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Application of a structural model to a wholesale electricity market: The Spanish market from January 1999 to June 2007

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Application of a structural model to a wholesale electricity market:

The Spanish market from January 1999 to June 2007

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Abstract

The aim of this work is to analyse the agents' behaviour 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. The result of the structural model[4] supports the apparently competitive nature of the market analysed for the period 1999 to 2003, despite than fact that the Lerner index average was high during this period. It will therefore be important in future work to analyse whether the high average mark-up verified accords with the CTCs (stranded costs compensation which have the characteristics of contracts for difference) which frame the activities of the electricity producers.

Keywords: **electricity market, rigid demand, structural model, market power**

JEL classification: L13

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[4] Noticed that the robustness of the results obtained for the price elasticity of demand based on the strucutural model was corroborated when the variable was estimated outside the model and for different functional forms of the model.

1 FRAMEWORK

The aim of this work is to analyse the behaviour of agents in the Spanish electricity generation market during the period January 1999 to June 2007, before the MIBEL (Iberian Electricity Market) began operating, on the basis of monthly data.

The analysis has been undertaken within the theoretical framework of structural model s, which also corresponds to the theoretical framework of the "New Industrial Economics". 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 equilibrium. Therefore any analysis undertaken within this theoretical framework is based on a set of assumptions, with different perspectives, which incorporate both the assumed economic relationships and the functional forms of the equations representing the causal relationships in the model. These presuppositions influence the results obtained using this methodology.

The application of this methodology to the Spanish wholesale electricity market, taking into account the obvious specific features relating to the nature of the product and its strongly institutionalised context, offers an interesting scenario in which to test the applicability of this methodology by re-assessing some of its premises: functional forms of equations, estimation of endogenous variables and economic balance. To this end, the results were cross-referenced with results obtained outside the structural model using marginal cost estimates and the definition of price elasticity of demand for the different functional forms. The analysis focuses on an extended period, thus enabling the long- and medium-term strategies which prevail in a capital-intensive sector such as the electricity sector to be assessed. This focus also has the advantage of enabling the applicability of these methodologies to be tested, based on economic equilibrium, over extended periods of time

1.1 BRIEF BACKGROUND TO THE ELECTRICITY GENERATION MARKET DURING THE PERIOD UNDER ANALYSIS

Between 1988 and 1997 the legal framework for the Spanish electricity sector was the Marco Legal Estable (MLE). The MLE aimed to remunerate investments "correctly" and create incentives for efficient management in a manner similar to yardstick competition. Through Royal Decrees 1538/1987 and 40/1994, all the costs of the Spanish electricity generating power stations were guaranteed by the electricity tariff, calculated for each station using standard costing methods.

Spain transposed Directive 96/92/EC into Law 54/1997 of 27 November, which came into effect on 1 January 1998. As a result of this, all generators with an installed capacity of more than 50 MW who were not operating under the special regime[5], had to present their bids in a spot market auction of the uniform price market variety, in which the price defined at any given hour by the marginal technology, that is, the price at which the purchase and sale offers cross, would be the price for all the electricity traded during that hour.

Thus the Spanish electricity generating power stations lost the MLE guarantee that their investments would be remunerated. In order to resolve the situation, the new law established a transitional system known as Costes de Transicón a la Competencia (CTC – "stranded costs"). This allowed the companies that owned the electricity generating power stations, who on 31/12/97 were covered by the MLE, to receive partial compensation for loss of income for a maximum period of 10 years (up to 31/12/2007). This compensation was derived from the difference between the previously guaranteed electricity tariff and the expected prices in the liberalised market. The market price that served as a reference in calculating the CTC was 6 ESP/kWh (36 €/MWh). This sum represented the cost of new entry into the Spanish electricity market or, in other words, the long-term marginal cost. The market price for the electricity sold included a fixed portion of 1.3 ESP/kWh (approximately 7.8 €/MWh) that would compensate for the electricity generating power station supply guarantee.

The period of time analysed in this work may be subdivided into two phases. In the first phase, which lasted until the start of 2004, the Spanish wholesale market was characterised by a certain level of stability, both regulatory and structural. Although the market was open to competition, in real terms a transitional regime was operating in which the revenue obtained by producers fell, to a greater or lesser extent, within the framework of the CTCs. This allowed the producers a guaranteed income, regardless of trends in market price. In the second phase, the structure of the market changed due to changes in electricity production and in the regulatory framework. With regard to the former, the business and production structure of the electricity sector in Spain altered following the entry of a group of new companies, the introduction of combined cycle natural gas plants and the increasing importance of plants based on renewable energy sources. As far as the changes in the legislative framework are concerned, these were essentially aimed at dynamising the wholesale market and making it more competitive. Within this context, the following legislative measures should be emphasised:

- Royal Decree 436/2004, which enabled producers operating under the special regime to sell energy at a regulated tariff or to sell it on the spot markets, the futures markets or even through bilateral contracts, in the latter case receiving a subsidy in addition to the revenue from this method of selling electricity.
- Royal Decree-Law 5 /2005, which established the end of the obligation to trade electricity on the daily and intra-daily markets.
- Royal Decree-Law 3/2006 which provisionally defined that the energy traded on the spot market between companies belonging to the same group would be treated as energy traded through bilateral contracts, with prices limited to 42.35 €/MWh. This measure remained in force until January 2007, when legislation

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[5] Small producers whose energy is produced from renewable energy sources or from cogeneration.

was published to provide a framework for the negotiation of bilateral contracts involving physical deliveries.

- Royal Decree-Law 7/2006, which ended the CTCs.

1.2 MAIN METHODOLOGICAL ISSUES

Taking econometric models as its basis, the structural analyses enable the causal relationships between the structure of the market and the behaviour of companies to be defined, supported by economic theory. The origins of this type of approach can be found in the work of the Cowles Commission on econometrics which, between 1939 and 1955, sought to develop econometric models that would enable economic theory to be related to mathematics and statistics. On this basis, a wide range of work on econometrics in general and in relation to the theory of equilibrium in particular was developed. Structural models emerged from this framework, associated with econometric models composed of multiple equations, capable of describing different kinds of economic behaviour (Reiss and Wolak, 2005).

Within the context of industrial economics this new conceptual framework is called *New Empirical Industrial Organization* (NEIO). It emerged at the end of the 1970s in clear opposition to the traditional paradigm for industrial economics which correlated structure, behaviour and profit.

The main criticism levelled against the traditional model by the authors of the NEIO was concerned with the fact that this model only explains the correlations existing between dependent and independent variables and does not resolve the problems of endogeneity (Kadiyali, et al., 2001). In fact, the traditional model does not allow the causal relationships existing between the variables that comprise the models to be shown, unlike the new paradigm (Reiss and Wolak, 2005).

However, as we shall see, the main criticisms that can be directed towards the NEIO lie in the obligation to internalise the deduction of certain variables belonging to the right-hand side of the equations in the structural models. Therefore, in the new conceptual framework mark-up cannot be observed and costs must be estimated or deduced using, for example, productive factor prices.

In this way the conclusions resulting from the application of structural models depend to a great extent on assumptions relating to the functional forms of the equations that comprise each model or the instrumental variables chosen. In the case of the definition of the behavioural parameter in the models used to analyse market power, the instrumental variables chosen may distort the estimates (Corts, 1999, cited in Perloff, et al., 2007, p. 47).

Independently of these kinds of constraints, as we shall see later, there are also problems concerning the identification of the model, which may, however, be solved using the methodology developed by Bresnahan (1982) and Lau (1982).

In the case of the electricity sector, the application of the structural model resulting from equilibrium and the consequent resolution of a system of equations was undertaken relatively late. For example, in the case of the English market, one of the most widely-studied electricity markets, as far as we are able to determine this methodology was applied for the first time using the Bresnhan-Lau model by Wolfram (1999) to supplement the direct determination of market power. In the case of the Nordic electricity market, Nordpool, this approach was applied for the first time in 2000 by Hjalmarsson, based on a dynamic version of the Bresnahan-Lau model in order to analyse market power. The late application of this type of model to electricity sectors is, in part, the result of the fact that liberalisation only began in the electricity sectors at the end of the 1980s. Another, possibly fundamental reason for its late application arose out of the difficulty of inferring two of the main variables which define market power; price elasticity of demand and marginal costs. The econometric models applied to the electricity sector are therefore usually models containing only one equation (as affirmed by Fezzi and Bunn, 2006) located outside a purely structural framework in which quantity is considered an external variable. Price elasticity of demand is considered perfectly inelastic (for example, in Borenstein, et al., 2002; Goto and Karoly, 2004; Joskow and Kahn, 2002; Mansur, 2003; Wolak, 2002) or predetermined (for example in Borenstein, et al., 1999; Borenstein and Bushnell, 1999; Green and Newbery, 1992; Wolfram, 1999). With regard to marginal cost, this is generally determined outside the model (for example, in Borenstein, et al., 2002; Fabra and Toro, 2005; Joskow and Kahn, 2002; Puller; 2007; Wolfram, 1999). In the specific case of the Spanish electricity market, the work developed by Pérez-Arriaga in his book *Libro Blanco* (2005), which underscored some of the reforms taking place in the sector from this date onwards, is a clear example of the definition of estimated market power achieved by considering price elasticity of demand to be inelastic, and marginals defined outside the model.

The next section presents the theoretical framework which supports the work developed and is concerned with the analysis of the behaviour of agents. The issues that most directly related to the structural analysis are also presented.

1.2.1 DEFINITION OF AGENT BEHAVIOUR

The electricity production market is very similar to a market that adopts Cournot strategies, with restrictions of capacity (Kreps and Scheinkman, 1983). Within this framework, the quantities correspond to the decision variable.

Starting with the Nash-Cournot solution for the Spanish oligopolistic market and reprising the Cowling-Waterson formula (1976), the Lerner index and type of strategies developed by companies can be correlated using the θ[6] index.

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

$$\begin{cases} P = P(Q, D) \\ C = C(Q, W) \end{cases} \tag{1}$$

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.

The profit π of a company *i* is therefore provided by the following:

$$\pi_i = P(Q, D)q_i - C_i(q_i, W) \tag{2}$$

A first order condition for company profit maximisation is obtained by the order derivation of q_i in equation (2):

$$\frac{d\pi_i}{dq_i} = 0 \tag{3}$$

This derivation establishes the equality of marginal revenue and marginal cost:

$$P + \theta_i \frac{dP}{dQ} q_i = \frac{dC_i(q_i, W)}{dq_i} \tag{4}$$

The expression of the left-hand side of equation (4) corresponds to the marginal revenue of the company *i* and the expression on the right-hand side to its marginal cost.

With regard to marginal revenue, $\frac{dP}{dQ}$ is the slope of the demand curve and θ_i is the agent behaviour parameter *i*. Moreover:

$$\sum_{i=1}^{n} q_i \equiv Q \tag{5}$$

By reorganising equation (4) and dividing it by *PQ* the following relationship is obtained:

$$\frac{(P - Cmg_i)}{P} = \frac{s_i \theta_i}{|\varepsilon|} \tag{6}$$

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

In which Cmg_i is the marginal cost of the company *i*, s_i is its market share and ε is the demand price elasticity, given by $\frac{\frac{dP}{dQ}}{\frac{P}{Q}}$.

$s_i\theta_i$ is found in the interval $[0; 1]$. If $s_i\theta_i$ is equal to 0, the company strategy *i* falls within perfect competition. If this variable is equal to 1, the company strategy corresponds to one of collusion.

θ_i may, in turn, be reinterpreted within the framework of the theory of conjectural variations. Within this conceptual context, companies define their strategies by taking into account the "conjectures" they make with regard to the behaviour of their rivals in the light of any changes to their offers.

In this context, the variable v_i for the company *i* corresponds to the conjecture made by the company concerning the response in terms of production of its *n-1* competitors when the company alters its production:

$$v_i = \frac{dQ_{-i}}{dq_i} \tag{7}$$

in which Q_{-i} is the combined production of all the producers with the exception of producer *i*.

Thus, for the company *i*, the relationship between θ_i and v_i is given by:

$$\theta_i = 1 + v_i \tag{8}$$

v_i belongs to the interval $\left[-1; \frac{(1-s_i)}{s_i}\right]$. At the lower limit of the interval, a situation of perfect competition can be found, and at the upper limit a situation of collusion.

The main disadvantage of the theory of conjectural variations is that it is difficult to interpret, particularly when the results obtained for the ratio θ_i are not close to the results associated with well-defined strategic models (0, when the market is competitive; $1/s_i$, when perfect collusion is verified; 1, in the case of the Cournot strategy). The continuity of the variable θ_i, understood in the interval $[0;\frac{1}{s_i}]$, has no supporting theoretical model[7], meaning that the results must be interpreted cautiously[8]. Another criticism concerns its theoretical bases, namely the inconsistency of it being a static model in which agents act according to expectations regarding the dynamic responses of competitors or even taking as its basis the debateable assumption that a company's rivals react to a change in its behaviour. However, weak assumptions are common to a great many more complex approaches which form part of game theory, specifically with regard to the rationality of the agents and their access to

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[7] See for example Perloff, et al. (2007) or Kadiyali, et al., (2001).

[8] See for example Muller and Normann (2003) which highlights the difficulty in ensuring consistency of the conjectural variation models.

information. In addition, this approach is easy to apply and very useful in studies of market power (Church and Ware (2000)) although due caution should be exercised in interpreting the results.

Assuming, on the one hand, that the companies share the same production function *C*(q,W) and, consequently, that they will all produce the same quantity $q=q_i$ and, on the other hand, that the companies also share the same conjectures with regard to the strategies of their rivals, equation (6) may be extended to the entire industry[9]. In these circumstances, s_i corresponds to 1/n, and equation (6) will correspond to:

$$\frac{(P-Cmg)}{P}=\frac{\theta}{n|\varepsilon|} \tag{9}$$

In which Cmg is marginal cost and θ the industry behavioural variable. In this case, the variable θ will be understood in the interval [0;1].

If the cost functions and conjectural variations are not considered to be shared by the agents in the market, both sides of equation (6) are multiplied by s_i for each company and each equation is calculated to correspond to each company in the industry, obtaining the following relationship for the industry as a whole:

$$\frac{(P-\overline{Cmg})}{P}=\frac{\sum_i^n s_i^2\theta_i}{|\varepsilon|} \tag{10}$$

If it assumed that the company variables are similar, θ_i which is equal to $\overline{\theta\ }$ will be obtained:

$$\frac{(P-\overline{Cmg})}{P}=\frac{\sum_i^n s_i^2\theta_i}{|\varepsilon|}=\frac{\bar{\theta}\sum_i^n s_i^2}{|\varepsilon|}=\frac{\bar{\theta}HHI}{|\varepsilon|}=\lambda \tag{11}$$

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 is also related to the conjectural variations. This equation corresponds to the model described by Cabral (2000) which originated from the work of Cowling and Waterson (1976). In this context, if $\bar{\theta}\ =\ \frac{1}{HHI}$, perfect collusion is verified; when $\bar{\theta}\ =\ 1$, Cournot behaviour is verified and, finally, when $\bar{\theta}\ =0$, a perfectly competitive market prevails.

The models developed are based on equation (11) and aim to deduce the numerator of the equation from its left-hand side. Questions relating to the interpretation of the value obtained merit special attention. The results are interpreted as a parallel to the expected results produced by a recognised theoretical framework, namely the Cournot-Nash, collusion or competition framework.

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[9] The high degree of concentration of the Spanish market, mainly in the early years, allows to suggest that this assumption does not skew the results.

1.2.2 THE STRUCTURAL MODEL

Thus, returning to system equations (1) and displaying the behavioural variable θ, the following structural model is obtained:

$$\begin{cases} P = P(Q, D) \\ C = C(Q, W, \theta) \end{cases} \tag{12}$$

In defining a structural model, two inter-related questions have to be solved: identification, i.e. estimation of the structural parameters, and the endogeneity of the variables.

The question of identification occurs naturally in system equations, given that there are variables which appear on both their left and right sides. Thus, in a system equation at least one endogenous variable exists.

The necessary condition required to identify an equation is the order condition. This establishes that at least as many exogenous variables excluded from each equation must exist as the number of endogenous variables that form part of the solution to the problem. The rank condition establishes that the exogenous variable excluded from the first equation must have a population different to zero in the second equation. Thus, for example, in a system of two equations in which only one endogenous variable exists in the first equation, there will have to be an exogenous variable in the second equation that is the instrumental variable of the endogenous variable from the first equation.

In this work, the resolution of the problem of identification enables the demand function to be solved (in the first equation), i.e. the definition of price elasticity of demand, and the offer function (in the second equation). To this end, it is necessary to distinguish the different types of company behaviour in competitive situations or in situations in which market power is exercised after the occurrence of an external shock. Therefore, the demand function[10] should rotate in the face of an external shock rather than move in parallel. The inverse of the demand function is presented as follows:

$$P = \alpha + \beta_1 Q + \beta_2 D_2 + \beta_3 D_1 Q \tag{13}$$

In equation (13) the variables D are exogenous variables. Variable D1 may be the price of a substitute product or, in the case of the electricity market, changes in meteorological conditions, and D2 is the disposable income. The term $\beta_3 D_1 Q$ is what enables the equation to rotate.

The derivative of this equation, which corresponds to the function slope, yields the following expression:

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[10] Several industrial economics textbooks cover the topic. In this case it follows the deduction of Church and Ware (2000)... (2000).

$$\frac{dP}{dQ} = \beta_1 + \beta_3 D_1 \qquad (14)$$

By introducing equation (14) into equation (4), extended to the entire industry, the following is obtained:

$$P + \theta(\beta_1 + \beta_3 D_1)Q = \frac{dC(Q,W)}{dQ} \qquad (15)$$

Supposing:

$$\frac{dC(Q,W)}{dQ} = \rho + \varsigma_1 Q + \varsigma_2 W \qquad (16)$$

Then:

$$P = \rho + \varsigma_1 Q + \varsigma_2 W - \theta(\beta_1 + \beta_3 D_1)Q = \rho + (\varsigma_1 - \theta\beta_1)Q - \theta\beta_3 D_1 Q + \varsigma_2 W \qquad (17)$$

The system will have to be estimated using equations (13) and (17), which may be solved by excluding two exogenous variables W and D_2, the demand and supply functions respectively. To estimate the behavioural variable θ, supposing that the marginal cost is constant[11], it is sufficient to divide $\theta\beta_3 D_1$ in equation (17) by $\beta_3 D_1$, estimated with the resolution of equation (13).

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[11] Church and Ware (2000).

2 APPLICATION OF THE MODEL

2.1 APPROACHES

As previously mentioned, the application of the structural model is not exempt from uncertainties, which are very much concerned with the presuppositions allowed for the functional forms, explicative variables and instrumental variables chosen and, in general terms, the methodology itself.

This work makes 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 consequences of estimating the price elasticity of demand for the functional forms assumed for the demand function is tested.

In general, the application of the structural model materialises in this present case in the resolution of the following system emerging from the inverse of equation (13) and equation (17):

$$\begin{cases} Q_t = \alpha_1 + \gamma P_t + \varphi Z_t P_t + \beta Z_t + \sum_{i=1}^{n} \beta_i D_{ti} + u_{t1} \\ P_t = \alpha_2 + \sum_{j=1}^{m} \beta_j W_{tj} - \theta(\gamma + \varphi Z_t) Q_t + u_{t2} \end{cases} \tag{18}$$

in which:

- Z_t, is the exogenous variable which allows the demand function to change its slope.
- D_{ti}, are explicative variables of the demand function.
- W_{tj} are exogenous explicative marginal cost variables.

At this point it is important to note that the uncertainties regarding the functional models of the supply function have major implications for the results obtained. Moreover, this is the main criticism levelled at structural models (see, for example, Perloff, (2007)). This work seeks to overcome this weakness identified in structural models by not resolving the equations in the model simultaneously, applying limited information methods. This approach, although implying a certain loss of precision in comparison with the simultaneous resolution of equations (full information methods), has two advantages according to Green (2003). Firstly, it does not spread errors specific to one equation to another. Secondly, the associated methodologies, namely that of the 2 Stage Least Square will vary less than those which are related to full information methods, such as the 3 Stage Least Square. In this case, the limited information method makes it possible to resolve with greater certainty a model in which the functional forms of the equations of which it is composed are not certain.

Solving each equation separately does not prevent both from being inter-related, since the exogenous variables in one system equation in include the set of instrumental variables from the other equation.

The application of the structural model is based on the assumption that the demand equation is a linear function. However, in the case of supply, in addition to a linear functional form, a logarithmic functional form is also tested in which marginal cost is estimated on the basis of a function inspired by the Translog function.

The results were compared with the results obtained when the analysis is performed outside the framework of the structural model *strictu-senso*. In this case, equation (11) is solved by assuming that all the variables are exogenous, with the exception of the behavioural variable θ[12] and on the basis of estimates of market marginal costs.

The comparison of these results with the results previously obtained enables us to understand the implications of the endogenisation of the marginal cost parameter and, in a broader sense, the consequences and limitations of applying a pure structural model. The equation which represents demand is solved using a regression of this type:

$$Q_t = \alpha_1 + \omega P_t + \sum_{i=1}^{n} \beta_i D_{ti} + \mu_{t3} \qquad (19)$$

This regression is not merely solved by one functional form[13]. Four functional forms (linear, logarithmic, exponential and quadratic) are presented. This approach enables the consequences of using different functional forms in estimating demand price elasticity forms to be tested.

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

$$P_t = \frac{\mathrm{cmg_t}}{(-\lambda+1)} + \mu_{t4} \qquad (20)$$

in which cmg_t represents the marginal cost for month t. Finally, in both cases equation (11) is applied in order to interpret λ:

$$\frac{\bar{\theta} HHI}{|\varepsilon|} = \lambda \qquad (21)$$

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.

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[12] It could be considered unreasonable that the degree of market concentration is an exogenous variable. However, as will be seen the special case of the market and the analysis period this assumption may well be accepted.

[13] Following the methodology of Genesove andMullin (1998).

2.2 THE DEMAND FUNCTION EQUATION FOR ELECTRICITY

2.2.1 DESCRIPTION OF MARKET

The model chosen corresponds to the monthly demand-supply equation for the (daily and intra-daily) Spanish wholesale electricity spot market for the stated period.

OMEL is the wholesale market operator. The market is divided into the daily and the intraday markets. In the daily market, the electricity producers submit bids for the sale amounts of electricity on an hourly basis for the following day at a minimum price and the buyers (distributors, suppliers 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 was 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.

During the period under analysis, over 90% of electricity was traded on the daily market.

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, is responsible for resolving any technical constraints, as well as physical adjustments between production and consumption.

Another source of revenue for producers comes from remuneration 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 represent 70% to 80% of this price, with the remainder coming from the guarantee of capacity and from the system operation.

2.2.2 DEFINITION OF THE DEMAND FUNCTION

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

$$Q_{t(P)} = \alpha P_t + \sum_{k=1}^{M} \beta_k W_{kt} \qquad (22)$$

in which P_t, is the price of electricity and W_{kt} another factor k explaining the price trend.

2.2.2.1 DEMAND FUNCTION VARIABLES

Two distinct phases may be observed in the demand for electricity in the daily and intraday markets during the period under analysis:

- Up to February 2006, these markets represented over 95% of electricity consumption in Spain. This preceded the implementation of Royal Decree-Law 3/2006 which, during 2006, imposed a limit on the trading price for companies within the same group and a complete end to the obligation to purchase on the spot market (Royal Decree 5/2005).
- From March 2006 onwards, when these markets with their highs and lows, saw their importance in terms of total consumption substantially lowered, specifically with the withdrawal of most of Iberdrola's bids on the daily and intra-daily markets in response to Royal Decree-Law 3/2006.

Bearing in mind that electricity consumption reflects economic activity, any variables which reflect overall 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 speed 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 automotive gas oil 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 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 gas oil (Mendiluce, et al., 2009). On the contrary, the increase in purchasing power in Spain has been based on activities with low added value, such as civil construction.

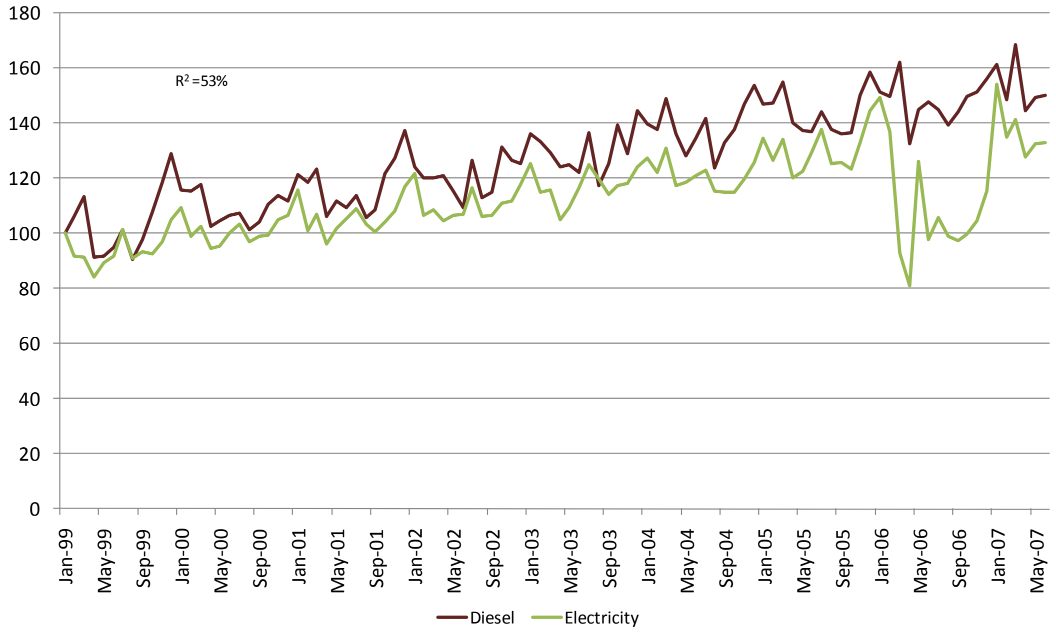
In addition, some studies have shown that in the previous decade the consumption of automotive gas oil in Spain evolved differently from that of other fuels, with a much lower price elasticity of demand, a characteristic which it shares with electricity consumption. This is due to the indirect support of the Spanish government in providing a fiscal subsidy for gas oil in comparison with other fuels as a means of supporting investments in the construction sector, namely highways (González-Marrero, et al., 2008).

Therefore for the period under analysis, automotive gas oil was chosen as the independent variable for the price of electricity, as it provides a better reflection of the evolution in economic activity in Spain in recent years. In addition, the seasonal nature of this variable is very similar to that of electricity consumption, as will be seen later.

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 gas oil consumption appears more volatile than electricity up to this date.

Figure 2-1 – Volumes of diesel fuel consumed and electricity traded

Base 100 in January 1999



Source: OMEL, Ministry for Industry, Tourism and Trade

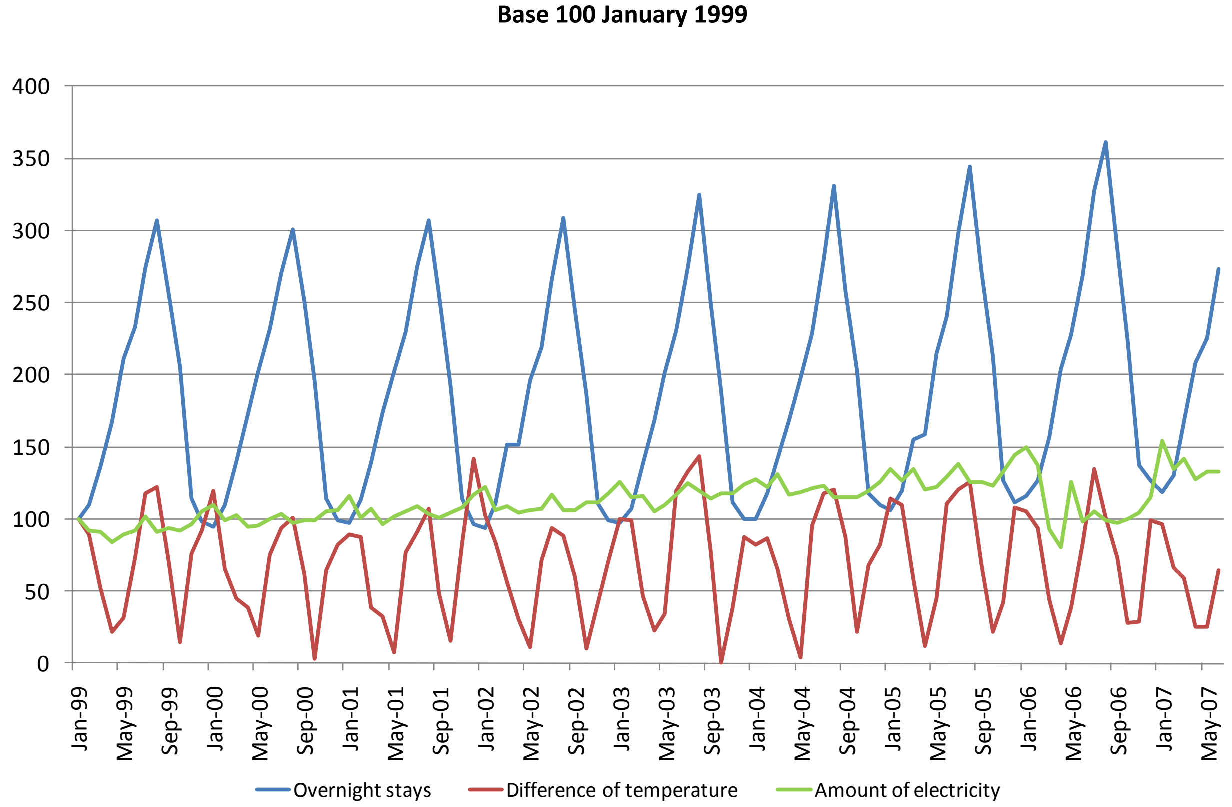
However, this variable is not an exogenous variable of electricity consumption. The consumption of electricity and automotive gas oil share some factors that explain their variations, which are very much related to cycles of economic activity and for which a set of instrumental variables must be taken into consideration, as will be demonstrated later.

It must be remembered that the identification of the model requires a number of exogenous variables for the consumption of electricity to be defined that are at least equal to the number of exogenous variables for the supply function of electricity. The variables chosen are those which explain in part the typical seasonal behaviour of demand.

It is known that the seasonal nature of the demand for electricity is due as much to the seasonality of economic activity as is to changes in temperature.

Therefore the feasibility of some variables representative of economic seasonality (“stays in hotels”, “industrial production”, “private consumption” and “working days”) and temperature (“average monthly temperature” and "temperature difference"[14]) was tested. However, some of these variables were abandoned as they were not statistically significant (working days per month, average monthly temperature, private consumption and industrial production). From the aforementioned set of variables, two were chosen which reflect the annual seasonal nature of the demand for electricity: the number of 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 2-2 – Evolution of amounts of electricity traded and variables which define seasonality



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

The incorporation of the variable "overnight stays" (number of overnight stays per month in the hotel industry) in the regression is due to the fact that consumption of electricity is greater in winter than in summer. As the number of overnight 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

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[14] Difference between the mean monthly temperature and the mean annual.

temperature each month in comparison with the average annual amount). The doubts raised by the introduction of this variable into the model led to Wald tests being performed for the rejection of the explicative variables in the model. The results are presented in the tables which follow for 79 (up to February 2006) and 95 observations (the complete series).

It can be observed that for 86 observations the H0 hypotheses for the elimination of the variables were rejected, with the exception of the "Temperature Differences" variable However, when the test was carried out for the "Overnight Stays" (number of overnight stays in hotels per month) and "Temperature Differences" variables together, the test rejected the H0 hypothesis for the elimination of variables for a lower level of significance than when it is performed on each of these variables separately. This result proves the relationship existing between the "Overnight Stays" and "temperature differences" variables.

In 95 observations, the H0 hypothesis is rejected in all cases, but only for a level of significance higher than 10%. This fact is explained by taking into account the fact that from February 2006, as we have seen, the regulatory changes imposed on the market altered the behaviour of the demand curve in the electricity wholesale markets in Spain.

Table 1 –Wald Test to eliminate variables

	Statistic $\chi 2$ [Prob.]	
	95 Observations	**79 Observations**
Overnight stays	**3.216 [0.073]**	**6.924 [0.009]**
Temperature difference	**3.830 [0.050]**	**0.9632 [0.326]**
Diesel oil	**2.938 [0.087]**	**65.198 [0.000]**
Overnight stays and temperature	**5.175 [0.075]**	**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".
- Temperature difference for each month compared to the average annual figure, "Temperature Difference".
- Automotive gas oil consumed each month, "Diesel oil".
- Amount of electricity traded on the daily and intra-daily markets each month, "Amount of Electricity".

- Average price of electricity traded on the daily and intra-daily 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 3/2006 and its implementation during 2006.

Table 2 – Correlation coefficient for variables

	Diesel	Overnight stays	Difference of temperature	Amount of electricity	Electricity price
Diesel	1	-0.30778	0.18648	0.88107	0.44659
Overnight stays	-0.30778	1	0.15409	-0.024948	0.079977
Difference of temperature	0.18648	0.15409	1	0.43088	0.24784
Amount of electricity	0.88107	-0.024948	0.43088	1	0.51977
Electricity price	0.44659	0.079977	0.24784	0.51977	1

Table 3 – Descriptive statistics for variables

	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

2.2.2.2 STATIONARITY OF 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 existence of spurious relationships between variables is associated with the fact that they are not stationary, corresponding in general to the fact that the variance and average are not constant over time.

The stationarity of each variable can be 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.

Stationary tests were performed for the series up to February 2006 and for the series up to June 2007, in order to take into account the legislative changes which took place in February 2006.

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 in the 95 observations[15] two variables exist, for which the null hypothesis of a unit root cannot be rejected: the “amount of electricity” and “electricity price” (with trend) variables.

Table 4 –ADF tests on demand function variables - 95 observations

	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

In 79 observations[16], in addition to the variables previously cited, the “electricity price” variable (without trend) is another variable for which the null hypothesis of a unit root cannot be rejected.

Table 5 –ADF tests on demand function variables - 79 observations

	Amount of electricity	Price of electricity (1)	Price of electricity (2)	Diesel oil	Overnight stays	Temperature difference
Choosen order	0	0	0	2	5	4
Trend	Yes	No	Yes	Yes	No	No
Statistic test	-2,7843	-2,9323	-3,2605	-7,4411	-9,4873	-4,4325
Critical value for the ADF statitistic	-3,4571	-2,8918	-3,4571	-3,4571	-2,8918	-2,8918

It is important to note that in comparison with the amount of electricity traded, electricity price is an extremely volatile variable.

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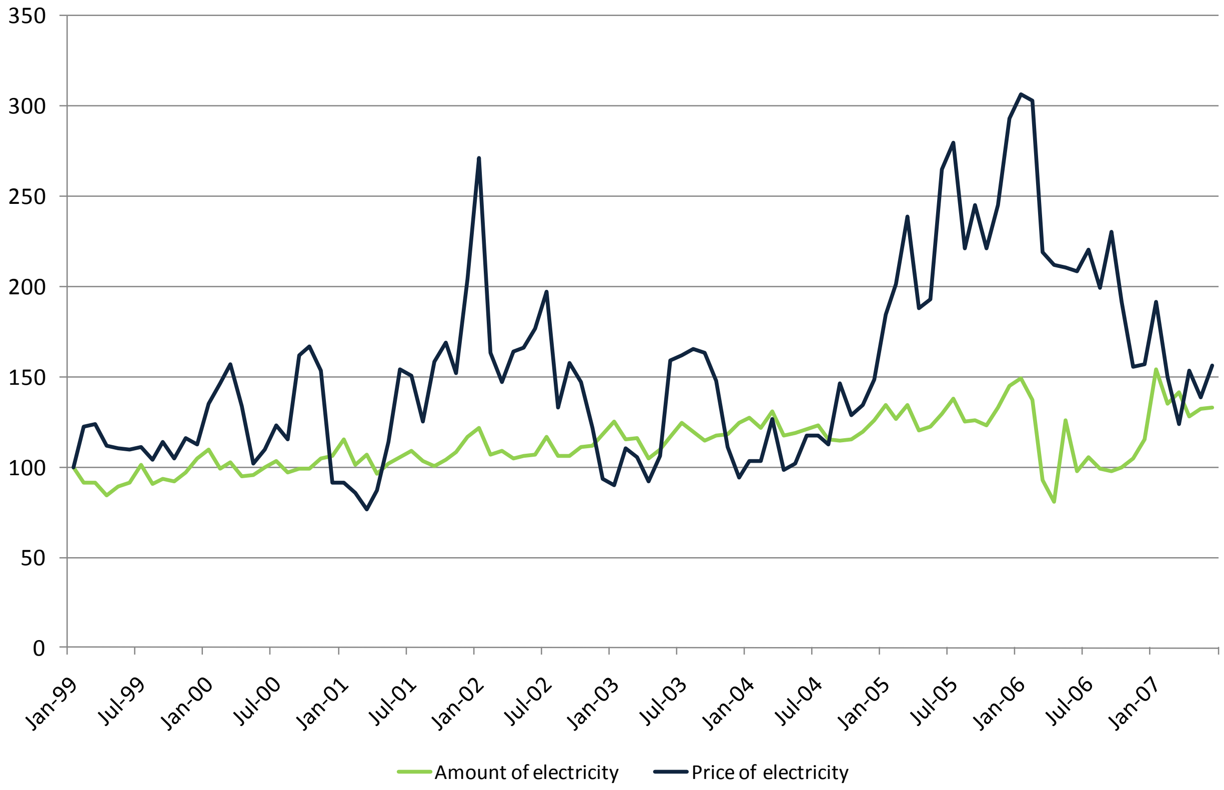
[15] Order 6 ADF test.

[16] Order 6 ADF test.

Figure 2-3 – Comparative trends for amounts and price in the daily and intra-daily markets



All the variables in first difference are stationary, both for the series with 79 and the series with 95 observations.

Table 6 –ADF tests series 1-95

	Amount of electricity	Price of electricity	Diesel oil	Overnight stays	Temperature difference
Choosen order	**0**	**1**	**6**	**6**	**6**
Statitistic test	**-10.4**	**-9.0906**	**-7.2401**	**-8.5362**	**-4.9508**
Critical value for the ADF statistic	**-2.8922**	**-2.8922**	**-2.8922**	**-2.8922**	**-2.8922**

Table 7 – ADF tests series 1-79

	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 characterised in terms of integration in the following way:

- “Amount of electricity”, I(1), for 79 and 95 observations.

- "Electricity price", I(1), for 79 and 95 observations[17].
- "Diesel oil", "Overnight stays" and "Temperature differences" are I(0), for 79 and 95 observations.

In a model composed of two or more non-stationary variables, the differentiation of the variables it contains does not provide adequate information in terms of levels unless the variables are co-integrated (Wooldbridge, 2006). Two I(1) variables will be co-integrated if a long-term balance exists between them. In this case, the relationship between the two variables is stationary.

As they are co-integrated, the variables cannot diverge for an indefinite period of time from the balance which characterises them (Banerjee, et al., 1993). The linear combination between two co-integrated variables, for example Xt and Yt, is stationary as long as the error term, μ_t, which represents the imbalance between the two variables is stationary:

$$\mu_t = X_t - Y_t \tag{23}$$

Thus, given the existence of two variables I(1) in the model, the analysis of their stationarity involves testing for the existence of a co-integration relationship.

In economic terms, it can easily be understood that in the short and medium tern 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 co-integration relationship between variables followed Johansen's methodology (Johansen, 1988), based on a VAR model (Vector Autoregression Model) transformed into an Error Correction Model (ECM). This approach has the advantage of presenting more efficient results for testing co-integration than the traditional ADF unit root test on remainders when more than one variable I(1) exists in the model (Pesaran, and Pesaran, 1997).

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[17] If we consider there is a trend, otherwise, for 95 observations it is I(0)

In Error Correction Models, the short-term dynamics (changes) and those of the long term (levels) are modelled simultaneously. Let us take the example given by Green (Green, 2000) and assume two co-integrated variables *Yt* and *Zt* I(1), with the co-integration vector given by [1;-θ]. Thus, *ΔYt*, *ΔZt* and (*Yt*,- *θZt*) are I(0). The error correction model will be:

$$\Delta Y_t = \alpha_1 \Delta X_t + \alpha_2 \Delta z_t - \alpha_3 [Yt, - \theta Zt] + \varepsilon_t \quad (24)$$

As X_t is the set of variables that are exogenous to the model, if the X_t variables are I(0), the model will be stationary. α_2, the factor in the error correction term, corresponds to the speed with which the variable Y_t is adjusted towards its long-term balance.

The ECM theoretical framework enables Johansen's methodology (Joahnsen, 1988) to be applied in order to test the co-integration of variables.

In this case, the VAR representation of the ECM model will be:

$$\Delta U_t = \alpha_{0U} - \aleph_U V_{t-1} + \sum_{i=1}^{p-1} \omega_{iU} \Delta V_{t-i} + \alpha_{2U} W_t + \varepsilon_t \quad (25)$$

in which:

- $V_t = (T_t', S_t')$, Tt is a vector of the endogenous price and quantity I(1) variables .
- S_t is a vector of the exogenous variables(1):
- $\Delta S_t = \alpha_{0S} + \sum_{i=1}^{p-1} \omega_{iS} \Delta V_{t-i} + \alpha_{2S} W_t + \mu_t$ (26)
- W_t is a vector of the exogenous variables I(0) ("overnight stays", "temperature difference" and "Diesel oil"), which does not include terms for trends and interceptions.

This model corresponds to a VECM (Vector ECM) in which $\aleph_U$ is the matrix which contains the long-term multipliers and in which the matrices $\omega_{1U}, \omega_{2U}, \omega_{3U} \ldots \omega_{p-1U}$ capture the dynamics of the short-term. The O model does not consider the trend term, bearing in mind that the interpretation in the strict sense of a co-integration relationship implies that the regression of the two co-integrated variables is stationary and without trend (Wooldbridge, 2006).

The characteristic of the matrix $\aleph_U$, r, corresponds to the number of co-integration vectors (relationships), with h being the number of endogenous variables (in this case, 2) if:

- r = h, all variables are stationary, meaning any linear combination of variables is also stationary.
- r = 0, individually the variables are I(1) and are not therefore co-integrated.
- 0 < r < h-1, individually the variables are I(1), with r co-integration vectors. In this case there is 1 vector.

First the order of the VAR model must be defined. Subsequently, the number of co-integration vectors must be defined.

Information criteria (Akaike, Schwarz) suggest that the VAR model for the equation (25) has only one order.

The statistics[18] presented in the following tables 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 8 – Statistics for the Maximal Eigenvalue (86 observations) 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 9 – Trace statistics (86 observations) 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

The results for 102 observations, although similar to the results presented, do not express the existence of an order relationship very clearly which, for reasons already explained, is to be expected.

In this way, it may be considered that the variables “Electricity price” and “Amount of electricity” are co-integrated, i.e. $Q_t - P_t \sim I(0)$.

It may be recalled that one of the main objectives of this work is to test the consequences of considering the different functional forms involved in the application of the structural model, without focussing on the processes of short term imbalances. Error Correction Models will therefore not be used in this work to estimate parameters.

Thus the “simple” linear demand form (not taking into account “Temperature differences” as a variable which “rotates” the demand function) developed through the OLS will be:

$$Q_{t(P)} = \alpha + \beta_0 P_t + \beta_1 Diesel_t + \beta_2 Stays_t + \beta_3 Dif.temp._t + \varepsilon_t \qquad (27)$$

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[18] Based on Liflihood Ratios tests.

The ADF test for the stationarity of remainders of the demand function defined in (19) corresponds to the contents of the following table, confirming the analyses performed in this area.

Table 10 –ADF test for the stationarity of remainders (86 observations)

Choosen order	**0**
Statitistic test	**-7.331**
Critical value for the ADF statistic	**-4.595**

2.2.2.3 INSTRUMENTAL VARIABLES

Once the variables incorporated in the demand models have been defined, it's 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. In this way, 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 oil". "Temperature difference" was considered an exogenous variable. The test was performed using the Wu-Hausman T_2 statistic. In this exercise, instrumental variables had to be defined for each of these variables. Thus the performance of the test also provided a solution for the existence of endogeneity, in order to comply with the rank condition.

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 the "electricity price" variable. 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) for Brent crude oil, the "crude oil price" variable, with 3 months lag.
- The average monthly price (Eur/t) for coal, the "coal price" variable, with 3 and 12 months lags.
- Average monthly hydro index (hydrological potential), the "hydraulicity" variable.

With regard to the definition of the supply function, the reasons for choosing this variable are explicit.

There is an evident correlation between the market price and the instrumental variables chosen, as can be seen in the following table which presents some of the main statistics of an OLS model, taking the market price as the dependent variable and the instrumental variables as the independent variable.

Table 11 –OLS model statistics for market price and instrumental variables (series Jan 99 - Feb-2006)

	R^2	76%
t Statistic	Coal price (-3)	-2.39
t Statistic	Coal price (-12)	4.28
t Statistic	Hydro inflows	-4.90
t Statistic	Oil price (-3)	3.07
ADF Residuals test/statistic		-5.905/-4.574

It can also be observed that the ADF test carried out[19] suggests that the model is stationary, despite the market price being I(1) and the fact that, as we shall see, the instrumental variables are also I(1), with the exception of "Hydraulicity", which is stationary.

A second group of instrumental variables was defined, related to consumption of automotive gas oil and overnight stays in hotels. In this case, instrumental variables were chosen which reproduce the seasonal nature of these variables and the economic trend[20]:

- The "Diesel oil" and "Overnight stays" variables 12 months lagged.
- The monthly trend for the industrial production index, the "Industrial production" variable, and the monthly GDP estimate, the "GDP" variable.

The inclusion of instrumental variables with lags enables short-term adjustments to be taken into account and the model thus becomes dynamic.

Table 12 shows that the "GDP" and "industrial production" instrumental variables are stationary, as are "Diesel oil" and "Overnight stays".

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[19] 0 order, taking into account Schwarz and Akaïke criterium.

[20] Data from theInstituto Nacional de Estadisticas and from Ministerio de Industria, Turismo Y Comercio.

Table 12 –ADF test on GDP and industrial production instrumental variables

	86 observations		102 observations	
	GDP	**Industrial production**	**GDP**	**Industrial production**
Choosen order	**4**	**2**	**6**	**3**
Trend	**Yes**	**Yes**	**Yes**	**Yes**
Statitistic test	**-8.963**	**-9.483**	**-3.940**	**-5.354**
Critical value for the ADF statistic	**-3.467**	**-3.467**	**-3.457**	**-3.457**

The results of the T_2 Wu-Hausman statistic given by statistic F reject the hypothesis that the model does not experience endogeneity. However, with regard to particular variables, the *t* statistic for remainders of the number of overnight stays does not reject the hypothesis that the variable is not endogenous for a level of significance of 10%.

Table 13 – T_2 Wu Hausman and remainder tests

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 month lag, as this variable is not endogenous.

Bearing in mind the significant number of instrumental variables, an overestimation test was performed. For this purpose, regression was performed on the remainders after applying the Two-Stage Least Square method in two stages on the exogenous variables (“Overnight stays”, “Diesel oil”, “Coal price”, “Oil price”, “Hydraulicity”, “GDP”, “Industrial production”), in which R^2 was equal to 0.06. This, multiplied by the number of observations, resulted in 2.88, a figure below 3.84, the critical value of 5% de $\chi 2$ for a degree of freedom[21]. This test enables the null hypothesis that all the instrumental variables are exogenous not to be rejected.

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[21] Number of exogenous variables outside the model (5) minus the number of endogeneous variables (4).

2.2.3 THE DEMAND FUNCTION WITHIN THE FRAMEWORK OF THE STRUCTURAL MODEL

2.2.3.1 RESULTS CALCULATED

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

- January 1999 to June 2007.
- January 1999 to February 2006.
- January 1999 to December 2003.
- January 2004 to June 2007.

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 (13) and assuming a linear demand function, the demand function will be given by, (model 1):

$$Q_t = \alpha + \beta_1 \mathrm{P_t} + \beta_2 \mathrm{Diesel_t} + \beta_3 \mathrm{DifTemp_t} + \beta_4 \mathrm{Dorm_t} + \beta_3 \mathrm{DifTemp_t P_t} + \varepsilon_\mathrm{t} \qquad (28)$$

in which:

- Q_t, is the “amount of electricity” variable in month *t*.
- $\mathrm{P_t}$, is the “Electricity price” variable in month *t*.
- $\mathrm{Diesel_t}$, is the “Diesel oil” variable in month *t*.
- $\mathrm{DifTemp_t}$, is the “Temperature difference” variable in month *t*.
- $\mathrm{Dorm_t}$, is the “Overnight stays” variable in month t.

However, as we shall see, most of the variables are not significant when the model is presented in this way. The choice was therefore made to use a model in which the temperature difference variable was only included as a rotation variable, (model 2):

$$Q = \alpha + \beta_{1\mathrm{a}} \mathrm{P_t} + \beta_{2\mathrm{a}} \mathrm{Diesel_t} + \beta_{3\mathrm{a}} \mathrm{Dorm_t} + \beta_{4\mathrm{a}} \mathrm{DifTemp_t P_t} + \varepsilon_\mathrm{t} \qquad (29)$$

Regression was performed on 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 main tests carried out on each regression are presented, together with the main statistics applicable to regressions including instrumental variables:

- GR^2 correlation statistic (Pesaran and Smith, 1994).
- Sargan statistic, for the specificity of the regression.
- Test for autocorrelation of remainders, based on the Lagrange multipliers method.
- Ramsey-Reset functional form text.
- Heteroscedasticity test, based on the Lagrange multipliers method.

The chosen model is shaded in orange. The selection criterion is the level of significance of the "price" variable. As can be observed, the chosen models were in general more robust than the others. For the period January 1999 to December 2003 significant results were obtained for both models. We didn't obtained significant results for the analysis which go beyond December 2003. This is not surprising bearing in mind that from 2004 onwards, the operational framework of the market was changed several times and it could not be considered in equilibrium, even from a long-term perspective. Given this, the period chosen for analysis was the period January 1999 to December 2003.

For reasons of simplicity, the results for the chosen equation (model 2) only are presented

Table 14 – Statistics and tests applied

	January 1999 - December 2003	January 1999 - February 2006	January 2004 - June 2007	January 1999 - June 2007
N.º Observations	**48**	**72**	**42**	**90**
GR^2	**0.4933**	**0.7407**	**0.5069**	**0.31587**
Sargan χ2 (3)	**0.6208 [0.733]**	**6.1052 [0.047]**	**0.1219 [0.727]**	**0.3912 [0.822]**
Serial Correlation χ2 (1)	**0.00102 [0.975]**	**1.0626 [0.303]**	**3.8361 [0.050]**	**30.2981 [0.069]**
Functional form χ2 (1)	**0.1873 [0.665]**	**0.2240 [0.636]**	**1.0093 [0.315]**	**10.7329 [0.188]**
Heteroscedasticity χ2 (1)	**0.9998 [0.317]**	**2.9048 [0.088]**	**0.8800 [0.348]**	**0.77637 [0.378]**

The following table shows that in the case of the "model 1" equation, during the period chosen only the Diesel variable is significant at a level of 10%, whilst in "model 2" all the variables with the exception of the constant are significant at this level.

The structural model is then applied to the model 2 equation for the period January 1999 to December 2003.

Table 15 – Comparison of results of regression of “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]
Dieselt	0.0064399	2.3929 [0.021]	0.0067753	6.4709 [0.000]

2.2.3.2 PARAMETERS: DEMAND FUNCTION CURVE AND PRICE ELASTICITY OF DEMAND

From equation (29) two parameters were obtained that are essential for the model as a whole: the inverse of the demand function curve and the price elasticity of demand.

The former results from the following equation:

$$\frac{\frac{dQ_t}{dP_t}}{\frac{Q_t}{P_t}} = \left(\beta_1 + \beta_4 \overline{D\imath fTemp}\right)\frac{\bar{P}}{\bar{Q}} \qquad (30)$$

in which $\frac{\bar{P}}{\bar{Q}}$, is the ratio of the average values of the market prices and amounts traded and $\overline{D\imath fTemp}$., is the average for the temperature difference. In this case, $\frac{\frac{dQ_t}{dP_t}}{\frac{Q_t}{P_t}}$= -0,0933.

The latter is obtained as follows:

$$\frac{dP_t}{dQ_t} = \frac{1}{\frac{\mathrm{dQ_t}}{\mathrm{dP_t}}} = \frac{1}{(\beta_1+\beta_{4DifTemp})} \qquad (31)$$

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

2.2.4 THE DEMAND FUNCTION OUTSIDE THE STRUCTURAL MODEL

In this section, the demand function is defined outside the framework of the structural model *strictu-senso*. The model will not only be developed for a single functional form[22], but the functional forms considered in the work of Genesove and Mullin (1998) will also be presented (linear, exponential, quadratic and exponential). The equations were adapted to this work in order to take into account independent variables other than price.

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[22] Following Genesove and Mullin (1998).

The results obtained, specifically in relation to price elasticity of demand, will be compared with each other and also compared with the 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.

2.2.4.1 DEFINITION OF EQUATIONS

The general functional form is given by the equation (32).

$$Q_{t(p)} = \beta(\alpha - P_t)^{\gamma} + \varepsilon_t \tag{32}$$

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

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

$$Q_{t(p)} = \beta(\alpha - P_t)^{\gamma} + \sum_{k=1}^{M} \beta_k W_{kt} + \varepsilon_t \tag{33}$$

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. It should be recalled that the independent variables are “electricity price”, “overnight stays”, “Diesel oil” and a dummy variable whenever the period under analysis includes the year 2006.

In this case, the price elasticity of demand for the linear form will correspond to:

$$\frac{\frac{dQ_t}{dP_t}}{\frac{Q_t}{P_t}} = -\beta_1 \frac{\bar{P}}{\bar{Q}} \tag{34}$$

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

$$\frac{\frac{dQ_t}{dP_t}}{\frac{Q_t}{P_t}} = -2\beta(\alpha - \bar{P}) \frac{\bar{P}}{\bar{Q}} \tag{35}$$

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

$$Q_{t(p)} = \beta(\alpha - P_t)^{\gamma} \prod_{k=1}^{M} W_{kt}^{\beta_k} + \varepsilon_t \tag{36}$$

Using logarithms:

$$lnQ_{t(p)} = \ln(-\beta) + \gamma \ln(P_t) + \sum_{k=1}^{M} \beta_k \ln(W_{kt}) + \varepsilon_t \tag{37}$$

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

$$\frac{\frac{dQ_t}{dP_t}}{\frac{Q_t}{P_t}} = \frac{dln(Q_t)}{dln(P_t)} = \gamma \tag{38}$$

In this work, the general equation for the exponential functional form is given by:

$$Q_{t(p)} = \beta e^{p_t \frac{\gamma}{\alpha}} \prod_{k=1}^{M} W_{kt}^{\beta_k} + \varepsilon_t \tag{39}$$

Using logarithms:

$$lnQ_{t(p)} = \ln(\beta) + \frac{\gamma}{\alpha}\mathrm{P_t} + \sum_{k=1}^{M} \beta_k \ln\,(W_{kt}) + \varepsilon_t \tag{40}$$

The price elasticity of demand corresponds to:

$$\frac{\frac{dQ_t}{dP_t}}{\frac{Q_t}{P_t}} = \frac{\beta\gamma(\alpha-P_t)^{\gamma-1}}{\beta(\alpha-P_t)^{\gamma}}\ p = \frac{\gamma}{(\alpha-P_t)}\mathrm{p} \cong \frac{\gamma}{\alpha}\overline{\mathrm{P}} \tag{41}$$

2.2.4.2 RESULTS

The regression of the demand function was performed for each functional form. As in the previous section, the results are only presented for regressions when the level of significance of the price variable is equal to or less than 5%. Only in these cases will the price elasticity of demand be used to resolve the equation (11). The tests performed are the same as those presented in the previous section. In each case, the model chosen is shaded in orange. The selection criterion is the level of significance of the “electricity price” variable. It should be noted that for the period January 1999 to December 2003 significant results were obtained for all the functional forms with the exception of quadratic forms.

LINEAR FUNCTIONAL FORM

Table 16 – Statistics and tests applied

	January 1999 - December 2003	January 1999 - February 2006	January 2004 - June 2007	January 1999 - June 2007
N.º Observations	48	72	42	90
GR^2	0.4933	0.7407	0.5069	0.31587
Sargan χ2 (3)	0.6208 [0.733]	6.1052 [0.047]	0.1219 [0.727]	0.3912 [0.822]
Serial Correlation χ2 (1)	0.00102 [0.975]	1.0626 [0.303]	3.8361 [0.050]	30.2981 [0.069]
Functional form χ2 (1)	0.1873 [0.665]	0.2240 [0.636]	1.0093 [0.315]	10.7329 [0.188]
Heteroscedasticity χ2 (1)	0.9998 [0.317]	2.9048 [0.088]	0.8800 [0.348]	0.77637 [0.378]

Table 17 – Chosen regression

	January 1999 - December 2003	
	Estimate	T-Ratio [Prob.]
Constant	-537.0519	-0.2067 [0.837]
P_t	-446.941	-2.420 [0.020]
$Dorm_t$	6.0365	1.944 6 [0.058]
$DifTemp_t$	156.3425	2.4853 [0.017]
$Diesel_t$	0.006949	6.8757 [0.000]

LOGARITHMIC FUNCTIONAL FORM

Table 18 – Statistics and tests applied

	January 1999 - December 2003	January 1999 - February 2006	January 2004 - June 2007	January 1999 - June 2007
N.º Observations	48	72	42	90
GR^2	0.5316	0.77414	0.5069	0.26067
Sargan χ2 (3)	1.4281 [0.490]	3.3414 [0.188]	0.1219 [0.727]	0.27512 [0.600]
Serial Correlation χ2 (1)	1.4665 [0.226]	0.4068 [0.524]	3.8361 [0.050]	11.2540 [0.001]
Functional form χ2 (1)	0.03592 [0.850]	0.1310 [0.717]	1.0093 [0.315]	0.06000 [0.806]
Heteroscedasticity χ2 (1)	3.1908 [0.074]	1.3175 [0.251]	0.880 [0.348]	1.1008 [0.294]

Table 19 – Chosen regression

	January 1999 - December 2003	
	Estimate	T-Ratio [Prob.]
Constant	-6.6898	-2.0853 [0.043]
$Ln(P_t)$	-0.098241	-2.1803 [0.035]
$Ln(Dorm_t)$	0.10104	2.4368 [0.019]
$Ln(DifTemp_t)$	0.041384	2.1857 [0.034]
$Ln(Diesel_t)$	1.0856	5.0425 [0.000]

EXPONENTIAL FUNCTIONAL FORM

Table 20 – Statistics and tests applied

	January 1999 - December 2003	January 1999 - February 2006	January 2004 - June 2007	January 1999 - June 2007
N.º Observations	48	72	42	90
GR^2	0.54375	0.6585	0.5649	0.50444
Sargan χ2 (3)	1.5991 [0.660]	3.9026 [0.272]	1.0471 [0.592]	1.0471 [0.592]
Serial Correlation χ2 (1)	1.5907 [0.207]	1.6272 [0.202]	3.1672 [0.075]	3.1672 [0.075]
Functional form χ2 (1)	0.6591 [0.417]	1.4912 [0.222]	0.00574 [0.940]	0.005739 [0.940]
Heteroscedasticity χ2 (1)	2.3468 [0.126]	0.08483 [0.771]	0.00159 [0.968]	0.001587 [0.968]

Table 21 – Chosen regression

	January 1999 - December 2003	
	Estimate	T-Ratio [Prob.]
Constant	-5.339	-1.9208 [0.061]
P_t	-0.030861	-2.2277 [0.031]
Ln($Dorm_t$)	0.099861	2.7127 [0.010]
Ln($DifTemp_t$)	0.034131	2.0502 [0.046]
Ln($Diesel_t$)	0.99384	5.4086 [0.000]

PRICE ELASTICITY OF DEMAND

The following table shows the price elasticity of demand calculated for the chosen periods and functional forms. The values presented for the different functional forms are close, being between -8.9% and -9.9%[23]. The value calculated for the structural model, for a linear equation[24], falls within this interval.

Table 22 – Price elasticity of demand

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

2.3 DEFINITION OF THE BEHAVIOUR VARIABLE

We will begin with a definition of the behaviour variable θ outside the structural model for the period 1999 to 2003, a period in which significant values were able to be obtained for the price elasticity of demand. The details of the estimate of its main variables, namely marginal cost, lie beyond the scope of this work, and only the main assumptions will be presented in this section. Later, the behavioural factor is estimated using the structural model for the same period, and the results obtained are compared with the results obtained outside this methodological framework.

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[23] Values around 10% are generaly considered (see for example Borenstein, et al. (1999))

[24] It is noted that in addition to this analysis we calculated the price elasticity of demand out of the Structural model, keeping the instrumental variables except the price of fuels that were considered without lag. In this case, the price elasticity of the demand is about -0.0847.

2.3.1 DEFINITION OF THE BEHAVIOURAL VARIABLE OUTSIDE THE STRUCTURAL MODEL FOR THE PERIOD 1999 TO 2003.

2.3.1.1 ASSUMPTIONS

The definition of the behavioural variable requires marginal cost to be defined. 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. This latter type of market corresponds to the uniform price market and is the type 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:

$$Cmgt = \frac{\sum_{h=1}^{n} Cmg_h Q_h}{\sum_{h=1}^{n} Q_h} \cong \frac{\sum_{h=1}^{n} Cv_h Q_h}{\sum_{h=1}^{n} Q_h} \tag{42}$$

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 intra-daily markets. In this way, the variable Q_h in equation (42) is known. However, the definition of the variable CV_h in this equation requires establishing a set of assumptions in order to enable:

1. Definition of the cost function variable associated with the technology/type of marginal power station, bearing in mind the nomenclature given by OMEL for the origins of the electricity that sets the market price.
2. Definition of the parameters that enable the cost variable to be calculated[25].

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[25] For this aim, we follow Steiner(2000), Wolfram(1999), between others.

In this context, the marginal cost for the system was calculated in the following 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 "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 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 inflow significantly below the average for the "dry" period of the water resources year. This approach is referred to as "marginal cost Portugal".

Parallel to this, when at a given hour *h*, of a month *m*, the power station supplying the closing price is defined as a conventional power plant by OMEL and if the cost variable is defined as corresponding at that hour to that of a fuel oil or coal power station, two different criteria are followed:

1. It is divided between the fuel oil or coal power station according to the average for electricity production for each of these technologies in the month *m* of the stated hour.[26]
2. It is defined as that of the fuel oil power station at the hours in which the amounts traded are above the hourly average for the respective year, and as that of the coal power station for the hours in which the amounts traded are above the hourly average for the respective year.

When power plants are defined according to criteria 2), the previous series are represented in this work as: marginal cost (a)'; marginal cost (b)' and marginal cost Portugal'.

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[26] This assumption is due to the fact that in power systems with nuclear power plants, such is the case of the Spanish system, coal power plants are, frequently, the marginal power plants.

2.3.1.2 BEHAVIOURAL FACTOR

In this section, the regression (20): $P_t = \frac{\overline{\mathrm{cmg_t}}}{(-\lambda+1)} + \mu_{t4}$ will be solved, in order to estimate the Lerner$\lambda\ index$, in which cmg_t is the marginal cost in the month t and, consequently, defines behavioural factor $\bar{\theta}$ by resolving equation (21): $\frac{\bar{\theta}HHI}{|\varepsilon|} = \lambda$.

ESTIMATE FOR LERNER INDEX

The Lerner Index is an indicator of the exercise of market power. Lerner Index trends may easily be associated with various external events. The increase in the Lerner Index from 2001 onwards coincides with the threat made by the European Union to the maintenance of 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.

A series of statistical tests were carried out, whose presentation lies beyond the scope of this work, showing that equation (20) is stationary and the autocorrelation of the remainders can be verified.

Table 23 shoes that the estimate for the Lerner Index presents high values of 0.2 or above, with the exception of the marginal cost b)' series. It should be noted that the existence of heteroscedasticity and autocorrelation of remainders led to an adjustment in the regression through the Newey-West variance matrix. It can also be noted that the regression in "marginal cost Portugal" presents results that are closer to reality.

An interpretation of these results requires the resolution of equation (21).

Table 23 - Results for the period 1999-2003

	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]**	-	-

	Marginal cost (a)'		Marginal cost (b)'		Marginal cost Portugal'	
	Coefficient	**T-Ratio [Prob.]**	**Coefficient**	**T-Ratio [Prob.]**	**Coefficient**	**T-Ratio [Prob.]**
λ	**0.3310**	**7.274 [0.000]**	**0.1412**	**2.139 [0.037]**	**0.3818**	**12.497 [0.000]**

DEFINITION OF THE BEHAVIOURAL VARIABLE DURING THE PERIOD 1999-2003

Thus, having made the estimates for the left-hand side of this equation in the previous section, the Herfindahl Index HHI[27] remains to be defined in order to estimate the behavioural parameter $\bar{\theta}$ during the period 1999-2003. Internalising an average HHI value[28] weighted by production equal to 30.5%, the estimates for the behaviour parameter $\bar{\theta}$ are presented in the following table.

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.

Estimates of the average value of the behavioural variable resulting from the resolution of equation (21) for the period under analysis, 1999-2003 are only presented for the linear demand function, as the price elasticity of demand presents values that are very close, regardless of the functional form of the demand function. It should be recalled that the estimated price elasticity of demand module was 9.33%.

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[27]. It’s important to refer that the Herfindahl was not calculated for Special regime producers. Nothwithstanding the production based on renewable sources is traded in the pool, in the period analysed their remuneration was independent from market price.

[28] By corporate group.

Table 24 – Behavioural variable by cost estimate for linear demand function during 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**	**0.127**

Marginal cost (a)'	Marginal cost (b)'	Marginal cost Portugal
0.101	**0.043**	**0.117**

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. In this work, despite the high mark-up, the results are inconclusive, and, with all the due care required by the application of the methodology for conjectural variables, the results for the marginal cost b) and b)' series indicate the existence of a competitive market.

2.3.2 THE SUPPLY FUNCTION EQUATION AND DEFINITION OF THE BEHAVIOURAL FACTOR WITHIN THE FRAMEWORK OF THE STRUCTURAL MODEL

Due to the problems in identifying structural models, in this context the supply equation must include the demand rotation component. Thus, equation (17) must be solved, represented in this case as:

$$P_t = \alpha_2 + \sum_{j=1}^{n} \beta_j \mathrm{Cmg}_j + \beta_8 Q_t - \theta \left(\frac{1}{(\beta_1 + \beta_4 DifTemp)}\right) Q_t + \varepsilon_t \qquad (43)$$

The *Cmg_j* variables represent the factors that enable the marginal cost to be calculated. The second variable on the right-hand 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 for this variable corresponds to the behaviour variable.

The marginal cost of the system is defined by the production costs of the power stations which set the closing price for the market.

The production of electricity is a capital-intensive activity in which investment costs represent a large part of the costs and variable costs correspond almost entirely to fuel costs.

As stated in the previous section, the power stations using conventional technologies which set the closing price are the coal and fuel oil[29] power plants, combined cycle natural gas plants and the hydroelectric power plants. Therefore the variables chosen to estimate the average marginal cost of the system are:

- The average monthly price of Brent oil with 3 months lag, Eur/bbl, which represents the cost of the natural gas combined cycle power s and the fuel oil 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. In addition, the price of oil is not immediately reflected in the marginal cost of the fuel oil plants, on the one hand, since this is a derivative and, on the other hand, due to the stock management policy in these centres.
- For coal power stations, the average monthly price, Eur/t, of coal with 3 months lag, in order to reflect the stock management policy.
- The hydraulicity coefficient, bearing in mind the importance of hydrological production.

These latter variables are exogenous to the model[30] and were included as instrumental variables in the previous equation.

Variables were chosen that are directly related to the theoretical marginal cost of the system, because this cost is not necessarily the actual marginal cost incurred. In the first case, the marginal cost only depends on factors which influence the variables cost production for the power stations which set the market prices: the average fuel prices and hydraulicity (hydrological inflows) for the month. In practice, the marginal cost of the system will also depend on technical restrictions and company strategies. These factors should be included in the behavioural variable λ. Equation (43) may therefore be re-written in the following way:

$$P_t = \alpha_2 + \beta_5 Oil_{t-3} + \beta_6 Coal_{t-3} + \beta_7 Hidr_t + \beta_8 Q_t - \bar{\theta}\left(\frac{1}{(\beta_1 + \beta_4 DifTemp)}\right) Q_t + \varepsilon_t \tag{44}$$

In which:

- Oil_{t-3}, is the average monthly price of Brent oil lagged 3 months.
- $Coal_{t-3}$, is the average monthly price of API#2 NW Europe coal lagged 3 months .
- $Hidr_t$ is the “hydraulicity” for the month t.
- $\bar{\theta}$, is the behaviour variable

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[29] Reuters data.

[30] As the T_2 Wu-Hausmann statistic present in the section shows.

However, it is debateable whether the marginal cost of the system function, which depends on fuel prices and hydro inflows, is a linear function. Nerlove therefore (1965) applied the Cobb-Douglas function when defining the production function for the electricity sector. Since then various functions have been applied, including Translog (for example, Christensen and Greene (1976) and, more recently, Maloney (2001)).

It was stated in the previous section that the marginal cost of the system is close to the variable cost of the power stations which set the closing price. These are the hydroelectric plants or power stations, according to hydro inflows. In this process of “choosing” between technologies, hydro inflows are taken to be external data. The choice between the power plants will be made by taking into account the competitiveness of each technology which, in turn, will directly depend on the relative price of each fuel. In this way, it was considered that the dual function of the Translog production function, i.e. the Translog function of the cost function, would be the most appropriate in this case. This inverse function generally includes the amounts produced. However, given the small size of the sample this approach may not be the most accurate as it implies a reduction in the degree of statistical freedom. Thus, as is the case with other authors (see, for example, Griffin and Gregory (1976)), it will only be applied separately to productive factors.

In this new framework, the relations shown in the equation (44) are revised in order to show the following variables:

$$P_t = P_t\left(\mathrm{Cmg_t}(\mathrm{fuel_t}, \mathrm{Hidr_t}), Q_t, \left(\frac{1}{(\beta_1+\beta_4 DifTemp)}\right) Q_t\right) \tag{45}$$

In which $\mathrm{Cmg_t}$ is the marginal cost function and $\mathrm{fuel_t}$ is the fuel function. The $\mathrm{Cmg_t}$ function is, in turn, given by :

$$\mathrm{Cmg_t} = (\mathrm{Fuel_t}(Oil_{t-3}, Coal_{t-3}), \mathrm{Hidr_t}) \tag{46}$$

The $\mathrm{Comb_t}$ function is applied to the dual Translog production function, i.e. to the Translog cost function, which shows the elasticity of substituting the two power station technologies:

$$\begin{aligned}\mathrm{lnFuel_t} = {} & \alpha_3 + \beta_9 \ln(Oil_{t-3}) + \beta_{10} \ln(Coal_{t-3}) + \\ & \tfrac{1}{2}(\beta_{11} \ln(Oil_{t-3})^2 + \beta_{12} \ln(Coal_{t-3})^2) + \beta_{13} \ln(Coal_{t-3}) \ln(Coal_{t-3})\end{aligned} \tag{47}$$

Thus, by using logarithms in equation (50) and integrating it into equation (52), the following is obtained:

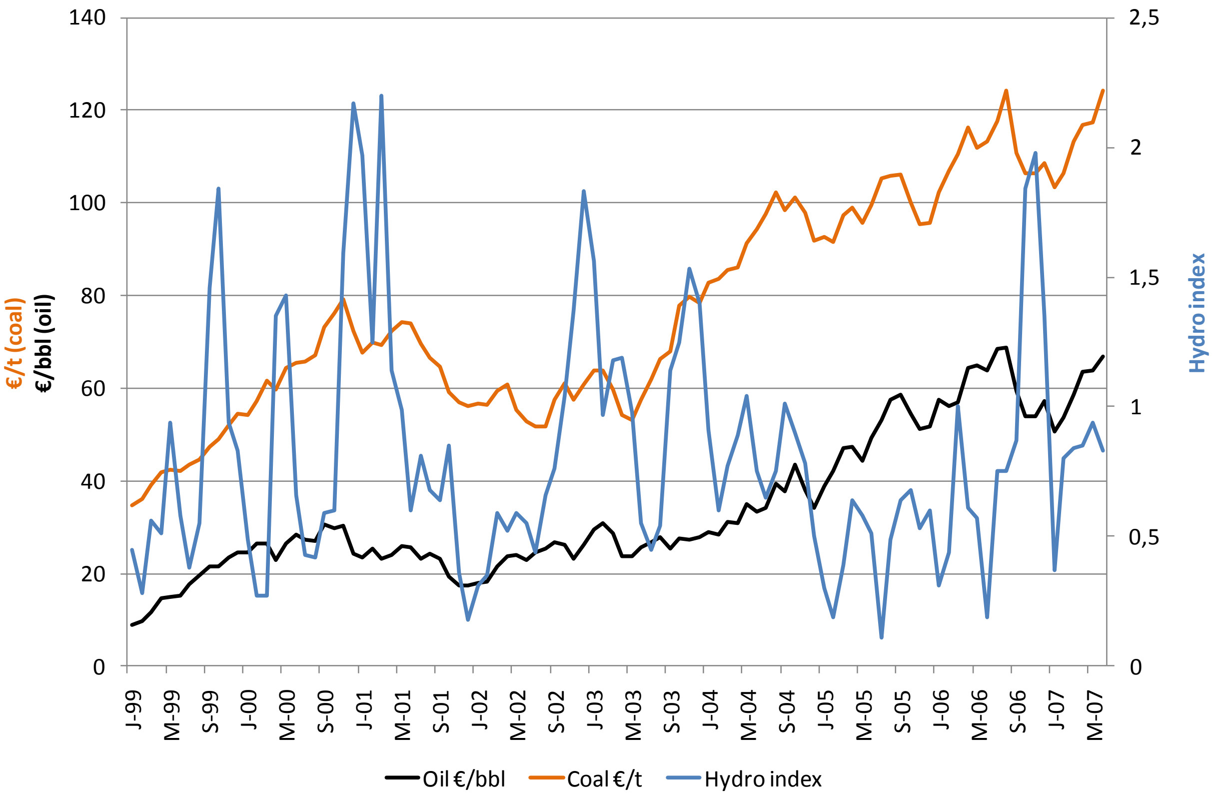
$$\begin{aligned} lnP_t = {} & \alpha_3 + \beta_9 \ln(Oil_{t-3}) + \beta_{10} \ln(Coal_{t-3}) + \tfrac{1}{2}(\beta_{11} \ln(Oil_{t-3})^2 + \beta_{12} \ln(Coal_{t-3})^2) + \beta_{13} \ln(Oil_{t-3}) \times \\ & \ln(Coal_{t-3}) + \beta_{14} \ln(Hidr_t) + \beta_{15} \ln(Q_t) - \bar{\theta}' \ln\left(\left(\frac{1}{(\beta_1+\beta_4 DifTemp)}\right) Q_t\right) + \varepsilon_t \end{aligned} \tag{48}$$

The behavioural variable $\bar{\theta}$ will be estimated for equations (44) and (48).

2.3.2.1 SUPPLY FUNCTION VARIABLES

Both the price of coal and the price of oil followed an upward trend during the period under analysis. It should be noted, however, that this trend was more mitigated during the period between January 1999 and December 2003, the period to which the model was applied. Hydro inflows, in turn, are characterised by instability around the unit.

Figure 2-4 – Variables which characterise marginal cost



The following table shows that there is little correlation between the variables[31].

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[31] The variable “Difference of temperature” is included in this analysis due to be one of the factors wich calculates the rotation variable, jointly with “quantities of electricity”.

Table 25 – Correlation coefficient for variables

	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 can be observed that the average value for hydro index was only 0.82 during the period under analysis, which was particularly dry.

Table 26 – Descriptive statistics for 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

2.3.2.2 STATIONARITY OF THE SUPPLY FUNCTION

The following tables show that the hydro coefficient is the only stationary variable which defines marginal cost.

Table 27 –ADF tests - 102 observations

	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	-1.086	-1.947	-1.882	-2.339	-5.089
Critical value for the ADF statitistic	-2.892	-3.457	-2.892	-3.457	-2.892

Table 28 –ADF tests - 86 observations

	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 oil and coal price variables are are integrated of order 1.

Table 29 –ADF tests for order 1 variables - 101 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	-8.731	-8.692	-7.048	-7.014
Critical value for the ADF statitistic	-2.892	-3.458	-2.899	-3.467

Table 30 – ADF tests for order 1 variables - 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 Johansen's method for a VAR model of order 1 indicated by information criteria, the statistics presented in the following tables 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.

In this way, 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: $Petr_{t-3} - Carv_{t-3} \sim I(0)$.

Table 31 – Statistics for the Maximal Eigenvalue (86 observations) 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 32 – Trace statistics (86 observations) 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

2.3.2.3 INSTRUMENTAL VARIABLES

Within the framework of the structural model, equation (51) is solved using the 2-Stage Least Square method. Thus the identification of this equation requires that the exogenous variables defined in the other equation in the model should be considered instrumental variables. It should be recalled that these variables were "overnight stays", "temperature differences" and "Diesel oil"[32]. The latter can already be found indirectly in equation (51), in

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[32] As see, this variable is not truely exogenous of the model. This is the reason why the variable was substitute by instrumental variables defined for the quantity of electricity and the diesel fuel consumption (GDP, Industrial production index and diesel fuel).

the demand variable rotation. So instead we used the average monthly temperature. It may be noted that this variable may also serve as an instrumental variable for the hydraulicity coefficient.

With regard to the variables which set marginal cost, the dynamic character of the existing relations in the case of the seasonality of fuel prices and the establishment of stock were considered, in addition to the periodicity (alternating wet and dry periods) of hydro inflows. Thus, in addition to the variables already mentioned, the following instrumental variables were considered:

- "Hydraulicity coefficient" lagged 3, 6 and 12 months.
- "Average coal price" lagged 12 months.
- "Average oil price" lagged 12 months.

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 33 – T_2 Wu Hausman and remainder tests

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 is important to note that the inclusion of fuel price variables 12 months lagged, together with the hydraulicity index with several lags, in equation (51) was tested. However, it was decided to include this with the instrumental variables since these variables are not significant to the model and also because the behavioural variable was not significant in any of the cases. It must be stressed that the test for the overestimation of instrumental variables allowed the null hypothesis that all instrumental variables were exogenous not to be rejected.

2.3.2.4 RESULTS

LINEAR FUNCTION

Various models were tested for the different instrumental variables whose use was considered predictable given the variables in equation (51).The model chosen presents a level of significance of less than 10% for the rotation of the demand, which can be interpreted as robust in the statistical tests that were carried out.

In this model, for 48 observations (up to December 2003), the variables were not very significant, specifically those relating to fuel prices. However, by extending the series to February 2006 (72 observations), all the variables became 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. It is close to the value obtained when analysis is performed outside the structural model for the marginal cost b) simulation excluding the period November 2002 to February 2003.

Table 34 – Statistics and tests applied

	January 1999 - December 2003	January 1999 - December 2003
N.º Observations	48	72
GR^2	0.31288	0.58631
Sargan χ2 (3)	2.0739 [0.355]	0.5188 [0.972]
Serial Correlation χ2 (1)	3.5441 [0.060]	8.8147 [0.003]
Functional form χ2 (1)	0.03194 [0.858]	0.01989 [0.888]
Heteroscedasticity χ2 (1)	0.4663 [0.495]	0.2584 [0.611]

Table 35 – Regression chosen

	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]

FUNCTION BASED ON THE TRANSLOG MODEL

Initially the Translog model was applied to the variables defined for the linear model. The resulting O model is called the “base logarithm model” in this text.

Table 36 – Results of applying the base logarithm model

	Coefficient	T-Ratio [Prob.]
Constant	32.1171	0.4287 [0.670]
a_1	-1.947	-0.07377 [0.942]
a_1^2	3.8156	0.4916 [0.626]
a_2	2.947	-
a_2^2	2.5758	-
a_1 x a_2	-6.3914	-0.36100 [0.720]
a_3	-0.041962	-0.04785 [0.962]
a_4	-0.22805	-0.3100 [0.758]
a_5	-3.4457	-0.4350 [0.666]

In which,

- a_1, is the coefficient of the logarithm for the “oil price” variable, with 3 months lag.
- a_2, is the coefficient of the logarithm for the “coal price”, with 3 months lag.
- a_3, is the coefficient of the logarithm for the “hydraulicity” variable.
- a_4, is the coefficient of the logarithm for the demand “rotation” variable.
- a_5, is the coefficient of the logarithm for the “amount of electricity” variable.

The instrumental variables in this model correspond to the logarithms for the instrumental variables in the model defined in the previous section.

The demand “rotation” variable is not significant in this model, although the statistics indicate that the model is robust.

Table 37 – Statistics and tests applied to the base logarithm model

N.º Observations	48
GR^2	0.28484
Sargan χ2 (3)	0.2054 [0.902]
Serial Correlation χ2 (1)	0.9603 [0.327]
Functional form χ2 (1)	0.08111 [0.776]
Heteroscedasticity χ2 (1)	0.08040 [0.777]

3 CONCLUSIONS

Structural models require analyses to be formulated with great accuracy, since they depend on a complex theoretical framework which involves the definition of balanced economic relationships such as the definition of the functional forms of the equations which comprise the model. In applying this methodology to the analysis of the exercise of market power, the methodological rigour associated with structural models may make it difficult to obtain results that consistently prove its existence. In this case, 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. Moreover, the value obtained for the behavioural variable, which is close to that of a competitive situation, is close to the results obtained outside the framework of the structural model, on the basis of estimates of marginal costs for production. However, the results are restricted to the period between 1999 and 2003, as a result of the changes which took place in the structure and functioning of the market from 2004 onwards, which removed the market from a state of balance.

It is important to focus with greater care on the results for the behavioural component.

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 electricity production, the exercise of market power will occur naturally in these markets, and this trend is very often impeded due to its framework. Typically, 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.

This study also points in this direction. The result of the structural model[33] supports the apparently competitive nature of the market analysed for the period 1999 to 2003, despite than fact that the Lerner index average was high during this period, although not as high as would have been expected given the high concentration and low price elasticity of demand. Similar results were obtained when the behavioural variable, within the theoretical framework of conjectural variables, was determined directly on the basis of estimates of marginal costs.

It will therefore be important in future work to analyse whether the high average mark-up verified accords with the CTCs which frame the activities of the electricity producers. The CTCs have the characteristics of contracts for difference[34]. In this way, the profit maximisation function (2) will have to be revised, given that during the exercise of this mechanism it would be expected that the average mark-up would be close to 0 and the results calculated for the behavioural variable will probably be different.

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[33] Noticed that the robustness of the results obtained for the price elasticity of demand based on the strucutural model was corroborated when the variable was estimated outside the model and for different functional forms of the model.

[34] At least on average (see Iberdrola case and the analysis of Fabra & Toro, 2005).

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