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A Comparison between the Presence and Absence of Regulation in the Spanish Electricity Market

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<http://dx.doi.org/10.5772/62953>

Abstract

There is an important gap in the literature on the promotion of competition in electricity markets in what pertains to the analysis of two different streams: the absence and presence of regulation. Accordingly, the main objective of this study is to analyze the interactions among market power indexes, marginal costs, and bidding strategies in the two mentioned scenarios, for comparative purposes. The methodology used is based on panel cointegration methods. The results point to the significant inclusion of different bidding strategies in the retail market: (i) fuel prices exercise a differential impact on the power plants' marginal costs, (ii) the marginal costs have a significantly positive effect on quantity sold and on net quantity, and (iii) the market power measures under regulation have a significantly positive long-term impact on the quantity sold and a negative impact on net quantity supplied in wholesale market. Although there is some literature on this issue, the main novelty of this article is the discussion of the regulatory implications that could have been adopted in order to control and mitigate the market power, to encourage new investments in new technologies, and to recover sunk costs with the transition to a competitive market.

Keywords: market power, marginal costs, regulation, competition, panel cointegration

1. Introduction

Reforms in the Spanish electric sector, as well as in other European countries, Consisted fundamentally on the transition of a vertically integrated system comprising production, transportation, distribution, and commercialization of energy to a system that splits them into

two main large groups: one group with regulated, noncompetitive activities such as transportation and distribution of energy and another with competitive, nonregulated activities such as production and commercialization of energy. This split-up aimed at increasing economic efficiency through price adjustments (short-term objectives) and at improving investment decisions, seeking to optimize the risks of those very same investments (long-term objectives).

In Spain, the total electricity output consists mainly of thermal power, hydroelectricity, and nuclear power. Thermal power accounts for over 80% of the total generating capacity while hydroelectricity accounts for around 15%. As a result, oil and coal prices changes strongly affect main industry players of the electric power industry. In order to face this problem, since 1997, Spain has gradually liberalized the electricity market so that the prices of fuel, gas, and coal fully reflect the costs of the production and of the costs of natural and environmental resources.

Hence, technologies with high fixed costs and low variable costs operate almost continuously in time and their payback is determined by the hourly prices set throughout the year. In the case of technologies with high variable costs whose production is discontinuous and reliant on exogenous variables, such as hydraulicity or wind speed, the market picks up one or other technology by unpredictable events leading to production yields turnouts. This adjustment is not possible in the electrical power industry because (a) most of the turnouts are not replicable and (b) the existence of sunk costs encourages the rejection of technologies whose payback is not enough to cover average costs but just the variable costs; therefore, it is unlikely for customers to pay electricity at the market price and that would be a required condition for the capacity reduction and adjustment.

Theory suggests that within the electrical power industry, both plant or grid level, when one fuel is substituted by another, there is a comovement in the commodity prices. In thermal power plants, fuel cost is the largest cost, accounting for 70% of the variable costs. The rise in coal prices, especially the coal price for electricity generation, directly increases the electrical producers operating costs and reduces corporate profits. As a consequence of high price increases, many electric power firms were confronted with heavy losses. As a result, in order to improve the operating conditions of electric power firms, the price of electricity increased to alleviate the coal–electricity price contradiction.

The Spanish electricity spot market pricing is characterized by a certain degree of nonconstant volatility and a strong seasonality. The fluctuation of demand over time, as a result of the optimal mix of production technologies, causes the electricity market to favor based-load plants with low variable costs. In this case, electric grid players, in order to recover fixed costs, tend to withhold their production as long as they can so that their revenues are higher than the lost opportunity costs.

As the supply function of the electrical system includes a wide variety of technologies, the market yields low rewards for some technologies and high rewards for others—e.g., some technologies with high fixed costs and low variable costs operate almost continuously and other technologies with high variable costs operate discontinuously. As a consequence, neither investments in different technologies nor adjustments to demands are easily replicable. In

addition, sunk costs discourage the abandonment of technologies whose remuneration does not cover average costs, only the variable ones.

The market price corresponds that way to a marginal price, in the way that it would be the price of which an extra unit of energy would be rewarded if the charge value would increase of one unit. This price corresponds to the latest offered price by the last generator to be dispatched on the pool, with that very same generator assuming a big market power, specifically when the difference between installed production capacity and network charge is reduced.

The existence of different kinds of agents in the market with different sizes, organization, and knowledge can lead to situations of asymmetric information (adverse selection) or even to collusive behaviors, creating favorable conditions to the existence of market power, with its elapsed consequences for social welfare.

From the supply side, the reduced number of companies can lead to strategic oligopolistic behaviors. This possibility is even worsened when demand increases leading companies to fight for markets shares.

As the different technologies of the supply function of the electricity market lead to specific price–quantity pairs for each of the 24 h of the following day, the aggregation of the bids of all power plants owned by a single generator allows for the obtainment of its hourly supply schedule. As a result, the quantity–price pair should be a point on its supply schedule. This procedure can continue as long as the number of possible realization of residual demand is not higher than the number of steps in the supply function. Therefore, the expected profit maximizing supply schedule should pass through all ex post profit maximizing price and quantity pairs [1, 2].

With an increasing concentration index and inelastic demand, producers are more willing to set prices well above marginal costs. Although in the presence of market concentration most models would predict prices above marginal cost, market conditions, regulation of electricity auction rules may strongly influence margins [1]. According to Ciarreta and Espinosa [2, 3], the sustainability of the Spanish electricity market was threatened by the difficulty in controlling market power and by an increasing reliance on bidding strategies in the spot market.

Between 2002 and 2006, Endesa and Iberdrola's large power production installed capacity vis-à-vis the global capacity of the Spanish market, as well as their pricing capacity in the wholesale market, gave them the market power in the electricity market. Moreover, the pool pricing offered throughout the different hourly periods was conditioned mainly by the differences between production technologies used by the power plants that generate the installed system.

In the Spanish market, as any normal oligopolist, Endesa had an incentive to underproduce, in order to raise the price received for the net electricity sold to the market, whereas Iberdrola overproduced due to an oligopsonistic incentive to reduce the price paid for the infra-marginal units purchased from the spot market. Due to Endesa's "net supplier" and Iberdrola's "net demander" behavior, Kühn and Machado [4] claim that market power might be exercised according to the firms' behavior as net demanders or net suppliers.

In line with this, this article aims at contributing to the analysis and evaluation of the market power exercise in which we propose to formulate and validate a conceptual model in which electricity companies will develop their actions without resorting to cooperation. The market equilibrium is deduced from a behavioral model analysis, via conjectural variations model, in which prices are external variables set by the market, businesses take decisions regarding the quantity to produce for each price levels taking into account that their decisions will affect the others and others' decisions will affect theirs.

Vertical integration between generation (liberalized) and distribution (regulated) neutralized market power [1–3] as distribution surplus was used for the Costs of Transition to Competition, namely CTC payments.

Although Endesa and Iberdrola's should have behaved as net sellers (to promote competition), as any positive surplus generated by a distribution company was shared among the generators according to percentages given by the CTC rights, incentives of vertically integrated firms to change prices determined they behave as net buyers or net sellers [4]. The incentives provided by the regulation led to lower prices than the ones predicted by the profit maximization behavior. Moreover, the CTC payment was conditional on an average pool price not higher than 36.06 €/MWh. If the electricity producer average price exceeded that amount the revenues obtained for the higher price were subtracted from future CTC payments [2].

The main purpose of this study is to empirically investigate the three following questions:

- i. Do fossil fuel prices and market power exercise a significant positive effect on marginal costs? To answer this question, we use a panel cointegration estimation of a regression model with marginal costs per power plant as the dependent variable, the fossil fuel prices are used as explanatory variables, and the two measures of market power, in the absence and in the presence of regulation, as a control variables;
- ii. Do marginal costs cause or improve bidding strategies of electricity generators? To answer this question, we use the panel cointegration estimation of a regression model with quantity sold in the wholesale market as the dependent variable, marginal costs per power plant and the two measure of market power in the absence and in the presence regulation are used as explanatory variables. Purchased quantity to sell in open market is used as a control variable.
- iii. Do marginal costs cause or improve net quantities transacted by electricity generators? To answer this question, we use the panel cointegration estimation of a regression model with net quantities as the dependent variable, the marginal cost per power plant is used as explanatory variable, and the measure of market power in the absence and under regulation are used as a control variable.

The quantitative evaluation of the two proposed models regarding the strategic behavior of the Spanish electricity companies allows to observe carefully the market power issue displayed by electricity companies and, on the other hand, the tacit coordination or collusion between electrical companies, in that each company knows exactly how and when their rivals change their quantities allowing them to change interdependently their sold and purchased quantities

in the pool market in order to maintain supply levels which grant them high profits. Therefore, the main objective of this article is to examine and validate the type of strategic behavior of every Spanish electric company and consequent influence in the market power resulting from the type of decision variable considered in the profit maximization and still empirically verify the analysis period considered if that strategic behavior is linked with the will of the electric companies to control the market or increase its market power decreasing that way the competitiveness effect.

After this brief introduction, the rest of the paper is structured as follows: the Section 2 provides the literature review. Section 3 describes the data and methodology used in the empirical analysis. Section 4 describes the econometric strategy and presents the empirical results. Section 5 concludes with some policy implications.

2. Literature review

Wholesale electricity markets have been analyzed over time, especially in deregulated markets as there are strong incentives to maximize profits taking advantages of low cost production.

Market power has also been under scrutiny, as several methodologies, approaches and conceptualizations have been used to avoid this problem. For example, Neuhoff et al. [5], based on Cournot models analyzed how regulatory mechanism in the transmission network influence market equilibrium.

The use of the supply function equilibrium has been used with linear marginal costs [6] and with constant marginal costs [7] to address the electricity supply market function. On the other hand, Fabra, Von der Fehr and Harbord [8] demonstrated that market power may be present in multiunit auction models.

The study of the Californian wholesale electricity market [9–11] provided good insights for the analysis of the wholesale market inefficiencies.

The Spanish market has also been subject to important analysis in recent years [2, 3, 12–14].

Furió and Lucia [12] analyzed the particularities of the Spanish intra-day market bidding behavior and concluded that some power generators have a clear economic incentive to be called up in the subsequent transmission constraints resolution process and avoid being dispatched in the day-ahead market.

Based on the different bidding behavior of large and small generators, Ciarreta and Espinosa [3] provided a measure of market power at different competitive levels explaining the reason why equilibrium prices are above the reference marginal costs, and finding that in the day-ahead market larger generators are able to increase prices well above the competitive benchmark.

Ciarreta and Espinosa [2] measured the gap between optimal price in the absence of regulation and real prices when analyzing the impact of regulation on the electricity wholesale market

from 2002 to 2005. They concluded that the regulation affected wholesale prices considerably, but at the beginning of 2006 became less effective due to changes introduced in the regulatory regime.

The market power exercise was also analyzed by Kühn and Machado [4], who demonstrated, using a two-step GMM econometric estimation, that the two major operators of the Spanish market (Endesa and Iberdrola) used the CTC payments to increase or decrease prices, according to their behavior as net buyers and net sellers in the market. Similarly, Fabra and Toro [15] also analyzed market power in the Spanish market, specifically the price formation in price-war stages and in collusion periods. They concluded that in price-war periods, Endesa's mark-up is negative while Iberdrola's is positive. On the other hand, in collusion periods, both firms had positive margins, which is a clear indication of market power exercise. Fabra and Toro [15] have also recognized the coexistence of low prices coordinated with mixed price strategies, which leads to multiple price equilibrium.

Moutinho, Vieira, and Moreira [16] addressed the long-term relationship between spot electricity market price and commodity prices using cointegration techniques. They conclude that the prices of fuel and the prices of Brent are intertwined as the latter tend to re-establish the price equilibrium.

The coexistence of competition in the electricity spot market and the CTC regulatory compensation mechanism is not compatible [17]. Although this situation leads to a decrease in prices, this study reveals that its joint existence enhances the power market exercise as it leads to an increase of the equilibrium price. Inadequate payments can promote both production inefficiency and delay or prevent new competition.

When discussing the factors that influence energy efficiency, conservation decisions, and the most appropriate policies for their promotion, Linares and Labandeira [18] claim that energy conservation policies are required. They propose the provision of information to consumers as well as economic instruments.

A generation-expansion model involving CO₂ emissions trading and green certificates was developed by Linares et al. [19]. Taking into account firms' oligopolistic behavior, they tried to respond to the needs of firms and regulators in electricity markets.

In the body of literature debating, the impact of wholesale price caps on investment in oligopolistic electricity markets, Grobman and Carey [20], Stoft [21], and Joskow and Tirole [22] study the long-term effects of price caps on investment in new generation units under different market structures. Biglaiser and Riordan [23] study the dynamics of price regulation for an industry adjusting to exogenous technological change. They show that price cap regulation leads to more efficient capital replacement decisions when compared to rate-of-return regulation.

Strategic real options models have been developed by combining real options arguments with differential games in order to model investment in oligopolistic industries [24–26]. More recently, Earle et al. [27] use a one time period model of Cournot competition with uncertain demand to show that price cap regulation in the presence of uncertainty might fail to increase production and therefore fail to increase consumer welfare.

3. Data, econometric methods, and results

In order to test the relationships that may exist between marginal costs, fossil fuel prices, net set selling quantities, and market power indexes in the Spanish OMEL (Operador del Mercado Ibérico de Energía) wholesale market, a rationalized cointegration analysis is going to be applied on a set of cross-firms panel data. Panel cointegration tests, panel unit root tests, and dynamic panel causality tests are going to be conducted to confirm the validity of the panel data model estimation.

The error correction model (ECM) is a linear regression equation that provides a description of the possible nature of interdependence of the short-run movements of the cointegrated variables under study, namely, marginal costs, and sets of bids quantities supplied from hydro-electrical, nuclear, coal, combined-cycle gas turbine, and fuel-oil power plants.

In this article, five panel tests are going to be run: Levin, Lin, and Chu test [28] (hereafter, LLC), Breitung test [29], Hadri test [30], Im, Pesaran, and Shin test [31] (hereafter, IPS), and ADF-Fischer test. While the first three assume a common unit root, the last two assume individual unit root process across the cross-sections.

3.1. Data and specification of variables

The marginal costs of power generation were obtained for all power plants in the portfolio. Then, plants were ranked in order of their ascending marginal costs as produced, in their quest for profit-maximization and start their production from the plant with lowest marginal cost. Based on the merit-order effect, plants are brought on line to meet increasing demand. Theoretically, daily changes in fuel and carbon prices can change the merit order through their effect on relative marginal costs of power generation.

The data of the demand and supply of Endesa, Iberdrola, Unión Fenosa, Hidrocantabrico, Viesgo, and other fringe competitive groups were gathered on a daily basis. A 24 h moving average was calculated for each production unit in the Spanish wholesale electricity market. Data regarding each agent of the wholesale electricity market were retrieved from OMEL database. Information regarding market prices, quantity offered, and quantity purchased to sell in open market was obtained from January 2002 until June 2006.

We adopted the expression of the marginal costs of a power plant given by Lagarto et al. [32]:

$MC_{p, fuel} = \frac{f \times cf}{LHV \times \eta_p}$, in which $MC_p = MC_{p, fuel}$; $MC_{p, fuel}$ is the marginal cost of fossil fuel of power plant p in Euros/; MWh MC_p is the marginal cost of power plant p in €/MWh; the Lower Heating Value in kcal/t is represented by LHV ; 859,845 kcal/MWh represents the conversion factor cf ; f is the fossil fuel price in €/t; and η_p is power plant efficiency in %. The daily periods analyzed were significantly conditioned by the differences among the various production technologies used by the power plants. We used the daily spot prices of fuel, coal and gas to compute the marginal costs. Data of major fuel sources (oil, coal, and gas) were retrieved from the Energy Systems database of a university research center. The unitary marginal costs of the nuclear and hydroelectric technologies are the ones referred in Ciarreta and Espinosa [1].

For measuring the market power under the absence of regulation (Lerner Index 1) the following expression was used: $(P_{OMEL} - cmg)/P_{OMEL}$, according to Ciarreta and Espinosa [3]. For measuring the market power under the presence of regulation (Price cap equal to 36.06 €/MWh), we used the Lerner index 2, given by: $(P_{OMEL} - P_{cap})/P_{cap}$.

3.2. Previous analysis: the impact of marginal costs by technology on mark-up

The supply of electricity follows peculiar characteristics as the marginal costs associated with the production of electricity depends on the technology being used. Fuel prices influence the production cost of electric power plants, as to produce electricity these plants are used in merit order, i.e., available power plants are used to generate electricity based on the ascending order of price. In this situation, the producer offers positive net-supply with positive mark-ups and pushes down the price using its market power, while mark-ups are zero at the contracting point where net-supply is also zero [33].

In this previous analysis, it is relevant to explain the relationship between the variable mark-up and independent variables, whose multiplicative and qualitative effects will be measured by multiplying the marginal costs by the technology at the stock market closing time. This differentiation will be processed using binary variables, which assume a unitary value if, at the hour_{*i*} of the stock market closing time, the technology “*j*” is considered zero; otherwise $j = 1 = \text{coal}, 2 = \text{hydraulic}, 3 = \text{fuel oil}, 4 = \text{fuel gas}, 5 = \text{nuclear}, \text{ and } 6 = \text{gas combined cycle}$.

By analyzing the “*F*” statistic, one can conclude that the individual effects of each electricity firm, represented by the constant, are not all equal as assumed in the “Pooled” model. Instead, they are different as assumed in the “Fixed Effect” model. The interpretation of this test is that the specificities of each electricity company are important to explain the increase of the marginal costs causal OMEL mark-up.

As presented in **Table 1**, one can conclude that there is an average decrease in the mark-up of €0.5608 for the set of the electricity companies considered in the study, when marginal costs vary one unit using coal, regarding the remaining technologies. When using hydraulic technology at stock market closing time at peak hours, the impact of the variation of one unit on the marginal costs induces an average increase of €0.1479 in the mark-up of all electricity producers. One can witness that a unitary increase in the marginal costs using fuel oil technology induces an average decrease of €0.33534 units in the mark-up regarding the remaining technologies. The average decrease in the mark-up would be €0.2925 when fuel gas is used as technology and €0.3803 for the gas combined cycle for all the electricity producers when marginal costs vary one unit *ceteris paribus*.

Overall, the main evidence of the characteristics of those different production technologies is that coal plants set the prices mainly on the low demand periods, while hydroelectric plants prevail during peak hours. Consequently, since Endesa provides near 57% of electricity production generated from coal, while Iberdrola leads hydraulic adjustable production, both companies set the marginal price in the market. Finally, Endesa and Iberdrola play the role of pivot companies in the Spanish wholesale market. Their capacity is at least equal to the market's existing idle supply, especially during the peak demand periods.

	Pooled	Fixed effect	Random effect
Dcmg1	−0.51469 (0.0070)	−0.5608 (0.007472)	−0.548427 (0.007359)
Dcmg2	0.165627 (0.057316)	0.14790 (0.05709)	0.154585 (0.05714)
Dcmg3	−0.335053 (0.005512)	−0.33534 (0.0060)	−0.332651 (0.00591)
Dcmg4	−0.30791 (0.004286)	−0.29251 (0.004355)	−0.29770 (0.004346)
Dcmg6	−0.41119 (0.00663)	−0.38030 (0.006761)	−0.38789 (0.006727)
Constant	1.940205 (0.0013567)	1.97557 (0.01383)	1.96954 (0.01621)
F	1260.3	1248.9	
P Z			0.000

Table 1. The impact of the marginal costs, by technology, on the Mark-Up.

The abovementioned behavior of the main two firms of the Spanish electricity market opens a window of opportunity to address the relationship between competition and regulation. Although an expanding body of literature exists on the promotion of competition in electricity markets, there is an important gap in analyzing it in two different scenarios: the absence and presence of regulation. In such a way this study analyzes the interactions among market power indexes, marginal costs, and bidding strategies in the two mentioned scenarios. There are differences in pricing behavior between larger and smaller generators in the Spanish wholesale market. Given that demand is very inelastic and supply highly concentrated, larger generators, such as, Endesa and Iberdrola seem to be able to increase prices by a considerable amount, especially in peak hours.

As Vives [34] states, mark-ups decrease if producers have access to the same information, such as the expected signs in the behavior of market prices and marginal costs, potentially correlated. In the case of duopoly in the Spanish electricity market, Endesa and Iberdrola are able to increase or decrease the bid price, involving large amounts of kwh, given the sharing of information between the spot market and the open market, which might have underpinned the collusive behavior of these two players and their followers. This may justify the increase or decrease of mark-ups, or pushed toward an increase or decrease of the market price and marginal cost, explaining in this way the high or low prices in the market. However, for Ciarreta [35] not only the vertical integration of production and distribution activities explains a higher margin of cost-price for Iberdrola than for Endesa, but also it is plausible to admit the reversibility of this cost-price evolution, stressing that market power mitigation may be sustained by the threat of new regulation and the entry of new players in the market, as was

expected with the liberalization process which involves a greater incentive to competition in the production of electricity. On the other hand, the recovery of sunk costs with the CTC mechanism provides different incentives for different players. It is expected that in the OMEL market, there are new conditions for estimating accurately the production marginal costs per technology for, given the historic hourly quantity bids on the market by technology type.

After this previous analysis, in the next section, the main purpose of this econometric study is to answer the three questions described in introduction, in which panel cointegration estimation of a regression model is used under the absence and in the presence of regulation.

Tests assuming a common unit root process				Test assuming individual unit root process
Series name	LLC t^* -stat: H_0 : Unit root	Breitung t -stat: H_0 : Unit root	Hadri Z-stat: H_0 : No Unit root	IPS W- t -bar stat: H_0 : Unit root
Quantity purchased to sell in open market	-6.5448 [0.9950]	-7.3201*** [0.0000]	21.2876*** [0.0000]	-3.4255*** [0.0003]
Coal price	-3.2588*** [0.0000]	-4.0808*** [0.0000]	34.9151*** [0.0000]	-5.5105*** [0.0000]
Fuel-oil price	-4.7158 [0.7254]	-0.4339 [0.3322]	48.5190*** [0.0000]	0.7321 [0.7680]
Gas price	-6.8977 [0.8823]	-3.1011*** [0.0010]	19.8958*** [0.0000]	-3.3736*** [0.0004]
Sold Quantity	-4.3792* [0.0997]	-5.7878*** [0.0000]	30.1633*** [0.0000]	-2.2015** [0.0139]
Marginal cost	-4.5782 [1.000]	-16.3918*** [0.0000]	25.4702*** [0.0000]	-4.8489*** [0.0000]
Net quantity	-7.2965 [1.0000]	-8.4103*** [0.0000]	17.5772*** [0.0000]	-8.0987*** [0.0000]
Lerner index 1	-5.9166 [1.0000]	-18.6325*** [0.0000]	19.4469*** [0.0000]	-7.9349*** [0.0000]
Lerner index 2	-8.1611 [0.9791]	-7.7131*** [0.0000]	15.3261*** [0.0000]	-6.7004*** [0.0000]

Notes: *, ** and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Table 2. Panel unit root tests results.

3.3. Panel unit root tests

Panel data is generally characterized by unobserved heterogeneity with parameters that are cross-section specific. In some cases, it is not appropriate to consider independent cross-section units. The rejection of the null hypothesis of Panel unit root tests is difficult to interpret because it means that a significant fraction of cross-section units is stationary, although there is no explicit quantification of the size of this fraction.

Panel unit root tests are often grouped into two main categories: first-generation tests, which assume cross-sectional independence [31, 36, 37]; and second generation tests, which explicitly allow for some form of cross-section dependence [38]. This article applies panel unit root tests to ascertain whether or not the time series of each variable included in the Autoregressive Distributed Lag (ADL) contained a stochastic trend and to test whether the set of variables are stationary or not.

The panel unit root test is based on the following autoregressive specification [39]: $y_{it} = \rho_i \cdot y_{it-1} + \Delta_i \cdot X_{it} + \mu_{it}$, where $i = 1, 2, \dots, N$ represents companies observed over periods, $t = 1, 2, \dots, T$. X_{it} are exogenous variables in the model including individual deterministic effects, such as constants (fixed effects) and linear time trends, which capture cross-sectional heterogeneity, and ρ_i are the autoregressive coefficients. If $\rho_i < 1$, y_i it is said to be weakly trend-stationary. Conversely, if $\rho_i = 1$, then y_i contains a unit root; μ_{it} is the stationary error terms.

To test that all individual series of the panel contain a unit root, we use LLC, Breitung, IPS, and Hadri tests [28–31]. It tests the null hypothesis of data being stationary versus the alternative hypothesis in which at least one panel contains a unit root. The results of panel tests are difficult to interpret if the null hypothesis is rejected. In the LLC and IPS tests, cross-sectional means are subtracted to minimize problems arising from cross-section dependence.

Table 2 reports unit root tests for the following variables: quantity purchased in wholesale market to sell in open market, coal price, fuel-oil price, gas price, marginal cost, net quantity, Lerner index under absence (Lerner Index 1), and presence (Lerner Index 2) of regulation. The regressions contain an intercept and a time trend.

The LLC test rejects the presence of a unit root under significantly weaker evidence for the following variables: coal price and sold quantity. The Hadri test has a different (stationary) null hypothesis and provides strong evidence that all panels have a unit root. The Breitung and IPS tests cannot reject the presence of unit root in fuel-oil price.

Although there are cases in which the null hypothesis was rejected, it is possible to assume nonstationarity of the series, which holds the possibility of long-term relationships between the variables. Moreover, it is possible to include the variables in the cointegration study in which the null hypothesis was rejected in the following situations: first, assuming that they are first-order integrated and, second, when the panel test does not show such results due to the high probability of cross-section correlation.

3.4. Panel cointegration tests

After assuring nonstationarity, we used the methodology proposed by Engle and Granger [40] to test the cointegration hypothesis of the series as used afterward [41–44].

Pedroni [41] uses the residuals from the static long-run regression to construct seven panel cointegration tests: four of them assuming the homogeneity of the AR term, whereas the remaining tests are less restrictive, as they allow for heterogeneity of the AR term.

The statistics based on the homogeneous alternative hypothesis consist on pooled type estimates, or within-groups statistics [42]. When considering the heterogeneous alternative hypothesis, test statistics are formed by means of the estimated individual values for each panel unit i , which Pedroni [42] calls between-groups estimators.

This study relies on the Westerlund [43] test that suggests four cointegration tests that are based on structural rather than residual dynamics and allow for a large degree of heterogeneity. They test the null hypothesis by inferring if the error correction term is equal to zero. The null hypothesis of no cointegration is rejected in the case of rejection of the null hypothesis of no error correction [44]. Two tests are designed with an alternative hypothesis that the panel is cointegrated as a whole, while the other two test the alternative hypotheses that there is at least one individual series that is cointegrated. Each test is able to accommodate individual firm specific short-run dynamics, including serially correlated error terms and nonstrictly exogenous regressors, individual specific intercept, and trend terms, as well as individual-specific slope parameters.

As the relationship among the variables may be spurious even if the series are nonstationary, it is necessary to perform panel cointegration tests to make sure that there is indeed a long-term relationship.

As shown in **Table 3**, the results do provide strong support for the presence of cointegration, according to Pedroni's test statistics. However, the results of the Westerlund's test, as provided by the cross-sections, provide evidence of cointegration further indicating the possibility of a bidirectional long-run equilibrium relationship between marginal costs and the supply strategy. This is consistent across the different cases: in the absence or presence of regulation.

To test that all individual series of the panel contain a unit root, we use LLC, Breitung, IPS, and Hadri tests [28–31]. It tests the null hypothesis of data being stationary versus the alternative hypothesis in which at least one panel contains a unit root. The results of panel tests are difficult to interpret if the null hypothesis is rejected. In the LLC and IPS tests, cross-sectional means are subtracted to minimize problems arising from cross-section dependence.

Table 2 reports unit root tests for the following variables: quantity purchased in wholesale market to sell in open market, coal price, fuel-oil price, gas price, marginal cost, net quantity, Lerner index under absence (Lerner Index 1), and presence (Lerner Index 2) of regulation. The regressions contain an intercept and a time trend.

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Although there are cases in which the null hypothesis was rejected, it is possible to assume nonstationarity of the series, which holds the possibility of long-term relationships between the variables. Moreover, it is possible to include the variables in the cointegration study in which the null hypothesis was rejected in the following situations: first, assuming that they are first-order integrated and, second, when the panel test does not show such results due to the high probability of cross-section correlation.

3.5. Panel cointegration tests

After assuring nonstationarity, we used the methodology proposed by Engle and Granger [40] to test the cointegration hypothesis of the series as used afterward [41–44].

Pedroni [41] uses the residuals from the static long-run regression to construct seven panel cointegration tests: four of them assuming the homogeneity of the AR term, whereas the remaining tests are less restrictive, as they allow for heterogeneity of the AR term.

The statistics based on the homogeneous alternative hypothesis consist on pooled type estimates, or within-groups statistics [42]. When considering the heterogeneous alternative hypothesis, test statistics are formed by means of the estimated individual values for each panel unit i , which Pedroni [42] calls between-groups estimators.

This study relies on the Westerlund [43] test that suggests four cointegration tests that are based on structural rather than residual dynamics and allow for a large degree of heterogeneity. They test the null hypothesis by inferring if the error correction term is equal to zero. The null hypothesis of no cointegration is rejected in the case of rejection of the null hypothesis of no error correction [44]. Two tests are designed with an alternative hypothesis that the panel is cointegrated as a whole, while the other two test the alternative hypotheses that there is at least one individual series that is cointegrated. Each test is able to accommodate individual firm specific short-run dynamics, including serially correlated error terms and nonstrictly exogenous regressors, individual specific intercept, and trend terms, as well as individual-specific slope parameters.

As the relationship among the variables may be spurious even if the series are nonstationary, it is necessary to perform panel cointegration tests to make sure that there is indeed a long-term relationship.

As shown in **Table 3**, the results do provide strong support for the presence of cointegration, according to Pedroni's test statistics. However, the results of the Westerlund's test, as provided by the cross-sections, provide evidence of cointegration further indicating the possibility of a bidirectional long-run equilibrium relationship between marginal costs and the supply strategy. This is consistent across the different cases: in the absence or presence of regulation.

	Westerlund	Pedroni			
<i>Equation 1A: $MC_{it} = \beta_0 + \beta_1 Coal P_{it} + \beta_2 FuOl P_{it} + \beta_3 Gas P_{it} + \beta_4 Ler I_{noRegit} + \varepsilon_{it}$</i>	$G_T -4.241^{***}$ [0.002]	Panel v-Statistic	-0.0945 [0.537]	Group rho-Statistic	-56.190 ^{***} [0.000]
	$G_\alpha -68.228^{***}$ [0.000]	Panel rho-Statistic	-52.863 ^{***} [0.000]	Group PP-Statistic	-28.698 ^{***} [0.000]
	$P_T -9.472^{**}$ [0.012]	Panel PP-Statistic	-26.606 ^{***} [0.000]	Group ADF-Statistic	-3.308 ^{***} [0.000]
	$P_\alpha -57.460^{***}$ [0.000]	Panel ADF-Statistic	-3.516 ^{***} [0.000]		
<i>Equation 1B: $MC_{it} = \beta_0 + \beta_1 Coal P_{it} + \beta_2 FuOl P_{it} + \beta_3 Gas P_{it} + \beta_4 Ler I_{Regit} + \varepsilon_{it}$</i>	$G_T -5.505^{***}$ [0.000]	Panel v-Statistic	1.629* [0.063]	Group rho-Statistic	-131.619 ^{***} [0.000]
	$G_\alpha -106.822^{***}$ [0.000]	Panel rho-Statistic	-143.220 ^{***} [0.000]	Group PP-Statistic	-49.662 ^{***} [0.000]
	$P_T -13.852^{***}$ [0.000]	Panel PP-Statistic	-50.268 ^{***} [0.000]	Group ADF-Statistic	-4.165 ^{***} [0.000]
	$P_\alpha -108.782^{***}$ [0.000]	Panel ADF-Statistic	-4.102 ^{***} [0.000]		
<i>Equation 2A: $SQ_{it} = \beta_0 + \beta_1 Purch Q_{it} + \beta_2 MC_{it} + \beta_3 Ler I_{noRegit} + \varepsilon_{it}$</i>	$G_T -4.757^{***}$ [0.000]	Panel v-Statistic	2.716 ^{***} [0.003]	Group rho-Statistic	-51.502 ^{***} [0.000]
	$G_\alpha -60.334^{***}$ [0.000]	Panel rho-Statistic	-52.455 ^{***} [0.000]	Group PP-Statistic	-24.878 ^{***} [0.000]
	$P_T -11.548^{***}$ [0.000]	Panel PP-Statistic	-24.810 ^{***} [0.000]	Group ADF-Statistic	-4.707 ^{***} [0.000]
	$P_\alpha -54.626^{**}$ *[0.000]	Panel ADF-Statistic	-4.644 ^{***} [0.000]		
<i>Equation 2B: $SQ_{it} = \beta_0 + \beta_1 Purch Q_{it} + \beta_2 MC_{it} + \beta_3 Ler I_{Regit} + \varepsilon_{it}$</i>	$G_T -4.682^{***}$ [0.000]	Panel v-Statistic	2.322 ^{***} [0.010]	Group rho-Statistic	-52.006 ^{***} [0.000]
	$G_\alpha -59.936^{***}$ [0.000]	Panel rho-Statistic	-52.763 ^{***} [0.000]	Group PP-Statistic	-25.178 ^{***} [0.000]
	$P_T -11.134^{***}$ [0.000]	Panel PP-Statistic	-24.914 ^{***} [0.000]	Group ADF-Statistic	-4.764 ^{***} [0.000]
	$P_\alpha -49.431^{***}$ [0.000]	Panel ADF-Statistic	-4.579 ^{***} [0.000]		
<i>Equation 3A: $Net Q_{it} = \beta_0 + \beta_1 MC_{it} + \beta_2 Ler I_{noRegit} + \varepsilon_{it}$</i>	$G_T -5.460^{***}$ [0.000]	Panel v-Statistic	1.568* [0.058]	Group rho-Statistic	-38.280 ^{***} [0.000]
	$G_\alpha -73.812^{***}$ [0.000]	Panel rho-Statistic	-30.588 ^{***} [0.000]	Group PP-Statistic	-19.848 ^{***} [0.000]
	$P_T -12.963^{***}$	Panel PP-Statistic	-16.283 ^{***}	Group	-4.436 ^{***}

	[0.000]		[0.000]	ADF-Statistic	[0.000]
	P_{α} -62.119***	Panel	-3.679**		
	[0.000]	ADF-Statistic	[0.000]		
<i>Equation 3B: Net Q_{it} =</i>	G_T -5.341***	Panel v-Statistic	0.7152*	Group	-33.239***
$\beta_0 + \beta_1 M C_{it} +$	[0.000]		[0.237]	rho-Statistic	[0.000]
$\beta_2 L e r I_{R e g i t} + \varepsilon_{i t}$	G_{α} -72.295***	Panel rho-Statistic	-21.420***	Group	-16.654***
	[0.000]		[0.000]	PP-Statistic	[0.000]
	P_T -11.964***	Panel PP-Statistic	-12.786***	Group	-3.608***
	[0.000]		[0.000]	ADF-Statistic	[0.000]
	P_{α} -51.816***	Panel	-2.112**		
	[0.000]	ADF-Statistic	[0.017]		

Notes: Tests results were generated by EvIEWS and 'xtwest' Stata module. Pedroni's Panel statistics as well as all of Westerlund's are weighted. Dep. var. of coint. reg. = dependent variable of the cointegrating regression. Values in [] are robust *p*-values generated through bootstrapping because of cross-sectional dependence in the residuals. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table 3. Panel cointegration tests results.

Overall, according to the results displayed in **Table 3** for the three equations, it is possible to claim that all variables (quantity purchased in wholesale market to sell in open market, coal price, fuel-oil price, gas price, marginal cost, net quantity, Lerner index 1, and Lerner index 2) are cointegrated, i.e., we have uncovered meaningful long-run relationships.

3.6. Estimation of the cointegration vector

The traditional specification of Autoregressive Distributed Lag [ARDL (*p*, *q*)] is normally used for the estimation of dynamic heterogeneous panels [45] through the following equation: $y_{it} = \sum_{j=1}^p \lambda_{ij} \times y_{i,t-j} + \sum_{j=0}^q \delta_{ij}' \times X_{i,t-j} + \mu_i + \varepsilon_{it}$, in which *p* is the number of lags of the dependent variable, *q* is the number of lags of the explanatory variables, $i = 1, 2, \dots, N$, $t = 1, 2, \dots, T$, X_{it} is a vector (*k* - 1) of explanatory variables, δ_{ij} is a vector of unknown parameters, λ_{it} are scalars and μ_{it} is a specific term associated to each company.

It is possible to infer what deviations from the long-term equilibrium of the variables influence the short-term dynamics after assuring both the nonstationarity of the variables of the equation and the presence of cointegration among them. The answer to these deviations can be represented by an ECM represented by the following equation: $\Delta y_{it} = \phi_i (y_{i,t-1} - \theta_i' \times X_{it}) + \sum_{j=1}^{p-1} \lambda_{ij}^* \times \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}^{**} \times \Delta X_{i,t-j} + \mu_i + \varepsilon_{it}$, in which $\phi_i = -(1 - \sum_{j=1}^p \lambda_{ij})$, $\theta_i = \sum_{j=0}^q \delta_{ij} / (1 - \sum_{k=1}^p \lambda_{ik})$, $\lambda_{ij}^* = -\sum_{m=j+1}^p \lambda_{im}$, with $j = 1, 2, \dots, p - 1$ and $\delta_{ij}^{**} = -\sum_{m=j+1}^q \delta_{im}$, with $j = 1, 2, \dots, q - 1$.

The speed of adjustment from the error correction term, ϕ_i , and the vector of parameter of long-run equilibrium relationship, θ_i , will be given particular attention. It is expected that the former

would be different from zero and would be significantly negative under the assumption that the variables return to their long-run equilibrium.

The equation is estimated according to the assumptions made regarding the homogeneity of the short- and long-term parameters among the panel of companies.

For the panel cointegration estimation, we will use several estimation methodologies: the Pooled Mean Group (PMG), the Full Modified Ordinary Least Squares (FMOLS), and the Dynamic Ordinary Least Squares (DOLS).

All intercepts, ratios, and variances of the errors vary between the groups [46]. Although the PMG method allows the error variances, the short-run coefficients and the intercepts differ freely across groups, but it restricts the long-run coefficients to be similar throughout the panel as the method assumes dynamic fixed-effects [46].

As electric power firms operating in the same market are submitted to the same regulatory policies and movements in international fossil fuels prices, the long-run equilibrium relationships between the variables are expected to be similar between groups. Accordingly, the PMG method may be of interest.

Due to the greater flexibility in the presence of heterogeneity in the cointegration vectors and to the lower size distortion vis-à-vis the estimators within groups, we will complement our analysis using FMOLS and DOLS methods, as recommended by Pedroni [47].

Table 4 reports the long- and short-run estimates, based on different estimation strategies adopted. The results of FMOLS and DOLS techniques, displayed in the first two columns, provide information on the long-run relationship between marginal cost and independent variables included in Eq. 1A (absence of regulation) and Eq. 1B (presence of regulation). For each variable, the panel estimates are remarkably similar in sign and magnitude across the two techniques.

For the panel results, the prices of coal price and fuel-oil are negative, in the absence of regulation, while the price of gas is positive, statistically significant, but not similar in value across the FMOLS and DOLS estimation techniques. For example, 1 unit increase in the prices of coal, fuel-oil, and gas raises marginal costs by -0.061 €/MWh, -0.056 €/MWh, and 0.086 €/MWh, respectively, using the FMOLS estimator or -0.034 €/MWh, -0.058 €/MWh, and 0.063 €/MWh, respectively, using the DOLS estimator.

On the other hand, in the presence of regulation, 1 unit increase in the prices of coal, fuel-oil, and gas raises marginal costs by 0.1579 €/MWh, -0.1088 €/MWh, and -0.0589 €/MWh, respectively, using the FMOLS estimation technique, or by 0.1649 €/MWh, -0.1065 €/MWh, and -0.0892 €/MWh, respectively, using the DOLS estimation technique.

The Lerner index 1 (absence of regulation) is negative and the Lerner index 2 (presence of regulation) is positive, both statistically significant on marginal costs per power plant, using FMOLS or DOLS techniques.

There is a statistically significant effect for all independent variables on marginal costs, both in the absence and in the presence of regulation, when using the PMG estimation. In the

presence of regulation, the speed of adjustment is negative, as expected, but its magnitude (0.26) is somewhat large when compared to the value in the absence of regulation. This implies that the PMG model, in the presence of regulation, does return immediately to its equilibrium after a shock pushes it away from the steady state. On the other hand, in the absence of regulation, the PMG model does not immediately return to its equilibrium after a shock, as the magnitude (0.086) is somewhat small. In fact, as the convergence coefficient (error correction term) is statistically significant, it provides further evidence of the existence of a long-run relationship between the marginal costs and the explanatory variables.

The results of the long-run and short-run relationships show that the PMG estimates of the Lerner index in the absence of regulation have a negative statistically significant impact on marginal cost (−7.527 €/MWh for the long-run and −22.446 €/MWh, for the short-run). In the presence of regulation, the estimates for the Lerner index show positive impacts in the long-run relationships (9.280 €/MWh) and negative impacts in the short-run (−2.383 €/MWh).

$$\text{Equation 1A: } MC_{it} = \beta_0 + \beta_1 \text{Coal}P_{it} + \beta_2 \text{Fuel}P_{it} + \beta_3 \text{Gas}P_{it} + \beta_4 \text{Ler}I_{noRegit} + \varepsilon_{it}$$

	FMOLS	DOLS	PMG
Dependent variable:	Marginal Cost	Marginal Cost	Δ Marginal Cost
Convergent coefficients			−0.08632*** (0.014)
Long-run coefficients			
Coal price	−0.06015*** (0.0202)	−0.03454 (0.0228)	−0.05616* (0.0312)
Fuel-oil price	−0.0564*** (0.0060)	−0.0584*** (0.0064)	−0.0387*** (0.0096)
Gas price	0.0863** (0.0366)	0.06382 (0.0404)	−0.1901*** (0.061)
Lerner index 1	−8.8457*** (0.708)	−7.5481*** (0.943)	−7.5271*** (1.1093)
Short-run coefficients			
Δ Coal price			0.01844*** (0.0050)
Δ Fuel-oil price			−0.01135*** (0.0027)
Δ Gas Price			0.08198*** (0.0162)
Δ Lerner Index 1			−22.4461*** (1.900)
Hausman test (χ^2)			8.26(0.142)

R-square (r^2)	0.541	0.658	
<i>Equation1B</i> : $MC_{it} = \beta_0 + \beta_1 CoalP_{it} + \beta_2 FuelP_{it} + \beta_3 GasP_{it} + \beta_4 Lerner_{it} + \varepsilon_{it}$			
	FMOLS	DOLS	PMG
Dependent variable:	Marginal Cost	Marginal Cost	Δ Marginal Cost
Convergent coefficients			-0.26326*** (0.0463)
Long-run coefficients			
Coal price	0.1579*** (0.017)	0.16495*** (0.0186)	0.16448*** (0.0179)
Fuel-oil Price	-0.1088*** (0.005)	-0.1065*** (0.0059)	-0.09682*** (0.0057)
Gas price	-0.0589* (0.034)	-0.08928** (0.0395)	-0.08123** (0.0364)
Lerner Index 2	10.420*** (0.460)	10.6046*** (0.542)	9.2799*** (0.4887)
Short-run coefficients			
Δ Coal price			-0.00912 (0.0169)
Δ Fuel-oil Price			0.00749 (0.0120)
Δ Gas Price			-0.04196 (0.0315)
Δ Lerner Index 2			-2.3828*** (0.5823)
Hausman test (χ^2)			1.19 (0.945)
R-square (r^2)	0.483	0.564	
No. of firms	6	6	6
No. of observations	9756	9756	9846

Notes: All equations include a constant sector-specific term. Values in () are standard errors. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 4. panel cointegration estimation results.

Table 5 presents the results of the model specifying the quantity sold as the dependent variable, and **Table 6** presents the results of the model specifying the net quantity as the dependent variable, when the marginal cost and other explanatory variables are the independent variables. The focus is now on how the marginal costs, and the Lerner indexes affect bid

quantities. The results suggest that the coefficients are consistently positive across the alternative estimators and also highly significant.

When analyzing the long-run effect, the coefficients in Eqs 2A and 2B of the quantity purchased in wholesale market to sell in open market reveal a statistical and significant effect on the quantity sold in wholesale market (0.851 MWh or 0.858 MWh, in the absence of regulation, and 0.893 MWh or 0.910 MWh, in the presence of regulation, respectively, using FMOLS or DOLS estimators).

The marginal cost, show a positive effect and statistically significant at the 1% level on the quantity sold in the wholesale market, in the absence and presence of regulation. The Lerner indexes, both in the absence and in the presence of regulation, are also positive and statistically significant, but the difference between FMOLS and DOLS estimates is large: in absence of regulation, this means, the increase of market power induces an increase in the quantity sold around 14,183 and 15,485 MWh, whereas in the presence of regulation the increase is between 8040 and 7388 MWh.

The results show that the PMG estimates of the marginal costs have, in the absence of regulation, a statistically significant positive impact on the sold quantity both in the long-run (1983.37 MWh) and in the short-run (584.46 MWh). In the presence of regulation, we also found a positive impact on marginal cost in long-run relationships (1578.91 MWh) as well as in the short-run relationships (468.98 MWh).

In the absence of regulation, we found that the Lerner index has a positive effect on the sold quantity, both in the long-run as well as in the short run.

Table 6 shows that the Lerner index and marginal costs provide statistically significant effects on net quantities using FMOLS or DOLS estimators, former being negative and the latter positive, both in the absence and in the presence of regulation.

In general, throughout all equations, although the DOLS method has generated coefficients with values slightly higher than those obtained by the FMOLS method, we can conclude that the long-run results obtained by both methods, DOLS and FMOLS, are suited to the analysis.

<i>Equation 2A : $SQ_{it} = \beta_0 + \beta_1 PurchQ_{it} + \beta_2 MC_{it} + \beta_3 LerI_{noRegit} + \varepsilon_{it}$</i>			
	FMOLS	DOLS	PMG
Dependent variable:	Sold quantity	Sold quantity	Δ Sold quantity
Convergent coefficients			-0.0524*** (0.0136)
Long-run coefficients			
Purchased quantity to sell in open market	0.85117*** (0.025)	0.8577*** (0.0280)	0.98543*** (0.0701)
Marginal costs	1429.80*** (83.823)	1411.846*** (101.703)	1983.37*** (226.57)
Lerner Index 1	14182.94*** (2559.34)	15484.80*** (3198.87)	127935.86*** (6646.40)
Short-run coefficients			

Δ Purchased quantity to sell in open market			0.26344*** (0.082)
Δ Marginal costs			584.46*** (195.95)
Δ Lerner Index 1			4066.38** 1659.99)
Hausman test (χ^2)			-3.91
R-square (r^2)	0.665	0.610	
<i>Equation2B : $SQ_{it} = \beta_0 + \beta_1 PurchQ_{it} + \beta_2 MC_{it} + \beta_3 LerI_{Regit} + \varepsilon_{it}$</i>			
	FMOLS	DOLS	PMG
Dependent variable:	Sold quantity	Sold quantity	Δ Sold quantity
Convergent coefficients			-0.04979*** (0.0108)
Long-run coefficients			
Purchased quantity to sell in open market	0.89339*** (0.023)	0.91021*** (0.0260)	1.00889*** (0.0708)
Marginal costs	1141.84*** (80.538)	1151.06*** (101.76)	1578.91*** (229.45)
Lerner Index 2	8039.68*** (1648.76)	7388.14*** (190.72)	4001.013 (4522.50)
Short-run coefficients			
Δ Purchased quantity to sell in open market			0.2312*** (0.075)
Δ Marginal costs			468.98*** (181.35)
Δ Lerner Index 2			8317.59** (3439.04)
Hausman test (χ^2)			114.39*** (0.000)
R-square (r^2)	0.777	0.728	
No. of firms	6	6	6
No. of observations	9756	9756	9846

Notes: All equations include a constant sector-specific term. Values in () are standard errors. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 5. Panel cointegration estimation results.

<i>Equation3A : $NetQ_{it} = \beta_0 + \beta_1 MC_{it} + \beta_2 LerI_{noRegit} + \varepsilon_{it}$</i>			
	FMOLS	DOLS	PMG
Dependent variable:	Net quantity	Net quantity	Δ Net quantity
Convergent coefficients			-0.1627* (0.101)
Long-run coefficients			
Marginal costs	1454.20*** (218.61)	1676.32*** (258.24)	-2571.88*** (675.32)
Lerner Index 1	-28065.29*** (6882.92)	-29532.90*** (8402.43)	-25764.33 (17632.3)

Short-run coefficients			
Δ Marginal costs			685.706*** (209.12)
Δ Lerner Index 1			15214.38*** (4463.26)
Hausman test (χ^2)			17.41 (0.000)
R-square (r^2)	0.722	0.738	
<i>Equation 3B: $NetQ_{it} = \beta_0 + \beta_1 MC_{it} + \beta_2 LerI_{Regit} + \varepsilon_{it}$</i>			
	FMOLS	DOLS	PMG
Dependent variable:	Net quantity	Net quantity	Δ Net quantity
Convergent coefficients			−0.06206*** (0.0180)
Long-run coefficients			
Marginal costs	2043.93*** (210.13)	2213.19*** (259.70)	108.536 (75.413)
Lerner Index 2	−21207.82*** (4885.84)	−20263.54*** (5707.98)	9537.00*** (1467.26)
Short-run coefficients			
Δ Marginal costs			251.508* (141.10)
Δ Lerner Index 2			−8014.105 (10323.91)
Hausman test (χ^2)			4.89 (0.179)
R-square (r^2)	0.724	0.740	
No. of firms	6	6	6
No. of observations	9756	9756	9846

Notes: All equations include a constant sector-specific term. Values in () are standard errors. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table 6. panel cointegration estimation results.

4. Discussion and regulatory implications

All the results of the estimation of the relationship between marginal costs, the Lerner indexes, and bid quantities justify some reflections on the implications of regulatory policy in the period analyzed for this electricity market. Our results suggest that the coefficients are consistently positive across the alternative estimators and also highly significant. The marginal cost, show a positive effect and is statistically significant at the 1% level on the quantity sold in the wholesale market in the absence and the presence of regulation. The Lerner indexes, both in the absence and in the presence of regulation, are also positive and statistically significant.

With these evidences it is possible to claim that the exercise of market power is explained by the dominance the two major players have over the various technologies underlying the quantities that are bid in the market pool, which involve technologies with high fixed costs and low variable costs operating almost continuously over time (case of coal plants) so that

their remuneration is determined by setting hourly rates of the day throughout the year, with closing prices above marginal production costs for these plants. With high variable cost technologies, whose production is discontinuous and dependent on exogenous variables such as hydraulicity and wind intensity, bids in periods of high demand may be justified given the capacity constraints of coal plants. For that reason, the market overcompensates some technologies and subcompensates others due to unpredictable phenomena at the moment of production shifts. This adjustment is not possible in the electricity generation sector because most investments are not replicable and because the existence of sunk costs discourage the abandonment of technologies whose compensation does not cover average costs, but only the variable costs, so the discrepancies persist. As such, the intervention of regulatory mechanisms is needed to create the necessary conditions for resizing the capacity. On the other hand, the prevalence of market power exercise reflects different vectors of efficiency (efficiency in resource allocation, technical efficiency, and production scale efficiency) of the various market players, especially between the two major firms, Endesa and Iberdrola, and other remaining companies operating in the spot electricity market. The inefficiency caused by the misallocation of resources has theoretically minimum consequences, but we need to know the elasticity of demand, the increase in prices caused by market power, and the slope of the average costs of companies exercising market power. The (allocative) market efficiency variation caused by one (or more) of the reasons abovementioned can nearly always be corrected by means of regulatory actions

Our results show that the presence of the CTC regulatory mechanism has a positive, artificial effect on marginal costs. During the period of analysis, the supply of the two largest companies in the electricity market is based on the coal (Endesa) and hydroelectric power (Iberdrola). The creation of this compensatory mechanism for the sunk costs of electricity producers basically smoothen out the fluctuations of the final price of electricity in the pool. In this way, it behaves as a maximum price. On the other hand, CTCs also constitute a control mechanism of capacity payments requiring a certain level of activity investment in the various technologies over time. Considering that in the period of analysis, the level of CTC has been set higher than the market equilibrium prices, which in turn are smaller than the marginal cost of those technologies, it is expected that the market power effect has a positive signal in what pertains to the marginal cost associated with technologies with lower variable costs.

The price cap criterion used by the Spanish authorities to mitigate the market power was very important in the transition context of the Spanish electricity market. The incentives provided by the regulation interfered with the day-ahead market and led to lower prices than the ones practiced by the profit maximization behavior. As we observed, during 2002–2006, there were significant differences between real prices and marginal costs and between real prices and the regulated price cap. As a consequence, they were taken into account when analyzing the market power indexes in the absence and in the presence of regulation.

In other words, it is possible to contend that the CTCs served as an incentive bid for the purchase and sale of electricity at low prices. Moreover, they do not promote competition as predicted with the liberalization of the market because it discourages the entry of new market

players and reinforce the dominant position of large power firms, likely leading to price wars and collusion as had been admitted by Fabra and Toro [15].

On the other hand, the scope of the CTCs, as a market power mitigation mechanism, appears to be virtual as well, since this same mitigation was achieved considering that the players altogether exercise net demander and net supplier behaviors, i.e., that majority of sales bids are lower than the majority of purchase bids in the OMEL market for sale in the open market, otherwise, there is a strengthening in the exercise of market power can occur. The net supplier (Endesa) and net demander (Iberdrola) assumptions behaviors are in line with what has been admitted and referenced by Kühn and Machado [4] and Ciarreta and Espinosa [2], and reinforces the idea of collusion admitted by Fabra and Toro [15].

Our results of this study are tuned with the previous studies [48] corroborating that in order to mitigate the market power problem in OMEL electricity spot market and to ensure the functioning of competitive market conditions, it would be necessary to strengthen regulatory intervention that seems to have been scarce and ineffective. As a result, it is suggested that in order to complement the regulatory compensatory incentive mechanism to sunk costs through implementation of CTCs, the establishment of the rate of return of setting rules for investment decisions should also have been implemented in order to ensure the desired remodeling of electricity generation as established by Directive 2001/77/EC of the European Parliament and by the Council on the promotion of electricity produced from renewable energy sources in the internal electricity market.

The idea of this type of regulation (Rate of return) is that revenues should cover the costs so that economic profit is controlled, and there are no financial transfers to the company. As such, it is expected that the regulated company will obtain an adequate return based on the investment carried out.

However, as has been accepted by Biglaiser and Riordan [49], under the regulation involving the price-cap, cost reduction is more likely to occur in the early years of a regulatory regime, since the setting of ceilings for the revenues of the players are set up based on an established cost review for a given period. As such, it seems questionable to use such procedures in the implementation of CTC mechanisms, since it was expected to expire in 2010 when it was terminated in 2006. This anticipated recovery of sunk costs was associated with larger differences between the market price and marginal costs generating higher mark-ups, and consequently higher profits for market players and greater market power. As such, the regulation was ineffective or nonexistent to ensure the desirable conditions of effective competition in the electricity market.

5. Conclusion

In the Spanish electricity market, the major relationship between production and commercialization is characterized by the (bilateral) contract between the producer and the distributor, in which this technical and commercial relationship is not subject to regulation. In order to

answer the first posed question, under the promotion of competition assumption, where the market price should be equal to marginal cost, our results show that fuel prices exercise mixed impact effects on marginal costs per power plant (coal, oil, gas, CCGT, nuclear, and hydro-electric). The two measures of market power exercise proposed show statistically significant effects on marginal costs both in the long- and short-run. In the long-run, as a significant reduction on marginal costs in the absence of regulation and an increase in the marginal cost in the presence of regulation, as far as FMOLS or DOLS estimators are concerned. In the short-run, there is a decrease on marginal costs in the absence of regulation and a small decrease on marginal costs for the entire panel considered, according to the PMG estimator.

Related to the second posed question, our results point to the significant inclusion of net seller's behavior strategies in the Spanish electricity market, both in the absence and in the presence of regulation. In the long-term and short-term, the Lerner Indexes, marginal costs, and purchased quantity to sell in open market have a significantly positive impact on the sold quantity, under and in the absence of regulation, as far as the FMOLS, DOLS, and PMG estimators are concerned.

Answering to the last question, our results point to the significant inclusion of net quantity behavior strategies in the Spanish electricity market. In the long-term, the Lerner Indexes and marginal costs have a significantly negative and positive impact on the net quantity, respectively, under and in the absence of regulation, as far as the FMOLS and DOLS estimators are concerned.

These two statistically significant evidences found through the two abovementioned models allow, on the one hand, admitting that the scope of promoting the CTC regulatory mechanism to compensate for the sunk costs of power companies operating in OMEL market was successfully achieved and faster than expected based on the performance of the largest electricity producers. These strategic bidding behavior and capacity withholding involve generating firms bidding some prices above the variable production costs of their units with the intent of forcing the market-clearing price above competitive levels.

Based on this evidence, and as referred to in the previous section, the great novelty of this work demands a closer look at virtually nonexistent regulatory policies during an important period of transition to competition in the Spanish electricity market, and under a strong market power exercise by two major players. As such, we think that during the period under analysis, the market operator should have given the electricity market regulating entity room for intervention in the market with the implementation of the rate-of-return mechanism. This type of regulation would have as major constraint that revenues should cover costs so that the economic profit could be controlled, and there are no financial transfers to the electricity company. In this way, it is expected to obtain an adequate return based on the size of the investment carried out by the company, either with the transition to competition or with the introduction of new production plants with cleaner technologies.

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References

- [1] Ciarreta, A., Espinosa, M. P. Supply function competition in the Spanish wholesale electricity market. *Energy Journal*. 2010; 31(4): 137–158.
- [2] Ciarreta, A., Espinosa, M. The impact of regulation on pricing behavior in the Spanish electricity market (2002–2005). *Energy Economics*. 2012;34(6): 2039–2045.
- [3] Ciarreta, A., Espinosa, M. P. Market power in the Spanish electricity auction. *Journal of Regulatory Economics*. 2010; 37(1): 42–69.
- [4] Kühn, K., Machado, M. Bilateral market power and vertical integration in the Spanish electricity spot market. *CEPR Discussion Papers*, Madrid. 2004; 4590.
- [5] Neuhoﬀ, K., Barquin, J., Boots, M., Ehrenmann, A., Hobbs, B., Rijkers, F. Network constrained Cournot models of liberalized electricity markets: The devil is in the details. *Energy Economics*. 2005; 27(3):495–525.
- [6] Baldick, R., Grant, R., Kahn, E. Theory and application of linear supply function equilibrium in electricity markets. *Journal of Regulatory Economics*. 2004; 252:143–167.
- [7] Holmberg, P. Asymmetric supply function equilibrium with constant marginal costs. *Energy Journal*. 2007; 28(2):55–82.
- [8] Fabra, N., von der Fehr, N., Harbord, D. Modeling electricity auctions. *The Electricity Journal*. 2002; 15(7):72–81.
- [9] Joskow, P., Kahn, E. A quantitative analysis of pricing behavior in California’s wholesale electricity market during Summer 2000. *Energy Journal*. 2002; 0(4):1–35.
- [10] Borenstein, S., Bushnell, J., Wolak, F. Measuring market inefficiencies in California’s restructured wholesale electricity market. *The American Economic Review*. 2002; 92(5): 1376–1405.
- [11] Wolak, F.A. Measuring unilateral market power in wholesale electricity markets: The California market, 1998–2000. *American Economic Review*. 2003; 93(2):425–430.

- [12] Furió, D., Lucia, J.J.. Congestion management rules and trading strategies in the Spanish electricity market. *Energy Economics*. 2009; 31(1):48–60.
- [13] Moutinho, V., Moreira, A. C, Mota, J. Evaluating the strategic supply per power plant: evidence from the Spanish wholesale electricity market. *International Journal of Energy Technology and Policy*. 2015; 11(2):97–126.
- [14] Moutinho, V., Moreira, A. C., Mota, J. Measuring the simultaneous quantity game in the OMEL spot electricity market. *International Journal of Energy Economics and Policy*. 2015; 5(1):305–320.
- [15] Fabra, N., Toro, J. Price wars and collusion in the Spanish electricity market. *International Journal of Industrial Organization*. 2005; 23(3/4):155–181.
- [16] Moutinho, V., Vieira, J., Moreira, A. C. The crucial relationship among energy commodity prices: Evidence from the Spanish electricity market. *Energy Policy*. 2011; 39(10):5898–5908.
- [17] García-Martín, J. A. Spot market competition with stranded costs in the Spanish electricity industry. WP 0106. 2001;CEMFI, Madrid.
- [18] Linares, P., Labandeira, X. Energy efficiency: Economics and policy. *Journal of Economic Surveys*. 2004; 24(3):573–592.
- [19] Linares, P., Santos, F., Pérez-Arriaga, I. Scenarios for the evolution of the Spanish electricity sector: is it on the right path towards sustainability? *Energy Policy*. 2008; 36(11):4057–4068.
- [20] Grobman, J., Carey, J. Price caps and investment: long-run effects in the electric generation industry. *Energy Policy*. 2001; 29(7):545–552.
- [21] Stoft, S. *Power System Economics: Designing Markets for Electricity*. Piscataway, NJ: Wiley-Interscience; 2002.
- [22] Joskow, P., Tirole, J. Reliability and competitive electricity markets. *The RAND Journal of Economics*. 2007; 38(1):60–84.
- [23] Biglaiser, G., Riordan, M. Dynamics of price regulation. *The RAND Journal of Economics*. 2000; 31:744–767.
- [24] Baldursson, F. Irreversible investment under uncertainty in oligopoly. *Journal of Economic Dynamics and Control*. 1998; 22(4):627–644.
- [25] Lambrecht, B. The impact of debt financing on entry and exit in a duopoly. *The Review of Financial Studies*. 2001; 14(3):765–804.
- [26] Grenadier, S. Option exercise games: An application to the equilibrium investment strategies of firms. *The Review of Financial Studies*. 2002; 15(3):691–721.
- [27] Earle, R., Schmedders, K., Tatur, T. On price caps under uncertainty. *The Review of Economic Studies*. 2007; 74(1):93–111.

- [28] Levin, A, Lin C-F., Chu C-S., J. Unit root tests in panel data: asymptotic and finite-sample properties. *Journal of Econometrics*. 2002; 108(1):1–24.
- [29] Breitung, J. The local power of some unit root tests for panel data. In: Baltagi, B. H., Fomby, T., Hill, R (Eds), *Nonstationary panels, panel cointegration, and dynamic panels*. *Advances in Econometrics*, Vol. 15. London: Emerald Group Publishing Limited; 2001. pp. 161–177.
- [30] Hadri, K. Testing for stationarity in heterogeneous panel data. *The Econometrics Journal*. 2000; 3(2):148–161.
- [31] Im, K., Pesaran, M., Shin, Y. Testing for unit roots in heterogeneous panels. *Journal of Econometrics*. 2003; 115(1):53–74.
- [32] Lagarto, J., Sousa, J., Martins, Á. The impact of the Iberian electricity market on the competitive behavior of generating companies using a conjectural variations approach. In: *7th International Conference on the European Energy Market (EEM)*; 23–25th June; Madrid. 2010.
- [33] Holmberg, P., Newbery, D. The supply function equilibrium and its policy implications for wholesale electricity auctions. *Utilities Policy*. 2010; 18(4):209–226.
- [34] Vives, X. Strategic supply function competition with private information. *Econometrica*. 2011; 79(6):1919–1966.
- [35] Ciarreta, A. A note on strategic delegation: The role of decreasing returns to scale. *Economics Bulletin*. 2009; 29(1):277–285.
- [36] Choi, I. Unit root tests for panel data. *Journal of International Money and Finance*. 2001; 20(2):249–272.
- [37] Maddala, G., Wu, S. A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics*. 1999; 61(S1):631–652.
- [38] Pesaran, H. A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*. 2007; 22(2):265–312.
- [39] Mahadevan, R., Asafu-Adjaye, J. Energy consumption, economic growth and prices: A reassessment using panel VECM for developed and developing countries. *Energy Policy*. 2007; 35(4):2481–2490.
- [40] Engle, R., Granger, C. Co-integration and error-correction: Representation, estimation and testing. *Econometrica*. 1987; 55(2):251–276.
- [41] Pedroni, P. Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics*. 1999; 61(S1):653–678.
- [42] Pedroni, P. Panel cointegration; asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric Theory*. 2004; 20(3): 597–625.

- [43] Persyn, D., Westerlund, J. Error-correction-based cointegration tests for panel data. *Stata Journal*. 2008; 8(2):232–241.
- [44] Westerlund, J. Testing for error correction in panel data. *Oxford Bulletin of Economics and Statistics*. 2007; 69(6):709–748.
- [45] Blackburne III, E., Frank, M. Estimation of nonstationary heterogeneous panels. *Stata Journal*. 2007; 7(2):197–208.
- [46] Pesaran, H., Shin, Y., and Smith, R. Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association*. 1999; 94(446):621–634.
- [47] Pedroni, P. Purchasing power parity tests in cointegrated panels. *Review of Economics and Statistics*. 2001;83(4):727–731.
- [48] Moutinho, V., Moreira, A. C., Mota, J. Do regulatory mechanisms promote competition and mitigate market power? Evidence from Spanish electricity market . *Energy Policy*. 2014; 68:403–412.
- [49] Biglaiser, G., Riordan, M. Dynamics of price regulation . *Rand Journal of Economics*. 2000; 31(4):744–767.