Price Wars and Collusion in the Spanish Electricity Market*

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Abstract

We analyze the time-series of prices in the Spanish electricity market by means of a time varying-transition-probabilities Markov Switching model. Accounting for demand and cost conditions, we show that the time-series of prices is characterized by two significantly diff

1 Introduction

During the last decade a wave of reform has swept across many of the formerly regulated electricity industries. Electricity markets have been created in Britain, Norway, Sweden, the United States, Australia, Argentina, and Spain, to name but a few. The details differ from country to country, but the different processes of reform share some common features. These include the breaking up of the formerly vertically integrated companies; the unbundling of generation, transmission, distribution and retailing; the reliance on spot markets as a means to allocate production and determine prices; and the design of new institutional mechanisms to govern access to the transmission network.

This new form of regulation has given rise to a new set of problems associated with the achievement of efficiency goals. The extent to which firms can exercise market power is one of the issues that has attracted most of the attention of researchers and practitioners alike. While most of the literature on market power in electricity markets has focused on the analysis of strategic behavior in static settings, little attention has been devoted to the analysis of dynamic strategic behavior.[1] Nonetheless, both theory and experience suggest that the daily repetition of electricity auctions might have a dramatic effect on market performance. In a dynamic setting firms may learn to coordinate their strategies, and hence compete less aggressively with each other over time, through collusive agreements. Understanding dynamic behavior is important for the design of new rules that reduce the scope of market power.

In this paper we examine the dynamic interaction among the Spanish electricity producers using the time-series of prices and firms' market shares during 1998. Unlike previous studies, it is not our aim to measure market power through the direct estimation of price-cost margins (see Borenstein, Bushnell and Wolak (2003), Borenstein and Bushnell (1999) and Wolfram (1998, 1999), among others). Although highly illustrative, this approach is faced with some problems. First, reliable data on firms' marginal costs may not be available. Second, computing the costs that would result in a competitive market is complex due to the stochastic nature of these costs and the intertemporal links associated with the operation of some production units (specially so, in systems where hydro resources abound, such as Spain). Last, it is arguable whether marginal cost pricing should be taken as a benchmark to measure market power given that, in the presence

[1] There are some exceptions to the literature involving static models in electricity markets: Fabra (2003) constructs a dynamic bidding game to compare the sustainability of collusion in electricity markets organized as either uniform or discriminatory auctions; Garcia, Reitzes and Stacchetti (2001) introduces the intertemporal linkages brought about by the storability of hydro power; and Puller (2000) performs an empirical analysis of collusion in the Californian electricity market.

of capacity constraints, even the one-shot equilibria would result in prices exceeding marginal costs (see Kreps and Scheinkman (1983)).

Instead, our approach exploits changes in prices and firms' market shares over time in order to infer the potential to exercise market power in a dynamic context.[2] The time-series of prices in the Spanish electricity market during 1998 shows an anomalous behavior, characterized by the occurrence of six to seven episodes during which prices drastically fall below their usually prevailing level. These episodes, which seem to be uncorrelated with demand movements, are preceded by changes in the major firms' market shares. The static models of price competition in electricity markets (see Green and Newbery (1992) and von der Fehr and Harbord (1993)) are not suitable to explain this phenomenon, as they all predict a positive relationship between demand conditions and prices, once the differences in cost conditions have been accounted for. The outburst of these periods of intense rivalry thus seems to suggest that firms have followed more complex dynamic strategies than the simple repetition of the static one-shot equilibria.

The regime-switching models of the type pioneered by Green and Porter (1984) provide a possible explanation for what we observe in the Spanish data set (see also Abreu, Pierce and Stacchetti (1986)). In these models, firms move between cooperative and punishment periods (price wars) as a way to enforce collusive outcomes. Under imperfect monitoring (i.e. imperfect information about firms' past actions or market conditions), firms are unable to distinguish whether changes in the observable variables are due to changes in market conditions or to cheating by one of the cartel members. Thus, in order to discourage deviations, reversions to some short-run unprofitable behavior must be employed when one of the observable variables behaves *as if* a deviation had occurred.

The Spanish electricity market does not precisely correspond to the Green and Porter's (1984) formulation. In particular, the source of imperfect information does not come from the unobservability of demand, as its realized value is made public at the end of the bidding process. The existence of imperfect information in the Spanish electricity market derives instead from the unobservability of firms' available capacities, as they are subject to random and publicly unknown shocks, out of firms' control (e.g. capacities may suffer unforeseen outages, or be increased due to an excess of hydro resources[3]). This fact has an important implication: for any firm, a departure

[2]See Bresnahan (1998) for a review of the New Empirical Industrial Organization, which exploits similar techniques.

[3]These are the so-called run-of-the-river resources, i.e. when the dams are already at full capacity, firms cannot stop the water that comes in from flowing over the dam. These resources are of great importance in the Spanish system, specially during winter.

in its market share from its collusive allocation could be the result of either cheating by a competitor, or of a shock suffered by one of its rival's capacity.[4] In other words, firms in the Spanish electricity market are faced with the same kind of signal extraction problem as the one in Green and Porter's model.

There is an alternative branch of the literature on collusion in markets subject to variable demand, exemplified by the models of Rotemberg and Saloner (1986) and Haltiwanger and Harrington (1991). In these models, which assume perfect monitoring, price wars do not arise as equilibrium phenomena. Instead, the sustainability of collusion is maintained through smoother price adjustments, which depend on current or future demand conditions. We believe that the Green and Porter's theory is better suited to explain dynamic behavior in the Spanish electricity industry, for several reasons. First, as explained above, the fact that capacities are subject to unobservable shocks makes perfect monitoring an unrealistic assumption in this market. Second, in Rotemberg and Saloner (1986), future demand movements are unpredictable, whereas electricity demand is driven by a strong seasonal pattern. Third, the existence of tight capacity constraints might have an impact on both punishment and deviation profits that may reverse the predictions made by Haltiwanger and Harrington (1991) concerning the sustainability of collusion over the demand cycle (see Fabra (2001)). Last, price movements in the Spanish case resemble more the price wars phenomena described in Green and Porter rather than the smooth and cyclical price adjustments in Rotemberg and Saloner (1986) and Haltiwanger and Harrington (1991).

Therefore, our aim is to assess whether the behavior of pool prices in the Spanish electricity market is consistent with some kind of dynamic interaction, as the one predicted by Green and Porter's theory. For this purpose, we first construct a simple theoretical model that introduces some of the specific rules of the auction process (mainly, the existence of Stranded Cost Recovery Payments). This model unveils firms' one-shot bidding incentives, and allows to uncover some of the possible variables (referred to as *trigger variables*) that firms could be using to discourage deviations in order to support collusive strategies of the Green and Porter type. We then model the pattern of pool prices by means of an autoregressive Markov Switching model in the mean with time varying transition probabilities. This process allows for distinct price-cycle phases, with the switching probabilities depending on the trigger variables identified within the theoretical framework. The statistical model thus enables us to test whether the pattern of prices is characterized by different price levels, whether the effects of the trigger variables are statistically significant,

[4]Due to the complexity of the bidding process, involuntary mistakes may also lead to similar phenomena.

and whether the signs of these effects coincide with those predicted by the simple bidding game.

Our results support the hypothesis that two distinct price levels characterize the time series of prices in the Spanish electricity market during 1998. Furthermore, most of the triggers considered appear significant and they report the predicted signs. In particular, we find that the decrease in one of the major generator's market share and the increase in all firms' market revenues appear as plausible triggers for price wars. By interpreting the effects of the triggers, we are able to infer some of the properties of the collusive strategy that firms might have followed. Last, as we explain in more detail in Section 3, the results also support the view that firms' pricing behavior has been highly influenced by the recovery of Stranded Costs and the way in which these have been reimbursed. In summary, our results suggest that the Spanish electricity producers might have been alternating between episodes of collusion and price wars, giving strong support to Green and Porter's theory.

While there are some differences, we follow similar techniques as previous empirical analysis of dynamic interaction (see Porter (1983, 1985), Coslett and Lee (1985), Ellison (1994) and Hajivassilou (1999)). Porter (1983, 1985) investigates the stability of the 18th century US railroad cartel by means of a simultaneous equation switching regression model where the intercept in the industry supply equation is allowed to change according to a Bernoulli distribution. Porter's data set and methodology have been reworked in subsequent studies. Both Coslett and Lee (1985) and Ellison (1994) introduce serial correlation in the switching process, thereby allowing for persistence in the state of prices (in contrast to Porter's model). These studies find evidence of switches in firm conduct between punishment and collusive phases, and thus give additional empirical support to the Green and Porter model. However, the analysis of the variables that trigger price wars has received little attention or poor statistical support, despite it being central to the theory (see Porter (1985) and Ellison (1994)).

Our paper contributes to the existing literature in several respects. First, as far as we are aware of, it constitutes one of the few empirical analyses of collusion in the electricity industry.[5] The underlying bidding game from which we derive our empirical predictions is also one of the few that captures the effect that Stranded Cost Recovery payments have on firms' bidding behavior

[5]Again, an exception is Puller (2000), who assesses the applicability of the models developed by Rotemberg and Saloner (1986) and Haltiwanger and Harrington (1991) in the California's electricity market. He testes for the statistical significance of some variables that capture the relationship between current and future demand conditions. For most of the time span of his analysis, he rejects the hypothesis of efficient collusion.

(and probably the only one that considers their effects in dynamic bidding games).[6] Furthermore, our empirical results give more support to the Green and Porter model than previous studies - in both Porter (1985) and Ellison (1994) the triggers considered reported opposite signs to those predicted by the theory, or they did not appear to be significant.-

This paper is structured as follows. In Section 2 we briefly describe the Spanish electricity industry. In Section 3 we construct a simple theoretical model of the Spanish electricity market. In Section 4 we present the econometric approach and in Section 5 we interpret the results in the light of the theoretical predictions. Section 6 of the paper concludes.

2 The Spanish Electricity Industry

2.1 Market Rules

In 1997, the Spanish electricity industry experienced a process of fundamental change. It evolved from a system in which the allocation of output among the electricity producers was based on yardstick competition to one that relied on market forces as a way of finding the most economic use of the available resources. Under the current regulatory design, transactions are organized through a series of sequential markets -the daily market and the intradaily markets- and technical processes governed by the System Operator.

The daily market concentrates most of the transactions.[7] All available production units, excluding those already committed to a physical contract, are obliged to participate in it as suppliers. They are asked to submit, each day on a day-ahead basis, the minimum prices at which they are willing to make their generation available in each of the 24 hourly markets.[8] The demand side is made of the distributors and qualified consumers, who are also required to submitl a ibuA CC

decreasing merit order, respectively. The intersection between the industry supply and demand curves determines the market clearing price (the so-called System Marginal Price or SMP), which will be received (paid) by all suppliers (demanders) which offered to supply (consume) at lower or equal (greater or equal) prices. The System Operator has the responsability of studying and solving the technical constraints that may have derived from the daily market. Closer to real time, the intradaily market sessions allow market participants to fine-tune their positions previously undertaken in the daily market. The physical balance in the network between the production and the consumption of electricity is ensured at all times by the System Operator through the ancillary services markets.

Generators have three potential sources of revenues: market revenues, capacity payments, and stranded cost recovery payments.[9] Firstly, as already described, a generator may earn revenues through the daily, intradaily and ancillary services markets; in these markets, each generator's revenue is given by the market clearing price in the relevant demand period, times its quantity despatched. Secondly, all the production units that have participated in the daily market are entitled to obtain a capacity payment. Given that the capacity payment remained constant over the time span we analyze and given that firms earn capacity payments independently of their pricing decisions, these payments should have no impact on the pattern of prices. We will therefore omit them from our analysis.

Last, the incumbent generators are entitled to earn the so-called Competition Transition Charges (CTC) during a ten-year period. These charges are in place to compensate firms for the value of their stranded investments. The maximum amount of these payments[10] was computed as the difference between the net present value of the revenues that firms were entitled to receive under the old regulatory regime and firms' expected revenues in the market place, assuming that the competitive price would be equal to 6 PTAS/kWh.[11] The amount of CTCs to be paid to the whole industry in a particular year is computed as follows: the government fixes the retail price to be paid by non-eligible consumers; from this fixed amount, the costs incurred by the distribution companies in their market transactions, plus the regulated costs of distribution and transmission and the subsidies to the consumption of national coal are extracted; the residual

[9]Firms also receive subsidies for the consumption of national coal.

[10]This maximum level of CTCs payments was fixed at 1.988.561 millions pesetas, 295.276 of which were subsidies to national coal, and the rest was the maximum to be divided among the incumbent firms. In 1998, firms perceived CTCs which amounted to 105.385 millions of pesetas.

[11]This threshold is applied to the final price, which results from summing the SMP plus capacity payments, the costs of distribution and transmission and other regulated components.

Firm/ Technology	Hydro	Coal	Fuel-Gas	Nuclear	TOTAL	Shares
Endesa	6.048	6.461	3.990	3.518	20.017	45.8
Iberdrola	8.333	1.217	3.277	3.254	16.080	36.8
Union Fenosa	1.733	1.986	784	749	5.252	12.0
Hidrocantabrico	430	1.574	13	165	2.162	5.0
TOTAL	16.524	11.238	8.214	7.686	43.662	100.0
Shares	37.9	25.7	18.8	17.6	100.0	

Table 1: Installed Capacity by Firm and Technology, 1998 (GW)

amount is shared among firms on the basis of some predetermined shares.[12,13]

2.2 Market Structure and Technology Shares

The Spanish electricity generation market is highly concentrated. Prior to the regulatory reform of 1997, the industry was already consolidated as a four-firm oligopoly, where the two largest participants - Endesa and Iberdrola - controlled almost the 80% of total available generating capacity, and the remaining 20% was divided between two smaller firms -Unión Fenosa and Hidrocantábrico- and several fringe companies.

In terms of the technology structure, it should be noted that hydro power represents more than one third of total available capacity. This implies that industry costs will be highly influenced by the stochastic value of hydro reserves. In addition, technology resources are not evenly distributed across firms: whereas most of the hydro resources are in hands of the major producers, the smaller producers' assets are mainly thermal.

Table 1 summarizes the capacity shares by company (last column) and technology type (last row) in the Spanish electricity market.

[12] These were fixed at 51.2% for Endesa, 27.1% for Iberdrola, 12.9% for Unión Fenosa and 5.7% for Hidrocantábrico. See Section 3 for an analysis of the role played by these shares.

[13] Furthermore, two conditions are imposed on the value of the CTC payments received by a firm over the transition period. First, this amount can never exceed the maximum entitlement established by Law. And second, from the maximum amount of CTCs a firm is entitled to, one must extract the excess (if positive) of its market revenues over the revenues that such a firm would have received with an average final price of 6 PTAS/kWh. See Lasheras (1998) and Garcia-Martin (1999) for a more detailed description.

2.3 The Pattern of Prices and Market Shares during 1998

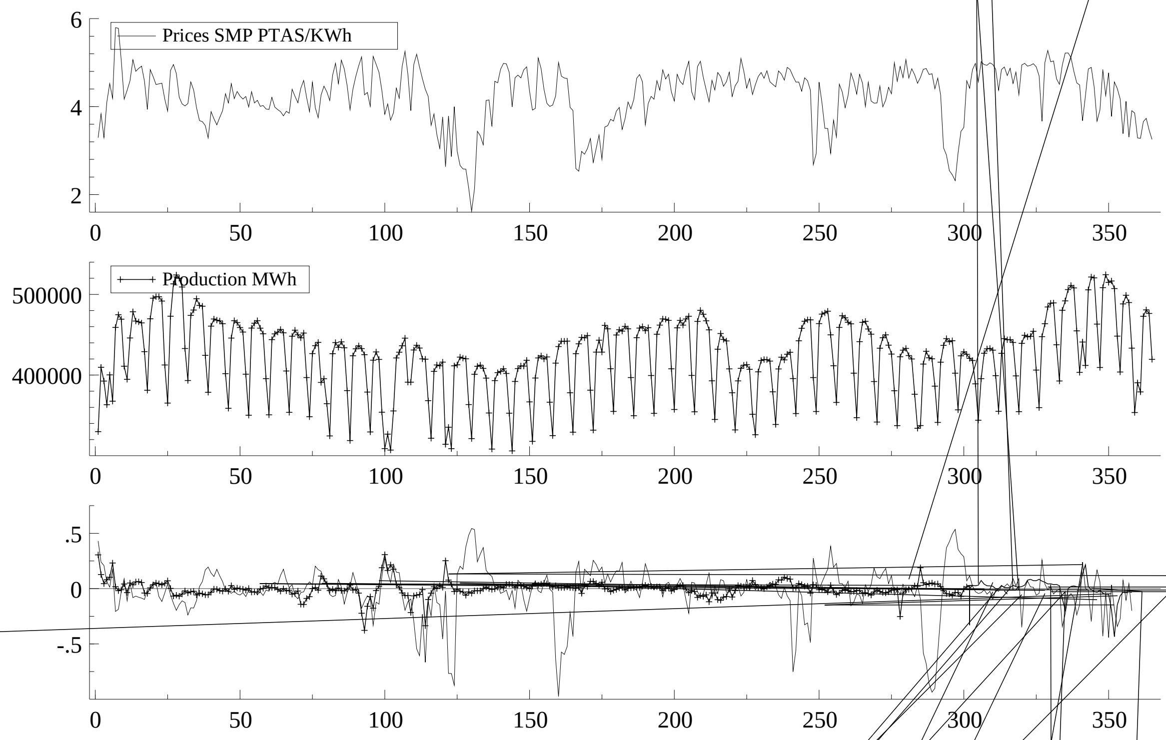
The pattern of prices and the changes in firms' market shares are probably the two most striking features that characterize the evolution of the Spanish electricity market during 1998. As can be seen from Figure 1, prices show a systematic relationship with the evolution of demand during most of the time. However, they depict five to seven drops that seem to be uncorrelated with movements in demand. We will refer to these phases as price wars, i.e. periods in which prices fall below the usually prevailing level, where the drop in prices cannot be explained by changes in demand or supply conditions.

Figure 2 depicts the pattern of market shares during 1998. During January, the two major generators, Endesa and Iberdrola, evenly shared the 80% of the market. During the remaining months of the first half of the year, the market shares of the dominant generators are characterized by high volatility, with both firms' market shares moving in opposite directions. After the second semester of the year, Endesa and Iberdrola's market shares seem to have converged to a more steady state, with Endesa's share reaching almost a 50% of the market as opposed to Iberdrola, whose market share was reduced to the 30%. The market shares of Unión Fenosa and Hidrocantábrico stayed roughly constant over the year, with the exception given to the periods in which their nuclear and thermal stations were off due to maintenance reasons.

Last, Figure 3 plots the ratio of Endesa's and Iberdrola's market share on the pattern of prices during 1998. A visual analysis shows that price wars are preceded by drastic changes in the two major generators' market shares.

3 The Theoretical Framework

In this section we develop a simple model of the Spanish electricity market with four main objectives. First, to identify firms' one-shot bidding incentives. Second, to derive the industry supply equation that will be the basis for the empirical analysis. Third, to construct reasonable triggers upon which a collusive equilibrium of the Green and Porter type of model could be based. And last, to obtain some predictions concerning the effects of the trigger variables on the probability of starting a price war, and their interpretation. The validity of the Green and Porter model to accurately describe firms' dynamic behavior in our data set will be assessed in the light of our theoretical predictions.


Prices SMP PTAS/KWh
Production MWh

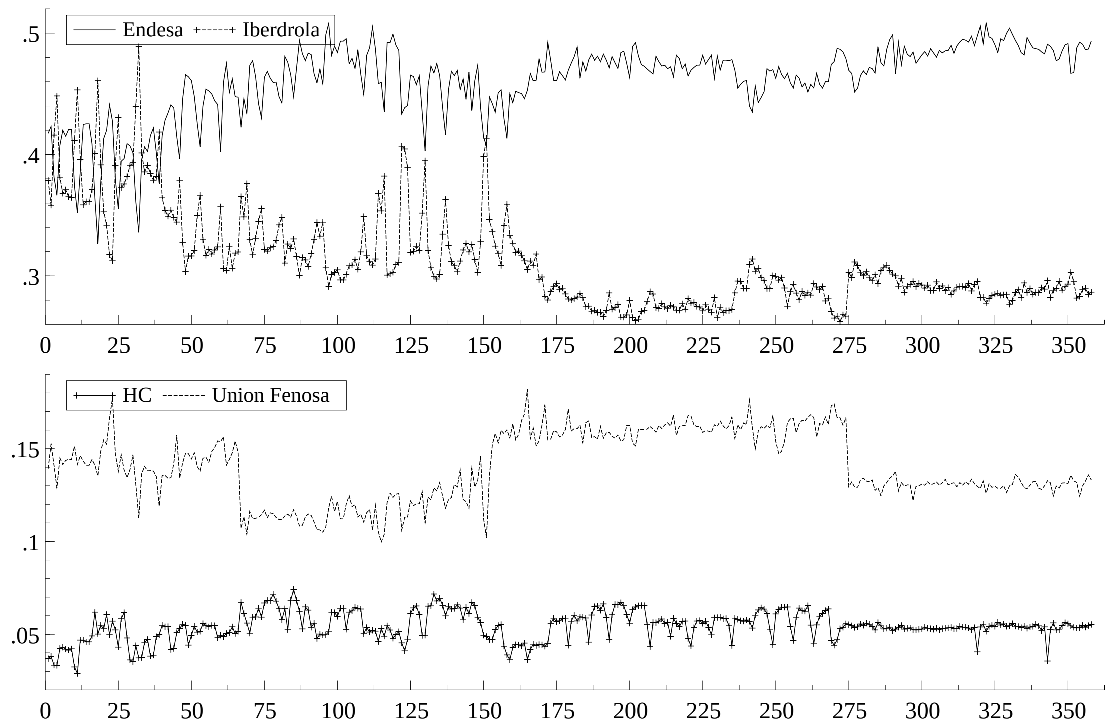


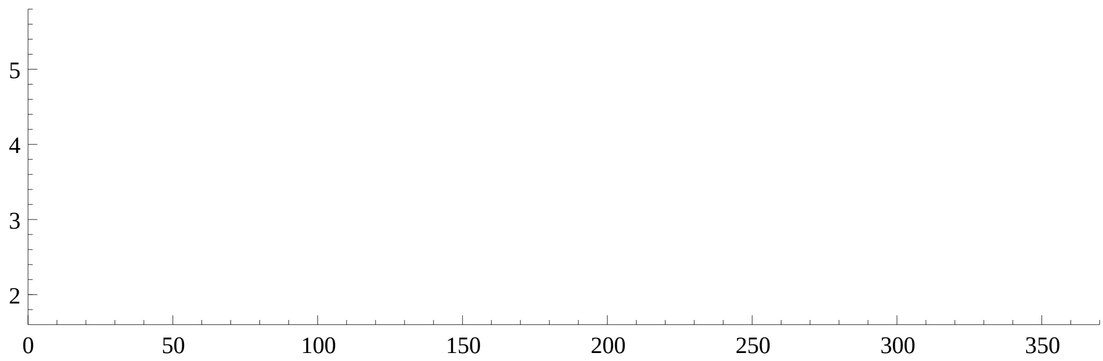
Figure 2: Market Shares, 1998

submitted their supply functions, the auctioneer selects the minimum price such that the market clears and each generator is producing on its supply function, i.e. the market price in period t, P_t, is the minimum price that solves $Q_t = \sum_{i=1}^{n} S_{it}(P)$. The market clearing condition then implies that the net demand facing generator i in period t when the other firms j have supply schedules $S_{jt}(P)$ is $Q_t - \sum_{j\neq i} S_{jt}(P)$. All scheduled production is paid at the market price.[15]

In the Spanish electricity market, generators have an additional source of revenues, namely, the revenues accrued from the Competition Transition Charges (CTC). These payments are determined as the difference between the (fixed) retail price τ and the market price P_t, times the total quantity demanded, $[\tau - P]\, Q_t$. This amount is shared among generators on the basis of some predetermined shares, α_i, $i = 1, ..., n$, with $\sum_{i=1}^{n} \alpha_i = 1$.[16]

[15]See Green and Newbery (1992) for an analysis of competition in electricity markets via supply functions.

[16]Note CTC payments play the same role as hedge contracts. With this interpretation, the parameter τ would represent the contract price and $Q_t\alpha_i$ the contracted quantity by generator i. Conceptually, the main difference between these two interpretations is that whereas CTC shares are exogenously given by regulation, contract coverage is an endogenous variable. Wolak (2002) demonstrates the influence that a generator's contract position has on its bidding incentives.


5
4
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250
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350

Using $\mu_{it} = \frac{\partial \sum_{j \neq i} Q_{jt}(P)}{\partial P} \frac{P_t}{Q_{it}} > 0$ to denote the price-elasticity of the residual demand faced by generator i in period t, Equation (2) can be rewritten as

$$P_t = MC_{it} + \frac{P_t}{\mu_{it}} \left[\frac{m_{it} - \alpha_i}{m_{it}} \right] \tag{3}$$

Equation (3) shows that a firm's bidding incentives are highly influenced by the difference between its market share and its CTC share. Whenever a firm i's market share is greater (lower) than its CTC share, the price that solves firm i's profit maximizing condition is above (below) its marginal costs. This implies that those firms for which the difference $[m_{it} - \alpha_i]$ is positive will have less incentives to bid aggressively as compared to those firms for which such a difference is negative.

Furthermore, the price elasticity of the residual demand curve faced by firm i, μ_{it}, determines the extent of market power that it is able to exercise. If the residual demand is perfectly elastic (very large μ_{it}), firm i will optimally bid at marginal costs, whereas if the residual demand is completely price-inelastic (e.g. μ_{it} is close to zero), firm i will optimally bid to maximize its profits over the residual demand.[17] Thus, the less elastic the residual demand (equivalently, the steeper its rivals' supply functions are), the more important will be the difference $[m_{it} - \alpha_i]$ in determining a firm's bidding incentives.

To simplify notation, we rewrite Equation (3) as

$$P_t = MC_{it} + P_t \Theta_{it} \tag{4}$$

where

$$\Theta_{it} = \frac{1}{\mu_{it}} \frac{m_{it} - \alpha_i}{m_{it}}.$$

Solving (4) for Θ_{it},

$$\Theta_{it} = \frac{P_t - MC_{it}}{P_t}$$

shows that Θ_{it} is firm i's price-cost margin, whose magnitude depends on both the elasticity of firm i's residual demand and on the difference between its market share and its CTC share. Note that a negative mark-up is not inconsistent with profit maximizing behavior, and that it does not imply the absence of market power.

[17]These two extreme cases correspond to the Bertrand and Cournot models. See Wolak (2002) for a particularly clear explanation of this.

3.1.1 Deriving the Industry Supply Equation

Before moving into the analysis of the collusive strategies, let us exploit the information provided by firms' profit maximization problem to derive the industry supply equation that will be used in the econometric analysis of Section 4. For estimations purposes, we will employ aggregate data and therefore use the individual supply curves to construct a supply curve at the industry level. Taking the average of Equation (4) over all firms, the supply relationship at the industry level can be written as

$$P_t = MC\left(Q_t, \mathbf{Z}_t\right) + P_t\Theta_t$$

where $MC\left(Q_t, \mathbf{Z}_t\right)$ represents the industry marginal cost function, and Θ_t gives the average industry price-cost margin.

In order to get a structural form for the supply equation, we let industry variable costs take the form

$$C\left(Q_t, \mathbf{Z}_t\right) = Q_t^{\delta}\mathbf{Z}_t^{\lambda}$$

where $\mathbf{Z}_t$ are cost shifters and δ and λ are the constant elasticity of variable costs with respect to output and to the demand shifters, respectively (note that δ should exceed one for marginal costs to be non-decreasing in output, and λ should be negative or positive depending on whether $\mathbf{Z}_t$ is a downward or upward cost shifter). The supply equation at the industry level can then be written as

$$P_t = \frac{\delta Q_t^{\delta-1}\mathbf{Z}_t^{\lambda}}{1-\Theta_t}. \tag{5}$$

Taking logs in both sides of the supply Equation (5),

$$\log P_t = \beta_0 + \beta_1 \log Q_t + \beta_2 \log \mathbf{Z}_t - \log\left(1-\Theta_t\right) \tag{6}$$

By construction, the parameters $\beta_0 = \log\delta$ and $\beta_1 = (\delta - 1)$ should be positive given $\delta > 1$; and the parameter $\beta_2 = \lambda$ should be either negative or positive depending on whether the variables $\mathbf{Z}_t$ are downward or upward cost shifters. Last, note that the last term of the Equation, $-\log\left(1-\Theta_t\right)$, will have an impact on the mean of prices, which will be positive or negative depending on the sign and magnitude of Θ_t.

3.2 The Dynamic Bidding Game

First, a caveat. In standard unregulated markets, the sustainability of collusion allows firms to raise joint revenues above the one-shot equilibrium level. The particular way in which the Spanish

electricity market is regulated stops this from happening, given that firms' total revenues are fixed and independent of spot market prices.[18] An increase in market prices raises market revenues, but this is completely offset by the decrease in CTC payments. Therefore, the effect of higher prices is not to raise total revenues, but to shift them away from the reimbursement of CTCs towards an increase in market revenues. To the extent that firms have different shares in these two sources of revenues (i.e. market shares do not coincide with CTC shares), the role of prices is simply to distribute total revenues among firms. This creates a conflict of interests: firms whose market share lies below its CTC share will benefit from lower prices, whereas firms whose market share lies above its CTC share will benefit from higher prices.[19]

Suppose that firms aim at maximizing total profits. Given that total revenues are fixed, total profit maximization requires total cost minimization. The optimal market share allocation should then be such that marginal costs are equalized across firms. Given this market share allocation, the optimal trigger strategies take the same form as in Green and Porter (1984): firms bid according to the collusive scheme as long as they do not observe large discrepancies with respect to the collusive outcomes; otherwise, firms are called to bid aggressively during a finite number of periods, and to revert to cooperative behavior until no such discrepancies are observed again. For this trigger strategy to be incentive compatible, actual cheating must increase the likelihood of such discrepancies being large, so that reversions to non-cooperative behavior become more likely. Likewise, price wars should be triggered when the observable variables behave as if a deviation had taken place. Hence, in order to identify the trigger variables that support this equilibrium, one should ask which among the observable variables would be a good signal of cheating. This purports to characterizing firms' optimal deviations.

For simplicity, assume $i = 1, 2$, and index firms such that $m_{1t} < \alpha_1$ and $m_{2t} > \alpha_2$. In words, firm 1's market share lies below its CTC share (so that $\Theta_{1t} < 0$), and the opposite is true for firm 2 (so that $\Theta_{2t} > 0$). Given that marginal costs are equalized across firms, $MC_{1t} = MC_{2t} = MC_t$, we can encounter three possible cases:

$$\textbf{Case 1:} \quad P_t = MC_t + \Theta_{1t} < MC_t + \Theta_{2t}$$
$$\textbf{Case 2:} \quad MC_t + \Theta_{1t} < MC_t + \Theta_{2t} = P_t$$
$$\textbf{Case 3:} \quad MC_t + \Theta_{1t} < P_t < MC_t + \Theta_{2t}$$

[18] To see this, just sum Equation (1), net of production costs, over all firms. Total revenues are τQ_t, i.e. equal to consumers' payments at the regulated retail tariff.

[19] Furthermore, given that new entrants are not entitled to receive CTCs, they might impose a barrier of entry which makes this type of collusion more easily sustainable.

Under Case 1, P_t is such that firm 1's FOC is satisfied, so that it has no incentives to deviate. On the contrary, P_t lays below firm 2's profit maximizing price, so that it would have incentives to bid less aggressively in order to drive prices up, thereby increasing its market revenues even at the expense of losing CTC payments. Firm 2's deviation would lead to an increase in firm 1's market revenues, both because of the increase in the market price and the increase in its market share caused by firm 2's less aggressive behavior. Just the contrary occurs under Case 2. Firm 2 has no incentives to deviate, whereas firm 1 would have incentives to bid more aggressively in order to drive prices down, thereby increasing its CTC payments even at the expense of (possibly) losing market revenues. This deviation would cause a decrease in firm 2's market revenues, both because of the decrease in its market share and the decrease in the market price. Last, under Case 3, both firms would have incentives to deviate, in the same directions as the ones described in the previous cases.

Applying this reasoning to our data set, the first thing to notice is that Endesa's market share always lies below its CTC share, whereas the opposite is true for Iberdrola (see Figure 4). Thus, we can reinterpret the previous paragraphs by reading Endesa where it says firm 1, and Iberdrola where it says firm 2. This leaves us with three mutually exclusive conjectures as to when, why and what should (and should not) trigger price wars in the Spanish electricity market.

Conjecture 1. There is no collusion. Price wars are random events, unexplained by changes in firms' market shares or revenues.

Conjecture 2. Under the collusive strategy, Iberdrola has short-run incentives to deviate. Price wars should be triggered when Iberdrola's market share decreases and all firms' market revenues increase.

Conjecture 3. Under the collusive strategy, Endesa has short-run incentives to deviate. Price wars should be triggered when Endesa's market share increases and Iberdrola's market revenues decrease.

In the following section, we will let the data decide which of these predictions is best suited to explain the pattern of prices in the Spanish electricity industry. We will first assess whether price wars are statistically significant. If the answer is *No*, Conjecture 1 would be verified, i.e. changes in firms' market shares or revenues do not help to explain the occurrence of periods of low prices.

If the answer is *Yes*, we would then be interested in analyzing the sign of these trigger variables in determining the probability of entering into a price war. This would allow us to uncover the

type of strategies firms are following.

If the data supports Conjecture 2, we could then conclude that the collusive scheme is such that Iberdrola has one-shot incentives to deviate, i.e. the collusive price is below Iberdrola's profit maximizing price. Otherwise, decreases in Iberdrola's market share coupled with an increase in all firms' revenues could not be interpreted as a sign of cheating. Thus, if they increase the probability of entering into a price war, it must ne because they are interpreted as a good sign of cheating.

In contrast, if Conjecture 3 is verified by the data, we could conclude that the collusive scheme is such that Endesa has one-shot incentives to deviate, i.e. the collusive price is above Endesa's profit maximizing price. If this were not the case, increases in Endesa's market share and decreases in Iberdrola's revenues would be inconsistent with the theoretical predictions. Again, if they increase the probability of entering into a price war, it must ne because they are interpreted as a good sign of cheating.

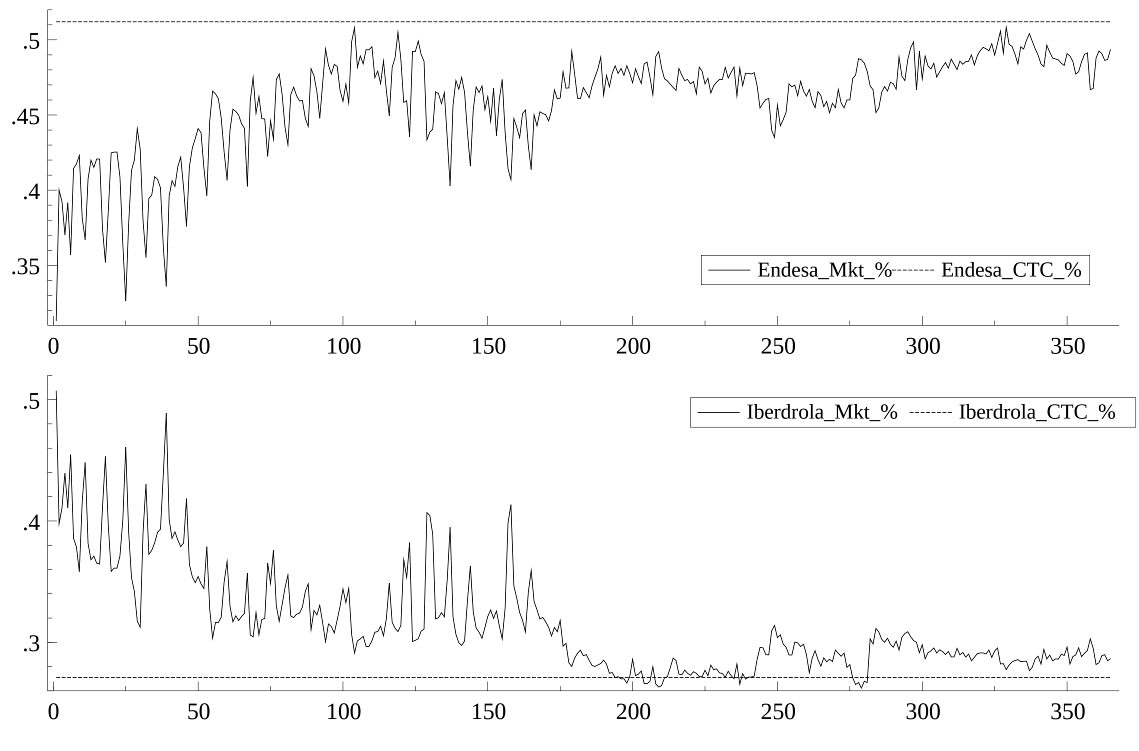


Figure 4: Endesa's and Iberdrol'as Market Shares and CTC Shares, 1998

4 The Econometric Analysis

In order to model the behavior of the system marginal price in the Spanish electricity market we consider an autoregressive Markov switching model in the mean with time varying transition probabilities (TVTP). The TVTP model encompasses the fix transition probability model (FTP), as it may allow the switching probabilities to either change or not change over time. Furthermore, in contrast to the FTP in which the expected duration of a phase of low/high prices is constant, the TVTP is linked to the notion of time-varying duration in the Markov switching framework.

The autoregressive TVTP Markov-switching model of prices allows for distinct price-cycle phases (collusive price phase/ price war phase) with state dependent means, and for dynamics of prices with the lagged predetermined variables.[20] The state of prices is not known with certainty. The econometrician can neither observe the state of prices nor deduce the state indirectly. These states are assumed to be path dependent and evolve according to a first-order Markov process with TVTP coefficients. The TVTP model with state dependent mean can be presented as:[21]

$$\begin{aligned} P_t - \mu_{s_t} &= \rho(P_{t-1} - \mu_{s_{t-1}}) + \beta x_t + \varepsilon_t \\ \mu_{s_t} &= \mu_0(1 - s_t) + \mu_1 s_t \\ s_t &= 0,\ 1. \end{aligned}$$

where P_t is the pool price in period t, μ_{s_t} is the mean of prices in state s_t, which can either be a collusive state, $s_t = 0$, or a price war state, $s_t = 1$ (i.e. $\mu_0 \geq \mu_1$), and x_t are a group of weakly exogenous variables.

The stochastic process on S_t can be summarized by the transition matrix:

$$P(S_t = s_t | S_{t-1} = s_{t-1}, z_{t-1}).$$

The transition probabilities are given by:

$$\Lambda_{t-1} = \begin{pmatrix} q(z_{t-1}) & 1 - p(z_{t-1}) \\ 1 - q(z_{t-1}) & p(z_{t-1}) \end{pmatrix}, \tag{7}$$

[20]In this respect, we depart from Ellison (1994). Ellison (1994) allows for autoregressive residuals which in our view could be a sign of misspecification because of the omission of lagged dependent variables (see Mizon (1993)).

[21]The price equation could include the trigger-variables (z_t). However, we formulate our model with the trigger-variables influencing only the transition probabilities, to emphasize the contribution of the TVTP on the price dynamics.

where we assume serial correlation of the states (a collusive period is likely to be followed by another collusive period) and where z are the variables that are likely to influence the transition probabilities (which we henceforth refer to as 'trigger variables').[22,23]

In searching for a particular functional form of the transition probabilities, we will use the logistic function:

$$P(S_t = k|S_{t-1} = l, z_{t-1}) = \frac{\exp(\lambda_{lk,0} + \lambda_{lk,1} z_{t-1})}{1 + \exp(\lambda_{lk,0} + \lambda_{lk,1} z_{t-1})}, \ k, \ l = 1, 0.$$

We are interested in characterizing the probability of starting a price war. This is given by

$$1 - q(z_{t-1}) = P(S_t = 1|S_{t-1} = 0, z_{t-1}) = 1 - \frac{\exp(\lambda_{00,0} + \lambda_{00,1} z_{t-1})}{1 + \exp(\lambda_{00,0} + \lambda_{00,1} z_{t-1})}. \quad (8)$$

Thus the parameter estimate $\lambda_{00,1}$ reflects the influence of z_{t-1} on $1 - q(z_{t-1})$.[24]

With autoregressive dynamics of order 1 the conditional joint density distribution, f is given by:

$$\begin{aligned}
f(P_t|P_{t-1}, z_{t-1}, x_t) &= \sum_{s_t=0}^{1} \sum_{s_{t-1}=0}^{1} f(P_t, S_t = s_t, S_{t-1} = s_{t-1}|P_{t-1}, z_{t-1}, x_t) \\
&= \sum_{s_t=0}^{1} \sum_{s_{t-1}=0}^{1} f(P_t|S_t = s_t, S_{t-1} = s_{t-1}, P_{t-1}, z_{t-1}, x_t) \\
P(S_t &= s_t, S_{t-1} = s_{t-1}|P_{t-1}, z_{t-1}, x_t) \\
&= \sum_{s_t=0}^{1} \sum_{s_{t-1}=0}^{1} f(P_t|S_t = s_t, S_{t-1} = s_{t-1}, P_{t-1}, z_{t-1}, x_t) \\
P(S_t &= s_t|S_{t-1} = s_{t-1}, z_{t-1})P(S_{t-1} = s_{t-1}|z_{t-1})
\end{aligned}$$

[22] Two issues need to be stressed. First, we have explicitly written lagged z_t, because it will be the lagged of these variables that will influence the probabilities of switching across regimes. And second, in Green and Porter's model, firms stay in a price war for a given number of periods (conditionally on no deviations having taken place along the punishment path). Hence, it would be reasonable to make the transition probability $p(z_{t-1})$ dependent on the number of periods firms have been in a price war, i.e. on duration, d_{t-1}. We are aware that omitting the dependence of $p(z_{t-1})$ on d_{t-1} might lead to inconsistent estimates of the response of z_{t-1} on p. This should not affect our main results however. We are only interested in determining the probability of entering into a price war, $1 - q(z_{t-1})$, which should not be dependent on duration.

[23] In order to obtain consistent and normally distributed estimates from our maximun likelihood estimators presented, the trigger-variables chosen should be conditionally uncorrelated with the states, given the current prices (see Engle, Hendry and Richard (1983) and Filardo (1994)). This would allow us to estimate consistently our TVTP model using jointly the conditional maximum likelihood estimator (MLE) and the filtering methods proposed in Hamilton (1989). This is the case of our trigger variables.

[24] Note that the sign of marginal effect of z_{t-1} on the probability of starting a priceewa

and the likelihood function is:

$$L(\theta) = \sum_{t=1}^{T} \ln f(P_t|P_{t-1}, x_t, z_{t-1}; \theta),$$

where θ are the parameters of interest. The states are unobserved by the econometrician and the filter developed in Hamilton (1989) is used to jointly estimate the parameters of the model and the process of the states.

The previous statistical model can be adapted to analyze the time series of prices in the Spanish electricity market. If we consider cross-price effects in the supply equation derived in Section 3, we can alternatively express Equation (6) in deviations from their means as:

$$\begin{aligned} \log P_t - \mu_{s_t} &= \rho(\log P_{t-1} - \mu_{s_{t-1}}) + \beta_1(\log Q_t - E(\log Q_t) + \\ &\quad +\beta_2(\log \mathbf{Z}_t - E(\log \mathbf{Z}_t)) + \varepsilon_t^s \end{aligned} \tag{9}$$

with $\varepsilon_t^s \sim N(0, \sigma_s)$. The mean of prices is given by,

$$\begin{aligned} \mu_{s_t} &= \mu_0(1 - s_t) + \mu_1 s_t \\ \mu_0 &= \frac{\beta_0 + \beta_1 E(\log Q_t) + \beta_2 E(\log \mathbf{Z}_t)}{1-\rho} + \frac{\Phi_0}{1-\rho} \\ \mu_1 &= \frac{\beta_0 + \beta_1 E(\log Q_t) + \beta_2 E(\log \mathbf{Z}_t)}{1-\rho} + \frac{\Phi_1}{1-\rho} \\ s_t &= 0,\ 1 \end{aligned}$$

and Φ_0 and Φ_1 are the expected values of $-\log(1-\Theta_t)$ during collusive periods and price wars, respectively.

Our data contains daily observations on the (quantity-weighted average) System Marginal Price, total demand, production by technology-type, the market shares and revenues obtained by each generator and several deterministic seasonals. The time span goes from the 1^{st} of January 1998 until the 31^{st} of December 1998. Using this information, we can explicitly define the supply shifters to be the amount of demand served by hydro resources and the value of imports. Simplifying notation, Equation (9) can be explicitly rewritten as

$$p_t - \mu_{s_t} = \rho(p_{t-1} - \mu_{s_{t-1}}) + \beta_1 q_t + \beta_2 hydro_t + \beta_3 imp_t + \varepsilon_t^s \tag{10}$$

where p_t is the log of prices, q_t is the log of total quantity produced, and $hydro_t$ and imp_t are the supply shifters, all measured in deviations from their means. The potential endogeneity problem in our supply equation is dealt with by instrumentalizing total demand with weekdays

and weekend dummies. These dummies are highly correlated with demand but uncorrelated with the supply shocks.

The choice of the variables governing the transition probabilities (trigger variables) is based on the theoretical discussion presented in Section 3. The variables $Share_{it}$, where i = Endesa, Iberdrola, Unión Fenosa, Hidrocantábrico, are intended to capture a plausible trigger in a cartel that switches to a price war when a firm obtains a suspiciously large change in its market share. The variable $Share_{it}$, is constructed as follows:

$$Share_{it} = \Delta \log (m_{it})$$

where $m_{it} = \frac{Q_{it}}{Q_t}$ represents firm i's market share in period t, Q_{it} denotes firm i's production, $Q_t = \sum_{i=1}^{4} Q_{it}$ denotes total production at time t, and Δ represents changes with respect to the previous period's value. Furthermore, we consider the changes in the sum of the square values of the four major generators' market shares. We refer to this potential trigger variable as the Herfindahl-Hirschman index (HHI) and construct it as follows:

$$HHI_t = \Delta \sum_{i=1}^{4} m_{it}^2$$

Last, the variables Rev_{it}, where i = Endesa, Iberdrola, Unión Fenosa, Hidrocantábrico, are intended to capture a plausible trigger in a cartel that switches to a price war regime when a firm obtains a suspiciously large change in its revenues. The variable Rev_{it} is constructed as follows:

$$Rev_{it} = \Delta \log (P_t Q_{it})$$

where $P_t Q_{it}$ represents firm i's market revenues in period t.

Market shares and revenues depict a strong weekly seasonal component that would enter into the definitions of the trigger variables. In order to only consider the unexpected changes in market shares and revenues of each of the generators, the trigger variables have been constructed on deseasonalized values of production levels and revenues.[25]

Table 2 gives summary statistics for the trigger-variables. The average rates of growth in Endesa and Hidrocantábrico's market shares are positive, whereas those of Iberdrola and Unión Fenosa are negative. There are large fluctuations in the growth of all generators' market shares.

[25]The deseasonalization is implemented using an unobserved component model. This model is estimated in the series of production and revenues of each of the generators and the Kalman filter is used to extract the different components. A local trend model with trigonometric seasonal and an irregular component is chosen as the benchmark specification. The estimated models are available from the authors upon request.

Table 2: Summary Statistics of the trigger variables

	Mean	Variance	Min	Max
$ShareEndes_t$	0.00065798	0.020834	-0.080410	0.085940
$ShareIber_t$	-0.00083766	0.032663	-0.12362	0.15103
$ShareUF_t$	-0.00038319	0.049617	-0.23095	0.18478
$ShareHC_t$	0.00067825	0.085675	-0.38827	0.37296
$RevEndes_t$	-0.0014945	0.16416	-1.0392	0.99135
$RevIber_t$	-0.0026525	0.14251	-0.73729	0.76504
$RevUF_t$	-0.0022038	0.17819	-1.2065	1.1438
$RevHC_t$	-0.0012811	0.19764	-1.1025	1.2165
HHI_t	0.00052649	0.018088	-0.080097	0.069116

This is easily observed by looking at their maximum values and comparing them with their means. For instance, Iberdrola and Unión Fenosa's market share changes rise as high as 15 % and 18 %, respectively. Drops in their market shares are of a similar magnitude. These drastic changes are not isolated events, as can be seen by the high variance of the rate of growth of all generators' market shares. The time series of revenues depict a similar pattern, though there is a more extreme variation of these quantities as measured by the minimun and maximun values recorded.

5 The Empirical Results and their Interpretation

We will consider nine different models that differ in the variables that are used as triggers. The different models are labelled from 1 to 9, corresponding respectively to the use of $ShareEnd_{t-1}$, $ShareIber_{t-1}$, $ShareUF_{t-1}$, $ShareHC_{t-1}$, $RevEnd_{t-1}$, $RevIber_{t-1}$, $RevUF_{t-1}$, $RevHC_{t-1}$ and HHI_{t-1}.

Estimates are computed by numerically maximizing the conditional likelihood. Table 4 reports a summary of evaluation statistics for each of the estimated models based on the predicted residuals. The diagnostic statistics comprise a Chi-square test for second order residual error autocorrelation, Chi-square test for conditional heteroscedasticity of order one, as well as a Chi-square test for normality. Their corresponding p-values are reported in the first, second and third row, respectively. The different models estimated seem to be a good statistical specification given the diagnostic statistics.

Table 3 reports results for our set of models. The signs of the coefficients associated with the exogenous variables are as expected. The coefficient associated with total production, β_1, is positive: as demand increases more expensive technology units are needed to cover demand,

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
	$ShareEndes_{t-1}$	$ShareIber_{t-1}$	$ShareUF_{t-1}$	$ShareHC_{t-1}$	$RevEndes_{t-1}$	$RevIber_{t-1}$	$RevUF_{t-1}$	$RevHC_{t-1}$	HHI_{t-1}
log-lik	362.3427	364.6100	364.5987	361.6949	364.8321	363.6321	365.8765	363.8577	363.8326
ρ	0.5105	0.5077	0.5149	0.5158	0.5178	0.5210	0.5195	0.5151	0.5059
	(0.0435)	(0.0408)	(0.0407)	(0.0424)	(0.0415)	(0.0424)	(0.0410)	(0.0405)	(0.0422)
β_1	0.3644	0.3630	0.3518	0.3589	0.3535	0.3527	0.3510	0.3627	0.2436
	(0.0501)	(0.0491)	(0.0517)	(0.0504)	(0.0485)	(0.0483)	(0.0484)	(0.0486)	(0.0330)
β_2	-0.0428	-0.0432	-0.0309	-0.0293	-0.0304	-0.0297	-0.0304	-0.0430	-0.0434
	(0.0114)	(0.0104)	(0.0143)	(0.0102)	(0.0140)	(0.0116)	(0.0136)	(0.0105)	(0.0106)
β_3	0.1412	0.1427	0.1350	0.1319	0.1342	0.1328	0.1341	0.1412	0.1432
	(0.0161)	(0.0155)	(0.0163)	(0.0151)	(0.0160)	(0.0155)	(0.0158)	(0.0154)	(0.0158)
μ_0	1.4585	1.4589	1.4512	1.4498	1.4512	1.4502	1.4509	1.4581	1.4590
	(0.0092)	(0.0087)	(0.0099)	(0.0086)	(0.0101)	(0.0092)	(0.0099)	(0.0088)	(0.0088)
μ_1	1.1716	1.1730	1.1636	1.1597	1.1646	1.1616	1.1636	1.1708	1.1732
	(0.0180)	(0.0170)	(0.0215)	(0.0200)	(0.0212)	(0.0202)	(0.0209)	(0.0176)	(0.0174)
$\lambda_{00,0}$	3.4829	3.6596	3.4128	3.2667	3.4363	3.3869	3.4410	3.5387	3.6293
	(0.3957)	(0.4228)	(0.3840)	(0.3688)	(0.3840)	(0.3821)	(0.3832)	(0.3892)	(0.4247)
$\lambda_{11,0}$	1.6775	1.7010	1.3967	1.1524	1.4952	1.4626	1.5628	1.7475	1.7037
	(0.4721)	(0.4339)	(0.5673)	(0.4166)	(0.5388)	(0.4974)	(0.5397)	(0.4514)	(0.4419)
$\lambda_{00,1}$	-23.7087	24.8507	-13.0691	3.2550	-3.6317	-3.4959	-3.4003	-3.0883	-41.1896
	(16.8936)	(9.2572)	(6.8500)	(4.3177)	(1.5319)	(1.9238)	(1.3451)	(1.4061)	(17.891)
$\lambda_{11,1}$	16.5392	-11.2178	12.5771	-3.9420	2.6518	2.9628	3.0957	1.7404	19.0179
	(18.0136)	(8.7648)	(7.7837)	(4.3457)	(1.6740)	(2.0165)	(1.778)	(1.2519)	(17.1449)
σ	0.00519	0.0051	0.0050	0.0050	0.0050	0.0050	0.0050	0.0051	0.0051
	(0.00043)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)

Table 3: Parameters Estimates of TVTP models for the Spanish Electricty SMP. ρ is the estimate of the autoregressive parameter. β_1, β_2 and β_3 are the estimates of the response of the log prices to demand at period t, the amount of hydro at period t and the electricity imported by REE, respectively. μ_0 and μ_1 are the estimates of the means of the log of prices in the collusive and price war states. $\lambda_{00,0}$, $\lambda_{11,0}$, $\lambda_{00,1}$ and $\lambda_{11,1}$ are the estimates of the parameters governing the transition probabilities and σ is the standar deviation of the residuals of the estimated model. Standard errors are in parenthesis.

Table 4: Specification tests

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
	$ShareEndes_{t-1}$	$ShareIber_{t-1}$	$ShareUF_{t-1}$	$ShareHC_{t-1}$	$RevEndes_{t-1}$	$RevIber_{t-1}$	$RevUF_{t-1}$	$RevHC_{t-1}$	HHI_{t-1}
Error Autocorrelation	0.4136	0.3054	0.3528	0.3292	0.2836	0.3358	0.3007	0.4241	0.3398
ARCH	0.5384	0.4163	0.8752	0.9779	0.9412	0.9978	0.9868	0.5042	0.4566
Normality	0.8691	0.7939	0.7073	0.8073	0.6735	0.6671	0.6243	0.7369	0.8522
Likelihood Test	0.285	0.029	0.029	0.546	0.023	0.078	0.008	0.062	0.064

Table 5: Marginal effect of the trigger variables on the transition probabilities

Trigger Variable	$\frac{\partial P(S_t=1\|S_{t-1}=0,\bar{z}_{t-1})}{\partial z_{t-1}}$	$\frac{1}{T}\sum_{i=1}^{T}\frac{\partial P(S_t=1\|S_{t-1}=0,z_{t-1})}{\partial z_{t-1}}$
$ShareEndes_{t-1}$	0.69342	0.76353
$ShareIber_{t-1}$	-0.61946	-0.78819
$ShareUF_{t-1}$	0.69342	0.76353
$ShareHC_{t-1}$	-0.61946	-0.78819
$RevEndes_{t-1}$	0.10967	0.12455
$RevIber_{t-1}$	0.11012	0.12120
$RevUF_{t-1}$	0.071883	0.076407
$RevHC_{t-1}$	0.084767	0.097190
HHI_{t-1}	1.0556	1.3059

and this leads to an increase in prices. The coefficient associated with the hydro resources, β_2, is negative as expected: given that hydro is a substitute for more expensive thermal resources, the greater the proportion of total demand that is served by the hydro resources, the lower the pool price should be. And last, the coefficient associated with imports, β_3, is positive as expected: the higher the prices in the Spanish pool the more profitable it is to import electricity from France at cheaper prices.[26]

Table 3 also presents enough evidence to support the hypothesis that two distinct levels characterize the time series of prices. The point estimates of the state-dependent means are statistically different and their magnitude differ statistically and economically according to the asymptotic standard errors. The sample dichotomizes into phases that exhibit a low (price war phase) and a high pool price (collusive phase), given the technology and production information embodied in Equation (10). This result is consistent with Green and Porter's first main prediction, namely, that there will be periodic switches in oligopolistic conduct. Table 3 also lists the estimates for the transition probability equation. All of the points estimates of the $\lambda_{00,0}$ and $\lambda_{11,0}$ parameters are statistically significant at the 5 % level; but some of the points estimates of the $\lambda_{00,1}$ and $\lambda_{11,1}$ parameters are not significantly different from zero. Nevertheless, a test for joint significance of these point estimates rejects the null of a FTP model for all models except for Models 1 and 4 (associated with the triggers $ShareEnd_{t-1}$ and $ShareHC_{t-1}$, respectively) at the 5% significance level.

[26]More precisely, the contract signed between Red Eléctrica and Electricité de France established that imports would flow in from France as soon as the Spanish pool price raised above 2.7 PTAS/kWh. The maximum quantity guaranteed by this contract equals 550 MWh.

Table 6: Dating of Price Wars in the Spanish Electricity Market

Price Wars	First	Second	Third	Fourth	Fith	Sixth
Duration in days	7	13	2	3	4	20
Percentage Change in Price w.r.t. Collusion	-61	-40	-37	-31	-42	-23
Percentage Change in Iberdrola's Share	-31	-42	-31	-17	-31	-21

In more detail, for the parametrization of the transition probability $[1 - q(z_{t-1})]$ in Equation (8), the test for the non influence of the trigger-variables in the process for the transition probabilities is a test for $H_0 : \lambda_{00,1} = 0$ and $\lambda_{11,1} = 0$. The null considers a restricted model where the trigger variables do not influence the transition probabilities of switching, to and from, the two different price states. Under the null of no time variation in the transition probabilities, the FTP model is rejected if $\Psi = 2 \times (\log(\theta) - \log_R(\theta))$ exceeds the χ^2 (2), where $\log(\theta)$ and $\log_R(\theta)$ are the log-likelihoods of the restricted and unrestricted model. The results for the FTP model indicated a value for the likelihood of 361.05.[27] The p-values resulting from these tests are reported in the last row of Table 4. The hypothesis of a FTP is rejected at the 5% except for Model 1 and Model 4 . For Models 6, 8 and 9 we only get a slight rejection at the 5% significance level.

The fact that Models 1 and 4 do not seem relevant is highly illustrative of the dynamic interactions in this market: it would seem as if Endesa does not have incentives to deviate because the collusive strategy is designed to fully satisfy its interest (Conjecture 2); and as if the smallest participant, Hidrocantábrico, is acting as a follower, not involved in the collusive agreement. Last, our results show that the TVTP model is preferred to the FTP model, i.e. there is further information in the trigger-variables in order to explain the transition dynamics from low to high price states (thereby rejecting Conjecture 1). This is consistent with Green and Porter's second main prediction, namely, that price wars are not just random events, but their occurrence is linked to movements in some of the variables that could be taken as good signals for cheating.

Figure ?? plots the smooth probabilities of being in a low state of prices for the models that use market shares of Iberdrola as the associated trigger variable. Though the smoothed probabilities differ across models, they all deliver similar pictures (and are thus omitted here). The classification of the states and the dating of the price wars is done using the smoothed probabilities. At every point in time, a smoothed probability of being in an given state is calculated, and we assign that

[27]The results of the FTP model are not reported in this paper and are available from the authors upon request.

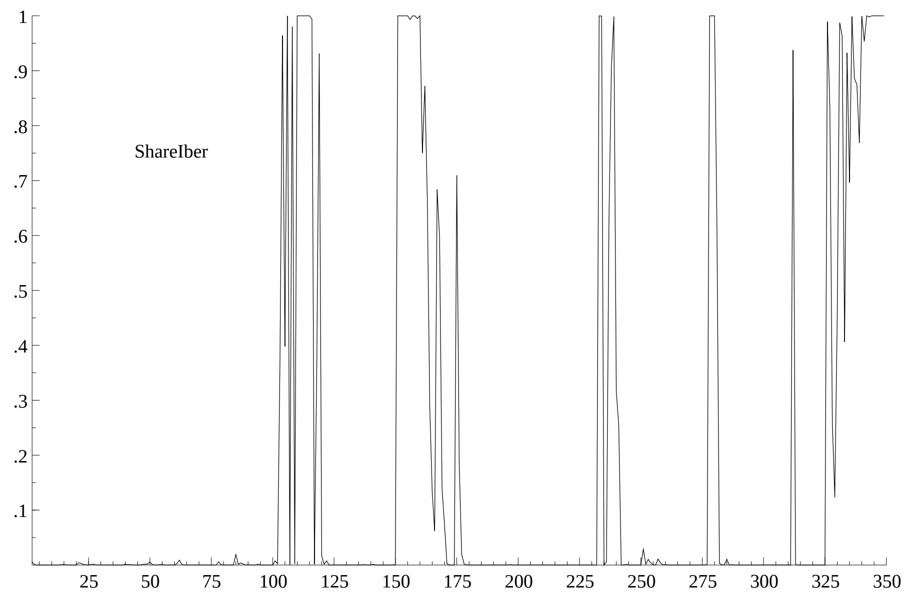


Figure 5: Smooth probabilities of being in a price war when the trigger used are markets shares of Iberdrola

observation to a given regime according to the highest filtered probability, i.e. $\Pr(s_t = 1 \mid P_t) < 0.5$ and $\Pr(s_t = 1 \mid P_t) > 0.5$. This rule minimizes the total probability of misclassification in the sample. We will consider the definition of a price war whenever a state of low price is followed by a state of the same nature. This definition allows a corresponding dating of price wars in the Spanish electricity market. The average duration of a price war ranges from slightly less than five days to almost six days.

Last, in order to quantify the effect of a variation of the trigger variables in the transition probability of entering into a price war, we have calculated the marginal effect of increases z_{t-1} in $[1 - q(z_{t-1})]$, evaluated at the average $\overline{z}_{t-1}$,

$$\frac{\partial P(S_t = 1|S_{t-1} = 0, \overline{z}_{t-1})}{\partial \overline{z}_{t-1}},$$

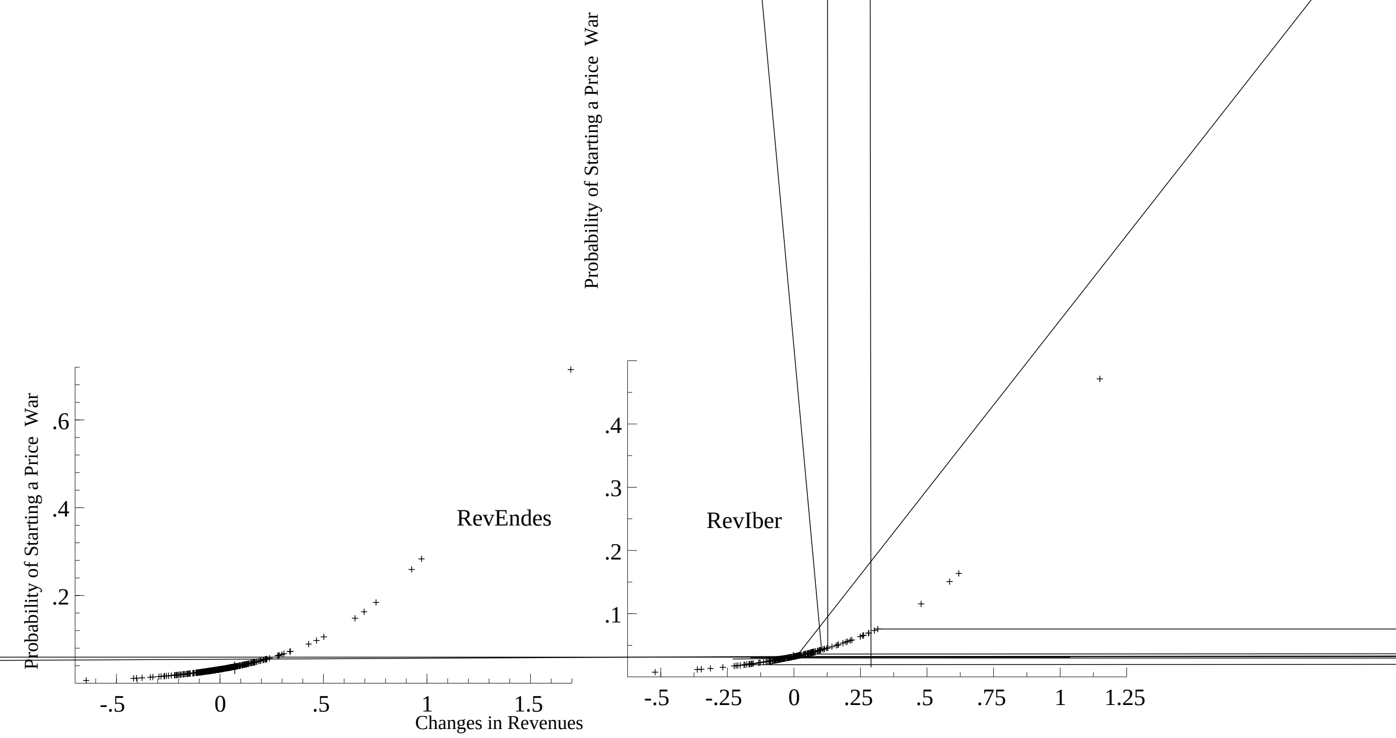
and the average marginal effect,

$$\frac{1}{T}\sum_{t=1}^{T}\frac{\partial P(S_t = 1|S_{t-1} = 0, z_{t-1})}{\partial z_{t-1}}.$$

This information is provided in Table 5, and it is complemented in Figure 6 with the cross plots of the transition probabilities $P(S_t = 1|S_{t-1} = 0, z_{t-1})$ with the trigger variables associated with the dominant generators.

The signs of the marginal effects coincide with those of Conjecture 2 (see Section 3). First, the marginal effect of $ShareIber_{t-1}$ is negative.[28] That is, decreases in Iberdrola's market share

[28]The marginal effect associated with $ShareEnd_{t-1}$ is positive. This is also consistent with prediction B. However,


Probability of Starting a Price War
.6
.4
.2
RevEndes
-.5
0
.5
1
1.5
Changes in Revenues
Probability of Starting a Price War
.4
.3
.2
.1
RevIber
-.5
-.25
0
.25
.5
.75
1
1.25

of tacit agreement. In the spirit of Green and Porter (1984), we have exploited the movements in industry prices, firms' market shares and revenues to distinguish competitive from collusive behavior. This makes the empirical analysis of market power easier, as it overcomes the problems involved in the estimation of marginal cost functions, as well as the need to establish a meaningful benchmark with which to compare the observed outcomes.

The sharp drops in prices that are verified in the data suggest that the electricity generators might have been alternating between episodes of collusion and price wars. According to Green and Porter (1984), these periods of intense rivalry should be triggered when the observable variables behave as if a deviation had taken place. Hence, we have considered some of the variables that could be a good sign of cheating, and have evaluated whether these have indeed influenced the probability of triggering a price war. Most of the triggers that we have considered appear to be significant and report the same signs as those predicted by the theory. Interestingly enough, we have found that decreases in Iberdrola's market share, coupled with increases in all firms' market revenues, considerably increase the probability of entering into a price war period. In other words, it seems as if price wars are triggered by the fear that Iberdrola might attempt to adopt a less aggressive bidding strategy in order to increase its market revenues at the expense of reducing the whole industry's Competition Transition Charges. In other words, it seems as if the collusive agreement were designed to fully satisfy Endesa's objectives (which could be acting as a sort of market leader). In addition, this purports to the view that the way in which the CTC payments have been computed has had an important impact in firms' bidding incentives.

Having said all this, we would not like to push the idea too far that the pattern of prices that we observe in the Spanish data is consistent with an equilibrium phenomenon. The incentive structure embedded in the Green and Porter (1984) model requires a high degree of rationality, which cannot be reasonably expected in a market that has only recently started to operate. Their model predicts that deviations should not take place in equilibrium. In contrast, it is likely that deviations in our data set are taking place given that firms are still learning 'how to play the game' and are unaware of the consequences that a deviation could trigger. In our view, this should be interpreted more as an adjustment or learning process, rather than as a series of abortive states to sustain collusion.[29]

[29] As Borenstein *et al.* (2001) have put it: *"In any new market, it may take participants time to learn about how market rules, market fundamentals and their own behavior affects prices...A trader in these markets is constantly changing her beliefs about these (price) distributions, and must recognize that her knowledge of the underlying distribution of prices is imperfect. Furthermore, in dynamic and new markets, the distribution that a firm faces is*

Last, it is fair to recognize that there could be several alternative explanations, other than collusion, for the phenomena that we observe in the Spanish data. For instance, if firms were not pursuing collusive strategies, the existence of periods of low prices could be accounted for by mixed strategy pricing or by the lack of coordination on the multiple price equilibria (see von der Fehr and Harbord (1993)). However, if this were the case, there should be no reason to observe such a persistence in each price state as we observe in the data. Furthermore, there should not be a systematic relationship between the trigger variables and the occurrence of price wars, i.e. their coefficients should be non-significant.

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constantly changing as market rules are modified and as other firms modify their behavior."

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