# Price Adjustments and Transaction Costs in the European Natural Gas Market

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**ABSTRACT**

The presence of long-term contracts indexed to oil prices is a key feature of the evolution of the European natural gas industry. During the 2000's, the European Commission (EC) promoted reforms to establish a single and integrated natural gas market, leading to the development of short-term regional markets based on hubs. This paper tests the hypothesis that asymmetric price responses in the continental European hubs derive from transaction costs. By applying linear and nonlinear error correction models, it assesses the price transmission dynamics and the degree of integration between the German, the Belgium and the Dutch spot markets. The models identified cointegration relations, price asymmetries and transaction costs in these markets. Results show a high degree of integration across regions, with prices converging rapidly to their long-run equilibrium. However, asymmetric price adjustments reveal the presence of transaction costs in the German regional hub.

**Keywords:** Natural gas prices, Market integration, Threshold Vector Error Correction Model, Transaction costs

https://doi.org/10.5547/01956574.40.1.rgar

## 1. INTRODUCTION

A unified and liberalized natural gas market in continental Europe is still a distant prospect that requires the development of regional markets. Notwithstanding the notable progress, increasing the number of physical transactions between markets is still required to reduce bottlenecks in transport networks and interconnection points. Under the regulatory reforms promoted by the European Commission, hubs with high liquidity play an important role on market integration, reducing price uncertainty and the transaction costs[1] of natural gas trade.

Moreover, hold-up problems[2] may arise in the absence of long-term, price-indexed contracts. Hold-up and limited liquidity issues may introduce price uncertainty in natural gas markets.

[1] The concept of transaction costs was initially applied to firms and organizations (Commons, 1934; Coase, 1937), This concept was later broadened to incorporate the idea of Pareto inefficiency and market failures (Williamson, 1981). To Arrow (1969), transaction costs can be interpreted as the cost of using the market mechanism, i.e., the cost to organize market exchange.

[2] Hold-up problems arise when agents establish a noncontractible relationship before a (contractual) transaction occurs, for instance, as a result of bargaining power, deficient legal system or lack of a standardized contract.

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Thus, the European transition from long-term contracts to hub-based spot markets raises some concerns regarding the presence of transaction costs.

The transaction costs encompass many more aspects than just the (natural gas) transport expenditure. They can be any costs with respect to temporal and financial expenses connected to the search for information, financing the trading process and legal duties (Shepherd, 1997). A possible way to evaluate the role played by transaction costs in market integration is through the degree of (non-)price convergence between hub markets.

This paper tests the hypothesis that asymmetric price responses in the continental European hubs are derived from transaction costs. Asymmetric price responses might reflect different transaction costs depending on what is the trade direction and are particularly interesting to observe because of the increasing role of non-operational agents (traders etc.) in the European hubs. To do so, we assess the degree of integration between the German, the Belgium and the Dutch natural gas spot markets and estimate nonlinear error correction models that allow for short-term regime specific price dynamics. Through this methodology we can identify price asymmetries and transaction costs, possibly offering arbitrage opportunities. To our knowledge, this methodology was mostly applied to agricultural commodities' markets, with few applications to energy markets. Therefore, by applying this methodology to the European gas market we argue that this can be used in energy markets to evaluate transaction costs and asymmetric price responses, providing case studies for other markets that plan to go through liberalization processes, like the Brazilian market (Mathias and Szklo, 2007) or the Chinese market (Ishwaran et al., 2017).

Besides this introduction, section 2 summarizes the evolution of natural gas markets in Europe and presents different views of market integration found in the literature. Section 3 describes the data selection and section 4 the methodological procedure adopted. The results of the tests and the models employed in the analysis are discussed in section 5, with special attention to the cointegration relations, the price regimes and the asymmetric price responses between the German, the Belgian and the Dutch markets. Section 6 brings final remarks.

## 2. INTEGRATION OF THE NATURAL GAS MARKETS IN EUROPE

During the 1960's and 1970's natural gas became an important source in the European energy mix. Throughout those decades, the European natural gas industry grew vertically integrated based on natural monopolies of national companies. Despite the pressures for introducing more competition in the continental European natural gas industry during the second half of the 1980's and the 1990's[3], the market liberalization process started only in 1998, with Directive 98/30 of the European Commission (EC). Bourbonnais and Geoffron (2007) showed that, until the mid-2000's, the integration of the European natural gas markets was a sparse phenomenon. Throughout the 2000's, under new regulatory reforms, spot markets based on hubs emerged, challenging the long-term contracts structure based on take-or-pay clauses.

High investments in transport infrastructure are required for expanding supply in the natural gas industry, so that the economic feasibility of these investments strongly depends on the pricing structure and predictability (Komlev, 2013). Over the last years, some companies have introduced flexibility clauses and started trading in the spot market, but the substantial part of their contracts is still long-term based (Statoil ASA, 2015). Meanwhile, the EC kept pushing on regulatory reforms to promote a single integrated market for natural gas. In this sense, the benefits associated

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[3] For instance, Adelman and Lynch (1986) highlighted the importance of a short-term market for the European natural gas, so that the price transmission mechanism could benefit from greater transparency.

with reduced market power of the national (and vertically integrated) oil and gas companies may be offset by price uncertainties associated with the liberalization process, thus reducing incentives for investments in infrastructure expansion.

Several empirical studies rely on the Law of One Price (LOP)[4] to evaluate the effectiveness of natural gas market integration (Asche et al., 2002; Siliverstovs et al., 2005; Bourbonnais and Geoffron; 2007; Robinson, 2007; Brown e Yücel, 2009; Renou-Maissant, 2012; Asche et al., 2013; Growitsch et al., 2013). Firstly, most of these studies do not consider a complete interpretation of what market integration stands for. They usually focus on price series and do not account for physical factors related to market integration in their analysis—flow constraints, for example. Secondly, in practice, market failures and economic inefficiency are pervasive and perfectly competitive markets are hard to find. So, how to assess price transmission asymmetries within an integrated market framework where the LOP prevails?

Regarding the first aspect, different definitions for market integration can be found in the economic literature. Market integration can be a measure of the expected rate of price transmission (Fackler and Goodwin, 2001) or related to price transmission efficiency and equilibrium in the presence of trade flows (Barrett, 2001). Another view comes from Gonzalez-Rivera and Helfand (2001) that consider both geographic elements—such as space—and economic elements, defining integrated markets as the set of places that share the same commerce and the same long-term information. Moreover, in Ihle (2012) a fourth different interpretation emerges, defining the integration of markets as a relationship characterized by long-term dynamics. In this study, we share Ihle's (2012) view, thus referring to market integration as a dichotomous variable for which there is (or there is not) a physical and informational long-term trade flow. This definition is particularly interesting especially because for Ihle (2012) the informational flow (i.e., the price transmission) incorporates the dynamics of the error correction models (as further described in section 4).

As for the second aspect, economic inefficiencies may hinder price convergence, leading to a departure from the LOP. Several studies in the literature are based on the idea that arbitrage is the force which eliminates deviations from the LOP, occurring when the price differential is sufficiently greater than the transport cost of the goods (Lo and Zivot, 2001). This could be the case for the natural gas trade in continental Europe hubs: if transaction costs play a significant role, arbitrage opportunities might occur (Nick 2016), leading to a milder form of the LOP. The asset-specific investments on pipelines, valves, compressor stations, underground storage facilities and city gates leads to uncertainty, opportunism strategies and hold-up problems, increasing these transaction costs (Joskow, 1988; Von Hirschhausen and Neumann, 2008). Hubbard and Weiner (1991), for instance, identified that price negotiations in the United States (US) natural gas industry were often driven by market power and/or transaction costs. In the natural gas industry, transaction costs are commonly associated with its transport infrastructure. Long-term contracts, take-or-pay provisions and ex-ante prices or price adjustments provide the mechanisms to reduce contractual conflicts (Crocker and Masten, 1991) and, consequently, to avoid informational, administrative, bureaucratic, bargaining, among other transaction costs incurred by the parties in the natural gas trade.

Suffice it to say that the concept of transaction costs is at the heart of such inefficiencies. Nick (2016) remarks that short-run price deviations from equilibrium are persistent in the European market and assesses intertemporal arbitrage through a non-linear approach—a feature that should

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[4] The LOP states that, in the absence of trade barriers and transaction costs, and taking the exchange rate into account, a product will have identical prices in two perfectly competitive markets (Krugman and Obstfeld, 2003).

be taken more heavily into account in empirical studies. However, although mentioned[5], the role of transaction costs in the equilibrium is left behind and not fully explored.

In this sense, this study contributes to the literature in different aspects. First, methodologically, when it explicitly models transaction costs in a market integration perspective. Second, it explores price equilibrium through a nonlinear modeling approach, exploring asymmetries which are not perceived by linear models. Finally, the methodological framework relies on a conceptualization of market integration that is mostly applied in agricultural economics and could be explored by energy economic studies.

## 3. DATA SELECTION

To evaluate the liberalization policy pursued by the EC we focus on the hub based continental Europe spot market, therefore not including the British NBP hub, yet a fully liberalized market. Following the interpretation of market integration, we assessed the existence of physical trade in both directions (i.e., entry and exit) in continental Europe. We chose the period between 2013 and 2014 because of data availability and due to the new regulatory guidelines for trans-European energy infrastructure[6]. The hubs that best meet these criteria in this period are the Dutch TTF, the Belgian ZTP and the German NCG (ACER, 2014; ENTSOG, 2014). Figure 1 shows (in dark circles) their location and the available natural gas infrastructure.

Besides physical trade, another relevant measure for market integration is liquidity. Liquidity can be measured through churn rates, number of parties, spread, price volatility and other indices, like price transmission mechanisms. In 2013, the Dutch TTF churn rate reached 19.3, being above the British NBP (18.3) and far above the German NCG (3.3) and the Belgian ZTP (1.7) (GTS, 2015; NCG, 2015; Huberator, 2015). Table 1 presents a summary of the number of active participants, the total traded gas volumes (over the counter plus exchange) and the ratio of physical deliveries for these hubs in 2014. Although the German NCG had a great number of active participants, the volumes traded on the Dutch TTF were considerably higher, resulting in a performance ratio of 1.1, far above the two other hubs. The increasing number of parties and gas trade volumes also reflects the greater Dutch TTF liquidity (GTS, 2015).

In relation to the informational aspect of market integration, we departed from the LOP to assess price transmission between natural gas hubs. Assuming that the purchase power parity (PPP) holds, the LOP establishes that the price on market 1 at time t ($Y_{1t}$) is equal to the price on market 2 at time t ($Y_{2t}$), and that deviations from this price equality might occur due to the presence of transaction costs ($\theta$), as shown in Equation 1 below.

$$Y_{1t} = (1 - \theta) Y_{2t} \tag{1}$$

In the absence of transaction costs ($\theta = 0$), the LOP prevails; and in the presence of maximum transaction costs ($\theta = 1$), market failures abolish the price mechanism. Moreover, inefficiencies can lead to an arbitrage condition between these two markets. In this case, arbitrage—here defined as the possibility to profit from price differentials between markets—will exist only if $(1-\theta)\, Y_{1t} - Y_{2t} > 0$ or, alternatively, $(1-\theta)\, Y_{2t} - Y_{1t} > 0$.

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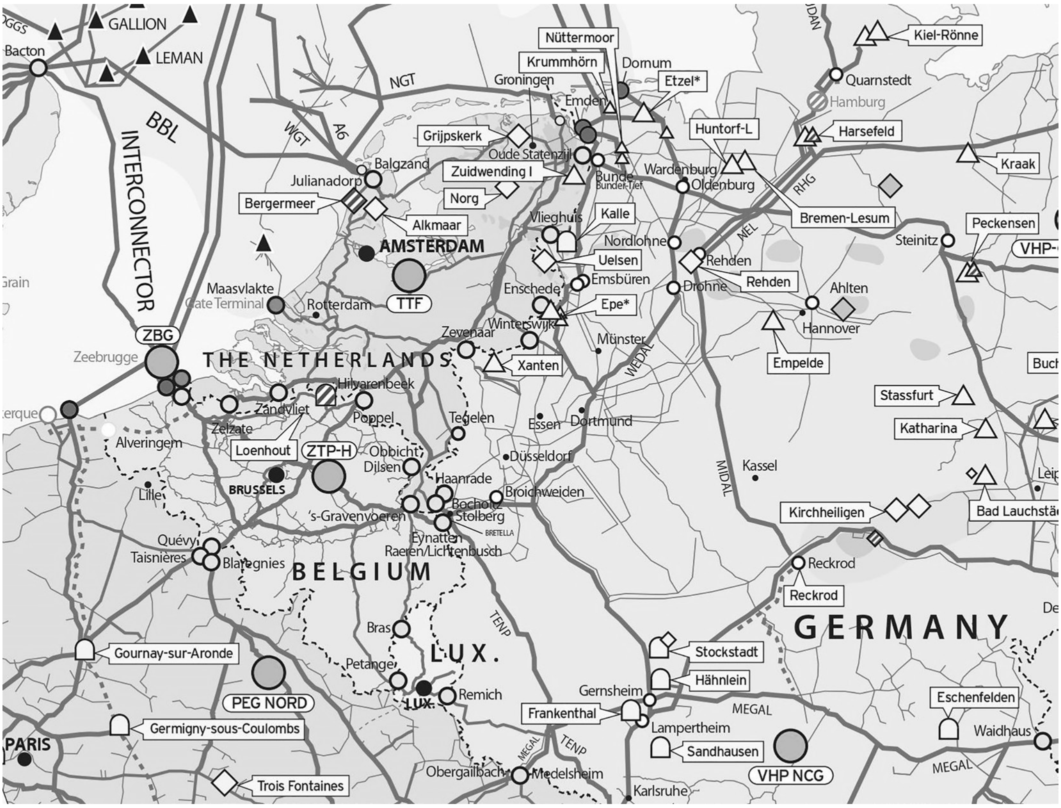
[5] "(…) the exhaustion of arbitrage opportunities at European gas hubs may be constrained by significant transaction costs resulting from low liquidity and by physical constraints (…)" Nick (2016, p. 12).

[6] Regulation (EU) No 347/2013, of 1 June 2013, and Regulation (EU) No 1391/2013, of 14 October 2013.

**Figure 1: TTF, ZTP and NCG hubs and the natural gas infrastructure.**



*Source*: adapted from ENTOG (2014).

**Table 1: Number of active participants, traded volume and performance ratio in 2014.**

| | Active Market Participants | Traded Volume (TWh) | Performance Ratio[a] |
|---|---|---|---|
| Dutch TTF | 125 | 13,216 | 1.1 |
| German NCG | 314 | 1,981 | 0.6 |
| Belgian ZTP | 66 | 91 | 0.2 |

*Source:* ACER/CEER (2015).

[a] Physically delivered volumes in the hub divided by country demand.

## 3.1 Sample description

The sample covers the period from April 2013 to December 2014 to comprise a full European gas year[7], resulting in 456 observations for the Dutch TTF, the Belgian ZTP, and the German NCG hubs. Data were obtained from NetConnect Germany and Powernext / PEGAS[8] (NCG, 2015; Pegas, 2015). Daily reference prices quoted in Euros per megawatt-hour (€/MWh) were used[9]. Price

7. The European gas year typically starts in October 1st and goes until September 30th of the following calendar year.

8. NetConnect Germany (NCG) groups different Transport System Operators (TSOs) and performs the management and operation of the NCG, the leading German hub. Powernext / PEGAS is a virtual trading platform for the following hubs: TTF, NCG, GASPOOL, ZTP, PEG Nord and PEG Sud PEG TIGF.

9. The reference price considers the volumes traded on the day prior to the delivery for contracts negotiated through the Trayport ETS platform, which is a trade platform for forward and futures energy market contracts. For the natural gas market,

**Table 2: Unit root tests in level and first differences for hubs price series.**

| | ADF | | ERS | | PP | | KPSS | |
|---|---|---|---|---|---|---|---|---|
| Hub | level | 1st diff | level | 1st diff | level | 1st diff | level | 1st diff |
| German NCG | –0.64 | –3.675*** | 14.66 | 0.666*** | –7.23 | –465.9*** | 2.764*** | 0.126 |
| Dutch TTF | –0.49 | –3.541*** | 15.05 | 4.124* | –6.53 | –433.3*** | 2.292*** | 0.129 |
| Belgian ZTP | –0.47 | –3.507*** | 6.948 | 1.047*** | –6.58 | –412.2*** | 3.029*** | 0.128 |

*Note:* Significant at * 10%; ** 5%; or *** 1% level.

**Table 3: Sample Descriptive Statistics—Spot Market.**

| | # Obs. | Mean | Median | Mode | SD | Skewness | Kurtosis | Max. | Min. |
|---|---|---|---|---|---|---|---|---|---|
| German NCG | 456 | 23.69 | 24.73 | 26.36 | 3.66 | –0.52 | –0.74 | 32.45 | 15.46 |
| Dutch TTF | 456 | 23.39 | 24.41 | 26.31 | 3.66 | –0.48 | –0.78 | 32.51 | 15.16 |
| Belgian ZTP | 456 | 23.43 | 24.45 | 26.40 | 3.67 | –0.47 | –0.75 | 32.73 | 15.25 |

series were not transformed into logarithms, since the transformation would assume an isoelastic relationship between prices, which is not consonant with the LOP (Nick, 2016).

Four different unit root tests were applied over the time series. For the Augmented Dickey-Fuller (ADF), Kwiatkowski–Phillips–Schmidt–Shin (KPSS) and Phillips-Perron (PP) tests, the results confirmed that all series are stationarity in first difference at a significance level of 1%. The only exception is the Elliott, Rothenberg and Stock (ERS) test for the Dutch TTF hub where stationarity is confirmed at a significance level of 10% (Table 2).

Once the unit roots tests confirmed the stationarity of the times series in first differences, we could check the series main statistics. The tests confirmed the absence of outliers in the sample, as presented in the boxplot graph in Figure A.1 in the Appendix. Table 3 shows an average price of approximately 23.5 €/MWh, with median around 24.5 €/MWh. The series feature standard deviation of 3.6 €/MWh, with a minimum around 15.5 €/MWh and a maximum around 32.5 €/MWh.

Figure 2 shows the daily prices evolution for the selected markets.

Bivariate Johansen cointegration tests were performed on the stationary series in first difference to check for cointegration. The number of lags was chosen based on the Akaike (AIC), Bayes (BIC) and Hannan-Quinn (HQ) information criteria[10]. Table 4 shows the results between the Dutch TTF, Belgian ZTP and German NCG price series. The null hypothesis of no cointegration (rank equals zero) is fully rejected and the tests confirm the cointegration of order one for all price series, which allows for an error correction model specification, as described in the following section.

## 4. ECONOMETRIC METHODOLOGY

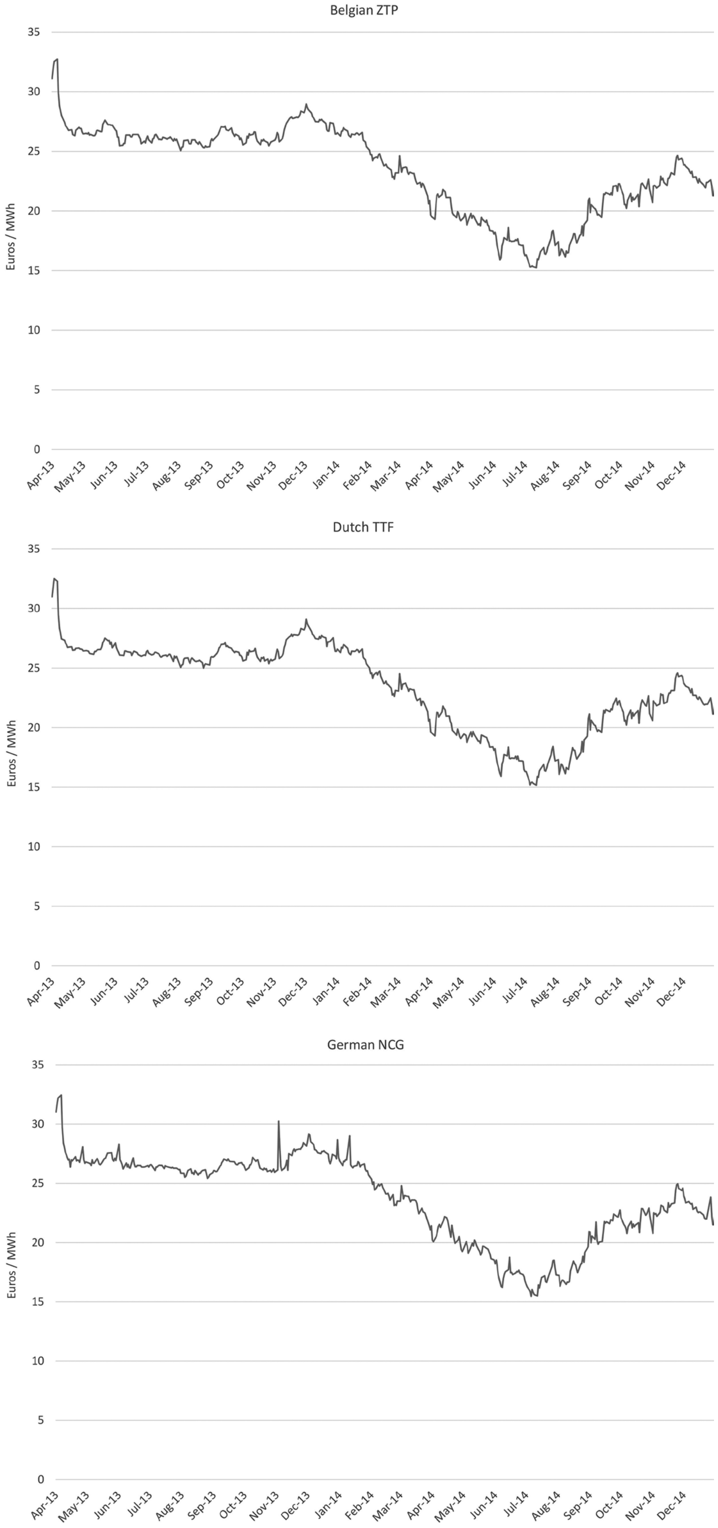
### 4.1 Vector Error Correction Model (VECM)

The VECM represents an autoregressive process that treats all variables as endogenous. The model relies on the Granger Representation Theorem (Engle and Granger, 1987), which states

the platform meets the physical and financial markets, with the participation of industrial customers, utilities, suppliers and financiers, such as banks, investment funds and brokerage. The reference prices for deliveries on weekends and Mondays is calculated based on Thursday and Friday volumes, respectively (Trayport ETS, 2015).

[10] The right specification of the number of lags is important because the model loses information when many lags are established, while a low number can make it inaccurate. All the tests returned a one lag specification.

**Figure 2: Hubs daily reference prices – April 2013 to December 2014. Values in €/MWh.**



*Source*: NGC (2015) and Pegas (2015).

**Table 4: Bivariate Johansen Cointegration Tests (Trace Statistic) 04/2013–12/2014.**

| | Dutch TTF | Belgian ZTP | |
|---|---|---|---|
| Belgian ZTP | 89.55*** | — | rank = 0 |
| German NCG | 144.36*** | 135.57*** | |
| Belgian ZTP | 2.83 | — | rank = 1 |
| German NCG | 5.00 | 5.11 | |

*Note:* Significant at *** 1% level.

that, if the variables in a vector $Y_t$ are cointegrated, they have an error correction representation. This representation differs from a pure VAR (Vector Autoregressive) process, as shown in Equation 2 (Engle and Granger, 1997; Lütkepohl, 2005).

$$\Delta Y_t = \alpha\ ECT_{t-k} + \sum_{i=1}^{k-1} \Gamma_i \Delta Y_{t-i} + \varepsilon_t \tag{2}$$

where $\Delta Y_t$ is the first difference operator of prices ($\Delta Y_t = Y_t - Y_{t-1}$). The error correction term ($ECT_{t-k}$) is preceded by the coefficient matrix α that represents the speed and the direction of the long-run adjustment to the equilibrium for every *t*. The short-term dynamics is represented by the vector of the coefficients $\Gamma_i$ that quantifies the influence of prior periods, and $\varepsilon_t$ is the white noise. According to the Granger Representation Theorem (Engle and Granger, 1987), the error correction term can also be expressed by $\alpha\ \beta' Y_{t-k}$, where β is the cointegration vector and $\beta' Y_{t-k}$ (= $ECT_{t-k}$) represents the cointegration relations for every *t.*

As noted by Escribano (2004), the linear properties of the error correction process might be restrictive, since the elements of the VECM are assumed to be constant, implying on a unique long-run equilibrium. Thus, the VECM does not capture asymmetric adjustment towards equilibrium or other features of the economic behavior, such as transactions costs, price asymmetries and arbitrage opportunities (Balke and Fomby, 1997; Escribano, 2004).

### 4.2 Threshold Vector Error Correction Models (TVECM)

The TVECM incorporates nonlinearities to the error correction processes by defining threshold variables. The principle of threshold models is that the error correction process depends on the value of a threshold variable. When this variable exceeds certain value, a change in the regime of the short-term price dynamics occurs. The threshold value allows for the identification of regimes that are characterized by error correction processes with distinct estimated parameters. Lo and Zivot (2001) note that the TVECM is better interpreted as a piecewise linear model, because parameters are constant in each regime, but vary across regimes.

The model can capture arbitrage possibilities within the LOP and, moreover, the existing asymmetries in the return to the equilibrium process (Balke and Fomby, 1997). Since the middle regime $\boldsymbol{\theta}_- \leq \mathbf{ECT_{t-k}} \leq \boldsymbol{\theta}_+$ can be interpreted as a no-arbitrage condition, it allows the identification of short-term arbitrage opportunities in the lower ($\mathbf{ECT_{t-k}} < \boldsymbol{\theta}_-$) and in the upper ($\mathbf{ECT_{t-k}} > \boldsymbol{\theta}_+$) regimes, when they occur. The transition between regimes is assumed to occur abruptly, but the TVECM specification with three regimes in Equation 3 is useful to identify upper and lower deviations from the no-arbitrage condition, especially considering a binary condition, where there is or there is not an arbitrage opportunity.

**Table 5: Granger-causality for lag 1 and maximum lag order (Toda-Yamamoto procedure).**

| Model (dependent ~ explanatory variable) | Degrees of Freedom | Lags | F-value | Pr (>F) |
|---|---|---|---|---|
| NCG ~ TTF | 904 | 1 | 61.682 | 0.0000*** |
| | 305 | 75 | 1.5143 | 0.0105** |
| NCG ~ ZTP | 904 | 1 | 37.54 | 0.0000*** |
| | 305 | 75 | 1.4877 | 0.0136** |
| ZTP ~ TTF | 870 | 1 | 19.251 | 0.0000*** |
| | 428 | 5 | 2.772 | 0.0177** |
| TTF ~ NCG | 904 | 1 | 6.9165 | 0.0086*** |
| | 305 | 75 | 0.7543 | 0.9234 |
| ZTP ~ NCG | 904 | 1 | 9.5078 | 0.0021*** |
| | 305 | 75 | 0.6573 | 0.9827 |
| TTF ~ ZTP | 870 | 1 | 0.5795 | 0.4467 |
| | 428 | 5 | 1.3916 | 0.2262 |

*Note:* Significant at * 10%; ** 5%; or *** 1% level.

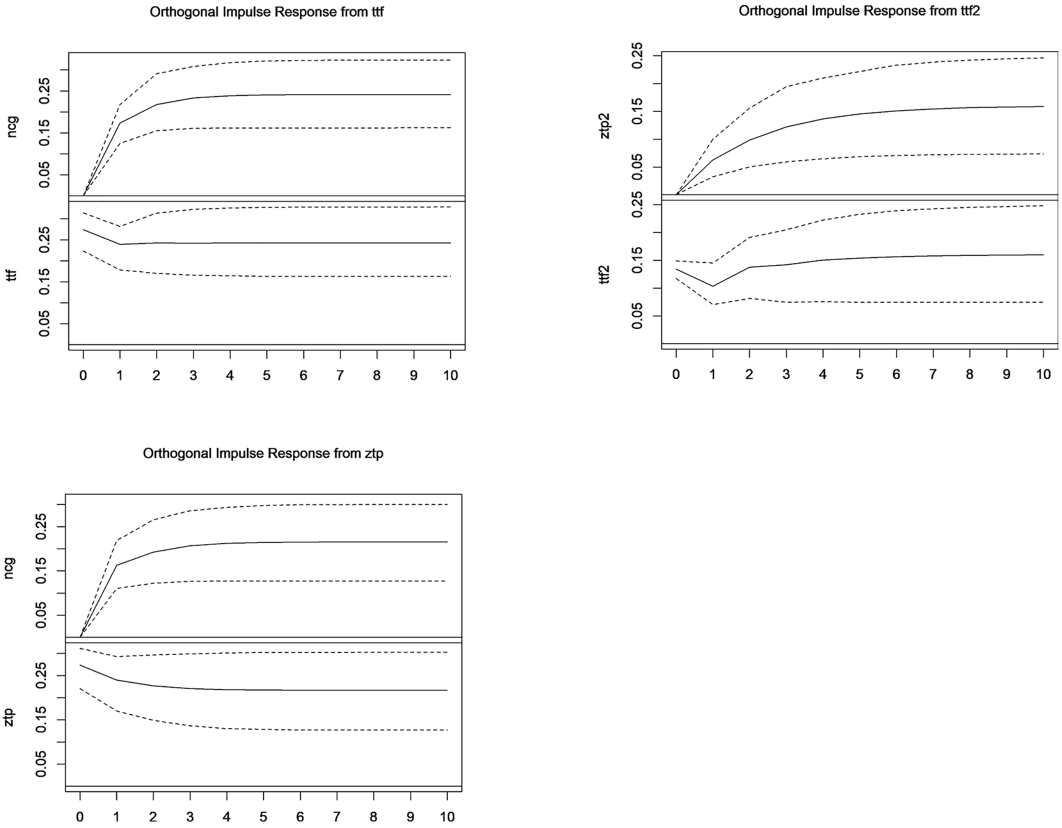
$$\Delta Y_t = \begin{cases} \alpha^{(1)} ECT_{t-k} + \sum_{i=1}^{k-1} \Gamma_i^{(1)} \Delta Y_{t-1} + \varepsilon_t, & if\ ECT_{t-k} < \theta_- \\ \alpha^{(2)} ECT_{t-k} + \sum_{i=1}^{k-1} \Gamma_i^{(2)} \Delta Y_{t-1} + \varepsilon_t, if\ \theta_- \le ECT_{t-k} \le \theta_+ \\ \alpha^{(3)} ECT_{t-k} + \sum_{i=1}^{k-1} \Gamma_i^{(3)} \Delta Y_{t-1} + \varepsilon_t, & if\ ECT_{t-k} < \theta_+ \end{cases} \tag{3}$$

The parameters in Equation 3 follow the VECM representation in Equation 2, except for the lower ($\theta_-$) and the upper ($\theta_+$) thresholds, that can be endogenously or exogenously defined, i.e., the threshold value can be either or not calculated by the model. In the endogenous case, after the least squares estimation, the threshold value is given by the point that minimizes the sum of squared residuals (Lo and Zivot, 2001); and in the exogenous case, the analyst defines threshold parameters based on his/her own assessment. A sensitivity analysis might be useful, especially in the second case. However, as it is not possible to precise the transport costs for every transaction made, we opted for an endogenous regime change mechanism, avoiding a misspecification of the model. The endogenous threshold values for $\theta_-$ and $\theta_+$ are then obtained and assessed according to values found in the literature for the European case.

## 5. RESULTS AND DISCUSSION

According to the bivariate Johansen cointegration tests shown in Table 4, the price series were fully cointegrated, so we have applied the Granger causality test to confirm the hierarchy between the variables. The null hypothesis of the test is of a non (Granger)-causality between two variables. The test confirmed a hierarchical relationship in which the Dutch TTF prevails over the other hubs, i.e., the Dutch TTF price *causes* the German NCG and the Belgian ZTP prices to move (NCG ~ TTF and ZTP ~ TTF). The Belgian ZTP price *causes* the German NCG to move (NCG ~ ZTP), but does not *affect* the Dutch TTF (TTF ~ NCG), and the German NCG price has a lower impact over the other prices (ZTP ~ NCG and TTF ~ NCG). Table 5 reports the results for the pair-wise Granger causality tests for lag order 1 (as the information criteria) and for a larger number of

**Figure 3: Impulse response functions for 100 bootstraps with 95% confidence interval.**



*Source*: own elaboration.

(expected) lags, as the Toda-Yamamoto procedure (Toda and Yamamoto, 1995). The results for the long-run (75 lags) hold for the NCG hub (NCG ~ TTF and NCG ~ ZTP), but not for the ZTP ~ TTF model (5 lags) at 1% level of significance and should be assessed with care when used for forecasting. Furthermore, as Davidson (1998) suggests, the long-run cointegration relationship between ZTP and TTF seems to be solved by the other two (NCG ~ TTF and NCG ~ ZTP) as reported in the results of the Johansen analysis for the 3-variable system (Table A.3) in the Appendix.

In addition, Figure 3 provides the results of the impulse response functions that highlight the effects of price asymmetries, especially on the NCG models, while a smoother effect occurs on the ZTP ~ TTF model.

Once stablished the cointegration and the hierarchy between the variables, we defined which error correction model specification to choose. To do so, we applied the Hansen and Seo (2002) test for linear versus threshold cointegration in vector error correction models, an algorithm-based method that perform a joint grid search over the threshold and the cointegrating vector to implement maximum likelihood estimation (MLE) of the threshold model. The test does not provide a probability distribution for the MLE, which is its main limitation, so we have applied the test for the three models using 200, 600 and 1,000 bootstraps. Table 6 shows that the test statistics for the $\Delta$ZTP/$\Delta$TTF model do not reject the null hypothesis of a linear error-correction model, independently of the number of bootstraps (p-value varies from 0.684 to 0.691). Thus, the relation between the Belgian ZTP and the Dutch TTF prices is better represented by a linear VEC model.

**Table 6: Hansen and Seo tests–linear vs. threshold cointegration.**

| | ΔZTP /ΔTTF | | ΔNCG/ΔTTF | | ΔNCG/ΔZTP | |
|---|---|---|---|---|---|---|
| bootstraps | test | p-value | test | p-value | test | p-value |
| 200 | 12.15 | (0.685) | 24.76 | (0.000) | 20.46 | (0.045) |
| 600 | 12.15 | (0.691) | 24.76 | (0.003) | 20.46 | (0.061) |
| 1,000 | 12.15 | (0.684) | 24.76 | (0.008) | 20.46 | (0.063) |

**Table 7: TVECM for German NCG/Dutch TTF and German NCG/Belgian ZTP spot prices.**

| Coefficients | Model (Δ dependent / Δ explanatory variable) | |
|---|---|---|
| | ΔNCG/ΔTTF | ΔNCG/ΔZTP |
| constant | 0.032 | 0.01 |
| | (0.173) | (0.643) |
| $ECT^{-}_{t-1}$ | −0.984*** | −1.117*** |
| | (0.000) | (0.000) |
| $ECT^{+}_{t-1}$ | −0.925*** | −0.835*** |
| | (0.000) | (0.000) |
| $\Gamma^{(1)}_{t-1}$ | 0.114 · | 0.075 |
| | (0.096) | (0.282) |
| $\Gamma^{(2)}_{t-1}$ | −0. 046 | 0.004 |
| | (0.558) | (0.959) |
| threshold $\theta^{-}$ | −0.71 | −0.76 |
| threshold $\theta^{+}$ | 0.33 | 0.55 |
| observations | 454 | 454 |
| % obs regime$^{-}$ | 0.50% | 0.70% |
| % obs regime$^{0}$ | 89.60% | 95.20% |
| % obs regime$^{+}$ | 9.50% | 4.20% |
| SSR | 181.54 | 183.73 |

*Note:* Significant at *** 0.1% level.

Regarding the threshold cointegration for the ΔZTP/ΔTTF model, we observe in Table A.1 in the Appendix that virtually all observations (99.5%) are classified in a single regime (regime$^{-}$), supporting the results found by the Hansen and Seo test (Table 6). Therefore, the short-term price dynamics may be represented by a standard linear VECM and no transaction costs can be found during the period of the analysis. The results for the linear VEC models with the diagnostic tests for the Johansen systems are presented in Table A.2 in the Appendix.

On the other hand, as shown in Table 6, the linearity hypothesis is rejected for the ΔNCG/ΔTTF model under a 1% level of significance (p-value varies from 0 for 200 bootstraps to 0.008 for 1,000 bootstraps). The linearity hypothesis is also rejected for the ΔNCG/ΔZTP model under a 10% level of significance (p-value varies from 0.045 for 200 bootstraps to 0.063 for 1,000 bootstraps). Thus, based on these results, the TVECM might be a better specification to analyze the German NCG price dynamics than the linear VECM.

Table 7 presents the results for the TVECM univariate models for the German NCG hub. The threshold effect only occurs on the error correction term (ECT), so that the value for the middle threshold ($\theta^{0}$) is taken as null (as in Balke and Fomby, 1997). As a result, we have one constant for both regimes, but two ECT coefficients for each regime ($ECT^{-}_{t-1}$ and $ECT^{+}_{t-1}$), and two short-term coefficients, representing the one lagged dependent variable ($\Gamma^{(1)}_{t-1}$) and the one lagged explanatory variable ($\Gamma^{(2)}_{t-1}$).

In the specification of the TVEC models, we have added a constant to capture common long-run tendencies, but they are not significative at any level in both cases. Regarding the ΔNC-

G/ΔTTF model, the regime classification suggests that 10% of the observations resulted in daily price differentials that could lead to arbitrage opportunities (45.4 days precisely) in a competitive market condition. Most of these opportunities would happen in the upper regime (regime$^+$) when the price differential between the German NGC and the Dutch TTF stayed above 0.33 €/MWh, with few opportunities happening in the lower regime (regime$^-$), when the price differential was below –0.71 €/MWh.

Moreover, the ECT coefficients for both regimes of the ΔNCG/ΔTTF model are significative at 1% level and have the expected negative sign, indicating the return to the equilibrium. The convergence ratio to the long-run equilibrium can be measured by dividing 1 by the ECT coefficients (–0.984 for the upper and –0.925 for the lower). The results indicate that it usually takes one trading day, for both regimes, to return to the equilibrium. Thus, real data systems are crucial for the trading orders to be fulfilled, reducing transaction costs.

Concerning the ΔNCG/ΔZTP model, we note that 95.2% of the observations are in the no-arbitrage regime (regime$^0$). The results have the expected negative sign for the ECT coefficients and a fast return to the long-run equilibrium price differential. Given the few number of daily price differentials found in the ΔNCG/ΔZTP model (4.2% in regime$^+$ and 0.7% in regime$^-$), we focus on the analysis of the ΔNCG/ΔTTF price differentials.

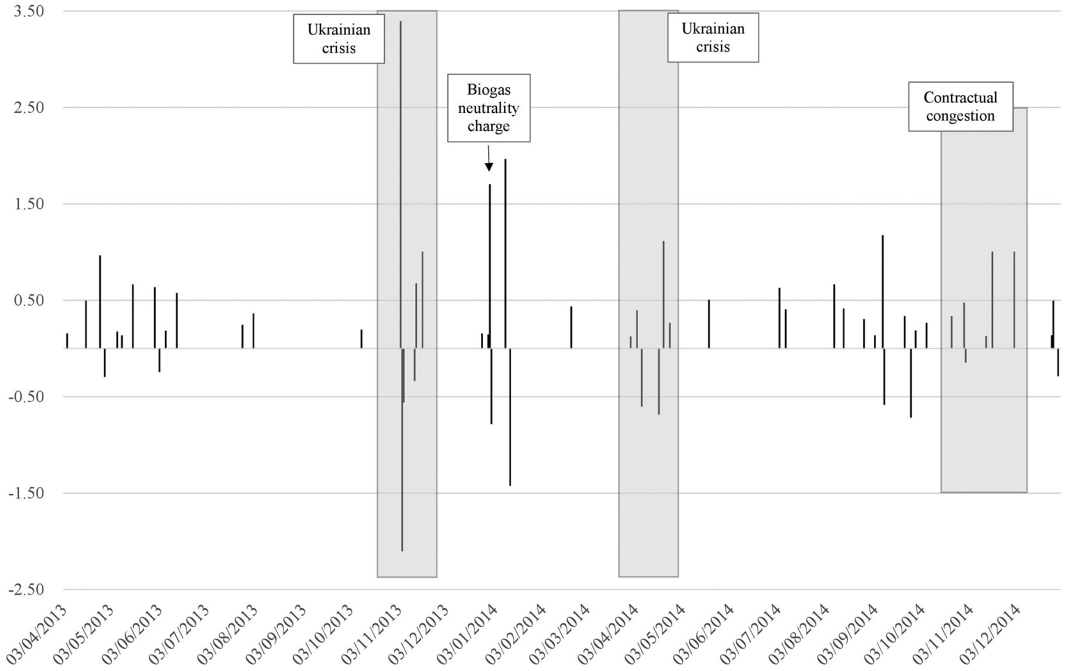
The asymmetric threshold values found in the ΔNCG/ΔTTF model reflect the fact that the transport costs are different for the entry and exit of the hubs marketing areas. The threshold values reflect these asymmetries which cannot be identified by the linear VEC model. It means that the TVECM could identify the presence of transaction costs leading to asymmetric price responses. Moreover, sample tests were applied to check if the true difference in the thresholds means was not equal to zero. The results (see Table A.4 in the Appendix) confirmed that the means of the threshold values were not the same for the models ΔNCG/ΔTTF, with a 95% confidence interval.

Suffice it to say that the more appropriate market mechanisms are (as in the Dutch TTF hub, for example) the lower are the transaction costs. The natural gas volumes entering the German market from the Dutch TTF face higher transaction costs, since the German market structure is characterized by vertically integrated firms which may exercise considerable market power (Heinrich, 2008; Growitsch et al., 2015). The daily price differentials found in the TVECM between the German NCG and the Dutch TTF are shown in Figure 4.

The negative values in Figure 4 indicate a price differential between ΔNCG and ΔTTF below the lower threshold (–0.71 €/MWh), and the positive values, a differential above the upper threshold (0.33 €/MWh). The return to the equilibrium within a day can observed, especially when price differentials are far from equilibrium, with high positive values being compensated by negative ones in a day-trade basis, and vice-versa. The quick return to the equilibrium condition helps to explain the abrupt transition between regimes in the TVECM. The prompt market responses have been pushing the hub prices to converge quickly, reducing the price spreads to the minimum level of transport costs (ACER, 2015).

The price spreads may attain values higher than 1 €/MWh. Considering that the average transport cost in the German market was 0.46 €/MWh (Growitsch et al., 2015), there would be some room for arbitrage opportunities between the German and the Dutch market on a daily trade basis. For instance, in Figure 4, we observe that, during the 4th quarter of 2014, contractual congestions at interconnection points led to price differentials in the German NCG area (ACER, 2015). We also

**Figure 4: Price differentials between German NCG and Dutch TTF hubs – April 2013 to December 2014.**



*Source*: own elaboration.
*Note*: The lower threshold is –0.71 €/MWh and the upper 0.33 €/MWh.

note the effect of the German biogas neutrality charge[11], on January 2014, and the impact on price differentials of the Ukrainian crisis[12], from October to December 2013 and on April 2014.

The daily price differentials found in the TVECM between the German NCG and the Dutch TTF occur if the first difference operator of prices (between the two markets) exceed a certain (endogenously defined) threshold. The TVECM price differentials reflect a different concept than the one of Flow Against Price Differentials (FAPDs) adopted by the European Commission[13]. In the FAPDs events the threshold values are symmetric, not correctly reflecting the transaction costs incurred in the natural gas trade. Because of this, some FAPDs events might be biased, not reflecting the price asymmetries in the right direction.

## 6. FINAL REMARKS

Notwithstanding the substantial effort towards markets integration (Renou-Maissant, 2012; Growitsch et al., 2015; Nick, 2016), there remain concerns regarding the intensity of competition in European natural gas spot markets. The fact that the liberalization process reduced the market power of vertically integrated firms does not imply absence of market power in liberalized hub markets,

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[11] https://www.net-connect-germany.de/en-gb/Transparency-information/Prices/Biogas-Neutrality-Charge

[12] The crisis led to reverse flows of natural gas from Germany to East European countries, such as Poland and Hungary.

[13] A FAPDs event occur when commercial nominations for cross border capacities are such that gas is set to flow from a higher price area to a lower price area, considering a minimum threshold of price for gas set at 0.5 €/MWh. Based on price information for adjacent areas, and with the closure of the day-ahead markets (D-1), the price for delivering gas in each hub on day D is known by market participants, which can establish price differentials (European Commission, 2014).

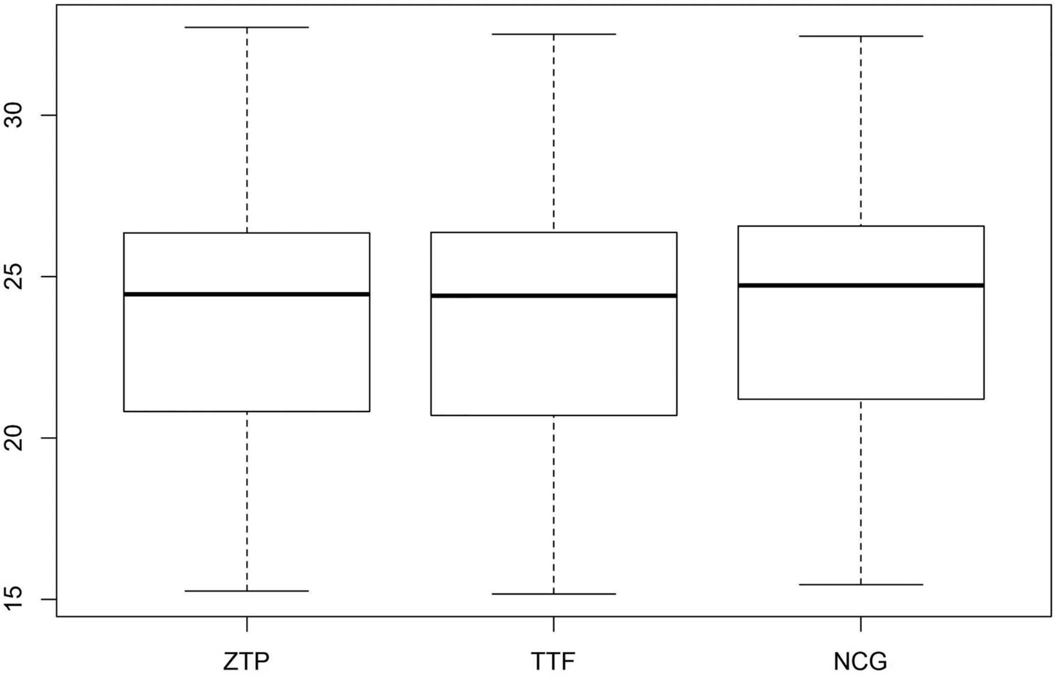
particularly in those with a low number of suppliers. A highly concentrated market structure of natural gas hubs may be conducive to market power, as well as asymmetric price responses (Murry and Zhu, 2006).

In this context, our analysis of short-term price dynamics indicates that departures from the LOP are quickly corrected. However, the results suggest that daily price differentials occur more frequently in the German hub. In fact, the German market structure is characterized by vertically integrated firms which may exercise considerable market power. Introducing more competition in the German market seems of paramount importance for advancing in the market integration by reducing transaction costs that lead to price differentials. Countries like Germany and Netherlands can reduce seasonal and transport disruption price volatilities due to their installed storage capacity (GIE, 2015). Regarding the spread, results show that there are transaction costs leading to asymmetric price responses.

Finally, it should be remarked that our methodology does not allow to investigate the nature of the transaction costs in European gas markets. Understanding the determinants of transaction costs are and how to minimize them are of fundamental importance to further advance in the liberalization process. This seems to be a promising agenda for future research.

## APPENDIX: SUPPLEMENTAL MATERIAL

**Figure A.1: Boxplot for TTF, NCG and ZTP time series (456 observations). Values in Euros/MWh.**



*Source*: own elaboration.

**Table A.1: TVEC model for Belgian ZTP / Dutch TTF spot prices.**

| Coefficients | Model (Δ dependent / Δ explanatory variable) |
|---|---|
| | ΔZTP /ΔTTF |
| constant | −0. 001 |
| | (0.970) |
| $ECT^{-}_{t-1}$ | −0.556*** |
| | (0.000) |
| $ECT^{+}_{t-1}$ | 0.374*** |
| | (0.000) |
| $\Gamma^{(1)}_{t-1}$ | 0.0879 |
| | (0.516) |
| $\Gamma^{(2)}_{t-1}$ | −0. 052 |
| | (0.701) |
| threshold $\theta^{-}$ | 0.58 |
| threshold $\theta^{+}$ | 0.63 |
| observations | 437 |
| % obs $regime^{-}$ | 99.50% |
| % obs $regime^{0}$ | 0.20% |
| % obs $regime^{+}$ | 0.20% |
| SSR | 134.48 |
| AIC | −2,557.25 |

*Note:* Significant at *** 0.1% level.

**Table A.2: VEC univariate models for the selected hubs.**

| Coefficients | Model (Δ dependent / Δ explanatory variable) | | |
|---|---|---|---|
| | ΔZTP/ΔTTF | ΔNCG/ΔTTF | ΔNCG/ΔZTP |
| constant | 0,011 | 0,227*** | 0,166*** |
| | (0,576) | (0,000) | (0,000) |
| $ECT_{t-1}$ | −0,579*** | −0,625*** | −0,505*** |
| | (0,000) | (0,000) | (0,000) |
| $\Gamma^{(1)}_{t-1}$ | −0,442** | −0,601*** | −0,540*** |
| | (0,001) | (0,000) | (0,000) |
| $\Gamma^{(2)}_{t-1}$ | 0,469*** | 0,633*** | 0,595*** |
| | (0,000) | (0,000) | (0,000) |
| β | −0,999 | −0,995 | −0,995 |
| observations | 437 | 454 | 454 |
| $\sigma\hat{}u$ | 0,392 | 0,499 | 0,506 |
| F(4,N−4) | 4,789*** | 20,25*** | 16,53*** |
| | (0,000) | (0,000) | (0,000) |
| $\chi^2(2)_{serial}$ | 1,532 | 0,425 | 0,988 |
| | (0,464) | (0,808) | (0,609) |
| $\chi^2(45)_{ARCH}$ | 73,53*** | 63,26* | 51,61 |
| | (0,000) | (0,037) | (0,231) |
| $\chi^2(2)_{normal}$ | 531,09*** | 6.747,2*** | 6.024,5*** |
| | (0,000) | (0,000) | (0,000) |

*Note:* Significant at * 10%; ** 5%; or *** 1% level.

**Table A.3: Johansen procedure for the 3-variable system.**

| rank[a] | test | 10% | 5% | 1% | | eigen[b] | ttf.l2 | ncg.l2 | ztp.l2 |
|---|---|---|---|---|---|---|---|---|---|
| r <= 2 | 4.91 | 6.50 | 8.18 | 11.65 | | ttf.l2 | 1.0000 | 1.0000 | 1.0000 |
| r <= 1 | 99.57 | 15.66 | 17.95 | 23.52 | | ncg.l2 | –1.0016 | 0.0522 | 0.1784 |
| r – 0 | 240.13 | 28.71 | 31.52 | 37.22 | | ztp.l2 | –0.0027 | –1.0522 | –0.6343 |

[a] Test statistic and critical values of test for 10%, 5% and 1% level of significance.

[b] Cointegration relations represented by the eigenvectors, normalized to first column.

**Table A.4: Sample F-test for the ΔNCG/ΔTTF threshold values (for variances) and Welch t-test (for threshold means).**

| | F–test for variances[a] | Welch t–test for means[b] |
|---|---|---|
| Test statistic | F – 1.06 | t=–15.02 |
| df | 453 | 906 |
| p–value | 0.5335 | < 2.2e–16 |
| 95% confidence interval | [0.88, 1.28] | [–1.13, –0.87] |
| Sample estimates[c] | 1.06 (ratio of variances) | –0.69 (mean of $\theta^-$)<br>0.30 (mean of $\theta^+$) |

*Note:* We first tested for the ratio of variances of the lower and the upper thresholds based on a normal distribution sample. Once known that the samples have the same variances, the Welch t-test confirmed that the thresholds have different means.

[a] Alternative hypothesis ($H_1$): true ratio of variances is not equal to 1.

[b] Alternative hypothesis ($H_1$): true difference in means is not equal to 0.

[c] Threshold values found for the ΔNCG/ΔTTF is −0.71 (θ−) and 0.33 (θ+).

## ACKNOWLEDGMENTS

We thank the financial support from the National Council for Scientific and Technological Development—CNPq (Process 140906/2016-9) and from FAPERJ (Process E-26/200.426/2015—Bolsa Nota 10) for the full-time postgraduate fellowships that sponsored this research.

## REFERENCES

ACER (2014). "ACER Annual report on congestion at interconnection points in Q4/2013." Luxemburg, February 2014.

ACER (2015). "ACER annual report on congestion at interconnection points in 2014." Luxemburg, November 2015.

ACER/CEER. (2015). "Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2014." Luxemburg, November 2015.

Adelman, M. and M. Lynch (1986). "Western Europe Natural Gas Trade." MIT, Center for Energy Policy Research, International Natural Gas Trade Project Report, 3: 1–178.

Arrow, K.J. (1969). "The organization of economic activity: issues pertinent to the choice of market versus nonmarket allocation." *The analysis and evaluation of public expenditure: the PPB system*, US Government Printing Office Washington, DC, 1: 59–73.

Asche, F., P. Osmundsen, and R. Tveterås (2002). "European market integration for gas? Volume flexibility and political risk." *Energy Economics* 24(3): 249–265. https://doi.org/10.1016/S0140-9883(02)00003-8.

Asche, F., B. Misund, and M. Sikveland (2013). "The relationship between spot and contract gas prices in Europe." *Energy Economics* 38(C): 212–217. https://doi.org/10.1016/j.eneco.2013.02.010.

Balke, N.S. and T.B. Fomby (1997). "Threshold cointegration." *International economic review* 38(3): 627–645. https:// https://doi.org/10.2307/2527284.

Barrett, C.B. (2001). "Measuring integration and efficiency in international agricultural markets." *Review of Agricultural Economics* 23(1): 19–32. https://doi.org/10.1111/1058-7195.00043.

Bourbonnais, R. and P. Geoffron (2007). "Delineation of energy markets with cointegration techniques." *The Econometrics of Energy Systems*. Palgrave Macmillan, London, 168–185. https://doi.org/10.1057/9780230626317_8.

Brown, S.P. and M.K. Yücel (2009). "Market arbitrage: European and North American natural gas prices." *The Energy Journal* 30(Special Issue): 167–185. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol30-NoSI-11.

Coase, R.H. (1937). "The nature of the firm." *Economica* 4(16): 386–405. https://doi.org/10.1111/j.1468-0335.1937.tb00002.x.

Commons, J.R. (1934). *Institutional Economics: Its place in the political economy*. Madison: University of Wisconsin Press.

Crocker, K.J. and S.E. Masten (1991). "Pretia ex Machina? Prices and Process in Long-Term Contracts." *Journal of Law and Economics* 34(1): 69–99. https://doi.org/10.1086/467219.

Davidson, J. (1998). "Structural relations, cointegration and identification: some simple results and their application." *Journal of Econometrics* 87(1): 87–113. https://doi.org/10.1016/S0304-4076(98)00007-4.

European Commission (2014). "Quarterly Report on European Gas Markets, Market Observatory for Energy." DG Energy, 6(3–4) and 7(1–2).

Engle, R.F. and C.W. Granger (1987). "Co-integration and error correction: representation, estimation, and testing." *Econometrica* 55(2): 251–276. https://doi.org/10.2307/1913236.

ENTSOG. (2014). "Transmission capacity map 2013." Brussels, Belgium. Retrieved from http://www.entsog.eu/maps/transmission-capacity-map/2013.

Escribano, A. (2004). "Nonlinear error correction: The case of money demand in the United Kingdom (1878–2000)." *Macroeconomic Dynamics* 8(1): 76–116. https://doi.org/10.1017/S1365100503030013.

Fackler, P.L. and B.K. Goodwin (2001). "Spatial price analysis." *Handbook of agricultural economics* 1(2): 971–1024. https://doi.org/10.org/1016/S1574-0072(01)10025-3.

Gonzalez-Rivera, G. and S.M. Helfand (2001). "The extent, pattern, and degree of market integration: A multivariate approach for the Brazilian rice market." *American Journal of Agricultural Economics* 83(3): 576–592. https://doi.org/10.1111/0002-9092.00179.

Growitsch, C., M. Stronzik, and R. Nepal (2015). "Price convergence and information efficiency in German natural gas markets." *German Economic Review* 16(1): 87–103. https://doi.org/10.1111/geer.12034.

GTS. (2015). "Monthly volumes at the Dutch TTF January 2011–September 2016." Hoofddorp, Netherlands: [s.n.]. Retrieved from https://www.gasunietransportservices.nl/en/about-gts/publications.

Hansen, B.E. and B. Seo (2002). "Testing for two-regime threshold cointegration in vector error-correction models." *Journal of Econometrics* 110(2): 293–318. https://doi.org/10.1016/S0304-4076(02)00097-0.

Heinrich, A. (2008). "Gazprom's expansion strategy in Europe and the liberalization of EU energy markets." *Russian Analytical Digest* 34(08): 8–11.

Hubbard, R.G. and R.J. Weiner (1991). "Efficient contracting and market power: evidence from the US natural gas industry." *The Journal of Law and Economics* 34(1): 25–67. https://doi.org/10.3386/w3502.

Huberator. (2015). "Zeebrugge hub reports – data publication 2013 and 2014 – Hub Volumes." Retrieved from http://www.huberator.com/en/information/hub_volumes.

Ihle, R., B. Brümmer and S.R. Thompson (2012). "Structural change in European calf markets: decoupling and the blue tongue disease." *European Review of Agricultural Economics* 39(1): 157–180. https://doi.org/10.1093/erae/jbr042.

Ishwaran, M., W. King., M. Haigh, T. Lee, and S. Nie (2017). "Roadmap for Natural Gas Market Liberalisation and Regulatory Reform." *China's Gas Development Strategies*. Springer, Cham. 309–322. https://doi.org/10.1007/978-3-319-59734-8_14.

Joskow, P.L. (1988). "Asset Specificity and the Structure of Vertical Relationships: Empirical Evidence." *Journal of Law, Economics, & Organization* 4(1): 95–117. https://doi.org/10.1093/oxfordjournals.jleo.a036950

Konoplyanik, A.A. (2012). "Russian gas at European energy market: Why adaptation is inevitable." *Energy Strategy Reviews* 1(1): 42–56. https://doi.org/10.1016/j.esr.2012.02.001.

Komlev, S. (2013). "Pricing the Invisible Commodity." Moscow, Russia: [s.n.]. Gazprom Export. Contract Structuring and Pricing Directorate. Discussion Paper.

Krugman, P. and M. Obstfeld (2003). *International Economics*. Addison-Wesley, Boston, USA.

Lo, M.C. and E. Zivot (2001). "Threshold cointegration and nonlinear adjustment to the Law of One Price." *Macroeconomic Dynamics*, Cambridge University Press, 5(4): 533–576. https://doi.org/10.1017/S1365100500000456.

Lütkepohl, H. (2005). New introduction to multiple time series analysis. [S.l.]: Springer Science & Business Media. https://doi.org/10.1007/978-3-540-27752-1.

Mathias, M.C. and A. Szklo (2007). "Lessons learned from Brazilian natural gas industry reform." *Energy Policy* 35(12): 6478–6490. https://doi.org/10.1016/j.enpol.2007.08.013.

Murry, D. and Z. Zhu (2008). "Asymmetric price responses, market integration and market power: A study of the US natural gas market." *Energy Economics* 30(3): 748–765. https://doi.org/10.1016/j.eneco.2006.10.002.

NCG. (2015). "Reference Prices." Retrieved from https://www.net-connect-germany.de/en-gb/Transparency-information/Prices/Reference-Prices-until-01102015.

Neumann, A. (2009). "Linking natural gas markets–is LNG doing its job?" *The Energy Journal* 30(Special Issue): 187–199. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol30-NoSI.

Nick, S. (2016). "The Informational Efficiency of European Natural Gas Hubs: Price Formation and Intertemporal Arbitrage." *The Energy Journal* 37(2): 1–30. https://doi.org/10.5547/01956574.37.2.snic.

Pegas. (2015). "Pegas Spot All Market Areas, 2015." Retrieved from http: //www.powernext.com.

Renou-Maissant, P. (2012). "Toward the integration of European natural gas markets: a time-varying approach." *Energy Policy* 51: 779–790. https://doi.org/10.1016/j.enpol.2012.09.027.

Robinson, T. (2007). “Have European gas prices converged?” *Energy Policy* 35(4): 2347–2351. https://doi.org/10.1016/j.enpol.2006.08.005.

Shepherd, A. W. (1997). “Market information services: Theory and practice.” FAO Agricultural Services Bulletin No. 125. Food and Agriculture Organization of the United Nations.

Siliverstovs, B., G.L’Hégaret, A. Neumann, and C. Von Hirschhausen (2005). “International market integration for natural gas? A cointegration analysis of prices in Europe, North America and Japan.” *Energy Economics* 27(4): 603–615. https://doi.org/10.1016/j.eneco.2005.03.002

Statoil ASA. (2015). “Annual Report 2014.” [S.l.]: StatoilASA. 215p. Retrieved from https://www.equinor.com/en/investors.html.

Toda, H.Y. and T. Yamamoto (1995). “Statistical inference in vector autoregressions with possibly integrated processes.” *Journal of Econometrics* 66(1–2): 225–250. https://doi.org/10.1016/0304-4076(94)01616-8.

Trayport ETS. (2015). “Gas Trading.” Retrieved from http://www.trayport.com/uk/markets2/gas-trading.

Von Hirschhausen, C. and A. Neumann (2008). “Long-term contracts and asset specificity revisited: An empirical analysis of producer–importer relations in the natural gas industry.” *Review of Industrial Organization* 32(2): 131–43. https://doi.org/10.1007/s11151-008-9165-0.

Williamson, O.E. (1981). “The economics of organization: The transaction cost approach.” *American journal of sociology* 87(3): 548–577. https://doi.org/10.1086/227496.