correlations among the system of natural gas, oil, and coal prices. The empirical model's justification is as follows.

Let r_t be a n x 1 vector of natural gas prices. An AR(1) process for r_t conditional on the data is specified as,

$$r_t = \mu + ar_{t-1} + \varepsilon_t \tag{1}$$

The residuals are written as,

$$\varepsilon_t = H_t^{1/2} z_t \tag{2}$$

where H_t is the conditional covariance matrix of r_t and z_t is a n x 1 *i.i.d.* random vector of errors. Two steps are required in order to estimate the DCC-GARCH model firstly, the GARCH parameters are estimated and secondly, the conditional correlations are estimated. The *n x n* conditional covariance matrix H_t is expressed as,

$$H_t = D_t R_t D_t \tag{3}$$

where R_t is the conditional correlation matrix of the standardized returns, and D_t is a diagonal matrix of time-varying standard deviations on the diagonal and expressed as,

$$D_t = diag\left(h_{1,t}^{\frac{1}{2}}, \dots h_{n,t}^{\frac{1}{2}}\right) \tag{4}$$

$$R_t = diag\left(q_{1,t}^{\frac{-1}{2}}, \dots q_{n,t}^{\frac{-1}{2}}\right) Q_t diag\left(q_{1,t}^{\frac{-1}{2}}, \dots q_{n,t}^{\frac{-1}{2}}\right) \tag{5}$$

The expressions for *h* are univariate GARCH models, where *H* is a diagonal matrix. The elements of H_t for the GARCH(1,1) model can be represented as,

$$h_{i,t} = \omega_i + \alpha_i \varepsilon_{i,t-1}^2 + \beta_i h_{i,t-1} \tag{6}$$

Q_t is a symmetric positive definite matrix containing the conditional variances-covariances and the q_t is the time varying variable of the matrix and the GARCH-DCC(1,1) model is given as,

$$\mathrm{Q_t} = (1 - \theta_1 - \theta_2)\overline{\mathrm{Q}} + \theta_1 \mathrm{z_{t-1}} \mathrm{z'_{t-1}} + \theta_2 \mathrm{Q_{t-1}} \tag{7}$$

where $\overline{Q}$ is the n x n unconditional correlation matrix of the standardized residuals $z_{i,t}$ *as* $z_{i,t} = \varepsilon_{i,t}/\sqrt{h_{i,t}}$. The non-negative parameters $\theta_1$and θ_2 are associated with the exponential smoothing process used to construct the dynamic conditional correlations. As long as $\theta_1 + \theta_2 < 1$, the DCC model is mean-reverting. These parameters are estimated by maximizing the Log Likelihood function given as,

$$L = -\frac{1}{2}\sum_{t=1}^{T}(2\log(2\pi)) + 2\log(|D_t|) + \log(|R_t|) + \mathrm{z}_t' R_t^{-1} z_t \tag{8}$$

Conclusively, the dynamic conditional correlation estimator is given as,

$$\rho_{i,j,t} = \frac{q_{i,j,t}}{\sqrt{q_{i,i,t} q_{j,j,t}}} \tag{9}$$

2.2. Empirical Findings

According to the empirical findings obtained via the econometric techniques described in the methodology section of the study, the estimated parameters of the DCC-GARCH model are reported in Table 2. In the table, each PANEL (for example, PANEL I) reports the findings corresponding to different exogenous variables as the first for BRENT, the second for WTI, the third for COAL, the fourth for COAL AND BRENT, and the fifth for COAL AND WTI. Moreover, each Panel (for example, Panel A1) of the table reports the findings as the first for the Mean equation, the second for the Variance equation, and the third for the model specifications. In particular, Table 2 reports the analysis carried out with endogenous variables such as TTF, ZEE, NBP, NGO, and LNG. The model is estimated by an AR(1) term in the mean equation. The DCC is estimated using a multivariate t distribution to be taken into account the return distribution's non-normality. Volatility clustering is supported by the statistical significance of the α and β terms.[1] Furthermore, the coefficients that are estimated have a sum of value less than one, which demonstrates the mean reversion of the dynamic conditional correlations.[2]

Table 2. Estimation Results of TTF, ZEE, NBP, NGO, LNG with BRENT, WTI, COAL, COAL AND BRENT, COAL AND WTI

	TTF	ZEE	NBP	NGO	LNG
PANEL I: BRENT					
Panel A1: Mean					
Constant	0.000792 (0.4726)	-0.000578 (0.1583)	0.000279 (0.6351)	0.000313 (0.4536)	0.000256 (0.7442)
$BRENT_{t-1}$	-0.113932 (0.0017)	0.036859 (0.1174)	-0.036453 (0.0151)	0.008008 (0.7035)	0.007440 (0.8480)
$BRENT_{t-2}$	-0.127947 (0.0000)	-0.013059 (0.5427)	-0.152560 (0.0000)	0.043468 (0.0493)	-0.019504 (0.5430)
Lag1	-0.002008 (0.9382)	-0.056561 (0.0034)	0.019280 (0.3410)	-0.033136 (0.0913)	0.006363 (0.9922)
Lag2	0.005614 (0.8024)	-0.038939 (0.0357)	-0.007152 (0.6090)	-0.035031 (0.0687)	-0.000631 (0.9993)
Panel A2: Variance					
Constant	0.000704 (0.0000)	5.06E-06 (0.0000)	0.000440 (0.0000)	1.02E-05 (0.0000)	0.000575 (0.0000)
$\boldsymbol{\varepsilon_{t-1}^2}$	0.192615 (0.0000)	0.089041 (0.0000)	0.394037 (0.0000)	0.083110 (0.0000)	0.072229 (0.0000)
$\boldsymbol{h_{t-1}}$	0.529825 (0.0000)	0.923727 (0.0000)	0.410806 (0.0000)	0.910450 (0.0000)	0.583554 (0.0000)
$BRENT_{t-1}$	0.006908 (0.0000)	0.000286 (0.1670)	0.007535 (0.0000)	-0.000316 (0.2902)	0.004190 (0.0000)
Panel A3: Model Statistics					
R^2	-0.008825	0.002587	0.000331	0.006472	0.000164
Log likelihood	5613.898	5930.820	5607.279	6451.969	5608.901
PANEL II: WTI					
Panel B1: Mean					
Constant	-0.000190 (0.5742)	-0.000614 (0.1321)	-0.000187 (0.6491)	0.000322 (0.4418)	6.79E-05 (0.9585)
WTI_{t-1}	0.024544 (0.1175)	0.013565 (0.4999)	-0.024322 (0.1382)	0.017733 (0.3479)	0.002009 (0.9580)

[1] The level of significance is at the 5% level unless otherwise mentioned.
[2] Series of interest do not have unit root. These tests are not reported here to save space.

WTI_{t-2}	-0.034017 (0.0479)	-0.023408 (0.2422)	-0.026420 (0.1819)	0.007558 (0.6781)	-0.020418 (0.6106)
Lag1	-0.109113 (0.0000)	-0.055922 (0.0037)	0.007547 (0.7055)	-0.033833 (0.0882)	0.001877 (0.9985)
Lag2	-0.017111 (0.3711)	-0.037160 (0.0441)	-0.033196 (0.0754)	-0.032431 (0.0914)	0.005034 (0.9961)
Panel B2: Variance					
Constant	1.79E-05 (0.0000)	4.96E-06 (0.0000)	3.50E-05 (0.0000)	1.03E-05 (0.0000)	0.000880 (0.0000)
$\boldsymbol{\varepsilon_{t-1}^2}$	0.241569 (0.0000)	0.088695 (0.0000)	0.290948 (0.0000)	0.084521 (0.0000)	0.069597 (0.0059)
$\boldsymbol{h_{t-1}}$	0.779153 (0.0000)	0.923995 (0.0000)	0.741639 (0.0000)	0.909137 (0.0000)	0.582327 (0.0000)
WTI_{t-1}	-0.000244 (0.4626)	6.19E-05 (0.7371)	0.000496 (0.1806)	-8.82E-05 (0.7238)	0.002697 (0.0000)
Panel B3: Model Statistics					
R^2	-0.008935	0.002062	0.004639	0.004647	0.000518
Log likelihood	6245.267	5929.744	5866.654	6450.269	5422.971
PANEL III: COAL					
Panel C1: Mean					
Constant	-0.000423 (0.3986)	-0.000341 (0.5750)	0.000894 (0.8031)	0.000292 (0.5655)	0.000339 (0.9052)
$COAL_{t-1}$	0.109206 (0.0015)	0.186001 (0.0000)	-0.060642 (0.6091)	0.038529 (0.2556)	0.180181 (0.0072)
$COAL_{t-2}$	0.028803 (0.4746)	0.021927 (0.6013)	-0.060162 (0.2470)	0.031079 (0.3767)	0.003388 (0.9743)
Lag1	-0.084743 (0.0004)	-0.042381 (0.0883)	0.046650 (0.3258)	-0.025483 (0.2599)	0.002984 (0.9944)
Lag2	-0.029369 (0.2026)	-0.053920 (0.0180)	-0.081421 (0.0461)	-0.053642 (0.0223)	-0.001936 (0.9947)
Panel C2: Variance					
Constant	2.18E-05 (0.0000)	9.43E-06 (0.0000)	0.003225 (0.0000)	8.28E-06 (0.0001)	0.001860 (0.2736)
$\boldsymbol{\varepsilon_{t-1}^2}$	0.219380 (0.0000)	0.076452 (0.0000)	0.167801 (0.0000)	0.092293 (0.0000)	-0.003234 (0.0631)
$\boldsymbol{h_{t-1}}$	0.793007 (0.0000)	0.930302 (0.0000)	0.538257 (0.0000)	0.906584 (0.0000)	0.589946 (0.1241)
$COAL_{t-1}$	0.000239 (0.7207)	0.002839 (0.0000)	0.037407 (0.0000)	0.000649 (0.0385)	0.000762 (0.6384)
Panel C3: Model Statistics					
R^2	-0.000719	0.010146	0.003427	0.005370	0.002403
Log likelihood	4095.758	3821.971	2779.278	4416.010	3241.863
PANEL IV: COAL AND BRENT					
Panel D1: Mean					
Constant	-0.000464 (0.3526)	0.000137 (0.8749)	0.000687 (0.8494)	0.000270 (0.5941)	0.000169 (0.9553)
$COAL_{t-1}$	0.102379 (0.0034)	0.137503 (0.0005)	-0.032500 (0.7805)	0.041340 (0.2253)	0.143880 (0.0648)
$COAL_{t-2}$	0.040373 (0.3178)	0.061208 (0.1271)	-0.059248 (0.5534)	0.022342 (0.5254)	0.008035 (0.9304)
$BRENT_{t-1}$	0.024565 (0.2474)	-0.066563 (0.0597)	-0.151172 (0.1732)	-0.010389 (0.6513)	-0.022844 (0.8406)
$BRENT_{t-2}$	-0.046589 (0.0394)	-0.008233 (0.7260)	-0.005313 (0.9665)	0.044303 (0.0714)	-0.030557 (0.7947)
Lag1	-0.086841 (0.0004)	0.041381 (0.1850)	0.007535 (0.8446)	-0.025732 (0.2605)	0.002590 (0.9941)
Lag2	-0.024430 (0.2970)	-0.085816 (0.0028)	-0.003459 (0.9350)	-0.055507 (0.0194)	0.004162 (0.9910)
Panel D2: Variance					
Constant	2.19E-05 (0.0000)	0.000319 (0.0000)	0.003349 (0.0000)	8.39E-06 (0.0001)	0.001903 (0.3164)

ε_{t-1}^2	0.220505 (0.0000)	0.286736 (0.0000)	0.143733 (0.0000)	0.087950 (0.0000)	-0.003314 (0.5780)
h_{t-1}	0.792342 (0.0000)	0.641416 (0.0000)	0.549891 (0.0000)	0.909838 (0.0000)	0.591765 (0.1529)
$COAL_{t-1}$	0.000139 (0.8419)	0.007481 (0.0000)	0.038572 (0.0000)	0.000857 (0.0119)	0.000924 (0.5886)
$BRENT_{t-1}$	0.000398 (0.4266)	0.005323 (0.0000)	0.009239 (0.3271)	-0.000668 (0.0699)	0.002210 (0.6436)
Panel D3: Model Statistics					
R^2	-0.001372	0.008502	-0.000185	0.008061	0.003598
Log likelihood	4098.418	3679.360	2742.462	4418.967	3230.217
PANEL V: COAL AND WTI					
Panel E1: Mean					
Constant	-0.000460 (0.3576)	0.000513 (0.6795)	0.001238 (0.7310)	0.000269 (0.5950)	0.000254 (0.9295)
$COAL_{t-1}$	0.105603 (0.0025)	0.133744 (0.0028)	-0.048782 (0.6798)	0.040107 (0.2392)	0.186924 (0.0070)
$COAL_{t-2}$	0.035783 (0.3770)	0.054966 (0.2034)	-0.019159 (0.7700)	0.029562 (0.3990)	0.007883 (0.9380)
WTI_{t-1}	0.018637 (0.2980)	0.001003 (0.9788)	-0.069448 (0.4479)	0.001108 (0.9576)	-0.033810 (0.6347)
WTI_{t-2}	-0.035568 (0.0796)	-0.043729 (0.1709)	0.002848 (0.9650)	0.004953 (0.8104)	-0.044584 (0.5625)
Lag1	-0.086288 (0.0004)	-0.000915 (0.9737)	0.009137 (0.8373)	-0.026926 (0.2429)	0.003746 (0.9922)
Lag2	-0.024633 (0.2888)	-0.012791 (0.5039)	-0.038889 (0.3483)	-0.051792 (0.0289)	0.000585 (0.9985)
Panel E2: Variance					
Constant	2.20E-05 (0.0000)	0.001020 (0.0000)	0.003348 (0.0000)	8.13E-06 (0.0001)	0.001844 (0.2405)
ε_{t-1}^2	0.219782 (0.0000)	0.094385 (0.0000)	0.144862 (0.0000)	0.086963 (0.0000)	-0.003184 (0.0193)
h_{t-1}	0.792783 (0.0000)	0.502505 (0.0000)	0.548923 (0.0000)	0.910934 (0.0000)	0.589404 (0.0994)
$COAL_{t-1}$	0.000119 (0.8641)	0.009353 (0.0000)	0.038553 (0.0000)	0.000935 (0.0055)	0.000724 (0.6474)
WTI_{t-1}	0.000341 (0.4550)	0.004710 (0.0000)	0.005914 (0.4672)	-0.000781 (0.0233)	0.001796 (0.5987)
Panel E3: Model Statistics					
R^2	-0.001105	0.007190	0.002561	0.005450	0.003298
Log likelihood	4097.749	3488.309	2741.897	4418.004	3249.202

Notes: 1) *p*-values are reported under the corresponding parameters in parentheses.
2) EViews econometric software is used for the analysis.

In Table 2, Panel A1 of PANEL I reports the percentage change in the BRENT for two lags for the symmetric responses, whereas Panel A2 is for the variance. It is estimated that the BRENT coefficient for TTF, NBP, and LNG are positive and statistically significant. This suggests that the higher is the BRENT higher the price and volatility of TTF, NBP, and LNG. However, the coefficients for ZEE and NGO for the BRENT are not statistically significant. Moreover, Panel A3 is for the model statistics and expresses that it is a panel system, and it is possible that the R^2 can be less than zero as in other PANELs. The same exercises applied in PANEL I are repeated respectively in the following PANELs in the table by replacing the related exogenous variables. In PANEL II, WTI is used rather than BRENT, and it is found that an increase in WTI eventually increases the price and volatility of LNG. In PANEL III, coal prices are replaced with oil prices, and apparently, the increase in COAL do increase the price and volatility of ZEE, NBP, and NGO. In PANEL IV, COAL and BRENT are used together as the exogenous variables, and the results imply that an increase in COAL and BRENT also increase the price and volatility of ZEE, NBP, and NGO. Finally, in PANEL V, COAL and WTI are used, and the findings indicate that an increase in COAL and WTI increase the price and volatility of ZEE, NBP, and NGO. Moreover, in PANELs IV and V, oil prices are statistically significant at the 10% level for NGO. The abovementioned implications of the empirical findings are summarized in Table 3 as follows.

Table 3. Empirical Findings for Price and Price Volatility Transmission

Variable (PANEL)	BRENT (I)	WTI (II)	COAL (III)	COAL AND BRENT (IV)	COAL AND WTI (V)
TTF	↑	-	-	-	-
ZEE	-	-	↑	↑	↑
NBP	↑	-	↑	↑	↑
NGO	-	-	↑	↑	↑
LNG	↑	↑	-	-	-

3. DISCUSSION

Natural gas has emerged as a significant energy source in the World due to growing global concern about the increasing energy necessity and the impact of Carbon Dioxide (CO_2) on climate change via emissions from fossil fuels, whereas natural gas is remarkably the cleanest one among other fossil fuels. Additionally, the fluctuations in natural gas prices have a growing impact on economic decisions. In recent years, there has been significant volatility in the price of natural gas. Consequently, it is in the best interests of national policy for governments to comprehend what causes price volatility in the energy markets, particularly in the natural gas markets.

Market demand and supply primarily determine the price of natural gas. On the other hand, prices commonly maintain a balance between demand versus supply. Therefore, the demand and supply of natural gas are typically affected by variations in price while changes in demand and supply also affect the price. Natural gas prices generally rise/fall when supply is low/high, and prices tend to increase/decrease with higher/lower demand levels. There are several exogenous factors affecting the natural gas market demand and supply other than price. The main supply-side factors are production, international trade, and storage levels, while weather conditions, the state of the economy, and the cost of other substituting energy commodities like coal and oil are the main factors that affect demand. As an energy source for electricity production and heating, there are a small number of short-term alternatives for natural gas. In the context of this study, prices of the substitutes like oil and coal, which sometimes may be a reasonable alternative to natural gas for power generators, manufacturers, and other major customers, may affect the demand

(EIA, n.d.). Therefore, the issue of competition and substitution with alternative energy sources might impact natural gas pricing. Depending on the cost of each fuel, certain large fuel consumers, such as industrial plants and power plants, can alternate amongst natural gas, coal, and oil. Hence, if the prices of alternative fuels fall, switching from natural gas may result in decreasing demand and the price of natural gas falling or vice versa. Moreover, as a result of developments in natural gas markets, consumption increased even more, and price volatility stimulated as well. Accordingly, as the natural gas demand gets higher, fluctuations in demand or supply over a short period of time potentially cause major price modifications.

In general terms, beyond pricing, there are various reasons for the volatility of natural gas prices, including the changes in prices of substitute energy commodities. Major factors affecting natural gas market volatility can be presented as supply, international trade, market information, weather conditions, storage, delivery restraints, and substitutable energy commodity prices. Accordingly, this paper aims to contribute to the literature on understanding energy price volatility modeling that would be beneficial to energy market players and policymakers in the way of prediction and exploration of the interdependence of natural gas, oil, and coal market prices and transmission of volatilities using recent data explained in Section 1.

Conclusion

In this study it is aimed to analyze the causes of the price volatility in natural gas prices of National Balancing Point (NBP), Henry Hub (NGO), Title Transfer Facility (TTF), Zeebrugge Hub (ZEE), and Japan Korean Marker (JKM) with prices of Brent Oil (BRENT), West Texas Intermediate Oil (WTI) and Newcastle Coal (COAL) using DCC-GARCH model for the joint period from June 2, 2014 to May 25, 2022 on a daily basis. In the study, NBP, NGO, TTF, ZEE, and JKM prices are taken as endogenous variables, while BRENT, WTI, and COAL are taken as exogenous variables. In the analysis carried out within the scope of the study, the effects of substitute energy commodities specified as exogenous variables on the volatility transmission of natural gas prices in different markets, which are endogenous variables, were examined. The key contribution of the study to the literature is to observe the volatility causes and interactions among the system of different natural gas markets via oil and coal prices benefiting the DCC-GARCH model. Price volatility of energy commodities is of great concern to all market players as well as policymakers. Since their introduction, a considerable amount of research has focused on applying the ARCH and GARCH models to analyze the volatility of energy commodity prices. The DCC-GARCH model's greatest utility for the series of analyses in this study is the ability to analyze the relationships between oil, natural gas, and coal energy commodity prices and their volatilities.

Eventually, crude oil and coal are close substitutes for natural gas, and as the prices of the substitutes change, they affect the price of natural gas. The empirical evidence of this study obtained via the analysis carried out with the DCC-GARCH model reveals that coal prices seem to be more effective in terms of natural gas price volatility as a substitute, and the higher the coal prices, the higher the price itself and volatility of the natural gas prices. Moreover, these findings are also compatible with Brent oil and WTI oil, but the relationship is more effective in coal because natural gas mainly replaces coal in practical terms as a substitute. This aspect provides a source of leverage in terms of natural gas price movements and volatility transmission from oil and coal to natural gas prices.

The implications of this study suggest that coal ranks first in substitution with natural gas and significantly impacts the fluctuation of natural gas prices. The situation of replacing coal with natural gas has gained more importance and has come to the fore, mainly due to reasons such as the recent COVID-19 pandemic, the Russia-Ukraine war, and high-grade fluctuations in energy commodity prices. While the demand for coal in the World increases, its price also increases, and natural gas prices and volatility are affected by this condition. Price increases in coal cause more natural gas usage, and natural gas prices also increase, eventually the natural gas price volatility. In addition, oil prices, another subject of the study, are also effective in the natural gas pricing system. The uncertainties and fluctuations in oil prices are undeniably felt in natural gas prices. According to the outcomes obtained in the study, this situation will increase the volatility in natural gas prices, and it is likely to see the mentioned effects with empirical results. In almost all of the results, excluding LNG, the effect of coal on natural gas price fluctuations is clearly seen, while the relevant effect of petroleum products remains slightly limited. Considering these results, it is essential that both commercial and management-based planning be carried out in a long-term and foresighted manner.

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Yazar Katkısı: Göktuğ ŞAHİN %100
Destek ve Teşekkür Beyanı: Çalışma için destek alınmamıştır.
Etik Onay: Bu makale, insan veya hayvanlar ile ilgili etik onay gerektiren herhangi bir araştırma içermemektedir.
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