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Application of a Structural Model to the Spanish Electricity Wholesale Market

Vítor Marques[1], Isabel Soares[2], Adelino Fortunato[3]

Abstract:

The aim of this work is to analyse the behaviour of agents in highly concentrated and strongly regulated electricity wholesale markets with rigid demand. In order to accomplish this aim, the analysis was based on the former Spanish electricity generation market, between January 1999 and June 2007, before the MIBEL (Iberian Electricity Market) has started. The analysis is carried out in the theoretical framework of the structural models. Despite the characteristics of this market, the paper suggests that the average high mark-ups observed in the period examined were very likely due to the implementation of anti-competitive strategies. Therefore, the analysis carried out shows that the opening of a wholesale electricity market without the prior increase in the number of market players does not prevent, by itself, the manipulation of the market, even when the market is strongly regulated.

Key Words: *Electricity, Structural Model, Market Power, Uniform Price Market*

***JEL Classification**: L13*

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[1] *Vítor Marques, , Rua Dom Cristóvão da Gama, 1 - 3° 1400 - 113 Lisboa Portugal, (351) 213033224, ERSE, email: vmarques@erse.pt*

[2] *Isabel Soares, University of Porto, CEF.UP*

[3] *Adelino Fortunato, University of Coimbra*

1. Framework

The aim of this study is to analyze the behavior of agents in the Spanish electricity market during the period from January 1999 to June 2007 before MIBEL (Iberian Electricity Market) started. The main questions that we tried to give an answer to are:

- Did market power exercise occur during a long period in this market?
- What kind of long term strategies have been observed during the analyzed period?

The analysis is carried out in the theoretical framework of structural models. This framework is based on the existence of causal relationships between related variables, explained by economic theory. These relationships are, in general terms, expressed by the resolution of a system of equations, thus implying economic equilibrium. Structural models provide a heuristic and causal approach about the market's economic relationships. Then also allowing for the answer to other questions, namely for the price elasticity of demand.

Section 2 presents the organization of the Spanish wholesale market. The methodological approaches are presented in section 3, namely the models developed. This section includes the survey of the various methodological approaches, and presents the particularities of the methodology applied: the research is carried out through the structural model methodology, and the results are tested with the direct estimations of the main variables. The structural model has two equations, one with the demand function and the other with the profit maximization function. The price elasticity of demand is estimated in section 4 through the first equation. The behavioral factor is estimated in section 5, through the profit maximization function

2. Framework

The former Spanish wholesale market can be characterized by being an Uniform Price Auction (UPA) Market. In these markets, the generator which sells the marginal quantity defines the system marginal price. This price is paid to all producers with accepted bids. In that case the price is defined for each hour. This market presents a strong regulatory framework. The main regulatory drivers were the stranded costs compensations (CTC), (from 1998 (Ley 54/1997), until 2006 (Real Decreto-ley 7/2006), with a decreasing influence in producers income over this period). It also has to be referred the price cap imposed to the transaction prices between producers and buyers belonging to the same companies (Real Decreto-ley

3/2006) and the limit imposed at the biggest companies in order to not increase their market share (Real Decreto-Ley 6/2000).

This market was highly concentrated. There were 4 main producers. However the two biggest, Endesa and Iberdrola represented about ¾ of the production sold in the wholesale market. But their importance tended to decrease (75% in 2002 and 60% in 2006).

3. Methodological Aspects

3.1 The Games

The market for power generation is very much like a market with Cournot strategies, with capacity constraints (Kreps and Scheinkman, 1983). Within this framework, the quantities correspond to the decision variable. Even when the price is assumed as a strategic variable, the results of the strategies are similar to the Cournot game, as there is capacity constraint in that kind of market (see Wolak and Patrick, 1997). Starting with the Nash-Cournot solution for the Spanish oligopolistic market and reprising the Cowling-Waterson formula (1976), the Lerner index and the strategies developed by companies can be correlated using the θ[4] index[5]:

$$\frac{(P-\overline{Cmg})}{P}=\frac{\bar{\theta}HHI}{|\varepsilon|}=\lambda \qquad (1)$$

in which $\overline{Cmg}$ is the weighted marginal cost for the industry, HHI the Herfindahl-Hirschman index and λ the factor measuring the level of market power, i.e. which corresponds to the Lerner index. In this case, the Lerner index is directly related to the level of concentration and also related to the firms' conjectural variations. In this context, if $\overline{\theta}=\frac{1}{HHI}$, perfect collusion is verified; when $\overline{\theta}=1$, Cournot behaviour is verified r and, finally, when , a perfectly competitive market prevails.

The interpretation of the producers' behavior done through the conjectural variation methodology presents some particularities. The conjectural variation methodology is a static methodology in which agents act according to expectations regarding the dynamic responses of competitors. Notwithstanding, this methodology can be applied in the present case because the "games" which occur each hour in a UPA market, like the former Spanish wholesale market, are similar to a repeated

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[4] See, for example, Chern and Just (1980) and Bresnahan (1982)

[5] This equation is based on the assumption that all companies share the same behavioral factor.

game, (see, Fabra and Toro, 2005). And, as referred Perloff et al. (2007, p. 109): "…, the theory of repeated games provides a game-theoretic basis for estimating static market conduct for conjectural variation models".

The issues relating to the interpretation of the value deserve special attention.

3.2 The Games

On the basis of the structural models, equilibrium exists in which the economic agents maximise their economic profits taking the demand and cost function into account:

$$\begin{cases} P = P(Q, D) \\ C = C(Q, W) \end{cases} \qquad (2)$$

In which P is the inverse of the demand function, which depends on the quantities Q and a set of variables D, and C is the cost function, which also depends on quantities and a set of exogenous variables W which do not influence the price function.

Thus, displaying the behavioural variable θ, the following structural model is obtained:

(3)

In our case, the chosen model corresponds to the system of equations of monthly demand and supply, in the Spanish wholesale spot market (daily and intra-day) for the specified period. Therefore, the application of the structural model materialises in this present case in the resolution of the following system:

$$\begin{cases} Q_t = \alpha_1 + \gamma P_t + \varphi Z_t P_t + \beta Z_t + \sum_{i=1}^{n} \beta_i D_{ti} + u_{t1} \\ P_t = \alpha_2 + \sum_{j=1}^{m} \beta_j W_{tj} - \theta(\gamma + \varphi Z_t) Q_t + u_{t2} \end{cases} \qquad (4)$$

Where:

- t, is the time factor related to the month.
- Zt, is the exogenous variable which allows the demand function to change its slope, i.e., which allow to rotate.
- Dti are explicative variables of the demand function.
- Wtj, are exogenous explicative marginal cost variables.
- θ, is the behavioral parameter, interpreted through the conjectural variation methodology: between 0 (Bertrand or perfect competitive strategy) and (perfect collusion).

Finally, so as to be able to estimate the Lerner index λ , we apply the following equation based on the derivative of the second equation (see Cowling, Waterson, 1976):

$$\frac{\bar{\theta}HHI}{|\varepsilon|} = \lambda \qquad (5)$$

It is important to note that the need to estimate exogenous explicative variables, in the majority of cases underlying economic relations, meant that monthly data had to be used, naturally focussing the work on the analysis of medium- and long-term equilibriums and strategies.

In structural models there is an identification issue: a system of equations at least one endogenous variable exists. The rank condition have to be warranted to overcome this issue: that the exogenous variable excluded from the first equation must have a population different to zero in the second equation. To solve this problem we have to choose a variable which rotates the demand function in the face of an external shock rather than move in parallel: $\theta(\gamma + \varphi Z_t)$, being Zt is the rotation variable .. In our case the “rotation” variable is a variable related with the temperature variations.

3.3 A Model Extension

As previously mentioned, any analysis carried out within this theoretical framework is based on a set of assumptions which can influence the results: on economic relations, as well as the functional forms of equations that represent the model, (see, Corts 1989).

Therefore, we make use of data which make it possible to estimate with some accuracy the marginal cost incurred. This allows the application of the structural model used to define market power and the behavioural variable to be tested, comparing the results with an almost direct estimate of these variables. Parallel to this, following the work of Genesove and Mullin (1998), the estimation of the price elasticity of demand based on a linear demand function is tested. In that case, the equation which represents demand is solved using a regression of this type:

$$Q_t = \alpha_1 + \omega P_t + \sum_{i=1}^{n} \beta_i D_{ti} + \mu_{t3} \qquad (6)$$

This regression is not only expressed as a linear functional form but it is also expressed as three other functional forms (logarithmic, exponential and quadratic).

Subsequently, the following regression is resolved, based on the Lerner index, in order to estimate the behaviour factor λ :

$$P_t = \frac{\mathbf{cmg_t}}{(-\lambda + \mathbf{1})} + \mu_{t4} \qquad (7)$$

In which $\mathbf{cmg_t}$ represents the marginal cost (that we estimate as an external variable) for month t.

In order to estimate θ , equation (8) is applied:

$$\theta = \frac{|\varepsilon|}{HHI}\lambda \qquad (8)$$

4. Demand Function

4.1 A Brief Description of the Market Organization

The OMEL[6] is the operator of the wholesale market, which is divided into the daily market and the intraday market. In the daily market, the electricity producers submit bids to sell quantities of electricity on an hourly basis for the following day at a minimum price and the buyers (distributors, retailers and eligible consumers) submit hourly bids to buy electricity at a maximum price. On the basis of these offers, OMEL constructs the hourly curves for the purchase and sale of electricity, in which the price at any given hour at which transactions are effected (called the system marginal price) results from the crossing of these curves.

Energy with physical delivery is also transacted through bilateral contracts with international entities. The publication of Royal Decree 5/2005 ended the obligation to transact all energy in the market regime on the wholesale market, thus enabling bilateral contracts to exist with national entities on the margins of this market.

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On the intraday market the final calculations are made on the actual day in order to adjust supply and demand. The intra-daily market consists of 6 blocks of offers. The system operator, Red Electrica de España (REE), is responsible for resolving any technical constraints, as well as physical adjustments between production and consumption.

Another source of income for producers comes from compensation for the availability of declared production ("power guarantee").

The final price of the electricity traded on the wholesale market, before distribution, comes in the main from the daily and intraday markets which generally

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[6] Before the beginning of MIBEL, OMEL was the acronym for: Compañia Operadora del Mercado Español de Electricidad, S.A.

represent 70% to 80% of this price, with the remainder coming from the guarantee of capacity and from the system operation.

4.2 Definition of the Demand Function

4.2.1 Variables of the Demand Function

In general, given the linear functional form, the demand function is presented as follows:

$$Q_{t(P)} = \alpha P_t + \sum_{k=1}^{M} \beta_k W_{kt} \qquad (9)$$

In which Pt, is the price of electricity and Wkt another factor k explaining the price trend.

Two distinct phases may be observed:

1. Entry into operation of combined cycle natural gas power plants from the beginning of 2004.
2. Various legislative changes that led to a sharp drop in the quantities of electricity traded in these markets from March 2006.

Thus, both in the application of the structural model as in the other case, the models were tested for 4 separate periods:

1. January 1999 to June 2007.
2. January 1999 to February 2006.
3. January 1999 to December 2003.
4. January 2004 to June 2007.

Bearing in mind that electricity consumption reflects economic activity, any variables which reflect overall[7] economic activity in Spain would appear to be the best option for explaining the long-term trends in the demand for electricity and therefore the Spanish GDP was the obvious choice of variable. However, the GDP is a variable for which data is provided quarterly. We sought to overcome this problem by estimating the monthly development of the GDP, specifically on the basis of other indicators such as industrial production. However, the estimation of the GDP on a monthly basis is not a significant variable.

It is known that in Spain the rate of electricity consumption grew at a pace faster than that of the GDP. The intensive increase in energy on this country operates in counter-cycle to the main western economies. Parallel to this, the consumption of diesel fuel has also increased by more than the GDP in recent years. These facts result from the increased purchasing power in Spain is not reflected in

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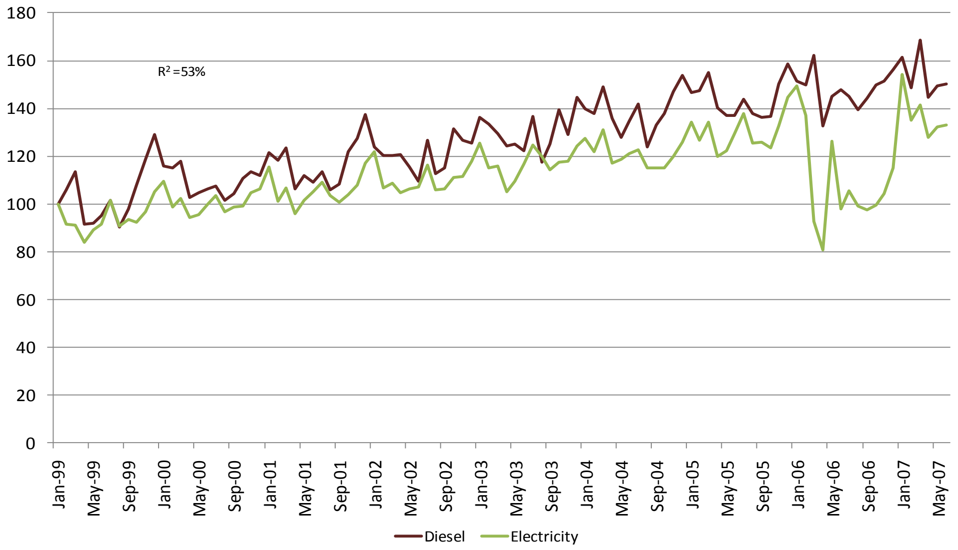
[7] See for example Jube, 2003

any change in the productive structure of the country, mirrored by an increase in the energy intensity of the GDP when calculated on the basis of electricity or diesel fuel (Mendiluce, et al., 2009) The increase in purchasing power in Spain has been based, however, in activities with low added value, such as civil construction. Moreover, some studies have shown that consumption of diesel fuel in Spain evolved differently from that of other fuels, with a much lower price elasticity of demand, a characteristic which it shares with electricity consumption. This was due to the indirect support of the Spanish Government subsidies on diesel, compared to other fuels, as a way to support investments in the construction industry, particularly highways (González-Marrero, et al., 2008).

Therefore for the period under analysis, diesel fuel was chosen as the independent variable for the price of electricity, because it better reflects the characteristics of the economic activity in Spain in the recent years. In addition, the seasonal nature of this variable is very similar to that of electricity consumption. The following graph shows that the trend for the consumption of gas oil and electricity developed in a relatively parallel manner up to February 2006, although diesel fuel consumption appears more volatile than electricity up to this date.

Figure 1. Volumes of diesel fuel consumed and electricity traded
Base 100 in January 1999



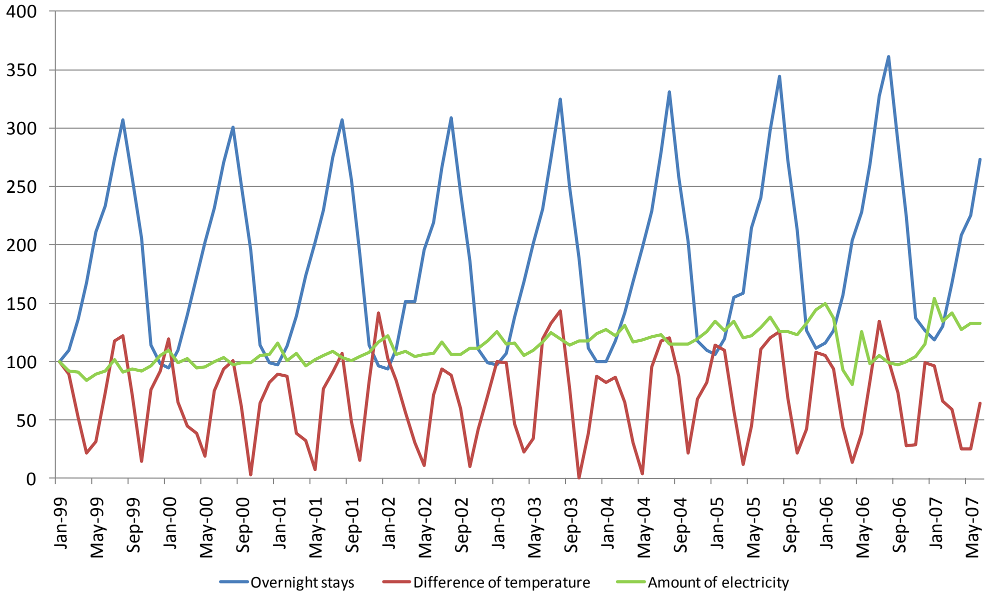
Source: OMEL, Ministerio de Industria, Turismo y Comercio

The consumption of electricity and diesel fuel share some factors that explain their variations, which are very much related to cycles of economic activity.

The chosen variables partly explain the typical seasonal behavior of the demand. The seasonality of demand for electricity is due both to the seasonality of economic activity and the evolution of temperature.

Therefore the feasibility of some variables representative of economic seasonality (“Overnight Stays in Hotels", "Industrial Production","Private Consumption" and “Working Days”) and temperature (“Average Monthly Temperature” and “Temperature Difference”[8]) was tested. However, some of these variables were abandoned as they were not statistically significant (“Working Days”, “Average Monthly Temperature”, “Private Consumption” and “Industrial Production”). Among the variables above, , two were chosen which reflect the annual seasonal nature of the demand for electricity the number of overnight stays in hotels each month, whose seasonality develops in inverse proportion to the demand for electricity and actual economic activity, and the monthly temperature difference in comparison with the average monthly figures. In the structural model, the latter variable was also considered the variable that enabled the demand function to “rotate” so that the cost component could be identified separately from the strategic component

Figure 2. Electricity traded and variables that define the seasonality Base 100 in January 1999



Source: Instituto Nacional de Estadisticas, Ministerio de Industria, Turismo Y Comercio

The incorporation of the variable “Overnight Stays” (monthly number of overnight stays in hotels) in the regression is due to the fact that consumption of

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[8] Temperature difference between the average monthly temperature and annual temperature

electricity is greater in winter than in summer. As the number of stays is far greater in summer than in winter, this variable has an inverse relationship to the amounts of electricity consumed, lessening the impact in summer of the variable “Temperature Difference” (Difference in temperature each month in comparison with the average annual amount). The doubts raised by the introduction of this variable in the model led to the use of the Wald test for the deletion of the model explanatory variables, proving that there is a relationship between the variables "Overnight Stays" and "Temperature Difference ".

Table 1. Wald test for deletion variables

	χ2 [Prob.]
Overnight stays	**6.924 [0.009]**
Temperature difference	**0.9632 [0.326]**
Diesel oil	**65.198 [0.000]**
Overnight stays and temperature	**12.577 [0.002]**

Table 2 presents the statistics that describe the variables chosen for the electricity demand function for the daily and intraday markets:

- Number of overnight stays in hotels each month, “Overnight stays".
- Difference of temperature between the average monthly temperature and annual temperature, "Temperature Difference ".
- Diesel fuel consumed in each month, "Diesel".
- Amount of electricity traded in the daily and intraday markets each month, "Amount of electricity."
- Average price of electricity traded in the daily and intraday markets each month, “Electricity Price".

In addition to these variables, a dummy variable must also be considered, which represents the change in the regulatory framework for these markets with the entry into force of Royal Decree-Law 3/.

Table 2. Correlation coefficients

	Diesel	Overnight stays	Difference of temperature	Amount of electricity	Electricity price
Diesel	1.000	-0.30778	0.18648	0.88107	0.44659
Overnight stays	-0.30778	1.000	0.15409	-0.024948	0.079977
Difference of temperature	0.18648	0.15409	1.000	0.43088	0.24784
Amount of electricity	0.88107	-0.024948	0.43088	1.000	0.51977
Electricity price	0.44659	0.079977	0.24784	0.51977	1.000

Table 3. Descriptive statistics

	Difference of temperature	Overnight stays	Electricity price	Diesel	Amount of electricity
Observations	102	102	102	102	102
Unit:	Celcius	Número	€/MWh	t	GWh
Minimum	0.03	9 797 643	18.25	1 795 801	13 322
Maximum	11.88	37 636 212	73.33	3 348 391	25 387
Average	5.72	19 621 752	36.83	2 542 182	18 546
Median	6.00	19 515 610	35.28	2 536 045	18 181
Standard deviation	3.03	7 543 818	12.59	360 072	2 443
Variance	9.19	5.69E+13	158.50	1.30E+11	5 969 390
Kurtosis	-0.96	-0.93	0.55	-0.81	-0.22
Skewness	-0.07	0.42	1.00	-0.06	0.38

4.2.2 Stationarity of the Demand Function

In time series, problems arising out of the spurious relationships are common, taking the form of variables with very high correlations that lack any causal relationship between them.The stationarity of each variable is tested using the ADF (Augmented Dick Fuller) unit root test, with the order of the test chosen by taking into account the combined analysis of Akaike and Schwartz information criteria.

Seasonal variations are analysed without trend, whilst the remainder are analysed with trend. Given its specific nature, the price variable is analysed with and without trend. The following table shows that there are two variables for which we cannot reject the null hypothesis of unit root: variables “Amount of electricity” and “Electricity Price” (with trend).

Table 4. ADF tests for the demand function variables

	Amount of electricity	Price of electricity (1)	Price of electricity (2)	Diesel oil	Overnight stays	Temperature difference
Choosen order	**6**	**0**	**0**	**6**	**6**	**4**
Trend	**Yes**	**No**	**Yes**	**Yes**	**No**	**No**
Statistic test	**-3.4089**	**-1.6893**	**-2.4479**	**-7.2726**	**-7.9847**	**-4.1163**
Critical value for the ADF statitistic	**-3.4666**	**-2.8981**	**-3.4666**	**-3.4666**	**-2.8918**	**-2.8918**

All variables in first difference are stationary.

Table 5. ADF tests for variables integrated of order 1

	Amount of electricity	Price of electricity	Diesel oil	Overnight stays	Temperature difference
Choosen order	**5**	**4**	**6**	**3**	**6**
Statitistic test	**-5.2783**	**-5.3921**	**-6.7172**	**-6.1681**	**-4.5459**
Critical value for the ADF statistic	**-2.8986**	**-2.8986**	**-2.8986**	**-2.8986**	**-2.8986**

Thus, the variables are characterized as follows in terms of integration:

"Amount of electricity" and "Price of electricity" are I (1).

"Diesel", Temperature Difference and "Overnight Stays" are I (0).

Thus, since there are two variables I (1) in the model, the stationarity analysis is carried out through testing the existence of a cointegration relationship.

In economic terms, it can easily be understood that in the short and medium term the demand for electricity and its price varies in inverse proportion in the short and medium term and this relationship is measured by the elasticity of the demand price. However, in the long-term, this inverse relationship can no longer be verified. Thus, if an inverse relationship between the long-term price and demand for electricity is considered, and a continuous growth in demand is maintained, this will be reflected in a lowering of the price of electricity, until it tends to become null. However, this trend is not verified; on the contrary, the increase in demand has been accompanied by an increase in the price of electricity, although not always at the same pace. This trend is understandable. The increase in the demand for electricity has been satisfied by recourse to more expensive production technologies (such as renewable energies) or by conventional fossil fuel technologies (natural gas, coal, fuel oil) which, in turn, are limited and have tended to become more expensive due to the limited reserves.

The test for the existence of a cointegration relationship between the variables follows Johansen's methodology (Johansen, 1988).

The statistics9 presented in the tables below clearly enable the H0 hypothesis of the non-existence of a co-integration relationship to be rejected, meaning that the H0 hypothesis for the existence of more than one co-integration relationship also cannot be accepted.

Table 6. Maximal Eigenvalue of the Stochastic Matrix for a VAR model of order 1

H0	H1	Statistic	Critical value 95%	Critical value 90%
r = 0	r=1	93.33	25.77	23.08
r <= 1	r=2	4.71	12.39	10.55

Table 7. Trace of the Stochastic Matrix for a VAR model of order 1

H0	H1	Statistic	Critical value 95%	Critical value 90%
r = 0	r=1	98.04	19.22	17.18
r <= 1	r=2	4.71	12.39	10.55

Thus, one can consider that the variables "Price of electricity" and "Amount of electricity" are co-integrated, i.e.: $Q_t - P_t \sim I(0)$.

We have to remember that this research focuses on medium or long term strategies. In other words, we seek to establish a "strategic summary" of the different strategies that have occurred in that "repeated game". Therefore, we do not need to examine the situations of short-term imbalances. Moreover, there is loss of degree of freedom when the data is monthly based, and there is 102 observations at most. The complexity of a model like a ECM model when applied to analyze changes of short term strategies (namely a Switching Model type used by Porter (1983)) may not be appropriate taking into account the range of assumptions on the variables and the assignment of different states (war or collusion) to the key variables (price, income) that define the state changes.

The "simple" linear demand form (not taking into consideration "Temperature Difference" as a variable that "rotate" the function) estimated through the OLS is:

$$Q_{t(P)} = \alpha + \beta_0 P_t + \beta_1 Diesel_t + \beta_2 Stays_t + \beta_3 Dif.temp._t + \varepsilon_t \tag{10}$$

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[9] Based on a likelihood ratio test

4.2.3 Instrumental Variable

Once the variables incorporated in the demand models have been defined, it is important to ensure the orthogonality of the model. This exercise is effected within the framework of structural models, in which, as we have seen, identification of the models requires compliance with the order condition Therefore, an analysis of the endogeneity of the variables in the first equation must be carried out and the instrumental variables defined, in addition integrating the exogenous variables which are part of the second equation.

The exogeneity of the variables in the equation that might be endogenous was tested, since they underscored an economic relationship with other variables, “Electricity Price”, "Overnight Stays" and “Diesel”. It was considered “Temperature Difference” as an exogenous variable.

An initial group of instrumental variables must be constituted which respect the following restrictions: on the one hand, they must not be correlated with the, “Amount of electricity” dependent variable in the first equation, but with “Electricity Price”. On the other hand, they will include the exogenous variables in the second equation. In this way, the two restrictions are respected; the exogenous variable is excluded from one equation but included in the other (Reiss and Wolak, 2005). The following variables were defined in this group:

- The average monthly price (Eur/bbl) of Brent crude “Oil Price”, with a 3 months lag.
- The monthly average price (Eur/t) of coal “Coal Price”, with 3 and 12 months lags.
- The monthly average hydro electrical productivity, “Hydro”.
- In the section related to the definition of the second equation, the reasons for choosing those variables are explained.

A second group of instrumental variables was defined, related to the consumption of diesel fuel and overnight stays. In this case, we chose the instrumental variables that capture the seasonality of these variables and the economic activity:

- The variables “Diesel” and "Overnight Stays" are 12 months lagged.
- The monthly trend for the industrial production index, variable “Industrial Production”, and the estimated of monthly GDP, variable "GDP".

The inclusion of instrumental variables with lags allows us to consider the short-term adjustments, thus taking the dynamic nature of the model.

The table below shows that "GDP" and "Industrial Production" instrumentals variables are stationary as "Diesel" and "Overnight Stays". The results of the statistical T2 Wu-Hausman Test, given by the F statistics, reject the hypothesis of the non endogeneity of the model.

Table 8. ADF test for instrumental variables: GDP and Industrial Production

	GDP	Industrial production
Choosen order	4	2
Trend	Yes	Yes
Statitistic test	-8.963	-9.483
Critical value for the ADF statistic	-3.467	-3.467

Table 9. T2 Wu Hausman Test and T-ratio for residuals

T_2 Wu-Hausman Statistic	
F(3, 66)= 3,7099 [0,016]	
Residuals T-ratio [Prob.]	
Diesel oil residuals	-2.2017 [0.031]
Electricity price residuals	1.7372 [0.087]
Overnight stays residuals	-1.2682 [0.209]

Thus, even outside the theoretical framework of structural models, the confirmed existence of endogeneity in the demand function requires the application of the Two-Stage Least Square method. The instrumental variables chosen are those previously referred to, with the exception of the "overnight stays" variable with 12 months lagg, as this variable is not endogenous.

Bearing in mind the significant number of instrumental variables, the overestimation of the model was tested. The results allowed us to not reject the null hypothesis of all the instrumental variables being exogenous.

4.3 The Demand Function in the Structural Model Context

4.3.1 Results Obtained

As previously stated, two events characterised the wholesale electricity market during the period under analysis: the introduction of combined cycle natural gas plants from the beginning of 2004 and the various changes in legislation which led to a sharp fall in the amounts of electricity traded on these markets from March 2006.

Thus, both in the implementation of the structural model, as in the other case, the models were tested for 4 separate periods as we already mentioned.

The impact of the changes to the framework of the daily and intraday markets from March 2006 onwards is analysed with the inclusion of a dummy variable.

Based on equation (3) and assuming a linear demand function, the demand function will be given by, (model 1):

$$Q_t = \alpha + \beta_1 \mathbf{P_t} + \beta_2 \mathbf{Diesel_t} + \beta_3 \mathbf{DifTemp_t} + \beta_4 \mathbf{Stays_t} + \beta_5 \mathbf{DifTemp_t P_t} + \varepsilon_t \qquad (11)$$

Being:

Q_t, is t “Amount of electricity” variable, in the month t.

$\mathbf{P_t}$, is “Electricity Price” variable, in the month t.

$\mathbf{Diesel_t}$, is “Diesel” variable in the month t.

$\mathbf{DifTemp_t}$, is “Temperature Difference” variable in the month t.

$\mathbf{Dorm_t}$, is "Overnight Stays" variable in the month t.

However, as we shall see, most of the variables are not significant when the model is presented in this way. Thus, we opted for a model in which the variable Temperature Difference is only included as a rotation variable (model 2):

$$Q = \alpha + \beta_{1a} \mathbf{P_t} + \beta_{2a} \mathbf{Diesel_t} + \beta_{3a} \mathbf{Stays_t} + \beta_{4a} \mathbf{DifTemp_t P_t} + \varepsilon_t \qquad (12)$$

The regression was performed for the demand function. The results of the regressions are only presented when the level of significance of the price variable is equal to or less than 5%. The chosen model is shaded in orange. The selection criterion is the level of significance of the variable “Electricity Price”. The chosen models are generally more robust than the others. For the period between January 1999 and December 2003, we obtained significant results for both models. The analyses beyond December 2003 don’t present significant results. This is not surprising given that since 2004, the framework of Spanish electricity market has changed several times in Spain, and the market could not be considered, even in long-term perspective, as being in equilibrium. For the above, the period chosen for analysis is the period between January 1999 and December 2003.

Therefore, the analysis is only made for this period.

The table below shows that in the case of the equation of "Model 1", in the chosen period, only the variable “Diesel” is significant for a 10% level of significance, whist in "Model 2", all variables with the exception of theconstant are significant to this level. The structural model is then applied to “Model 2”, for the period between January 1999 and December 2003.

Table 10. Comparison of the results of the regression "models 1 and 2" for the chosen period (January 1999 to December 2003)

	Model 1		Model 2	
	Estimate	t test [Prob.]	Estimate	t test [Prob.]
Constant	3620.7	0.1803 [0.858]	874.3508	.31121 [0.757]
P_t	-1298.1	-0.3188 [0.751]	-735.5126	-3.1054 [0.003]
$Dorm_t$	4.9648	0.7977 [0.430]	5.6684	1.7674 [0.084]
$Diesel_t$	0.0064399	2.3929 [0.021]	0.0067753	6.4709 [0.000]

4.3.2 Results Obtained

From equation (12) two parameters were obtained that are essential for the model as a whole: the inverse of the slope of demand function and the price elasticity of demand. The first parameter stems from the following equation:

$$\frac{\frac{dQ_t}{dP_t}}{\frac{Q_t}{P_t}} = \left(\beta_1 + \beta_4 \overline{DifTemp}\right)\frac{\overline{P}}{\overline{Q}} \qquad (13)$$

In which $\frac{\overline{P}}{\overline{Q}}$, is the ratio of the average market prices and quantities traded and $\overline{DifTemp}$, is the average temperature differences. In this case, $\frac{\frac{dQ_t}{dP_t}}{\frac{Q_t}{P_t}}$ = -0,0933.

The second parameter is obtained as follows:

$$\frac{dP_t}{dQ_t} = \frac{1}{\frac{dQ_t}{dP_t}} = \frac{1}{\left(\beta_1 + \beta_{4DifTemp}\right)} \qquad (14)$$

In the following section, the value of price elasticity of demand is compared with the values obtained with the application of the model not belonging to the structural model.

4.4 The Demand Function Outside the Structural Model

The demand function is defined outside the framework of the structural model in the strictu-senso. The model is not only be developed for a functional form, but the functional forms considered in the work of Genesove and Mullin (1998) are also presented (linear, exponential, quadratic and exponential). The equations were adapted to this work in order to take into account independent variables other than price. The results, in particular relating to price elasticity of demand, are compared with each other, and also compared with results obtained by applying the structural model. It should be stressed, however, that for reasons of comparability with previous results, the instrumental variables were maintained.

4.4.1 The Equations

The general functional form is given by equation (15).

$$Q_{t(p)} = \beta(\alpha - P_t)^{\gamma} + \varepsilon_t \qquad (15)$$

In which, β measures the size of the market demand, is the maximum willingness to pay, Pt is the price and γ is the convexity index. α tends to infinity and $\frac{\gamma}{\alpha}$ is a constant.

In this study, the general equation for linear and quadratic functional forms is given by:

$$Q_{t(p)} = \beta(\alpha - P_t)^{\gamma} + \sum_{k=1}^{M} \beta_k W_{kt} + \varepsilon_t \qquad (16)$$

in which β_k is the coefficient of the relationship between the independent variable W_{kt} and the monthly amounts traded on the daily and intra-daily markets, and γ is equal to 1 and 2 in the linear and quadratic equations, respectively. Remember that the independent variables are “Price Electricity", "Overnight Stays", “Diesel” and a dummy variable whenever the period under analysis includes the year 2006.

The price elasticity of demand in the linear form, in this case corresponds to:

$$\frac{\frac{dQ_t}{dP_t}}{\frac{Q_t}{P_t}} = -\beta_1 \frac{\bar{P}}{\bar{Q}} \qquad (17)$$

In the case of the quadratic form, the price elasticity of demand is given by:

$$\frac{\frac{dQ_t}{dP_t}}{\frac{Q_t}{P_t}} = -2\beta(\alpha - \bar{P})\frac{\bar{P}}{\bar{Q}} \qquad (18)$$

In this work, the generic equation that supports the logarithmic functional form is given by:

$$Q_{t(p)} = \beta(\alpha - P_t)^{\gamma} \prod_{k=1}^{M} W_{kt}^{\beta_k} + \varepsilon_t \qquad (19)$$

Using logarithms:

$$lnQ_{t(p)} = \mathbf{ln}(-\beta) + \gamma \ln(P_t) + \sum_{k=1}^{M} \llbracket \beta_k \ln(W_{kt} \rrbracket) + \varepsilon_t \qquad (20)$$

In this case, the price elasticity of demand is obviously given by:

$$\frac{\frac{dQ_t}{dP_t}}{\frac{Q_t}{P_t}} = \frac{dln(Q_t)}{dln(P_t)} = \gamma \qquad (21)$$

In this paper, the generic equation of the exponential functional form is given by:

$$Q_{t(p)} = \beta e^{p_t \frac{\gamma}{\alpha}} \prod_{k=1}^{M} W_{kt}^{\beta_k} + \varepsilon_t \qquad (22)$$

Using logarithms:

$$lnQ_{t(p)} = \mathbf{ln}(\beta) + \frac{\gamma}{\alpha} \mathrm{P_t} + \sum_{k=1}^{M} \llbracket \beta_k \ln(W_{kt} \rrbracket) + \varepsilon_t \qquad (23)$$

The price elasticity of demand corresponds to:

$$\frac{\frac{dQ_t}{dP_t}}{\frac{Q_t}{P_t}} = \frac{\beta\gamma(\alpha - P_t)^{\gamma - 1}}{\beta(\alpha - P_t)^{\gamma}}\, p = \frac{\gamma^{\square}}{(\alpha - P_t)^{\square}} \mathbf{p} \cong \frac{\boldsymbol{\gamma}}{\boldsymbol{\alpha}} \overline{\mathbf{P}} \qquad (24)$$

4.4.2 Results

The regression of the demand function was performed for each functional form. As in the previous section, the results of regressions were only presented whenever the level of significance of the variable price is equal to or less than 5%. Only in these cases the price elasticity of demand will be used in solving the equation (8). The tests performed are the same as presented in the previous section.

For each case, the selection criterion is the degree of significance of the variable "price electricity"10. The conclusions are very similar to those arising from the implementation of the structural model:

- The chosen models presented are generally more robust than the others.
- For the period between January 1999 and December 2003 significant results were obtained for all functional forms other than quadratic form.

The table below shows the price elasticity of demand calculated for the chosen periods and functional forms. The figures for the different functional forms are similar, between -0.089 and -0.099. The value calculated for the structural model for a linear equation, falls within this interval.

Table 11. Price elasticities of demand11

Price elesticity of demand	Equation		Structural model
	Functional form	Period	
-0.0886	Linear	Jan-1999_Dec-2003	No
-0.0982	logarithmic	Jan-1999_Dec-2003	No
-0.0986	Exponential	Jan-1999_Dec-2003	No
-0.0933	Linear	Jan-1999_Dec-2003	Yes

Those value are close to the values generally associated to the elasticity of demand in the electricity sector (in that case based on hourly data), around 10% (see Borenstein, Bushnell and Knittel (1999) or Patrick and Wolak (1997)). For the Spanish electricity sector, and also for hourly data, Alcalde et al (2002) defined 3% as the average elasticity of demand in 1998, and Khün and Machado (2003) estimated that the elasticity of demand was between 1.5% and 9% in 2001.

5. Optimality Equation

5.1 The Structural Model

Due to the problems in identifying structural models, in this context the supply equation must include the demand rotation component. Thus, the second equation of the system (6) has the following representation:

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[10] The presentation of the statistical tests is out of the scope of the present paper.

[11] The results outside the strucutural model is without the rotation variable.

$$P_t = \alpha_2 + \sum_{j=1}^{n} \boldsymbol{\beta}_j \mathbf{Cmg}_j + \beta_8\, Q_t - \lambda \left(\frac{1}{(\beta_1 + \beta_4 DifTemp)} \right) Q_t + \varepsilon_t \qquad (25)$$

The Cmgj variables represent the factors required to calculate the marginal cost. The second variable on the right side of the equation corresponds to demand. The last variable is the rotation variable for the demand function whose parameters were defined in resolving the demand equation. The coefficient of this variable corresponds to the behavioral variable. The marginal cost of the system is defined by the production costs of the power plant which define the closing price of the market.

The production of electricity is a capital intensive business where investment costs represent most of the costs, and variable costs correspond almost entirely to fuel costs.

As stated in the previous section, the power plants with conventional technologies which set the closing price are the coal and fuel oil power plants, natural gas combined cycle power plants and hydro plants. Thus, the variables chosen to estimate the average marginal cost of the system are:

- The average monthly price, EUR/bbl, of Brent oil with 3 months lag, which represents the cost of natural gas combined cycle power plants and the cost of fuel oil power plants. It is common practice for natural gas supply contracts to index their prices to the price of oil or its derivatives, with time lag between 3 and 6 months. Moreover, the oil price is not reflected immediately in the marginal cost of fuel oil power plants on the one hand, since this is a derivative and, on the other hand, due to the stock management policy of these plants.
- For coal power plants, the monthly average price of coal with a 3 months lag in, Eur/t, in order to reflect the stock management policy.
- Hydro coefficient, bearing in mind the importance of hydrological production.

The latter variables are exogenous to the model, having been included as instrumental variables in the previous equation. We chose variables that are directly related to a theoretical system marginal cost, because this is not necessarily the actual marginal cost incurred. In the first case, the marginal cost only depends on the factors which influence the variable costs of production of the power plants which set the market prices: average prices of fuels and average hydro (hydrological inflows) observed in that month. In practice, the marginal cost of the system will also depend on technical constraints and company strategies. These factors should be included into the behavioral variable λ. Thus, equation (25) can be rewritten as follows:

$$P_t = \alpha_2 + \beta_5 Oil_{t-3} + \beta_6 Coal_{t-3} + \beta_7 Hydr_t + \beta_8\, Q_t - \bar{\theta}\left(\frac{1}{(\beta_1 + \beta_4 DifTemp)}\right)Q_t + \varepsilon_{\square} \qquad (26)$$

Whereby:

Oil_{t-3}, is the average monthly price of Brent crude lagged 3 months.

$Coal_{t-3}$, is the average monthly Coal API # 2 NW Europe lagged 3 months.

$Hydr_t$, is the hydro inflows in the month t.

$\bar{\theta}$, is the behavioral variable.

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Whereby:

Oil_{t-3}, is the average monthly price of Brent crude lagged 3 months.

$Coal_{t-3}$, is the average monthly Coal API # 2 NW Europe lagged 3 months.

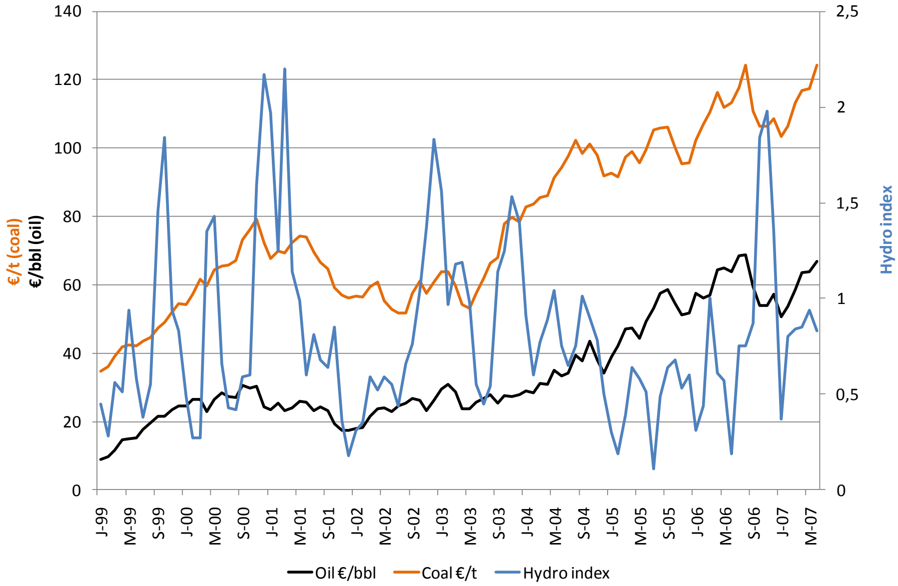
$Hydr_t$, is the hydro inflows in the month t.

$\bar{\theta}$, is the behavioral variable.

5.1.1 Variables of the Supply Function

Both the price of coal and the price of oil followed an upward trend during the period under analysis. Note, however, that this trend was more mitigated for the period between January 1999 and December 2003, for which the model was applied. For its part, the hydro is characterized by instability around the unit.

Figure 3. Variables that characterize the marginal cost



The table below shows that the variables are weakly correlated.

Table 12. Variables correlation coefficient

	Coal price (-3)	Coal price (-12)	Oil price (-3)	Hydro	Overnight stays	Difference of temperature	Amount of electricity
Coal price (-3)	1.000	0.49657	0.37879	-0.15651	0.024733	0.073055	0.53131
Coal price (-12)	0.49657	1.000	0.54121	-0.38592	0.0004151	0.070356	0.5765
Oil price (-3)	0.37879	0.54121	1.000	-0.05824	-0.016976	0.11474	0.46533
Hydro	-0.15651	-0.38592	-0.05824	1.000	-0.26575	-0.33473	-0.23867
Overnight stays	0.024733	0.0004151	-0.016976	-0.26575	1.000	0.15409	-0.024948
Difference of temperature	0.073055	0.070356	0.11474	-0.33473	0.15409	1.000	0.43088
Amount of electricity	0.53131	0.5765	0.46533	-0.23867	-0.024948	0.43088	1.000

The descriptive statistics for the variables which define marginal cost are shown in the following table. It is observed that the average hydro inflows was only 0.82 during the period under review, this period was remarkably dry.

Table 13. Descriptive statistics of variables

	Hydro index	Oil price	Coal price
Observations	102	102	102
Unit:	-	€/bbl	€/t
Minimum	0.110	8.659	25.160
Maximum	2.200	53.942	63.484
Average	0.819	30.369	43.177
Median	0.680	27.148	44.701
Standard deviation	0.461	10.625	10.520
Variance	0.212	112.895	110.671
Kurtosis	0.914	-0.427	-1.149
Skewness	1.122	0.514	-0.147

5.1.2 Stationarity of the Supply Function

The tables that follow show that the variable “Hydro index inflows” is the only stationary variable which defines the marginal cost.

Table 14. ADF tests for the variables of the supply function

	Oil Price (1)	Oil Price (2)	Coal Price (1)	Coal Price (2)	Hydro index
Choosen order	0	0	1	1	4
Trend	No	Yes	No	Yes	No
Statistic test	-1.317	-1.740	-2.095	-2.117	-4.428
Critical value for the ADF statitistic	-2.898	-3.467	-2.898	-3.467	-2.898

The variable prices of oil and coal are integrated of order 1.

Table 15. ADF tests for the variables of the supply function integrated order 1 - 85 observations

	Oil Price I(1) (1)	Oil Price I(1) (2)	Coal Price I(1) (1)	Coal Price I(1) (2)
Choosen order	0	0	0	0
Trend	No	Yes	No	Yes
Statistic test	-8.152	-8.139	-5.257	-5.218
Critical value for the ADF statitistic	-2.899	-3.467	-2.899	-3.467

Using the Johansen approach, and a VAR model of order 1, as indicated by the information criteria, the statistics presented in the tables below clearly allow the H0 hypotheses for the non-existence of one and two co-integration relationships to be clearly rejected, and point out that the H0 hypothesis for the existence of more than two co-integration relationships cannot be accepted.

Thus, two co-integration vectors exist which support the relationship already demonstrated between the price and amount of electricity variables $P_t - Q_t \sim I(0)$; as well as the co-integration relationship between coal and oil prices: $\mathbf{Oil}_{t-3} - Coal_{t-3} \sim I(0)$.

Table 16. Eigen value test for a VAR model of order 1

H0	H1	Statistic	Critical value 95%	Critical value 90%
r = 0	r=1	29.03	27.42	24.99
r <= 1	r=2	27.65	21.12	19.02
r <= 2	r=3	3.31	14.88	12.98
r <= 3	r=4	1.71	8.07	6.50

Table 17. Trace test VAR for a VAR model of order 1

H0	H1	Statistic	Critical value 95%	Critical value 90%
r = 0	r=1	61.70	48.88	45.70
r <= 1	r=2	32.67	31.54	28.78
r <= 2	r=3	5.02	17.86	15.75
r <= 3	r=4	1.71	8.07	6.50

5.1.3 Instrumental Variables

As part of the structural model, equation (26) is solved with a two-stage least-squares model. Thus the identification of this equation requires that the exogenous variables defined in the other equation in the model should be considered instrumental variables. Remember that these variables were: "Overnight Stays", “Diesel” and "Temperature Difference". The latter can already be found indirectly in equation in the demand variable rotation. So instead we used the average monthly temperature. Note that this variable may also serve as an instrumental variable for the hydro inflows.

It should be noted, however, that unlike the case of the demand equation, in this case the results of the Wu-Hausman statistics did not reject the possibility that the equation did not suffer from endogeneity. With regard to the variables in particular, the hypothesis of a non-endogenous variable was only rejected in the case of the t statistic for the demand (“Amount of electricity”).

Table 18. Wu Hausman T2 test

Statistic T_2 Wu-Hausman	
F(3,39) = 7.4746 [0.188]	
T-ratio for residuals [Prob.]	
Hydro residuals	**1.4842 [0.146]**
Coal price residuals	**0.2202 [0.827]**
Oil price residuals	**0.15004 [0.882]**
Amount of electricity residuals	**2.4569 [0.019]**
Rotation variable residuals	**-1.1293 [0.266]**

It should be noted that the test to the overestimation of the model do not reject the null hypothesis that all instrumental variables are exogenous.

5.1.4 Behavioural Parameter

We tested several models for different instrumental variables. The chosen model presents a level of significance lesser than 10% for the rotation variable of the demand, which can be interpreted as robust by the statistical tests conducted.

In this model, for 48 observations (up to December 2003), the variables are not very significant; particularly those variables related to fuel prices. However, when we extend the series until February 2006 (72 observations), all variables become more significant. It can equally be observed that consideration over a longer period of time does not alter the coefficient attributed to the rotation variable, which enables the behavioural factor to be defined. This value lies at around 0.054, indicating a competitive market.

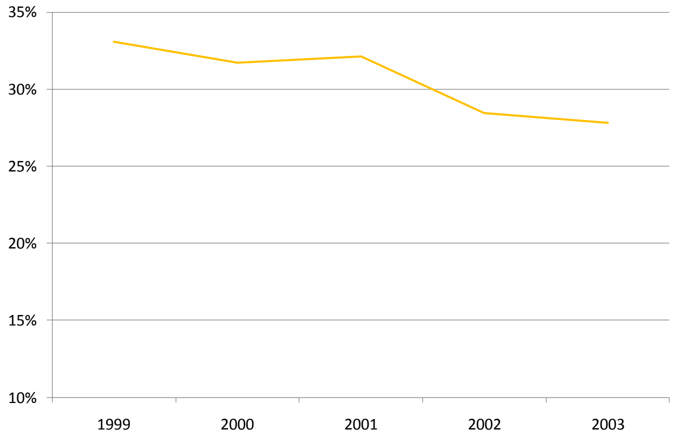
Table 19. Chosen regression

	January 1999 - December 2003		January 1999 - December 2003	
	Coefficient	T-ratio [Prob.]	Coefficient	T-ratio [Prob.]
Constant	-4.5369	-.75148 [0.457]	0.81635	-1.9208 [0.061]
Oil price (-3)	0.010074	0.2825 [0.779]	-0.039856	-1.9571 [0.054]
Coal price (-3)	0.049354	0 .3497 [0.728]	0.14786	4.8609 [0.000]
Hydro	-2.3575	-2.4650 [0.018]	0.053211	2.4592 [0.016]
Amount of electricity	0.0006352	1.7757 [0.083]	0.0002727	1.7863 [0.079]
Variable of rotation	0.053596	1.7591 [0.086]	0.053211	2.4592 [0.016]

5.1.5 Learner Index in the Period 1999-2003

Having estimated the behavioral factor for the analyzed period (about 0.0535) and the price elasticity of demand (-0.0933), it remains to define the Herfindahl Index, HHI, in order to estimate the Lerner index solving the equation (5). The Herfindahl Index was calculated by economic group based on data from OMEL and the Ministerio de Industria, Turismo y Comercio. Register that this index was only calculated for conventional producers, i.e., the power plants with positive environmental externalities (special regime) were not considered because the pay of their production was formed independently of the market prices, although part of this type of production was already traded on the market by this time.

Figure 4. Evolution of the Herfindahl index



Source: OMEL, Ministerio de Industria, Turismo y Comercio

Thus, the average HHI weighted by the production is equal to 30.5%. Applying equation (5), the Lerner index is 17.4%. The Lerner index associated with it is relatively high, despite the fact that the estimation of the producers' behavior approaches a Bertrand's game. We can conclude that given the conditions of the wholesale Spanish electricity market, namely the rigidity of demand and the high concentration, the discretion enjoyed by producers to get a high mark-up is wide.At this point, it is important to note that the concentration level of a market may be related to the efficiency of its agents and, consequently, the marginal cost and market structure will be two endogenous variables (see, for example, Church and Ware, 2000), distorting any behavioural analysis based on the Herfindahl Index. However, during the period under analysis, in the Iberian Peninsula the market structure for energy production does not result from competitive pressures, as is the case in the rest of Europe, but from the structure of the existing market before liberalisation. Furthermore, the technologies for producing electricity are shared by producers, and the efficiency of electricity producers is more dependent on the portfolio of technologies that on the efficiency of the power plants. Thus, in this case, it is assumed that there’s no an endogenous relationship between market concentration and the marginal costs.

5.2 Estimation of the Behavioural Outside the Structural Model

5.2.1 Marginal Cost Calculation

The definition of marginal cost is one of the main difficulties for the implementation of structural models. This is why we also estimate the cost function outside the model.

The marginal cost of a market can reflect the structure of the production costs for this market or only correspond to the marginal cost of the electricity generating power station that has sold electricity at the highest price, which corresponds to the marginal power station. The latter type of market corresponds to the “Uniform Price Market” and, as we already referred, it is the kind of market that has been operating in Spain.In this kind of market, the marginal cost of the market is very close to the cost variable for the power station which sets the market price. In monthly terms, marginal cost corresponds to the weighted average for the amounts traded at any given hour in the marginal cost schedule:

$$Cmgt = \frac{\sum_{h=1}^{n} Cmg_h Q_h}{\sum_{h=1}^{n} Q_h} \cong \frac{\sum_{h=1}^{n} Cv_h Q_h}{\sum_{h=1}^{n} Q_h} \qquad (27)$$

in which $Cmgt$ is the weighted marginal cost of the market in the month t, n is the number of hours h, is the month t, Cmg_h is the marginal cost of the market at the hour h, Cv_h is the cost variable for the marginal power station the hour h and Q_h is the amount traded on the market at the hour h.

OMEL, the operator for the Spanish daily and intraday markets, defines the origins of the electricity that has set the market price for each hour, i.e., the marginal offer, and groups them by technology type., However, the information supplied by

OMEL does not distinguish between certain technologies which define the closing price, namely between the coal and fuel oil power plants.

Moreover, OMEL provides the amounts traded on the daily and intraday markets. In this way, the variable Q_h equation (27) is known. However, the definition of variable Cv_h is based on a set of assumptions that can be grouped into:

1. Definition of the variable cost function associated with the technology / type of marginal plant.
2. Definition of parameters required to calculate the variable cost.

5.2.2 Definition of the Variable Cost Function Associated with the Technology/Type of Marginal Plant

The information provided by OMEL does not establish with certainty what type of power plant defines the system marginal cost, especially in the case of thermal power plants, of contracts concluded by the REE and power plants with renewable energy sources.

On another hand, the costs of hydroelectric power plants with pumping cannot be directly deduced from the information provided because they are associated to the hourly marginal costs during which the hydro power plant acquired energy to refill its reservoir. Thus, it was necessary to develop a set of assumptions that allows to associate different technologies and consequently different functions of the variable costs to the nomenclature presented by OMEL for the source of energy that sets the system marginal price (following Borenstein, et al., 2002; Steiner, 2000; Wolfram, 1999, among others, etc...). These assumptions12 were grouped in two groups to ensure that the marginal cost actually occurring during this period did not exceed the range presented. The presentation of the rules defining the marginal central is out the scope of this paper.

In short, in any case, only four types of technology define the market price during the period under review:

- Oil-fired power plant;
- Coal power plants;
- Combined-cycle natural gas power plants;
- Hydro plants.

In parallel with the technologies that define the market price, it’s important to set the variable cost function of marginal technologies. The variable cost of a thermal power plant will depend on four factors: its load, its efficiency for that load,

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[12] Is has to be highlighted that the assumptions were made in order to not underestimate the variables costs and, therefore, overestimate the mark-up.

the heating value of the fuel consumed and the price of the fuel. Assuming that the central i, which sets the market price at full capacity, the function of the variable cost at a determined hour, h, of this power plant, Cv_{hi} , is defined as follows13:

$$Cv_{hi} = Pcomb_j \times \varphi_{comb_j} \times \eta_i + O\&M \tag{28}$$

Where, $Pcomb_j$ corresponds to the price of fuel j, φ_{comb_j} is the calorific value of fuel j,η_i is the efficiency of the central and O&M the maintenance and operation variable costs. The costs of O&M are known and relatively stable.

Regarding the price of fuel consumed, this depends largely on the acquisition policy of the producer. Furthermore, we have to refer the particular case of the coal consumed in Spain. Much of this coal is domestic and has a cost of extraction and a calorific value that make it less competitive the imported coal, obliging the subsidization of its consumption by the Spanish government.

Meanwhile, the case of hydro power plants must be highlighted. The variable costs of these plants are near zero, and are merely related to maintenance and operation costs. In most cases, these plants are associated with reservoirs, with greater or lesser capacity to retain water, which corresponds to potential energy. In periods when the level of reservoirs is automatically reset, i.e. in periods of strong hydro inflows, which in the Iberian Peninsula represent some periods of the winter or spring, the value of the water held in reservoirs is almost zero. However, in other periods, it becomes a scarce resource, which should give it a value when used in the production of electricity. This value corresponds to the cost of the replaced technology.

Thus, there is an important set of unknowns in the setting the price of fuel. In order to overcome this situation, we follow three approaches for calculating the monthly variable cost. Two approaches are based on costs of production and generation efficiency patterns. In the third approach we use data related to the costs of production for the equivalent power plants in Portugal which are known. The first two approaches only differ by the value given to marginal cost of the hydro power plant, i.e., the costs of the replaced technology.

In short, the marginal cost of the system was calculated in three ways:

1. For production valued at the cost of the conventional power plants (coal, fuel oil) or combined cycle natural gas plants, the production costs are calculated on the basis of the average market prices for the fuels and the standard values for O&M costs and the revenue of the power stations. Production from hydroelectric plants is valued at the production costs for the plants (which correspond to O&M costs), with the exception of months in which hydro inflows is significantly below the average for the

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[13] During the analysed period, CO_2 costs were not yet recovered.

"dry" period of the water resources year, which are valued at the cost of the fuel oil plants. This approach is referred to as "marginal cost (a)".

2. The previous point also applies to hydroelectric production, which is valued at the cost of the fuel oil power plants, with the exception of months in which hydro inflows significantly, is above the average for the "wet" period of the water resources year, which are valued at the production cost of the hydroelectric plants (O&M costs). This approach s referred to as "marginal cost (b)".
3. For production valued at the cost of conventional power plants (coal, fuel oil) or combined cycle natural gas plants, the production costs are defined on the basis of costs verified in Portugal for equivalent technologies during the same period. The production of hydroelectric plants is valued at the hydroelectric plant production cost (which corresponds to O&M costs), with the exception of months in which a hydro inflows significantly below the average for the "dry" period of the water resources year. This approach is referred to as "marginal cost Portugal".

5.2.3 Behavioural Factor

At this section the regression (7) is solved in order to estimate the Lerner index λ, and, consequently, in order to define the behavioral factor $\bar{\theta}$, the equation (8) is also solved.

5.2.3.1 Evolution of Price and Marginal Costs

shows the marginal cost evolution for different assumptions. It is also noted that the evolution of marginal costs when calculated with the data observed in Portugal is very close to the others.

Whatever the cost function considered, periods when the marginal cost of the market approaches the market price succeed to periods when the marginal cost is significantly lower than the market price. This is known and has been already analysed in other studies (see Fabra and Toro, 2005).

In addition, extreme weather conditions occurred in some periods, namely between November 2001 and January 2002.

During this period, the increased demand, combined with a period of extreme drought, led to the inability of supply to meet demand at certain periods, with consequent outages and spikes in electricity prices in the daily and intraday markets. However, the beginning of 2001 was characterized by an above-normal rainfall that led to the filling of the reservoirs in the Iberian Peninsula. The management of reservoirs in Spain during 2001 by the producers of electricity could partly be blamed for what happened (Santana and Resende (2006)). The wholesale markets for electricity, such as the Iberian market, are markets where producers will tend to follow Cournot strategies with capacity constraint due to the design market.

The management of hydrological reservoirs by producers of electricity could have been influenced by these strategies.

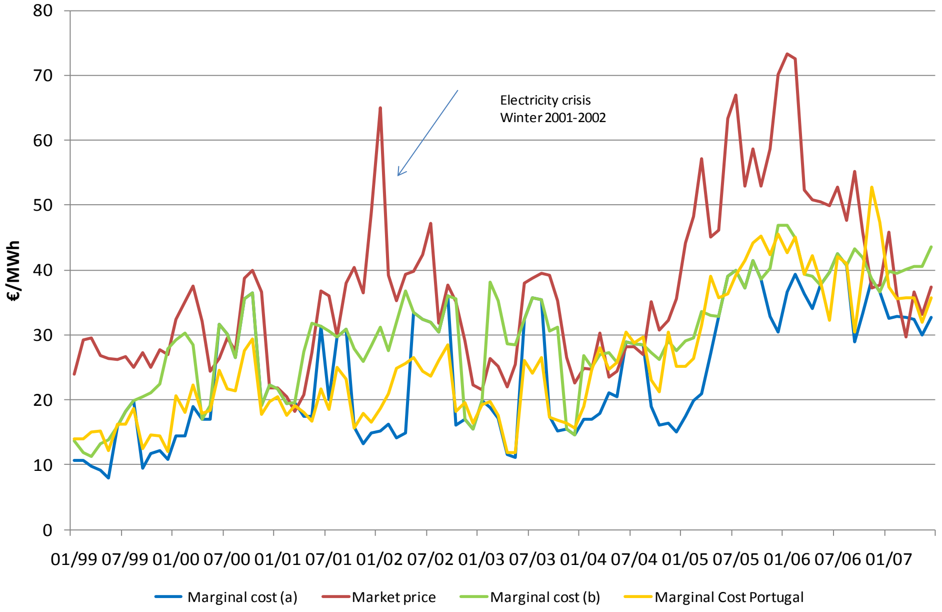
Figure **1** shows the marginal cost evolution for different assumptions. It is also noted that the evolution of marginal costs when calculated with the data observed in Portugal is very close to the others.

Whatever the cost function considered, periods when the marginal cost of the market approaches the market price succeed to periods when the marginal cost is significantly lower than the market price. This is known and has been already analysed in other studies (see Fabra and Toro, 2005).

In addition, extreme weather conditions occurred in some periods, namely between November 2001 and January 2002.

During this period, the increased demand, combined with a period of extreme drought, led to the inability of supply to meet demand at certain periods, with consequent outages and spikes in electricity prices in the daily and intraday markets. However, the beginning of 2001 was characterized by an above-normal rainfall that led to the filling of the reservoirs in the Iberian Peninsula. The management of reservoirs in Spain during 2001 by the producers of electricity could partly be blamed for what happened (Santana and Resende (2006)). The wholesale markets for electricity, such as the Iberian market, are markets where producers will tend to follow Cournot strategies with capacity constraint due to the design market. The management of hydrological reservoirs by producers of electricity could have been influenced by these strategies.

Figure 1. Changes in market prices and production costs

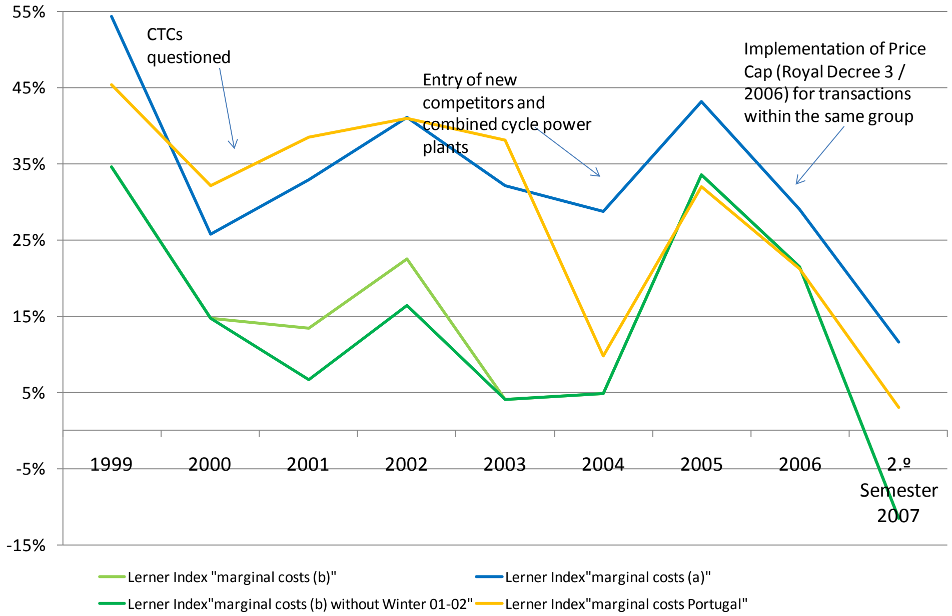


The Lerner Index is an indicator of the exercise of market power. The observation of the average annual rates of the Lerner Index, associated with each curve of marginal production, listed in Figure 2, shows that by the end of 2003 this indicator is in average above marginal curve by 15%, exceeding at times 50%, whatever the marginal curve considered. This indicates clearly that there is exercise of market power in that period.

We tried to eliminate the effect of peak prices that occurred between November 2001 and February 2002, taking off this period from the analysis. This was done for the series "marginal cost b), with higher marginal costs, resulting in a lower Lerner index. In this case, the average Lerner is about 7% and 15% in 2001 and 2002, respectively. However, from 2003 the existence of market power depends on the estimate considered for the marginal cost.

The evolution of the Lerner index can easily be associated with various external events. The increase in the Lerner index from 2001 coincides with the threat by the European Union to prevent Spain from maintaining the CTC payments. With the disappearance of this threat, the Lerner Index was seen to fall. Later, the entry of the new combined cycle natural gas power centres whose importance can be highlighted from 2004 onwards and which were not governed by the CTCs, coincides with a rise in this index. Finally, the implementation of Royal Decree-Law no. 3/2006 set a maximum price for trading in the pool amongst companies from the same group and offered a strong incentive to reduce the Lerner Index from this date onwards.

Figure 2. Evolution of the Lerner index



The series "marginal cost (a)" has, as expected, the higher index, and the series "marginal cost b)" is the series with the lowest index. The "marginal cost series Portugal" has a value close to this last series. In turn, this is the series that has the highest volatility.

Table 20. Descriptive statistics

	Marginal cost (a)	Marginal cost (b)	Marginal cost Portugal
Observations	**102**	**102**	**102**
Unit:	**€/MWh**	**€/MWh**	**€/MWh**
Minimum	**7.976**	**11.299**	**11.876**
Maximum	**42.565**	**46.960**	**52.792**
Average	**24.129**	**30.101**	**25.782**
Median	**20.189**	**30.363**	**24.242**
Standard deviation	**9.712**	**8.595**	**9.857**
Variance	**94.314**	**73.877**	**97.169**
Kurtosis	**-1.363**	**-0.586**	**-0.468**
Skewness	**0.215**	**-0.283**	**0.703**

As it would be expected the series marginal cost Portugal has a higher correlation with the series marginal cost (b), with which it shares the assumptions used to value the hydro productions. Market price series is noticeably more correlated with the series marginal cost (a) and marginal cost Portugal.

Table 21. Marginal costs correlation

	Marginal cost (a)	Marginal cost (b)	Marginal cost Portugal	Electricity price
Marginal cost (a)	**1.00**	**0.76**	**0.78**	**0.59**
Marginal cost (b)	**0.76**	**1.00**	**0.84**	**0.70**
Marginal cost Portugal	**0.78**	**0.84**	**1.00**	**0.68**
Electricity price	**0.59**	**0.70**	**0.68**	**1.00**

After setting the marginal cost as an exogenous variable in the model, it remains to consider the stationarity of the series. As noted, the price variable is integrated of order 1. The following tables show that this is also the case for marginal costs series.

Table 22. ADF-Tests for the marginal cost

	Marginal cost (a) (1)	Marginal cost (a) (2)	Marginal cost (b) (1)	Marginal cost (b) (2)	Marginal cost Portugal (1)	Marginal cost Portugal (2)
Choosen order	2	2	0	0	0	0
Trend	No	Yes	No	Yes	No	Yes
Statistic test	-1.545	-2.147	-1.484	-2.393	-1.440	-2.430
Critical value for the ADF statitistic	-2.892	-3.457	-2.892	-3.457	-2.892	-3.457

Table 23. ADF-tests for the marginal cost of integrated order 1

	Marginal cost (a) I(1) (1)	Marginal cost (a) I(1) (2)	Marginal cost (b) I(1) (1)	Marginal cost (b) I(1) (2)	Marginal cost Portugal I(1) (1)	Marginal cost Portugal I(1) (2)
Choosen order	1	1	0	0	0	0
Trend	No	Yes	No	Yes	No	Yes
Statistic test	-7.817	-7.854	-8.807	-8.877	-9.539	-9.609
Critical value for the ADF statitistic	-2.899	-3.467	-2.899	-3.467	-2.899	-3.467

However, the ADF test for the stationarity of the residuals of the regression (7) rejects the hypothesis of a unit root. Given that there is only one independent variable, this test is sufficient to test the stationarity of the model (Pesaran and Pesaran, 1997). It is expected that the variables “Electricity Price” and "marginal cost" are co-integrated, reflecting the relative stability of the mark-up.

Table 24. ADF test for stationarity of residuals (60 observations)

	Marginal cost (a)	Marginal cost (b)	Marginal cost Portugal
Choosen order	1	0	1
Statistic test	-4.669	-3.913	-5.880
Critical value for the ADF statitistic	-3.454	-3.454	-3.454

In the case of the series marginal cost b) without Nov. 01_ Fev.02, despite the stationary of equation (7), the tests performed, including Dick-Fuller, point to the existence of autocorrelation of the residuals. Therefore, we applied an autoregressive models with 1 lag in order to solve the equation (7) for the period between January 1999 and December 2003, for which they have obtained significant results for the price elasticity of demand14. The results can be seen in the table below. The Lerner indexes have high values. Their interpretation requires the resolution of equation (8).

Table 25. Results

	Marginal cost (a)		Marginal cost (b)		Marginal cost (b) without Nov.01_Feb.02		Marginal cost Portugal	
	Coefficient	T-Ratio [Prob.]	Coefficient	T-Ratio [Prob.]	Coefficient	T-Ratio [Prob.]	Coefficient	T-Ratio [Prob.]
λ	0.38776	9.6156 [0.000]	0.1975	4.4574 [0.000]	0.18326	3.7879 [0.000]	0.41285	20.3947 [0.000]
AR parameter	-	-	-	-	0.56706 Ut (-1)	(5.3326) [0.000]	-	-

5.2.3.2 Definition of the Behavioural Variable for 1999-2003

When we defined the price elasticity of demand for different functional forms, we concluded that only for the 1999 – 2003 period, equation (8) can be solved. In section **Error! Reference source not found.** we determined the HHI, being the average value 30.5%. With regard to price elasticity of demand, the estimated values in section **Error! Reference source not found.** are very similar regardless of functional form chosen. Thus, we applied the results obtained for the linear functional form: -0.0886.

Table 26. Variable behavior of cost estimate for linear demand function period 1999-2003

Marginal cost (a)	Marginal cost (b)	Marginal cost (b) without Nov.01_Feb.02	Marginal cost Portugal
0.119	0.060	0.056	0.126

It should be recalled that the closer $\bar{\theta}$ is to 1, the closer we are to finding strategic behaviour of the Nash-Cournot type, whereas when it is closer to 0, the agents are closer to a competitive situation. Therefore, despite the high mark-up, one cannot, apparently, prove the existence of an anti-competitive behavior, using the conjectural variation methodology.

However, we will try to refine the approach. As noted, during the period under review the producers of electricity in Spain were framed by CTCs. This

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[14] It has to be highlighted that the existence of heteroscedasticity and autocorrelation of the residuals led to the adjustment of the regression through the Newey-West matrix of covariances I the other cases.

methodology allows the incumbent producers to be compensated for the return on investment which was guaranteed before the market liberalization. In other words, CTC ensures the recovery of their stranded costs. The scheme was applied whenever the market price was less than 36 €/MWh. The compensation was calculated as the difference between the income declared by all the distributors for their activities in the electricity supply tariff and the costs of regulated activities, which include the costs of the energy traded in the market. The allocation of the compensation was made taking into account a share initially set for each company, which should reflect their stranded costs. Note that the amount of CTC allocated to the second largest company, Iberdrola, was lower than its market share, while the CTC allocated to Endesa, was higher than its market share. If the market price was higher than 36 €/MWh, the increased revenue would be deducted from the amounts of CTCs established annually. This scheme should be extended for 10 years from 1997.

Thus, the CTCs were organized similarly to contracts for difference, whose revenues were defined as functions that decrease with market prices.

Therefore, if the CTCs were applied to all quantities traded, the profit wouldn't grow with the market prices. To define the function maximizing the profits of a producer i, we reformulated the profit function in a market with CTCs given by Fabra and Toro (2005), as follows:

$$\pi_i = P(Q,D)q_i - C_i(q_i,W) + q_{iCTC}(CTC_{ui} + 36 - P(Q,D)) \tag{29}$$

Being, qiCTC the quantities framed by the contracts and CTC_{ui} the income per MWh produced that are allocated to producer i through the CTCs.

If qiCTC = qi, that is, if the quantities traded framed by CTCs, qiCTC, are equal to the quantities traded in the market, the maximization of the equation (28) results in:

$$CTC_{ui} + 36 = \frac{dC_i(q_i,W)}{dq_i} \tag{30}$$

In this case, any strategy for maximizing profit is independent of the price and we simply need to equate the marginal cost of production at CTC_{ui} added of 36 € / MWh, which corresponds to equal the marginal revenue (implicit in the scheme prior to the liberalization) and the marginal cost.

In 1999, almost all conventional power plants were framed by CTCs. The weight of the power plants framed by CTCs in total production fell sharply from 2002, with the entry of new plants (Vives, 2006).

Thus, in practice qiCTC < q, that is, the quantities traded framed by CTCs, qiCTC, are lower than those traded in the market which are independent of this mechanism. Assuming qiCTC as a constant, in this case, the profit maximization function result as follows:

$$P + \theta_i \frac{dP}{dQ} ⟦(q⟧_i - q_{iCTC}) = \frac{dC_i(q_i, W)}{dq_i} \qquad (31)$$

Rearranging this equation, we obtain the following relationship:

$$\frac{(P - Cmg_i)}{P} = \frac{⟦(s⟧_i - \frac{qi_{CTC}}{Q})\theta_i}{|\varepsilon|} \qquad (32)$$

This results15 in the following equation:

$$\frac{(P - \overline{Cmg})}{P} = \frac{\left(\sum_i^n s_i^2 ⟦-\frac{qi_{CTC}}{Q} s_i\right)\theta_i⟧}{|\varepsilon|} = \frac{\bar{\theta}\left(HHI - \sum_i^n ⟦\frac{qi_{CTC}}{Q} s_i\right)⟧}{|\varepsilon|} \cong \frac{\overline{\theta_{\mathbf{CTC}}} HHI_{CT\boxminus}}{|\varepsilon|} \qquad (33)$$

The parameter HHI_{CTC} is the difference between the market share of each company and the weight of their respective products framed by the CTC in the total production, multiplied by their market shares. Thus, this parameter is the Herfindahl index net of the weight of the power plants that give no benefit to producers, whenever they developed a strategy to manipulate the market price.

This parameter is smaller, the greater the weight of the energy produced by plants covered by the CTC. In 2003, about 10% of installed power plants did not correspond to conventional investments developed during the term of the MLE, that is, they weren´t framed by the regime of CTCs. In 1999, the share of power after the MLE was only 2%.

We defined an average value for HHI_{CTC} considering, for simplicity, that the production of plants not covered by the CTCs is proportional to its capacity as the weight of the production of these plants is the same for all companies. The average value thus found for this parameter was 1.71%. Thus, accepting a broad interpretation of HHI_{CTC} and the relation (8), we can apply the following equation:

$$\bar{\theta}_{\mathbf{CTC}} = \frac{\lambda|\varepsilon|}{HHI_{CT\boxminus}} \qquad (34)$$

The obtained values are between values that indicate the existence of Cournot strategies, which correspond to the unit, and values that indicate the existence of pure strategy of collusion, match .

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[15] The development of this deduction comes out of the scope of this paper.

Table 27. Variable behavior by cost function considering the CTC period 1999-2003

Marginal cost (a)	Marginal cost (b)	Marginal cost (b) without Nov.01_Feb.02	Marginal cost Portugal
2.12	**1.08**	**1.00**	**2.25**

The results obtained now clearly indicate that producers behaviors are "somewhere" between the Cournot behavior and the pure collusive behavior. This results are consistent with what some authors argue (see for exemple Vives, 2006) that after the suspicion on the part of producers that from 1999 the payments of CTCs could not be made, they may have developed strategies to increase the mark-up implicit in the market price.

6. Conclusions

In focussing on causal relationships, the new industrial school aims to infer the possible causes of a high level of concentration, such as can be verified in the Spanish market for the period under analysis and to determine whether this results from anti-competitive behaviour or, on the contrary, from more efficient efforts made by companies in the face of their competitors. However, the capacity to exercise market power and the realisation of anti-competitive strategies should not be confused, as this study demonstrates in terms of electricity production under a market regime. This is because, in the case of electricity production, the differences between these two trends are more marked than in other sectors, due to their specific characteristics. These characteristics take shape in the form of two related trends which only partially cancel each other out. On the one hand, electricity production can be based on “anti-competitive” strategies, even at relatively low levels of concentration, due to its characteristics, which include the price elasticity of demand below the unit, the difficulty in storing the product and the fact that it is a capital-intensive sector, with long periods required for a return on investments. On the other hand, this natural tendency to exercise market power and, above all, the fact that electricity is an essential commodity, make this sector extremely regulated, even when exercised under a market regime, including in economies that are more open to private initiatives, limiting the actions of economic agents (sometimes by anticipating the future actions of the regulators).

Thus, due to the nature of the electricity generation, the exercise of market power occurs naturally in these markets, and this trend is very often impeded due to its framework. In a pioneering study by Wolfram (1999), the author concludes, in the case of the former English and Wales market at the end of the 1990s, that prices were much higher than marginal costs, demonstrating the existence of market power. However, this difference was less than was to be expected, given the structure of the English market at the time. Fears of State intervention in the wholesale market can explain the “lower” mark-up.

This study also points in this direction. The average Lerner index is high, although it is expected to be much higher compared to the market conditions (particularly the high concentration and low price elasticity of demand). However, at that time the Spanish electricity sector was framed by CTCs, similar to contracts for difference, which would, nevertheless, make the average Lerner index lower, since the profit maximization function of the producers framed by CTC was independent from price strategies. The paper shows that the average high mark-up in the period examined is very likely due to the implementation of anti-competitive strategies.

Therefore, in the Spanish case, the opening of the market without the prior increase in the number of market players did not, by itself, prevent the manipulation of the market. This trend occurs even with the application of a methodology such as the CTC, which should have prevented the implementation of strategies to increase the mark-up by companies.

It could be refuted that a Lerner index based on market price, without the capacity payment (which exists in many markets, like Spanish to ensure the recovery of fixed costs) may not be a good indicator of power market because the prices in the wholesale markets do not always ensure the payment of the fixed costs (see Joskow (2006)). However, for the Spanish market during this period, fixed costs are partly recovered, taking into account the payment capacity of producers in place of about 7.8 € / MWh.

Finally, we have seen that the use of the structural methodology have obtained interesting results, similar to those obtained outside this methodological framework. The application of the structural model to the electricity sector was performed on the basis of a set of assumptions concerning the underlying economic relationships and the functional forms of the functions defining the endogenous variables, validated by using estimates for variables outside the framework of the structural model. Thus, the price elasticity of demand was defined with values that were very close, assuming a linear functional form for demand within the framework of the structural models for the values obtained outside this framework for log-linear, linear and exponential functional forms.

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