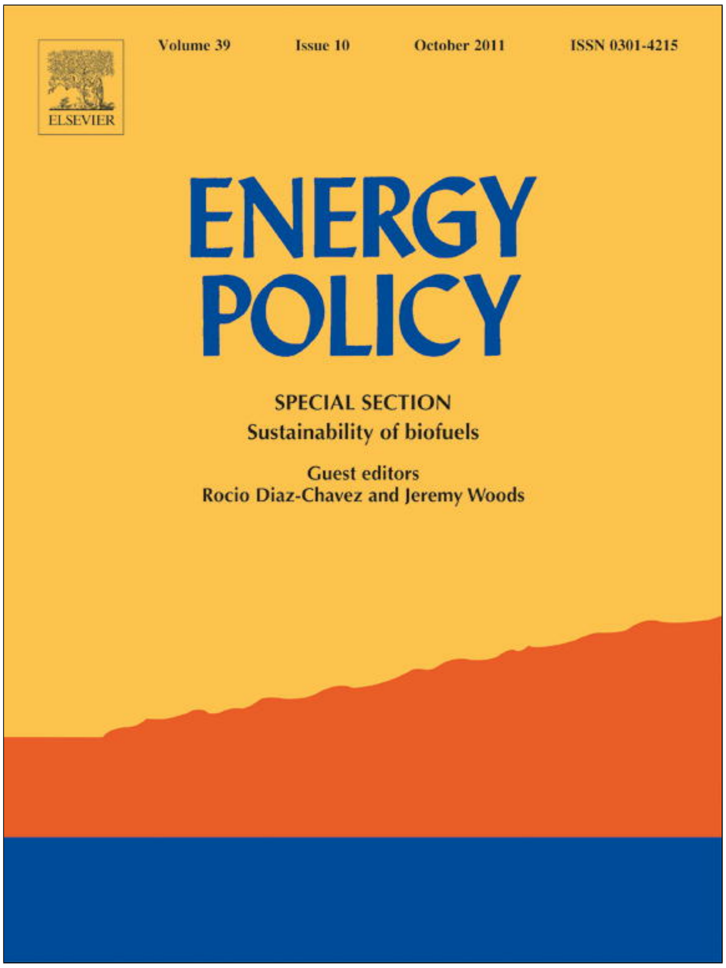
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The crucial relationship among energy commodity prices: Evidence from the Spanish electricity market

Victor Moutinho[a,]*, Joel Vieira[a], António Carrizo Moreira[b]

[a] Department of Economics, Management and Industrial Engineering, University of Aveiro, Campus universitário de Santiago, 3810-193 Aveiro, Portugal
[b] Department of Economics, Management and Industrial Engineering, GOVCOPP, University of Aveiro, Campus universitário de Santiago, 3810-193 Aveiro, Portugal

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ABSTRACT

The main purpose of this article is twofold to analyze: (a) the long-term relation among the commodities prices and between spot electricity market price and commodity prices, and (b) the short-term dynamics among commodity prices and between electricity prices and commodity prices. Data between 2002 and 2005 from the Spanish electricity market was used. Econometric methods were used in the analysis of the commodity spot price, namely the vector autoregression model, the vector error correction model and the granger causality test. The co-integration approach was used to analyze the long-term relationship between the common stochastic trends of four fossil fuel prices. One of the findings in the long-term relation is that the prices of fuel and the prices of Brent are intertwined, though the prices of Brent ten to "move" to reestablish the price equilibrium. Another finding is that the price of electricity is explained by the evolution of the natural gas series.

1. Introduction

The recent volatility of the price of crude oil–gas, fuel oil–coal, fuel oil–gas and gas–coal has led some to question whether or not a stable long-term relationship between the prices of crude oil and other commodities truly exists. However, in the long run, it is important to account for electricity generating technologies considering that fuels compete on a cost basis in electricity production. In order to understand why coal, crude oil and gas prices sometimes diverge from their long-term equilibrium, it is also important to control for various short-term factors that establish trends in the prices of electricity and other commodities.

Theories suggest that fuel substitution capabilities within the electricity sector, either at plant level or grid level, should contribute to the co-movement of commodity energy product prices. In addition, substitutability between crude oil, coal and gas products in the industrial sector, through direct use and cogeneration of electricity, can also influence the commodity price relationship. In Spain, the total electricity output consists of thermal power, hydroelectricity and nuclear power, among others. Thermal power accounts for over 80% of the total generating capacity whilst hydroelectricity accounts for around 15% (Crampes and Fabra, 2005). Therefore, the fluctuation of oil and coal prices has a great impact on the electric power industry.

Since 1997, Spain has gradually liberalized the electricity market. Therefore, fuel, gas and coal prices should fully reflect their resource costs, production costs, environmental costs, and market supply and demand situations. This is an adjustment of the irrational commodity prices in the market economy. An increase in the price of electricity could lead to an increase in the price level in the whole economy, since the connection between the prices of fuel, gas and electricity has not yet been implemented. The price of electricity does not reflect the increases of fuel prices. Thus, the increased costs caused by each commodity price should be absorbed by the power companies themselves.

Fuel cost is the most important cost item in thermal power plants, accounting for 70% of the variable costs (Crampes and Fabra, 2005). The increase in coal prices, especially when used for electricity generation, directly increases the operating costs of the enterprise and reduces corporate profits. Under such a dramatic price increase, the costs for electric power firms increased vastly, and many electric power companies incurred losses (Crampes and Fabra, 2005). In this case, an increase in the price of electricity in order to improve the operating conditions of power firms was a necessary measure. This ensures power supply and alleviates the coal–electricity price contradiction. It is also very important to analyze the impact of the coal price increase in the electric power sector, in particular, on the total costs for the electric power sector when the electricity price policy was being developed.

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* Corresponding author. Tel.: +351927674330; fax: +351234370215.
E-mail addresses: vmoutinho@ua.pt (V. Moutinho), jmv@ua.pt (J. Vieira), amoreira@ua.pt (A. Carrizo Moreira).

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A certain degree of non-constant volatility and a strong connection to the seasonal cycle are important characteristics of Spanish electricity spot market pricing. Mean reversion is known as the process by which prices return to a seasonal level after fluctuations. When there are particularly large increases, they are labeled jumps. In extreme cases, they are labeled spikes (Crampes and Fabra, 2005), which are abrupt or unanticipated price peaks that cross a certain threshold for a certain length of time. As referred by Jensen and Wobben (2009), these characteristics can be traced back to the cost of storing electricity and the fact that randomly occurring outages in generation and infrastructure capabilities have a more extreme effect on the price. However, Jensen and Wobben (2009), also refer to the fact that electricity markets are often able to correct strained supply conditions within 24 h, which is the time period between day-ahead auctions. This occurs due to additional imports and the activation of additional power sources.

Also important in spot market prices is the low installed price rate, usually 0 per unit. This is the case of Brent, oil, gas, carbon and fuel oil since they have limited storage capabilities.

This paper addresses the following questions: (1) is there a unique long-term relationship among commodity prices and between spot electricity price and commodity prices? If so, what is the nature of those relationships? (2) What are the short-term dynamics among commodity prices and between electricity prices and commodity prices? In what direction do they flow? (3) How important are the pricing strategies in each commodity market in explaining the variations in the Spanish spot electricity prices?

To the best of our knowledge, the causal relationship among gas, oil, coal and fuel in the electric Spanish market has not yet been studied. The purpose of this paper is firstly, to analyze the causal relationship among commodity prices and secondly, to analyze if the price relation between gas, oil, coal and fuel capture possible different long or short-term dynamics on the prices of electricity. The existence of a co-integration relationship provides arbitraging opportunities among the various commodities. This is crucial for pricing electricity involving a couple of commodities as well as investments options. We investigate the price dynamics among commodity prices and between electricity and commodity prices as well as major sources (fuel oil, gas, coal, Brent) by estimating a causal model for the price dynamics. In this sense, Spanish reservoir levels and Spanish electricity production from wind mills are treated as exogenous variables. Moreover, if there is a short-term departure from the long-run equilibrium forces will act to bring prices back into their long-run equilibrium.

2. Relevant literature

The relationship between fuel fossil prices has been largely investigated using different sets of historical data and different methodologies. De Vany and Walls (1995) analyze the degree of regional co-integration in the North American gas markets and describe the dynamic evolution of the prices within these markets. These illustrate a growing level of interconnections between markets as well as an increase of the shock absorbing velocity of prices within gas markets, thus, decreasing the efficiency of arbitration mechanisms. On other hand, the Engle–Granger co-integration tests (Engle and Granger, 1987) have evidenced the integration of natural gas spot prices as well as, the expansion of access to gas reservations through network connections between regional American markets.

King and Cuc (1996) analyze the strength of the co-integration of spot prices between different gas producers' basins in eight regional markets in North America. These were studied between the mid-1980s to the mid-1990s. The inferred results on the analysis of the varying parameter indicate an emerging price convergence within regional markets allowing for the price arbitrage within the eight North American regional markets. However, the same results also demonstrate a blunt division of the East–West regional natural gas prices. Serletis and Herbert (1999) use North American natural gas, fuel oil and power prices from 1996 to 1997 to show that natural gas prices and fuel oil prices are co-integrated, whereas power price series appear to be stationary.

Asche et al. (2000) investigate the co-integration degree of gas markets for France, Germany and Belgium. Their results demonstrate that the national gas markets of France, Germany and Belgium are highly integrated. Between January 1990 and December 1999, they investigated the time series of Norwegian, Dutch and Russian gas and the export prices to Germany, concluding that the German market is integrated. The results of Johansen's multi-varied model show that the three gas supplier countries compete closely in the same markets as prices move in the same direction through time but in different levels of range.

Gjolberg (2001) examine the existence of a medium and long term correlation between electricity and fuel oil in Europe. However, natural gas, crude oil and electricity prices result in co-integration. Crude oil is identified as having a leading role between 1995 and 1998, in other words, during an interim period after the deregulation of the UK gas market in 1995.

Ewing et al. (2002) using daily indexes from April 1, 1996 to October 29, 1999, evidence the behavior of stock prices in major companies within the oil and natural gas markets. Their bivariate model indicates significant diffusion of volatility from the natural gas sector to the oil sector. They also demonstrate that volatility is often interpreted as a proxy for information flow.

Emery and Liu (2002), using daily data from March 29, 1996 to March 31, 2000, note that future prices of electricity and natural gas are co-integrated.

Asche et al. (2002) analyzed the integration of Norwegian, Dutch and Russian natural gas markets. For this purpose, they applied Johansen's multi-varied methodology in order to construct econometric models for monthly exportation prices from those countries to Germany (from January 1990 to December 1997). . The results demonstrate that the suppliers/producers of gas in the three markets compete between them in the German market. Furthermore, the prices of their long-term relations, although different in proportional price range levels, have a tendency to move in the same direction over time.

From April 1997 to July 2000, Bessembinder and Lemmon (2002) studied the volatility of the electricity market in Pennsylvania, New Jersey and Maryland (PJM), concluding that this volatility was approximately 34% per day. By comparing this value to the daily volatility of the S&P 500 profitability index, it is possible to conclude that the observed value of the volatility in the PJM market is higher than the observed value in S&P 500 index (5.7% a day on S&P 500 daily profitability during one of the most volatile months, October 1987).

Huisman and Mahieu (2003) demonstrate that the evolution of electricity prices present a high daily volatility. It is normal to observe daily volatilities of 29% in the electricity market as opposed to the annual volatility of 20% in financial assets.

Serletis and Rangel-Ruiz (2004) infer that deregulation has weakened the relationship between U.S. crude oil and natural gas prices, thus, rejecting the hypothesis of common and co-dependent cycles between the prices. This leads them to conclude that the prices have been "decoupled".

Goodstein (2004) reveals that forward market prices do not constitute a prediction for future price levels. Future prices, added with the spot prices, inform the market about the availability (production+stocks) of commodities. The spreads (spot prices less future prices) will be positive when the stocks are low and negative when the stocks are high.

Jin and Jorion (2006) extended Rajgopal's work (1999) by adding the hedging factor. Therefore, they concluded that this weakens the relation between the stocks' profitability and the crude (oil) and gas prices. However, after analyzing 119 gas and crude oil industry firms they did not find any evidence to support the idea that hedging affects company values.

Asche et al. (2006), observe differences in the relationship between prices and time period through a co-integration analysis and using monthly wholesale prices on crude oil, natural gas and electricity. They found an integrated market during the period of deregulation in the United Kingdom and before the gas market was physically linked to the European continental market (from January 1995 to June 1998). Furthermore, fuel source prices may in turn respond to changes in electricity prices.

Panagiotidis and Rutledge (2007) analyze the relationship between UK wholesale gas prices and Brent oil price. Using recursive techniques, co-integration is shown over the entire sample period (1996–2003). Moreover they conclude that this co-integrating relationship is not affected by the opening of the Bacton–Zeebrugge gas Interconnector between the United Kingdom and continental Europe.

Henriques and Sadorsky (2008), through a four variable vector auto-regression model, study the empirical relation between alternative energy stock prices, technology and stock prices, oil prices and interest rates. They demonstrate that technology stock prices and oil prices each Granger-cause the stock price of alternative energy companies.

Chemarin et al. (2008) analyze the role of green certificates in the electricity production market, taking into account (a) the existence of cross participation between the French carbon market and the electricity spot market, and (b) the natural gas and crude spot prices. In their analysis, they include the climate conditions of France and the other countries. Through the application of the GARCH bi-assorted time series econometric models, they show that both markets are co-integrated

Mohammadi (2009) finds a stable long-term relation between real prices for electricity and coal, a bi-directional long-term causality between coal and electricity prices, and an insignificant long-term relation between electricity and crude oil and/or natural gas prices. He also finds no evidence of asymmetries in the adjustment of electricity prices to deviations from equilibrium.

Mjelde and Bessler (2009) show that electricity prices in US electricity market, during peak time, influence natural gas prices, which in turn influence crude oil. They also demonstrate that in the long run, price is revealed in the fuel sources market with the exception of uranium. In the study they use dynamic price information flows among US electricity wholesale spot prices and the prices of the major electricity fuel sources: natural gas, crude oil, coal and uranium.

Ferkingstad et al. (2011) demonstrate that the oil price, coal price and EUR/USD exchange rate are non-stationary. On the other hand, Nordic and German electricity prices, as well as British and Zeebrugge gas prices are stationary. Contrary to Mjelde and Bessler's (2009) study, Ferkingstad et al. (2011) find only positive innovation shock responses, for example, from natural gas to coal as opposed to a negative response in the US study. They also found a strong connection between gas and electricity prices as well as a causal link from (Zeebrugge) gas prices to the electricity markets. The US study, however, reaches the opposite conclusion.

Choi and Hammoudeh (2010) study the dynamic correlation relationships in order to identify, over time, the commodity and stock market correlations. They infer that Brent and WTI crude have a more volatile persistence as a response to geopolitical crises, while copper is more sensitive to financial crises. They also conclude that S&P 500 index is sensitive to both financial and geopolitical crises.

He et al. (2010) analyze the influence of coal-price adjustment on the electric power industry as well as the influence of electricity price adjustment on the macroeconomic environment of China. They demonstrate that an increase in the price of electricity has an adverse influence on the total output; electricity price increases have a contra-stationary effect on economic development whereas coal price increase causes a rise in the cost of the electric power industry. However, the influence gradually descends with the increase in coal price.

3. Relevant aspects of OMEL electricity market structure

Spanish electricity sector operators depend mainly on their capability to set prices in the wholesale market. This capacity to set marginal prices in the wholesale market, held by two major generators, cannot be solely explained by their vast installed capacity to produce electric energy in relation to the global capacity of the Spanish market. Moreover, it is necessary to take into account the structure of their respective scientific parks and production mix. Therefore, setting supply prices in the "pool", for the different hourly periods, is significantly conditioned by differences between the production technologies used by the power plants that generate the installed power of the system.

As a consequence of the characteristics of these different production technologies, coal plants set prices during periods of low (off-peak) demand, while hydroelectric plants set prices predominantly during peak hours. As a result, *Endesa* generates about 57% of electricity production from coal whereas *lberdrola* clearly dominates the adjustable hydroelectric production. Therefore, both companies normally set the marginal prices for the market.

Endesa and *Iberdrola* play a pivotal role in the Spanish wholesale market. Their capacity is approximately equal to the excess of supply that exists in the market, namely, during peak demand periods. Consequently, the combined supply of the other producers is insufficient to meet demand. Therefore, "pivot" companies can increase their prices in accordance with this demand without generally being expelled from the market. Several structural market characteristics allow for a strategic coordination among operators: for example, a market with homogenous and relatively transparent products where fluctuations in prices are detected almost immediately. Small electricity companies and other operators, as a whole, do not meet the necessary conditions to set the prices in the majority of hourly periods. In addition to *Endesa* and *Iberdrola*, other Spanish companies, namely, *Unión Fenosa, Hidrocantábrico* and *Viesgo* use, in the majority of hourly periods, the prices set by the two dominant operators. As previously mentioned, the two main Spanish operators, *Endesa* and *Iberdrola*, set the prices at about 60% to 80% of the offering price. Given that the quantities offered above the marginal price are not sold in the daily market, other operators tend to bid at zero price, aware that *Endesa* and *Iberdrola*'s bids are necessary to meet the demand during almost all hourly periods. This is because they are aware that all the electricity they offer will be sold in the daily market at the marginal price set in the "pool" (and not at the price at which the electricity was offered). Therefore, the two biggest operators can use their important production "mix" to present flexible bids accordingly to estimations of supply and demand. On the other hand, small operators such as *Unión Fenosa* and *Hidrocantábrico*, whose production mix is small, have less capacity to present competitive or flexible bids. For these operators, the decision to bid production at zero price constitutes the easiest way to sell the largest possibly quantity, as they know that *Endesa* and *Iberdrola* will raise their prices.

In spite of the current shared dominant position, the price levels in the Spanish market are being affected by an increase in the supply of low-cost energy within the "pool". This decrease in prices might indicate the weakening of the shared dominant position. However, the results of the market study reveal that this is mainly due to a strictly conjectural situation and that it does not significantly change the duopolistic structure of the reference market or the evaluation of the market power shared by the two main operators. It also does not change the comfortable situation of small operators as price takers.

4. Data and methodology

We focus on the Spanish electricity wholesale market and their major fuel sources (oil, coal, gas). We used the daily spot prices for Brent, fuel, coal, gas and the OMEL's electricity market from January 2002 until December 2005. We define the natural logarithms of the real prices for the four fossil prices included the electricity price. The nominal price of electricity is measured as the average retail price in wholesale OMEL market (cents per kilowatt hour daily), for coal as average physical price (API, per short ton), for natural gas as euro per thousand cubic feet at wellhead (Gas Zeebrugge) and for crude oil as euro per barrel first purchase price (Brent crude, IPE). All series are given in EUR.

In this study we opted to use econometric methods usually applied in the analysis of commodity spot prices, namely the vector autoregression (VAR) model, the vector error correction model (VECM) and the Granger causality test.

4.1. Vector autoregression model

The multivariate model has the advantage of being more general and less constraining as it allows for the possibility of simultaneous influence among the different variables and the existence of multiple linear independent co-integration vectors. The general formulation of a multiequational model is known as Vector Autoregressive (VAR) model and its specification is given by

$$\underset{(nxl)}{z_t} = \underset{(nxn)}{A_1}\,\underset{(nxl)}{z_{t-1}} + \underset{(nxn)}{A_2}\,\underset{(nxl)}{z_{t-2}} + \cdots + \underset{(nxn)}{A_p}\,\underset{(nxl)}{z_{t-p}} + CD_t + \varepsilon_t \tag{4.1}$$

in which z_t represents the vector of n jointly determined variables, the A_i matrixes contain the parameters associated to each z_{t-i} vector, D_t represents the vector of deterministic variables—constant, trend, seasonal dummy variable, pulse or shift dummy variable—and C represents the vector of coefficients associated to each of the deterministic components. ε_t represents the residual component, i.e. a random variable vector with normal distribution. As $\varepsilon_t \sim IN(0;\Sigma)$, this equation can be rewritten in order to have a clearer and more direct interpretation: it is a VECM-type representation, which is a mere transformation of the original VAR formulation that allows distinguishing short and long-term relations.

4.2. Vector error correction model

The VECM can be generically expressed as

$$\Delta z_t = \Pi z_{t-1} + \Gamma_1 \Delta z_{t-1} + \Gamma_2 \Delta z_{t-2} + \cdots + \Gamma_{p-1} \Delta z_{t-p} + CD + \varepsilon_t \tag{4.2}$$

where Δz_t represents the vector of the first differences of the vector z_t, $\Gamma_i = -I + A_1 + A_2 + \cdots + Ai$ with $i = 1,2,\ldots,p-1$ and $\Pi = -I + A_1 + A_2 + \cdots + A_p$. On the other hand, matrix Π can be decomposed in two matrixes (α and β) so that VECM has the following representation:

$$\underset{(nxl)}{\Delta z_t} = \underset{(nx(n-1))}{\alpha}\,\underset{((nxn-1))}{\beta'}\,\underset{(nxl)}{z_{t-1}} + \underset{(nxn)}{\Gamma_1}\,\underset{(nxl)}{\Delta z_{t-1}} + \Gamma_2 \Delta z_{t-2} + \cdots + \Gamma_p \Delta z_{t-p} + CD_t + \varepsilon_t \tag{4.3}$$

where β represents the long-term coefficient matrix also known as co-integration space, α represents the convergence speed of the different variables for the equilibrium situation and matrixes Γ contain the coefficients associated to the different z_{t-1} that represent the non-included short-term adjustments of the long-term relation.

According to Engle and Granger's (1987) definition, the n variables of a vector $z_t = [z_{1t}, z_{2t}, \ldots, z_{pt}]'$ are known as co-integrated of order $(d,b)[z_t \sim CI(d,b)]$ if:

i. All variables are integrated of order d, i.e., if z_t equals $I(d)$.
ii. There is one vector $\beta = (\beta_1, \beta_2, \ldots, \beta_p)$ in which $\beta' z_t = \beta_1 z_{1t}, + \beta_2 z_{2t}, + \cdots + \beta_p z_{pt}$ is a linear combination with integration order $(d-b)$, in which $d > b > 0$.

in which the matrix $\Pi = -I + A_1 + A_2 + \cdots + A_p$ included in the VECM equation can be decomposed in $\Pi = \alpha\beta'$ in which α represents the adjustment speed towards equilibrium and β the matrix with the co-integration vectors or, alternatively, the coefficients of the long-term relationship. We will find co-integration in the case there are $r \le (n-1)$ columns in β that are linearly independent and, when $I(1)$, then $\beta' z : (n-1)$. Then, if the trace of Π is $r \le (n-1)$ then there are r co-integration vectors.

The co-integration tests related with the Johansen approach consist in estimating the Eigenvalues (λ) associated to each of the hypotheses regarding the co-integration vectors: $r=0$, $r=1$, $r=2,\ldots,r=n-1$. In order to prove the co-integration existence it necessary to prove that there is at least one $\lambda_i \neq 0$ in which $i = 1,2,\ldots,n-1$.

The most usual and robust test, according to Harris and Sollis (2003), is the trace test defined by

$$\lambda_{traço} = -T \sum_{i=r+1}^{n} \mathrm{Ln}(1-\hat{\lambda}_i) \quad r = 1,2,\ldots,n-1 \tag{4.4}$$

in which the null hypothesis is: $H_0{:}\lambda_i = 0$ with $i = r+1,\ldots,n$. The test is sequentially run beginning for the hypothesis of the trace test being zero, i.e. $r=0$, against the alternative hypothesis of $r \ge 1$. In H_0 is not rejected, the sequence of tests is interrupted and the existence of no co-integration vector is supported. If H_0 is rejected, the sequence continues testing $r \le 1$ against $r > 1$.

Whenever H_0 is rejected, the sequence goes on until $H_0{:}r \le 1$ $(n-1)$. If one of the tests does not reject the null hypothesis the test stops and one can conclude that there are as many co-integration vectors as the number of rejections of the null hypotheses that occurred in the sequence test.

The critical values regarding the trace test vary according the specification given to VECM, in terms of deterministic components. In the case of small-size samples it is advisable to correct the test statistics substituting $-T$ for $-(T-nk)$ in Eq. (4.4), in which k is the number of lags considered (Harris and Sollis, 2003).

4.3. Granger causality

After defining VAR it is important to proceed with causality tests because they help in the identification of interdependence relations among variables and in deciding whether a multiequational approach can give way to a uniequational one. The concept of Granger causality can be helpful in the specification of VAR and VECM models as it underpins the decision in whether or not a certain dependent variable could be used in VAR (Harris and Sollis, 2003; Ghosh, 2002).

One variable, for example, y is said to Granger-cause x if the values y_{t-1} contain information that helps in foreseeing the value x_t. Assuming a model of this type:

$$\begin{bmatrix} y_t \\ x_t \end{bmatrix} = \sum_{i=1}^{p} \begin{bmatrix} \alpha_{11,i}\alpha_{12,i} \\ \alpha_{21,i}\alpha_{22,i} \end{bmatrix} \begin{bmatrix} Y_{t-1} \\ x_{t-i} \end{bmatrix} + CD_t \begin{bmatrix} u_{1,t} \\ u_{2,t} \end{bmatrix}$$

The null hypothesis of the y_t not Granger-cause the x_t variable may be tested according to the following restriction:

$$\alpha_{21,i} = 0, \quad i = 1,2,\ldots,p$$

H_0 is tested versus H_1 in order to find at least one $\alpha_{21,i}$ different than zero, in which case there is at least one past observation of y_t that explains x_t.

For the application of this type of tests the deterministic components of the regression must be correctly specified. Accordingly, this formulation must be previously addressed so that the VAR possesses the appropriate statistical properties. As some problems may arise due to some non-stationary variables, the VAR should be reformulated towards a VECM specification type so that the restrictions embrace stationary variables as well as potential co-integration vectors. The new formulation is the following one:

$$\begin{bmatrix} \Delta y_t \\ \Delta x_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} [\beta_1 \beta_2] \begin{bmatrix} y_{t-1} \\ x_{t-1} \end{bmatrix} \sum_{i=1}^{p=1} \begin{bmatrix} y_{11,i}y_{12,i} \\ y_{21,i}y_{22,i} \end{bmatrix} \begin{bmatrix} \Delta y_{t-i} \\ \Delta x_{t-i} \end{bmatrix} + CD_t \begin{bmatrix} u_{1,t} \\ u_{2,t} \end{bmatrix}$$

and the non-Granger-cause from x to y is tested according to

$$\alpha_1 = 0 \text{ and } \gamma_{12,i} = 0, \quad i = 1,2,\ldots,p$$

With this new situation it is necessary to prove y weak erogeneity vis-à-vis the co-integration vector and the lack of relevance of the inclusion of lagged effects. In the bivariate case, the Granger causality test is useful the worthiness of the inclusion of x in the VECM modeling of y behavior.

5. Empirical results

5.1. Relationships between fossil prices: co-integration results and discussion

The evolution of commodity prices of the four-year period under analysis is presented in Fig. 1.

According to Fig. 1, it is possible to conclude that the price volatility differs across fossil fuels. Also the crude, natural gas and coal series are less price volatile than fuel. On the other hand, coal was more volatile than natural gas and Brent throughout the 2002–2003 period. However, fuel oil was more volatile than natural gas during the 2004–2005 period. The high oil price levels of 2004 and 2005, which have attracted much attention, have actually been associated with declining volatility.

Augmented Dickey–Fuller (ADF) unitary root tests were used to determine the integration order of each price variable. The previous step, until verifying the possibility of co-integration of series for the variables (Brent, coal, gas and fuel spot price) was analyzed to identify the order of integration of each of these variables. The results obtained for the unitary ADF root tests are presented in Table 1.

A general-to-specific approach was adopted in order to deal with the number of mismatches: starting with a maximum of 36 lags, we eliminated the non-significant mismatches. According to the results, all variables are integrated. Therefore, it is possible to test co-integration because at least two series must be integrated. We also searched for breaks in the data structure that needed to be addressed in order to make the necessary corrections. When found in the fuel and coal price series, these breaks were "repaired" with a dummy. We also added a step-type dummy variable to correct the sudden increase in the level of Zeebrugge market prices.

5.2. Trace test

The trace test was used to determine the number of co-integration vectors. The Schwarz criterion was used for determining whether the contrast is within or outside the co-integration space.

Table 1
Unit root test results for the logged commodity prices.

Augmented Dickey-Fuller (ADF)		
Prices	**Levels**	**First differences**
POmel (spot electricity)	−2.51 315	−8.30 671**
P*Omel (P*=C mg)	−1.68 038	−8.30 675
PBrent (crude oil)	−2.38 481	−10.8789**
PFuel (fuel oil)	−1.60 519	−7.023 353**
PCoal (API)	−1.17 242	−8.4223**
Pgas (Zeebrugge)	−2.4626	−8.5024**

Note: the optimal lags for the ADF tests were selected based on optimizing Akanke's Information Criteria (AIC) using a range of lags.
***Significant at 10%.

** Significant at 1%.
* Significant at 5%.

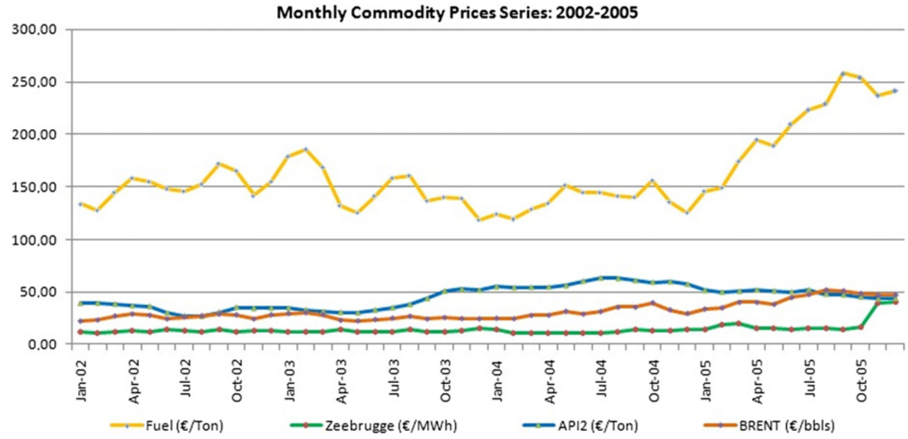

Fig. 1. Monthly commodity prices series.

This test is performed sequentially starting with the assumption that the trace Π is zero, i.e., $r=0$, against the alternative hypothesis $r \geq 1$. If H_0 is rejected then it is tested $r \leq 1$ against $r > 1$. Whenever the null hypothesis is rejected, the test continues until H_0:$r \leq 1(n-1)$. If no test rejects the null hypothesis, the test stops and it is concluded that there are as many co-integrating vectors as rejections of the null hypotheses, occurring as a result of the test.

According to the achieved outputs, the statistics tests and the critical values for different ranks (when the constant is within the co-integration space) are shown in Table 2.

5.2.1. Model 1a: co-integration between the variables Ln Fuel and Ln Brent

According to Table 2, the trace test indicates the presence of a co-integrating vector. While estimating the VECM, we tested the hypothesis in which the coefficient matrix α associated with each variable $Ln\mathrm{Pr}Brent; Ln\mathrm{Pr}Gas, Ln\mathrm{Pr}Coal$ equals zero. The most parsimonious VECM, i.e., the one resulting from the elimination of all coefficients not significantly different from zero, will be analyzed. For this effect, we used the Sequential Elimination of Regressors (SER) test strategy, which consists in the examination of the impact of the exclusion of a particular variable in the VECM based on a given information criterion. Sequentially, the variables involving a major reduction in the information criterion (in this case the Schwarz criterion), are withdrawn until it is not possible to reduce it anymore. A co-integration vector is a stationary of a possibly non-stationary vector time-series component. This combination might consist of only one of the series, which must be stationary. It is interesting to test if this is the case, especially since the ADF test suggests that several of the series are stationary.

To better analyze the dynamics of the various commodity prices we use the Engle and Granger (1987) two-step methodology. The first set requires estimating the parameters of the co-integrating vector. In the second step, the estimated parameters are used in the Error Correction form.

Ln Brent was used instead of Fuel because there is strong evidence that Ln Fuel is weakly exogenous to the co-integration vector.

In the long-term relationship established between Fuel prices and Brent prices, the latter are the ones that move to restore the balance. Regarding the results presented in Table 3, it is possible to conclude that the coefficient associated with the trend, although statistically significant, is negligible since it presents a very low value and indicates a very small difference between the path of Ln Brent and Ln Fuel. From a theoretical point of view, it is possible to justify this trend with the growing obsolescence (due to the environmental *influence*) of Fuel as an energy source.

With the results presented in Table 3 it is possible to claim that the estimated long-term relationship based on Ln Brent and step-type "trend" is the variable that influences Ln Fuel. In other words, when there is an imbalance in the long-term estimated relation (when equality is not the case) it is Ln Fuel that "moves", aiming to recover the equilibrium. The associated coefficient to this ECM will have a negative sign so that if, for example, the deviation is positive, there is a mechanism to "pull out" the endogenous variable and place it back into the long-term relationship. Moreover, the coefficient $\alpha_{Ln\ Brent}$ measures the adjustment speed of the endogenous variable to deviations from the long-run equilibrium. Given the above long-term relationship, the estimated coefficient $\alpha_{Ln\ Brent}$ was–0.1300 and this is interpreted as the rate of convergence to the long-run equilibrium. It means that the increase of Ln Brent in a given year includes the correction of about 0.6227 units of the imbalance in the long-term relationship of the previous year.

5.2.2. Model 1b: co-integration between the variables Ln Coal and Ln Brent

According to Table 2, the trace test points towards the lack of a co-integrating vector. The trace test does not reject the null hypothesis of zero co-integrating vectors. However, it rejects the null hypothesis of at least one co-integrating vector. Accordingly, we could not find evidence of co-integration between coal and Brent.

Based both on sample data and results found, there is a relationship of direct dependence between Brent spot prices and coal spot prices, which may be due to the collected sample. This is because there was a period (2004–2005) in which the price of coal fell and crude oil rose. In general, the prices of coal generally follow the trend of crude oil although not always synchronously.

The substitution effect is extremely low, especially in the short and medium term. We believe, though we have no numeric arguments, that the fluctuations in crude oil prices did not directly affect the price of coal (or vice-versa). In fact, we believe

Table 3
Johansen co-integration analysis of logged commodity prices for model 1a.

Model 1a	**ECM = Ln PBrent − 0.6227 Ln PFuel − 0.0003 trend** Number of lags used in the analysis: 16		
	PBrent	**PFuel**	**Trend**
Standardized β eigenvalues	1	−0.6227	−0.0003
with standard errors	0	0.0875	0.0000
Standardized α coefficients	−0.1300	0.0000	
with standard errors	0.0222	0.0000	

Table 2
Co-integration rank test for logged commodity prices.

Number of co-integration vectors	**Trace test [prob]**	**Trace test (*T*-nm)**	**Max test [prob]**	**Max test (*T*-nm)**
Model 1a	Relationship fuel oil–Brent crude oil			
$r=0$	41.14 [0.000]**	36.97 [0.000]**	40.22 [0.000]**	36.15 [0.000]**
$r \leq 1$	4.17 [0.719]	4.17 [0.720]	4.07 [0.731]	4.07 [0.733]
Model 1b	Relationship coal API–Brent oil			
$r=0$	12.60 [0.769]	10.90 [0.535]	12.09 [0.804]	10.46 [0.580]
$r \leq 1$	1.70 [0.972]	1.70 [0.972]	1.63 [0.975]	1.63 [0.976]
Model 1c	Relationship Gas Zeebrugge–Brent oil			
$r=0$	35.59 [0.000]**	34.52 [0.000]**	34.14 [0.000]**	33.11 [0.000]**
$r \leq 1$	1.07 [0.300]	1.07 [0.300]	1.03 [0.310]	1.03 [0,310]

Note: *Significant at 5%; ***Significant at 10%.

** Significant at 1%.

that the harmonious oscillation between both energy products is based on the worldwide pressure of demand for energy.

5.2.3. Model 1c: co-integration between the variables Ln Zeebrugge (Gas) and Ln Brent

Before performing the co-integration analysis between Ln Zeebrugge (Gas) and Ln Brent it is important to bear in mind that there is a fundamental difference between the Zeebrugge (Gas) over fuel: natural gas is not a refined oil-based product.

Although it is unknown to what extent natural gas will possibly be a substitute of oil, the fact is that Brent and natural gas compete both in terms of industrial use and the production of electricity. On the other hand, coal currently only contributes to the production of electricity. It is also known that a significant part of the supply contracts for natural gas use formulas for setting indexed price baskets of crude and/or refined products.

According to Table 4, the trace test indicates the presence of a co-integrating vector. The trace test rejects the null hypothesis that defends that there are zero co-integrating vectors and does not reject the null hypothesis that supports that there is at least one co-integrating vector. Evidence suggests that Ln Zeebrugge is weakly exogenous to the co-integration vector, which shows that, given the imbalances in the long-term relationship, Ln Zeebrugge responds as opposed to Ln Brent. In regards to the results, it can be claimed that the associated coefficient with the dummy is statistically significant and indicates a divergence between the path of Ln Brent and Ln Zeebrugge.

Table 4
Johansen co-integration analysis of logged commodity prices for model 1c.

Model 1c	**ECM = Ln PGas − 0.4307 Ln PBrent − 1.1073 dummy gas** Number of lags used in the analysis: 29		
	Pgas	**PBrent**	**Dummy gas**
Standardized β eigenvalues	1	−0.4307	−1.1073
with standard errors	0	0.1043	0.1346
Standardized α coefficients	−0.1066	0.0000	
with standard errors	0.0186	0.0000	

In conclusion, there is evidence to say that when there is an imbalance in the estimated long-term relationship (when equality is not the case), Ln Zeebrugge is the one that "moves" in order to recover the equilibrium towards the Ln Brent. In terms of interpretation of the relationship, we may say that the coefficient associated with this ECM will have a negative sign, and if the deviation is positive there will be a mechanism to "pull" the endogenous variable back to the long-term relationship. Moreover, this $\alpha_{Zeebrugge}$ coefficient measures the speed of adjustment of the endogenous variable to deviations relating the long-term equilibrium. From the above presented results and given the above long-term relationship, it should be emphasized the estimated $\alpha_{Zeebrugge}$ coefficient that was −0.1066, being this interpreted as the rate of convergence to the long-run equilibrium. Therefore, it means that the increase of Ln Zeebrugge, in a given year, includes a long-term imbalance correction of 0.1066 units *vis-à-vis* the previous year.

5.2.4. Model 2: co-integration between all commodities

In this multivariate model, shown in Tables 5 and 6, there is evidence of only one co-integration vector in which only the price of natural gas is significantly different from zero. It means that the co-integration among the prices of commodities in the general model is absent. This is surprising since in the bivariate analysis there is an indication of a long-term relation between the price of crude oil and the price of fuel and between the price of gas and price of crude oil.

5.3. Relationship between fossil prices and electricity prices

5.3.1. Model 3: co-integration between the variables Ln Omel-price and each fossil fuel

According to Table 7, the trace test indicates the lack of a co-integrating vector. The trace test does not reject the null hypothesis sustaining that there are no co-integrating vectors and rejects the null hypothesis sustaining there is at least one co-integrating vector. Given these results, we could not find evidence of co-integration of OMEL Price and each fossil fuel: fuel oil, coal, gas and Brent.

In order to assess the normality of univariate sample case for each of the variables we use the Jarque–Bera test. The test rejects

Table 5
Johansen co-integration analysis of logged commodity prices for model 2.

Model 2	**ECM = Ln Pgas − 1.2055 dummy gas − 0.0002146 trend** Number of lags used in the analysis: 36					
	PGas	**Ln P fuel**	**Ln P coal API**	**Ln PBrent**	**Dummy gas**	**Trend**
Standardized β eigenvalues with standard errors	1	0.0000	0.0000	0.0000	−1.2055	−0.000214
	0	0.0000	0.0000	0.0000	0.1577	6.9398e−005
Standardized α coefficients with standard errors	−0.0924	0.0000	0.0000	0.0000		
	0.0176	0.0000	0.0000	0.0000		

Table 6
Co-integration rank test for logged commodity prices for model 2.

Number of co-integration vectors	**Trace test [prob]**	**Trace test (*T*-nm)**	**Max test [prob]**	**Max test (*T*-nm)**
Model 2	Relationship fuel oil–Brent crude oil–Gas Zeebrugge–coal API			
$r=0$	76.62 [0.002]**	69.30 [0.015]**	39.07 [0.004]**	35.33 [0.016]**
$r=1$	37.55 [0.156]	33.97 [0.295]	26.45 [0.038]	23.92 [0.086]
$r=2$	11.10 [0.865]	10.04 [0.916]	9.55 [0.672]	8.63 [0.761]
$r \leq 3$	1.56 [0.978]	1.41 [0.984]	1.56 [0.979]	1.41 [0.985]

Note: *Significant at 5%; ***Significant at 10%.

** Significant at 1%.

Table 7
Co-integration rank test for logged commodity prices for model 3.

Number of co-integration vectors	Trace test [prob]	Trace test (*T*-nm)	Max test [prob]	Max test (*T*-nm)
Model 3a	Relationship price Omel electricity–fuel oil			
$r=0$	14.520 [0.069]***	14.33 [0.047]*	13.78 [0.089]***	13.6 [0.062]***
$r\leq 1$	0.19 [0.663]	0.19 [0.663]	0.18 [0.671]	0.18 [0.671]
Model 3b	Relationship price Omel electricity–coal API			
$r=0$	14.57 [0.616]	13.29 [0.316]	13.83 [0.676]	12.62 [0.372]
$r\leq 1$	1.28 [0.988]	1.28 [0.989]	1.21 [0.990]	1.21 [0.990]
Model 3c	Relationship price Omel electricity–Gas Zeebrugge			
$r=0$	11.31 [0.196]	11.16 [0.148]	10.74 [0.232]	10.59 [0.179]
$r\leq 1$	0.15 [0.696]	0.15 [0.696]	0.15 [0.703]	0.15 [0.703]
Model 3d	Relationship price Omel electricity–Brent oil			
$r=0$	19.86 [0.237]	14.58 [0.224]	18.86 [0.295]	13.84 [0.274]
$r\leq 1$	5.28 [0.565]	5.28 [0.567]	5.01 [0.602]	5.01 [0.603]

Note: ** Significant at 1%.

* Significant at 5%.
*** Significant at 10%.

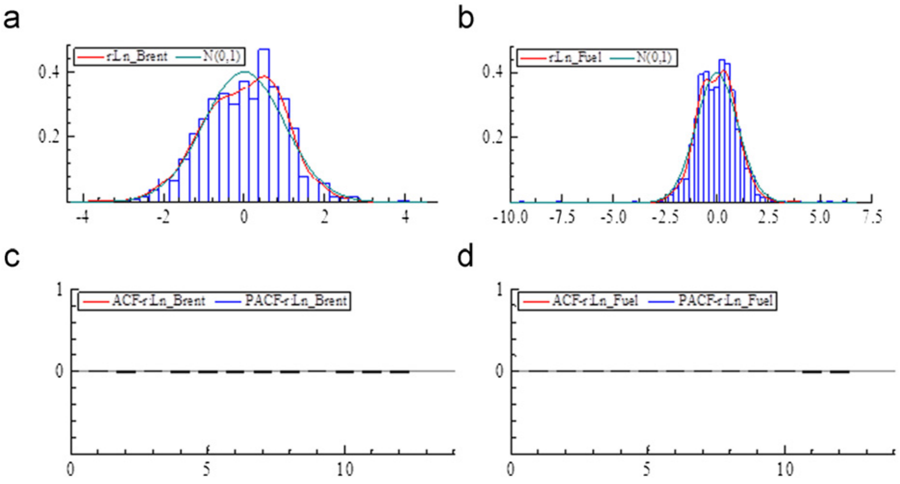

Fig. 2. Implied Empirical Density, Autocorrelogram and VAR Residuals: (a) brent price fitted residuals, (b) fuel oil price fitted residuals, (c) fitted residual autocorrelation function(ACF) and (d) fitted residual parcial autocorrelation function(PACF).

Table 8
Johansen co-integration analysis of logged commodity prices for model 4.

Model 4	**ECM=Ln Pgas −0.2398 Ln POmel −1.057 dummy gas −0.0001368 trend** Number of Lags used in the analysis: 36						
	PGas	**Ln Pomel**	**Dummy gas**	**Ln PBrent**	**Ln PCoal API**	**Ln P Fuel**	**Trend**
Standardized *β* eigenvalues with standard errors	1	−0.2398	−1.0577	0.0000	0.0000	0.0000	−0.0001
	0	0.0735	0.1252	0.0000	0.0000	0.0000	5.6448e−005
Standardized *α* coefficients with standard errors	−0.1208	0.0000		0.0000	0.0000	0.0000	
	0.0201	0.0000		0.0000	0.0000	0.0000	

the null hypothesis of normality for each univariate series. In addition, an investigation of the residuals showed no significant auto-correlation between the residuals as shown in Fig. 2.

5.3.2. Model 4: co-integration between Ln Omel-price and all fossil fuel commodities

According to the results presented in Tables 8 and 9, the multivariate model used to analyze the existence of co-integration vectors between Omel real price and the group of all commodities shows significant statistical evidence of a long-term co-integration vector involving Omel price and the price of the gas.

The relation between these two variables is coherent as the correlation between them is positive. Also, in alpha matrix only the coefficient associated to the price of gas the gas a significant value. Taking these results into account, it is possible to argue that a variation of 1% in the Omel price will induce a variation of 0,23% in the price of the gas.

5.3.3. Model 5: co-integration between the adjusted Omel-price and all fossil fuel commodities

Taking into account the perfectly competitive market, we decided to introduce the adjusted Omel price (PO**), which time

Table 9
Co-integration rank test for logged commodity prices for model 4.

Number of co-integration vectors	**Trace test [prob]**	**Trace test (*T*-nm)**	**Max test [prob]**	**Max test (*T*-nm)**
Model 4	Relationship POmel–Ln PFuel Oil–Ln PBrent–Ln_PCoal API–Ln_PGas			
$r=0$	101.48 [0.004]**	88.63 [0.049] *	45.24 [0.005]**	39.51 [0.032]*
$r=1$	56.25 [0.186]	49.12 [0.457]	25.65 [0.260]	22.40 [0.477]
$r=2$	30.60 [0.473]	26.72 [0.699]	16.05 [0.554]	14.01 [0.726]
$r=3$	14.55 [0.618]	12.71 [0.761]	12.56 [0.377]	10.97 [0.528]
$r\leq 4$	1.99 [0.956]	1.99 [0.956]	1.73 [0.970]	1.73 [0.971]

Note: ***Significant at 10%.

** Significant at 1%.

* Significant at 5%.

Table 10
Johansen co-integration analysis of logged commodity prices for model 5.

Model 5	**ECM 1=Ln PO** −0.74504 Ln Coal −0.42183 Ln Gas** **ECM 2=Ln PGAS −1.2143 dummy gas −0.0002082 trend** Number of Lags used in the analysis: 36						
	PGas	**Ln PO****	**Dummy gas**	**Ln PBrent**	**Ln P coal**	**Ln P Fuel**	**Trend**
ECM 1							
Standardized β eigenvalues with standard errors	−0.4218	1	−1.0577	0.0000	−0.7450	0.0000	−0.0001
	0.1698	0	0.1252	0.0000	0.1421	0.0000	5.644e−005
Standardized α coefficients with standard errors	0.0000	−0.1695		0.0000	0.0000	0.0000	
	0.0000	0.03311		0.0000	0.0000	0.0000	
ECM 2							
Standardized β s eigenvalues with standard errors	1	0.0000	−1.2143	0.0000	0.0000	0.0000	−0.00020
	0	0.0000	0.1534	0.0000	0.0000	0.0000	6.865e−005
Standardized α coefficients with standard errors	−0.09127	−0.0889		0.0000	0.0000	0.0000	
	0.01765	0.0441		0.0000	0.0000	0.0000	

Table 11
Co-integration rank test for logged commodity prices for model 5.

Number of co-integration vectors	**Trace test [prob]**	**Trace test (*T*-nm)**	**Max test [prob]**	**Max test (*T*-nm)**
	Relationship P**Omel–Ln PFuel Oil–Ln PBrent–Ln_PCoal API–Ln P Gas			
Model 5				
$r=0$	106.79 [0.001]**	94.04 [0.018]*	40.28 [0.025]*	35.47 [0.102]
$r=1$	66.52 [0.027]*	58.57 [0.128]	29.88 [0.090]	26.31 [0.224]
$r=2$	36.63 [0.186]	32.26 [0.381]	25.40 [0.054]	22.36 [0.136]
$r=3$	11.23 [0.857]	9.89 [0.923]	9.67 [0.660]	8.52 [0.771]
$r\leq 4$	1.56 [0.978]	1.37 [0.985]	1.56 [0.979]	1.37 [0.986]

Note: ***Significant at 10%.

** Significant at 1%.

* Significant at 5%.

series was set up based on the Omel production marginal costs. After using the VAR it was possible to define two co-integration vectors. As shown in Tables 10 and 11, the VECM with two vectors establishes (a) relations between the adjusted Omel price (PO**), the price of coal and the natural gas price, i. e., the adjusted Omel price would be proportional to the price of those two commodities that are important inputs in the electricity production, and (b) a long-term relation between the price of natural gas, the trend and the dummy variable, i.e., this vector helps explaining the evolution of the natural gas series.

5.4. Granger causality tests

The causality tests were set in an unrestricted VAR for both bivariate and multivariate analysis. In the first phase of the analysis, we considered the causality among all the prices of the commodities: Brent, coal, gas and fuel oil. The results of the Granger causality estimation are presented in Tables 12 and 13. In a second phase, we analyzed the Granger causality between the price of electricity and the price of the other commodities in two different situations: at the real market price level, and at competitive market level, where the electricity price should reflect the production costs. The results are presented in Tables 14 and 15.

We accomplished the Granger causality test for the multivariate models with deterministic variable departing from the bivariate models obtained previously. We performed enough adjustments so that all the estimated bivariate models could be included, and without restrictions, (based on an unrestricted VAR model) with the Real Omel Price and the adjusted POmel (price=marginal cost).

According to Table 12, in the bivariate model, at 1% significance level, there is significant evidence of causality between the price of fuel oil and the price of Brent. At 5% significance level there is significant evidence of causality between the price of Brent and the price of gas.

According to Table 13, in the multivariate model, at 1% significance level, there is significant evidence of causality between the price of fuel oil and the prices of gas, coal and crude oil. At 5% significance level there is significant evidence of causality between the price of Brent and the prices of gas, coal and fuel oil as well as causality between the prices of other commodities (gas, coal and fuel oil) and the price of Brent.

The Granger causality between the price of electricity and the remaining commodities are shown in Tables 14 and 15.

According to the results presented in Table 14 for the bivariate models, there is statistical evidence at 10% significance level to affirm that the prices of coal and Brent influence the price of electricity in the Omel market.

According to the results presented in Table 14 there is statistical evidence at 10% significance level that both the Omel price and the adjusted POmel (PO**) are influenced by the prices of the other commodities (Brent, fuel, coal and gas).

6. Conclusions and policy implications

One of the most popular economic models that analyses long-term relationships among variables is the co-integration model. This model allows the researcher to analyze the balance of long-period relationships.

Based on the study of long-term bivariate relationships, there is statistical significant and explanatory evidence that the prices of fuel and crude oil (Brent) are intertwined. In addition, the prices of Brent tend to “move” to reestablish the price equilibrium. Although it may seem paradoxical, this might by perfectly plausible from a demand perspective as this is what truly determines the price of raw materials. If there is an increase in demand, and taking into account a fixed production capacity, fuel and the raw material from which it is made, crude oil, becomes scarcer inherently making both commodities more expensive.

Table 12
Bivariate model of Granger causality test for fossil commodities.

Test	Test value	*p*-value
H_0: “Ln_PBrent do not Granger-cause Ln Gas”	16.631	0.046*
H_0: “Ln_Pfuel do not Granger-cause Ln_PBrent”	26.190	0.0003**
H_0: “Ln_PGas do not Granger-cause Ln_PBrent”	0.9636	0.5211
H_0: “Ln_PBrent do not Granger-cause Ln_PGas”	11.485	0.2670

Note: ***Significant at 10%.

** Significant at 1%.

* Significant at 5%.

Previously, we considered that the use of another mechanism, i.e. the influence in the price from supply side (an increase/decrease of the production capacity, an increase of the geo-strategic risk in the extraction zones, etc.). However, the models used during this research demonstrate demand dictates prices, thus, there is little evidence that supply has provoked significant oscillations in the price of crude oil, and consequently, fuel. In short, the price indexation of most commodities to the price of crude oil has favored the development of more remote sources of gas, thus, improving the supply and safety of new pipelines. On the other hand, there is an increase in the commercialization of gas. The prices of this commodity are influenced, on one hand, by the evolution of long term price contracts and, on the other hand, by the partial shift from gas to fuel in some large industries, namely in the electric industry.

In this study, the long-term results of the co-integration bivariate tests show that when there is a price differentiation throughout time, the prices of gas and fuel move towards the price of crude oil, as they are heavily dependent on this raw material. This allows main competitors to practice similar prices. Clearly, international players can closely gather information about the international behavior of the commodities market.

The multivariate analysis shows that another co-integration vector that defines a long-term relationship is the one that contributes to explain the evolution of the natural gas series.

According to the Granger causality bivariate tests, and at 5% significance level, there is no evidence of precedence between the Omel electricity price and the price of commodities. However, at 10% significance level, there is evidence of precedence between the prices of gas and coal and the Ln POmel. Given the strong correlation between the price of Brent and the price of fuel oil (Ln Fuel), it seems strange that there is no evidence of causality between the price of fuel oil and Ln POmel. On the other hand, as the trace test points to the lack of a co-integration vector, it is not possible to estimate any co-integration vector between the Omel price and the price of the commodities.

Table 14
Bivariate model of Granger causality test relating electricity and commodity prices.

Test	Test value	*p*-value
H_0: “Ln_POmel do not Granger-cause Ln_PFuel”	0.7747	0.8301
H_0: “Ln_Pfuel do not Granger-cause Ln_POmel”	11.992	0.1937
H_0: “Ln_POmel do not Granger-cause Ln_PCoal”	0.5125	0.9930
H_0: “Ln_PCoal do not Granger-cause Ln_POmel”	14.150	0.0521***
H_0: “Ln_POmel do not Granger-cause Ln_PBrent”	12.927	0.1143
H_0: “Ln_PBrent do not Granger-cause Ln_POmel”	13.155	0.0995***
H_0: “Ln_POmel do not Granger-cause Ln_PGas”	12.817	0.1220
H_0: “Ln_Gas do not Granger-cause Ln_POmel”	10.759	0.3488

Note: **Significant at 1%; *significant at 5%.

*** Significant at 10%.

Table 13
Multivariate model of Granger causality test for fossil commodities.

Test	Test value	*p*-value
H_0: “Ln_PBrent do not Granger-cause Ln_PGas, Ln_PCoal, Ln_PFuel”	1.3254	0.0143*
H_0: “Ln_PFuel do not Granger-cause Ln_PGas, Ln_PCoal Ln_PBrent”	1.3711	0.0070**
H_0: “Ln_PCoal do not Granger-cause Ln_PGas Ln_PBrent, Ln_PFuel”	1.1124	0.2028
H_0: “Ln_PGas do not Granger-cause Ln_PCoal, Ln_PBrent, Ln_PFuel”	0.9864	0.5220
H_0: “Ln_PGas, Ln_PCoal, Ln_PFuel do not Granger-cause Ln_PBrent”	1.2365	0.0505*
H_0: “Ln_PGas, Ln_PCoal Ln_PBrent do not Granger-cause Ln_PFuel”	1.2049	0.0749***
H_0: “Ln_PGas Ln_PBrent, Ln_PFuel do not Granger-cause Ln_PCoal”	1.0992	0.2291
H_0: “Ln_PCoal , Ln_PBrent, Ln_PFuel do not Granger-cause Ln_PGas”	1.0639	0.3091

** Significant at 1%.

* Significant at 5%.

*** Significant at 10%.

Table 15
Multivariate model of Granger causality test relating electricity and commodity prices.

Test	Test value	*p*-value
H_0: "Ln_POmel do not Granger-cause Ln_PBrent, Ln_PFuel Ln_Pcoal, Ln_PGas"	0.9519	0.6404
H_0: "Ln_PBrent, Ln_PFuel Ln_Pcoal, Ln_PGas" do not Granger-cause Ln_POmel"	1.1752	0.0822***
H_0: "Ln_PBrent do not Granger-cause Ln_POmel, Ln_PFuel Ln_Pcoal, Ln_PGas"	1.3332	0.0063*
H_0: "Ln_PO** do not Granger-cause Ln_PBrent, Ln_PFuel Ln_Pcoal, Ln_PGas"	1.2479	0.0912***
H_0: "Ln_PBrent, Ln_PFuel Ln_Pcoal, Ln_PGas do not Granger-cause "Ln_PO**"	1.998	0.0501***
H_0: "Ln_PBrent do not Granger-cause Ln_PO**, Ln_PFuel Ln_Pcoal, Ln_PGas"	1.3031	0.0109*

* Significant at 5%.
** Significant at 1%.
*** Significant at 10%.

Regarding the described multivariate model used to analyze the presence of a co-integration vector between the Omel real price and all remaining commodities, there is evidence to support one co-integration long-term vector that relates to and explains the evolution of the Omel price and the price of natural gas.

The causality test based on an unrestricted VAR that includes all variables (price of the commodities) reveals a significant evidence of three kinds of causality:

- At 1% level between the price of fuel oil and the prices of gas, coal and crude oil.
- At 5% significance level between the price of crude oil and the prices of the remaining commodities and between them and the price of the crude oil.
- At 10% significance level between the price of the gas, coal and crude oil and the price of fuel oil.

This tendency can be interpreted as a random source that affects the commodities' market pricing dynamics. However, admitting a series of expected prices, POmel (PO**), calculated base on the production costs (price = marginal cost), it was possible to find a vector that establishes a relationship between POmel (PO**) and the prices of coal and natural gas. These are important inputs in the production of electricity.

Summing up, it is possible to argue that coal and gas market prices can be understood as a major source of explanatory randomness in the electricity pricing dynamics. As negotiations evolve in industrial markets that are strongly dependent on commodities such as gas, fuel and coal, and as it is the case of the electricity market, it is important to analyze the co-integration between the price of electricity and the price of commodities having in mind that those commodities are important raw materials for the production of electricity.

In the future, the tendency for crude oil and other fossil fuel prices (gas, coal and fuel oil) to move quickly and follow one another will strengthen, due to the substitutability of the four products in the heating and electricity markets. Moreover, gas increasingly serves as an oil substitute in the generation of electricity, and the amount of fuel-gas in the electricity market is approaching that of oil due to a stiffer competition from alternative technologies in the electricity market.

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