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-probability Markov switching model. Accounting for changes in demand and cost conditions (which reflect changes in input costs, capacity availability and hydro power), we show that the time-series of prices is characterized by two significantly different price levels. Based on a Green and Porter (1984)'s type of model that introduces several institutional details, we construct trigger variables that affect the likelihood of starting a price war. By interpreting the signs of the triggers, we are able to infer some of the properties of the collusive strategy that firms might have followed. We obtain more empirical support to Green and Porter's model than previous studies.

Keywords: Electricity Markets, Tacit Collusion, Markov Switching.

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1 Introduction

During the last decade decentralized 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 mean 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 raised concerns about the ability of electricity producers to exercise market power and its effects on the efficiency of the market. The recent empirical literature on market power in electricity markets is now vast. The studies have identified strategic bidding and output decisions by individual firms (Borenstein and Bushnell (1999), Wolak (2000), Wolak (2003) and Wolfram (1998)) and have measured the departures of market outcomes from the competitive benchmark (Borenstein, Bushnell and Wolak (2002), Joskow and Kahn (2002) and Wolfram (1999)). All these studies have focused on the unilateral exercise of market power, but little attention has been devoted to analyze collusive attempts to exercise market power in a dynamic context.[1] Nonetheless, electricity markets present several features that facilitate the sustainability of collusion more than most other markets: trading takes place on a daily basis and it is organized as a uniform-price auction,[2] firms are capacity constrained, demand is very inelastic in the short-term, and there is typically a small number of players protected by high entry barriers. Both theory and experience suggest that these factors may allow firms to coordinate their strategies, and hence compete less aggressively with each other over time, through collusive agreements.

The analysis of the performance of the Spanish electricity spot market during 1998 provides a unique opportunity to perform an empirical analysis of firms' dynamic interaction. The availability of detailed data at the industry and firm level allows to exploit changes in prices, firms' market shares and cost fluctuations in order to identify potential attempts to exercise market power in a dynamic context. Furthermore, an analysis of this market allows to uncover some of the effects that firms' contract positions have had

[1] Puller's (2000) empirical analysis of collusion in the Californian electricity market is an exception.

[2] In a model applicable to electricity markets, Fabra (2003b) shows that the sustainability of collusion is easier in uniform-price auctions as compared to discriminatory auctions.

on their bidding incentives. The Spanish electricity producers are entitled to receive the so-called Competition Transition Charges (CTCs) as a mean of stranded cost recovery. Essentiality, these payments act as 'Contract for Differences', given that they are computed as a decreasing function of the market price. From a methodological perspective, the fact that firms' shares over these payments are fixed as determined by Law, allows to overcome the problem of identifying firms' contract positions as well as the possible endogeneity of contracts and market outcomes that arises in other contexts.

The time-series of prices in the Spanish electricity market during 1998 is characterized by the occurrence of five to seven episodes during which prices drastically fall below their usually prevailing level, in ways that seem to be uncorrelated with demand or cost conditions. This evidence is inconsistent with models of static bidding behavior (von der Fehr and Harbord (1993) and Green and Newbery (1992)), as these predict that prices should be fully explained by demand movements, once the changes in cost conditions have been accounted for. Further evidence confirms that firms have not behaved so as to maximize their individual profits. In particular, the mark-ups of the over-contracted are positive during most of the sample, contradicting the predictions of the models that assume individual profit maximizing behavior among contracted firms (Newbery (1998), Wolak (2000), and Section 4 of this paper).

Accordingly, our aim is to assess whether the periods of intense rivalry and the pattern of firms' mark-ups are consistent with some kind of dynamic interaction. Based on a discussion of the features of the Spanish electricity market, we argue that the potential dynamic interaction is best captured by models of imperfect monitoring, such as the ones pioneered by Green and Porter (1984). Nevertheless, the fact that firms are contracted implies that the underlying game needs to be modified with respect to Green and Porter's. In this paper, we characterize such a game in order to identify the trigger variables that firms could be using to support a collusive equilibrium, and to obtain predictions concerning the effects of those triggers on the probability of starting a price war. The analysis shows that an increase (rather than a decrease) in the market price could be interpreted as a good signal of cheating. Among the other trigger variables considered are the changes in firms' market shares and revenues.

Based on the theoretical predictions, we 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, and whether the signs of these effects coincide with those predicted by the theory.

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, the probability of starting a price war increases when the market share and revenues of the over-contracted (under-contracted) firm increases (decreases) and the market price increases above its usually prevailing level. This shows 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.[3]

The paper is organized as follows. In the next section, we provide an overview of the Spanish electricity industry. In Section 3 we motivate the analysis of the paper in the light of the pattern of demand, prices, and marginal costs in the Spanish electricity market during 1998. In Section 4 we set out a framework for the empirical analysis, which is presented in Section 5. Section 6 of the paper concludes.

2 The Spanish Electricity Industry

In 1997, the Spanish electricity industry experienced fundamental changes.[4] 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.

[3]Porter (1983), Porter (1985) and Ellison (1994) investigate the stability of the 19th century US railroad cartel. In both studies, the triggers considered reported opposite signs to those predicted by the theory, or they did not appear to be significant.

[4]The reforms were implemented through the Electricity Law 54/1997 of 27 November 1997. See Arocena, Kuhn and Regibeau (1999) and Fabra Utray (2004) for an overview and discussion.

The daily market concentrates most of the transactions.[5] 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.[6] The demand side is made of the distributors and qualified consumers, who are also required to submit the maximum prices at which they are willing to consume electricity, in a similar fashion as suppliers. On the basis of these supply and purchase bids, the Market Operator constructs the industry supply and demand curves, ranking the production and demand units in increasing and 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 produce (consume) at lower or equal (greater or equal) prices. The System Operator has the responsibility 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.

The basic structure of the Spanish electricity industry was transformed during the 1990s as a result of a consolidation process among the numerous regional electricity companies.[7] The result was a highly concentrated industry, both horizontally and vertically.[8] The two largest participants - Endesa and Iberdrola - control almost 80% of total avail-

[5]In 1998, the daily market concentrated 99% of all the electricity traded in the wholesale markets.

[6]The sale and purchase bids can be made by considering from 1 to 25 energy blocks in each hour, with the proposed price. The bid schedules have to be increasing (decreasing) in the quantity offered (demanded). The supply bids can be simple, or they can include additional conditions, such as indivisibility, load gradient, minimum income and scheduled shutdown.

[7]Part of this consolidation process was government-led. One remarkable instance of this was the government's decision to strengthen Endesa prior to its privatization in 1996, by allowing it to acquire FECSA and Sevillana, which controlled the 10% and the 9% of total capacity, respectively (see Marín and García-Díaz (2003)).

[8]Distribution remains a regulated activity. In 1998, large customers (with annual consumption exceeding 15 GWh) were qualified to contract with a competitive retailer or to participate directly into the market. The volume of electricity acquired by qualified consumers represented a very small fraction of the total market volume (1,000 GWh versus 154,000 GWh over 1998).

Firm/ Technology	Hydro	Coal	Fuel-Gas	Nuclear	Total MW	Shares
Endesa	6,134	6,684	3,869	3,185	19,872	45.6
Iberdrola	8,175	1,141	3,258	3,533	16,407	37.7
Unión Fenosa	1,733	1,972	784	765	5,254	12.1
Hidrocantábrico	410	1,127	0	149	1,686	3.9
Total MW	16,452	11,224	8,231	7.632	43,539	100.0
Capacity Shares	37.8	25.8	18.9	17.5	100.0	

Table 1: Installed Capacity by Firm and Technology (MW), 1998 (Source: CNE (2000)).

able generating capacity, and the remaining 20% is divided among two smaller firms - Unión Fenosa and Hidrocantábrico - and several fringe companies. Technology mixes vary widely across firms: whereas Endesa owns more than half of total thermal capacity, Iberdrola controls around a half of total hydro power. Table 1 summarizes the capacity shares by company and technology type in the Spanish electricity market.

Generators have three main sources of revenues: market revenues, capacity payments, and stranded cost recovery payments. 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 participate in the daily market receive a capacity payment per unit of capacity declared available. Given that firms earn capacity payments independently of their pricing decisions, these payments should have had no impact on the pattern of prices. We will therefore omit them from our analysis.[9]

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 was computed as the difference between the net present value of the revenues that firms were entitled to receive under the former regulatory regime and firms' market expected revenues, under the assumption that the competitive market price would be 3.6 Cent€ /kWh on average. The amount of CTCs to be paid to the whole industry in a par-

[9]As a robustness check, the empirical analysis was also carried out including the capacity payment (i.e. using the final price rather than the spot market price). The results were essentially unchanged.

ticular year is computed as the residual amount obtained from extracting the regulated costs (mainly, payments to distributor-which are reimbursed their costs of buying electricity in the spot market plus a rate of return-, payments to transmission and subsidies to national coal) from the total regulated revenues earned through the final tariff. The Law established that this residual amount would be shared among firms on the basis of some predetermined shares: 51.2% for Endesa, 27.1% for Iberdrola, 12.9% for Unión Fenosa and 5.7% for Hidrocantábrico.

Two conditions were imposed on the value of the CTCs to be received by a firm over the transition period. First, if the average price received by a firm exceeded 3.6 Cent€ /kWh, the extra revenues should be deducted from the firm's maximum CTC entitlement. And second, a firm's CTC revenues could not exceed the maximum entitlement established by Law. These two conditions imposed a price-cap and a price-floor on the pool price. On the one hand, it would not be profitable for any firm to raise prices over 3.6 Cent€ /kWh, as any increase in market revenues would be offset by the reduction in the firm's total CTC entitlement.[10] On the other hand, it would not be profitable to reduce prices to a level below the one that allowed a firm to obtain its maximum entitlement, given that the reduced market revenues would not be compensated by an increase in its CTC revenues.[11]

3 Motivation for the Analysis

In order to analyze firms' strategic behavior in the Spanish electricity market during 1998, we perform an empirical analysis using detailed information on demand, prices and other variables that allow for an accurate estimation of firms' marginal costs (Section 5.1 describes the data and the estimation technique). In this section, we present some preliminary evidence to motivate the type of analysis that we pursue in the remainder of the paper.

[10] This assertion is valid as long as firms do not discount the future stream of profits very strongly, and as long as they perceive full regulatory certainty about the payment of their total CTC entitlements. This second concern started to play a role from 1999 onwards, when the European Commission opened up an investigation to determine whether the CTCs were State Aids, in which case they would have been banned.

[11] The maximum amount of CTCs was fixed at € 11,951.5m, 1,774.6 of which were subsidies to national coal, and the rest was the maximum amount to be divided among the incumbent firms. In 1998, firms perceived CTCs which amounted to € 633.5m. The maximum entitlements of Endesa and Iberdrola were reduced by € 67.5m and € 47.15m respectively, because their average prices exceeded 3.6 Cent€ /kWh. See CNE (2000) and Nacional del Sistema Eléctrico (1998) for more detailed descriptions.

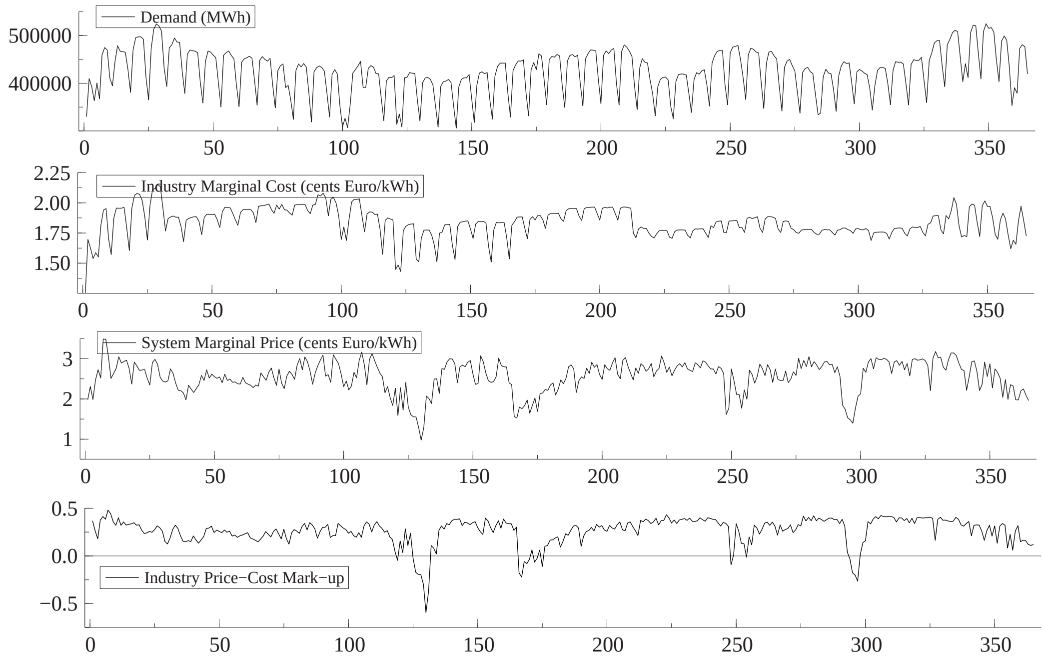

Figure 1: Total Demand, Marginal Costs, SMP and Price-cost Mark-ups in the Spanish Electricity Market, 1998

Figure 1 plots the time series of demand, prices and the estimated marginal costs and price-cost mark-ups in the Spanish electricity market from January 1998 to December 1998. Demand follows a strongly seasonal pattern that is mainly driven by weather conditions and labor patterns. The time series of costs also depicts a seasonal pattern, which can be attributed to demand movements, changes in the availability of hydro resources, and scheduled maintenance plans. Prices show a systematic relationship with the evolution of demand and cost conditions during most of the time. However, there are five to seven episodes in which prices fall below their usually prevailing levels. These price jumps seem to be uncorrelated with cost movements, as can be inferred from the series of price-cost mark-ups.

This pattern of prices is not consistent with the static models of price competition in electricity markets (see Green and Newbery (1992) and von der Fehr and Harbord (1993)), as they predict a positive relationship between demand conditions and prices, once the differences in cost conditions have been accounted for.[12] The outburst of these periods

[12]In Section 4 we provide a further explanation for why market outcomes are not consistent with models

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 this pattern of prices (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.

There are two main reasons why the Spanish electricity market differs from the classic Green and Porter's (1984) formulation: one concerns the source of imperfect information; the other is related to the differences in the underlying game, which have implications for identifying the optimal deviations and thus for the pattern of switches that would be consistent with the theory (see Section 4).

The information available to the Spanish electricity producers is richer than the one assumed in a Green and Porter type of model. In particular, the aggregate information on the prices and quantities demanded is made public at gate-closure. Nevertheless, even if the total quantity demanded is known with certainty, the total quantity traded in the market is uncertain, as it results from extracting total demand minus the volume negotiated through bilateral contracts (typically, exports and imports),[13] and the amount produced by must-take resources (mainly, co-generation and renewables). Furthermore, firms' available capacities are unobservable, as these are subject to random and publicly unknown shocks, which are out of firms' control (e.g. capacities may suffer random outages, or be increased due to an excess of run of river hydro power). This implies that a firm's departure from any agreed upon market share may result either from cheating by a rival firm, or from any of the random and unobservable factors mentioned above. In other

of individual profit maximization.

[13]Exports and imports result from long-term bilateral contracts signed between the Spanish and French, Portuguese and Moroccan System Operators. The interconnection between France and Spain is very limited: only approximately 800 MW of transmission capacity are available (excluding the ones committed for reliability purposes), 550 MW of which are almost permanently used by the contract EDF-REE. See CNE (2000) for a description of these contracts.

words, the Spanish electricity producers are faced with the same kind of signal extraction problem as in a Green and Porter type of 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, perfect monitoring is 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 (2003a)). Last, price movements in the Spanish market over 1998 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).

In the next sections, we assess whether the behavior of pool prices in the Spanish electricity market is consistent with Green and Porter's theory. For this purpose, we first construct a simple theoretical model to characterize firms' expected profit maximizing bidding behavior in the wholesale electricity market, accounting for some its institutional details. This model also allows to uncover some of the possible variables (referred to as *trigger variables*) that firms could be using to support collusive strategies of the Green and Porter type. The empirical analysis in Section 5 is based on the predictions of this model.

4 The Theoretical Framework

Consider an industry made of $n \geq 2$ firms who compete to supply electricity in every period t. Market demand, denoted $Q(\varepsilon_t)$, is assumed to be perfectly inelastic[14] and it is subject

[14]This is reasonable given that in the Spanish electricity consumers pay fixed tariffs which are independent of pool price movements. Eligible consumers are allowed to bid downward sloping demand functions,

to demand shocks ε_t. We assume that firm i, $i = 1, ...n$, has a variable cost function (i.e. net of fixed costs) of the form $C_{it} = C_{it}(q_{it})$, where q_{it} represents the quantity supplied by firm i. The derivative of the cost function with respect to output gives firm i's marginal costs, which are denoted MC_i.

Competition takes place by firms submitting supply functions to an auctioneer.[15] Firm i's supply function in period t, denoted $S_{it}(p)$, is an upward sloping function which gives the maximum quantity that it is willing to produce in period t in exchange of a price p. Given the demand shock realization ε_t, the residual demand facing firm i when its rivals have supply schedules $S_{jt}(p)$, $j \neq i$, is $Q_t(\varepsilon_t) - \sum_{j \neq i} S_{jt}(p)$, and it is denoted $DR_{it}(p, \varepsilon_t)$. Once firms have submitted their supply functions, the auctioneer selects the minimum price such that the market clears and each firm is producing on its supply function. All scheduled production is paid at the market clearing price.

In the Spanish electricity market, firms have an additional source of revenues, namely, the revenues accrued from the Competition Transition Charges (CTCs). We model these payments as the difference between the (fixed) retail price τ and the market clearing price, p, 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 $\sum_{i=1}^{n} \alpha_i = 1$. Note that CTCs play essentially the same role as 'Contracts for Differences': the firm supplies all its output in exchange of the market price, and receives the difference between the 'contract price', τ, and the market price, p, for the 'quantity contracted', $\alpha_i Q_t$. From a methodological perspective, the analysis of CTCs is simpler as the 'contract price' and the 'quantity contracted' are known and predetermined, i.e. they are not endogenous to what happens in the market.

Using the above notation, we can express firm i's variable profits in period t as a function of the residual demand faced by firm i, given the demand shock realization, ε_t, as follows:

$$\pi_{it}(p, \varepsilon_t) = pDR_{it}(p, \varepsilon_t) + [\tau - p] Q_t(\varepsilon_t) \alpha_i - C_i(DR_{it}(p, \varepsilon_t)). \tag{1}$$

Taking the first derivative of (1) with respect to p gives the market clearing price that maximizes firm i's profits given the supply functions submitted by its rivals and the

but in 1998 these represented a very small share of total demand (less than 1% in December 1998). Pumping storage also represents a small fraction of total demand.

[15] See Klemperer and Meyer (1989), whose analysis of supply function equilibria has been applied to electricity markets by Green and Newbery (1992) and Wolak (2000), among others.

demand shock realization ε_t embodied in the residual demand curve $DR_{it}(p, \varepsilon_t)$. Substituting firm i's profit maximizing price into its residual demand yields its profit maximizing quantity. Accordingly, firm i's profit maximizing supply curve is the upward-sloping function passing through all the profit maximizing price and quantity pairs for all the possible residual demand realizations that the firm might face.

The previous analysis implies that, independently of the residual demand realization, the following first-order condition must be satisfied in equilibrium:

$$p_t = MC_{it} + \frac{p_t}{\gamma_{it}} \frac{m_{it} - \alpha_i}{m_{it}}, \tag{2}$$

where p_t is the market price in period t, MC_{it} is firm i's marginal cost of producing the quantity $DR_{it}(p_t)$, μ_{it} is the elasticity of the residual demand curve faced by firm i in period t evaluated at p_t, $\gamma_{it} = -DR'_{it}(p_t)\frac{p_t}{DR_{it}(p_t)}$, and m_{it} is firm i's market share in period t, $m_{it} = \frac{DR_{it}(p_t)}{Q_t}$.[16]

Re-writing equation (2) in terms of the mark-up,

$$\frac{p_t - MC_{it}}{p_t} = \frac{1}{\gamma_{it}} \frac{m_{it} - \alpha_i}{m_{it}}, \tag{3}$$

shows that the profit-maximizing solution is a modified version of the standard monopoly inverse-elasticity rule. Given that we are considering the oligopoly case, the relevant elasticity is that of the residual demand faced by a firm, which takes into account the bidding behavior of its competitors. Furthermore, the profit-maximizing solution results from balancing the opposite effects that prices have on market revenues and CTC revenues. An increase in the market price increases the firm's market revenues proportionally to its market share, but reduces its CTC revenues proportionally to its CTC share. Therefore, whether the impact of a price increase on the firm's overall profits is positive or negative depends on whether the firm's market share is larger or smaller than its CTC share. As a result, whenever a firm's market share is greater (lower) than its CTC share, its profit-maximizing price is above (below) its marginal costs.

The above analysis has an important implication for our empirical investigation: if firms were bidding according to their individual profit maximizing strategies, we should observe negative (positive) mark-ups for the firms with a CTC share above (below) their market shares. Figure 2, which plots the relationship between Endesa's and Iberdrola's

[16] There are many solutions to equation (2), and therefore many supply function equilibria. Nevertheless, what is relevant for our current purposes is that equation (2) must hold in any pure strategy equilibrium.

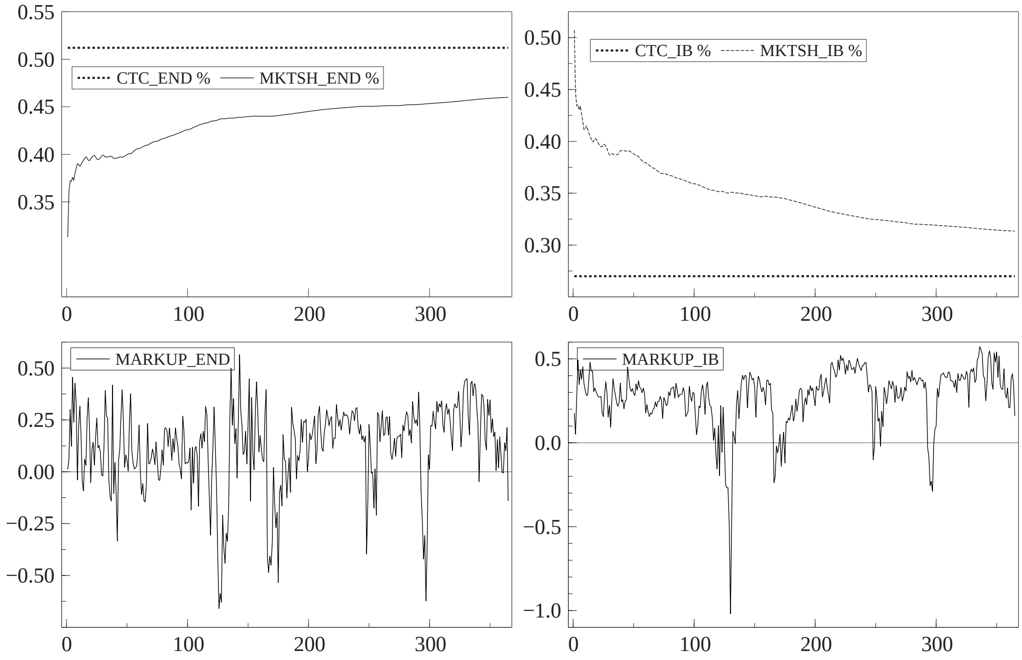

Figure 2: Endesa's and Iberdrola's Market Shares, CTC Shares and Mark-ups, 1998

market shares and CTC shares together with their mark-ups, shows that this is not the case. In particular, Endesa's market share always lies below its CTC share and its mark-ups are positive for most of the sample period.[17] This observation leads us to conjecture that firms may have been engaged in some tacit agreement that distorts the market price and firms' market shares from the ones that would result from individual profit maximization.

To explore this conjecture empirically, we derive firms' supply curves from the following joint profit maximization problem. Suppose that two firms, $i = 1, 2$, agree to bid in a way that maximizes a weighted sum of their profits. For a given demand shock realization, their objective is to choose the price that maximizes

$$\theta_1 \pi_{1t} (p, \varepsilon_t) + \theta_2 \pi_{2t} (p, \varepsilon_t), \tag{4}$$

where $\theta_i \in [0, 1]$, with $\theta_1 + \theta_2 = 1$, is the weight given to firm i's profits, $\pi_{it} (p, \varepsilon_t)$, as given in (1), $i = 1, 2$. Following the same steps as above, firms' joint profit maximizing

[17] Although our marginal cost estimates could be mis-measured, the potential error should be extremely large so as to reverse the sign of Endesa's mark-ups. See Section 5.1.

supply curves can be found by joining all the joint profit maximizing price and quantity pairs for all the possible residual demand realizations.

Regardless of the demand shock realization ε_t, the following condition must be satisfied under the joint-profit maximizing solution,

$$p_t = \Theta_{1t}\left[MC_{1t} + \frac{p_t}{\gamma_{1t}}\frac{m_{1t}-\alpha_1}{m_{1t}}\right] + \Theta_{2t}\left[MC_{2t} + \frac{p_t}{\gamma_{2t}}\frac{m_{2t}-\alpha_2}{m_{2t}}\right], \quad (5)$$

where

$$\Theta_{it} = \theta_i DR'_{it}(p_t)\left[\theta_1 DR'_{1t}(p_t) + \theta_2 DR'_{2t}(p_t)\right]^{-1} > 0,\ i = 1, 2.$$

The joint-profit maximizing price (5) is a weighted average of the individual profit maximizing prices for each firm, as expressed in (2). Given that firms are not producing on their profit-maximizing supply functions, each one may have a unilateral incentive to deviate.

In what follows, we will assume that the trigger strategies used to discourage individual deviations 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 deviations increase the likelihood of entering into a punishment phase. Likewise, price wars should be triggered when changes in the observable variables upon which firms infer their rivals' behavior are compatible with a deviation having taken place. Hence, in order to identify the trigger variables that could be used to 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 from the joint-profit maximizing solution.

For this purpose, index firms such that best response bidding by firm 1 results in a lower price than best response bidding by firm 2. From equation (2),

$$MC_{1t} + \frac{p_t}{\gamma_{1t}}\frac{m_{1t}-\alpha_1}{m_{1t}} < MC_{2t} + \frac{p_t}{\gamma_{2t}}\frac{m_{2t}-\alpha_2}{m_{2t}}.$$

This implies that, under the joint-profit maximizing solution, the market price (5) is above (below) the price that would result from best response bidding by firm 1 (firm 2). Accordingly, firm 1 would have one-shot incentives to deviate by bidding more aggressively, whereas firm 2 would have one-shot incentives to bid less aggressively. Firms' optimal deviations would result in an increase (reductions) in firm 1's (2's) market share. Also, the optimal deviation by firm 1 would lead to a reduction in firm 2's market revenues (since its market share and price would be lower), whereas the optimal deviation by firm 2 would lead to an increase in firm 1's market revenues (since its market share and price would be higher). Hence, changes in firms' market shares and revenues in these directions could signal deviations.

Again, we can apply this reasoning to our data set. Given that Endesa's market share always lies below its CTC share and given that its mark-up is positive, it must be the case that the market price is larger than the one that would result from best response bidding by Endesa. Therefore, we can reinterpret the previous paragraphs by reading Endesa where it says firm 1, and Iberdrola where it says firm 2. This allows us to draw the following empirical prediction. For the Green and Porter's model to be consistent with bidding behavior in the Spanish electricity market, it must be the case that increases in Endesa's market share and revenues, and reductions in Iberdrola's market share and revenues, increase the probability of starting a price war.

5 The Empirical Analysis

5.1 Data Description

For the empirical analysis, we will be using detailed daily data on price, quantities and other variables, some of which are expressed at the industry level, at the firm level, or at the plant level. The sample covers the period from January 1998 through December 1998. Table 2 provides summary statistics of all the variables we will use in our analysis.

Among our variables, we will use the daily aggregate industry production and the daily quantities produced by Endesa and Iberdrola, which we will denote by Q_t, Q_t^{END} and Q_t^{IB} respectively. All the quantity variables are measured in MWh. Our price variable is denoted SMP_t, which represents the demand-weighted average price in the daily market; it is measured in Cent€ /kWh.

In addition, we have constructed estimates of marginal costs and mark-ups (Borenstein et al. (2002), Joskow and Kahn (2002) and Wolfram (1999) use similar estimation techniques). For this purpose, we have first derived the shot-run thermal cost curve at the firm level by estimating the marginal production costs for each generating plant, on a daily basis.[18] The short-run marginal costs of a thermal plant (including nuclear, coal, oil and natural gas plants) depend on the type of fuel it burns, the cost of the fuel, the plant's heat rate (i.e. the efficiency rate at which each plant converts the heat content of the fuel into output), and the short-run variable cost of operating and maintaining the plant (O&M).[19] We have assumed that the costs of the fossil-fuels are those negotiated daily in the international input markets.[20] In addition, to calculate the cost of the coal plants, we have added an estimate of transportation costs based on the distance between each plant and the nearest harbor where coal is delivered. Lastly, we have assumed that the available capacity of each plant equals its average availability over a given month in those days in which the plant was not subject to scheduled maintenance or forced outages; a plant's available capacity is assumed to be zero otherwise.[21] By aggregating the capacities of a firm's thermal plants in increasing cost order, we obtain an estimate of its thermal cost curve in a given day (see Figure 3).

To obtain hourly marginal cost estimates, we need to intersect each firm's thermal cost curve with its thermal production in every hour, i.e. its total production net of its hydro production. For this purpose, we need to assume how firms allocate total hydro production during the day, given that we lack information on the hourly hydro production

[18]There are intertemporal and operational constraints that affect firms' costs (e.g. start-up costs or ramping rates). Our cost estimation does not take these into account (see Borenstein et al. (2002) for a discussion of how this could affect the estimates).

[19]The information on the types of fuel burned by each plant, together with their heat rates and operating and maintenance costs, has been obtained from Red Eléctrica de España (REE is the Spanish Transmission Owner and System Operator).

[20]We have not considered firms' obligation to burn domestic coal, and the subsidies obtained from so doing. For coal units, we use the MCIS Index, for fuel units we use the F.O.1% CIF NWE prices, and for gas units we use the Gazexport-Ruhrgas prices. All series are in Cent€/te. We have obtained this information from UNESA (the Spanish National Union of Electricity companies). For nuclear plants, we have assumed a fixed input cost equal to 0.5 Cent€/te; this does not affect the results as nuclear plants are never marginal.

[21]In a study of the British electricity market, Wolfram (1999) assigns each plant a capacity below its declared capacity to capture the strategic withholding aimed at increasing capacity payments (Patrick and Wolak (1997)). In the Spanish electricity market, capacity payments are fixed per kW declared available, implying that firms do not have incentives to under-declare their available capacities. Nevertheless, it must be noted that the scheduling of planned outages for maintenance may be subject to strategic considerations (e.g. it may be profitable to shift scheduled outages from off-peak to on-peak periods, see Patrick and Wolak (1997) for evidence on this).

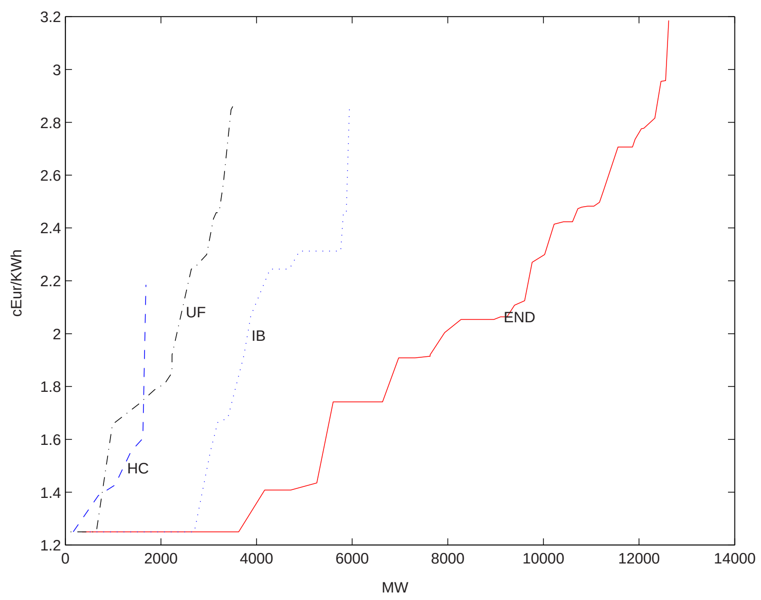

Figure 3: Representative Thermal Cost Curves at the Firm Level (on 27/12/98).

figures. Our data set distinguishes between each firm's daily pondage hydro and run of the river. Whereas firms can choose when to allocate the former, they cannot choose when to produce with the latter. Hence, we have allocated run of the river production evenly over the day. For pondage hydro, we have assumed that firms use it non-strategically and allocate it to high demand hours. This results in firms equalizing thermal production across the hours in which they allocate pondage hydro power, i.e. firms peak-shave each hour. Bushnell (2003) finds that strategic firms may have an incentive to increase hydro production in off-peak hours, rather than on-peak hours, thereby distorting the efficient use of hydro resources. Our methodology does not fully exclude this kind of strategic behavior given that we only assume non-strategic hydro allocation over the course of a day, i.e. firms could still be strategically allocating hydro over the year. Accordingly, we do not expect that the assumed peak-shaving procedure would considerably bias our cost estimates (or at least to the extent that the qualitative nature of the results would be reversed).

Since we will be using daily figures, we have used our hourly marginal cost estimates to compute a demand-weighted average. In the empirical analysis, we will be using marginal cost estimates for Endesa and Iberdrola only; these are denoted MC_t^{END} and MC_t^{IB}.

We have also computed firms' price-cost mark-ups, which are denoted $Markup_t^{END}$ and $Markup_t^{IB}$ for Endesa and Iberdrola (see Figure 2).

We have constructed additional variables aimed at capturing firms' strategic behavior. The choice of these variables is based on the theoretical discussion presented in Section 4. The variables $\Delta Share_{t-1}^{END}$ and $\Delta Share_{t-1}^{IB}$ are intended to capture a plausible trigger in an industry geared by a collusive agreement that switches to a price war when a firm's market share suffers a suspiciously large change (either positive or negative). They are measured as percentage changes in the firm's market share with respect to the previous period's value (lagged one period). The trigger variable ΔHHI_{t-1}, which represents the one period lagged value of changes in the Herfindahl-Hirschman index (i.e. the sum of the squared market shares of all firms in the industry), captures the changes in all firms' market shares. The variables ΔRev_{t-1}^{END} and ΔRev_{t-1}^{IB} are intended to capture a similar trigger, based on changes in firms' market revenues. Last, we consider the lagged changes in the weekly average price, $\Delta\overline{SMP}_{t-1}$.

The changes in firms' market shares and revenues shares depict a strong weekly seasonal component that would enter into the definitions of the trigger variables. In order to only consider their unexpected changes, the associated trigger variables have been constructed on deseasonalized values of production levels and revenues.[22]

5.2 The Empirical Model

As our statistical model we will 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

[22]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

	Mean	Variance	Min	Max
Q_t	423,350	47,462	305,950	524,500
Q_t^{END}	195,910	26,412	119,170	257,600
Q_t^{IB}	131,060	197,69	894,800	190,880
SMP_t	2.5525	0.3891	0.97613	3.1791
MC_t^{END}	2.5124	0.3914	1.2500	3.2830
MC_t^{IB}	2.4592	0.3577	1.3270	3.1098
$Markup_t^{END}$	-0.01310	0.2415	-1.0229	0.5645
$Markup_t^{IB}$	0.00176	0.2671	-1.8256	0.5494
$\Delta Share_{t-1}^{END}$	0.0005	0.0210	-0.09159	0.0992
$\Delta Share_{t-1}^{IB}$	-0.0008	0.0300	-0.11032	0.1344
ΔRev_{t-1}^{END}	-0.0016	0.1643	-1.0392	0.9913
ΔRev_{t-1}^{IB}	-0.0027	0.1426	-0.73729	0.7650
$\Delta \overline{SMP}_{t-1}$	-0.0021	0.1712	-0.53367	1.0237
ΔHHI_{t-1}	0.0002	0.0124	-0.03820	0.0410
$Distribution_t^{IB}$	170,840	222,97	115,040	230,330
$Availability_t$	16,812	527.6	15,805	17,772

for dynamics of prices with the lagged predetermined variables.[23] The state of prices is not known with certainty. The econometrician can neither observe the state of prices nor deduce the state directly. 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:[24]

$$\begin{aligned} SMP_t &= \mu_{S_t} + \beta \mathbf{Z}_t + \upsilon_t^s \\ \mu_{S_t} &= \mu_0(1-S_t) + \mu_1 S_t \\ S_t &= 0,\ 1. \end{aligned} \tag{6}$$

where SMP_t is the system marginal 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 $\mathbf{Z}_t$ is a group of variables that are likely to influence prices.

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

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

where s_t is a possible realization of the random variable S_t. We assume serial correlation of the states (e.g. a collusive period is likely to be followed by another collusive period). The variable w_{t-1} is likely to influence the transition probabilities, and it is henceforth referred to as 'trigger variable'.[25,26]

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

[24] Equation (6) could include the trigger-variables (w_{t-1}). 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.

[25] Two issues need to be stressed. First, we have explicitly written lagged w_{t-1}, because the theory predicts that firms should react immediately after they observe an anomalous behavior of the trigger variables. 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 $p(w_{t-1})$ 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 $p(w_{t-1})$ on d_{t-1} might lead to inconsistent estimates of the response of w_{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, $1 - q(w_{t-1})$, which should not be dependent on duration.

[26] In order to obtain consistent and normally distributed estimates from our maximum 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

The matrix of transition probabilities is given by:

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

where $q(w_{t-1}) = P(S_t = 0|S_{t-1} = 0,\ w_{t-1})$ and $p(w_{t-1}) = P(S_t = 0|S_{t-1} = 1,\ w_{t-1})$.

This specification only considers two different states, but it could be extended to allow for further regimes.[27] One difficulty at the time of dealing with this type of models is that conventional testing approaches to deal with the number of regimes are not applicable due to the presence of unidentified nuisance parameters under the null of linearity (that is, the transition probabilities) and because the scores associated with the parameters of interest under the alternative hypothesis may be identically zero under the null. Formal tests of the number of regimes within the Markov-switching framework employing the standardized likelihood ratio (LR) test designed to deliver (asymptotically) valid inference have been proposed by Davies (1977), Hansen (1992), Hansen (1996) and Garcia (1993). The possibility of three regimes is further analyzed in the following subsection.

In searching for a particular functional form of the transition probabilities, we will use the logistic function:[28]

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

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

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

Thus the parameter estimate $\lambda_{00,1}$ reflects the influence of w_{t-1} on $1 - q(w_{t-1})$.[29]

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.

[27] We are grateful to the referees for pointing this out.

[28] As in binary response models different specifications are available for mapping the index function $(\lambda_{lk,0} + \lambda_{lk,1} w_{t-1},\ k,\ l = 0, 1)$ into a probability. We could have tried other alternatives for our transformation function, $F(\cdot)$, such as a normal or a Cauchy cumulative distribution function instead of the logistic specification chosen. However, we have preferred the latter specification because of tractability reasons. For the normal and Cauchy cumulative distribution functions there is no close form expression for $F(x)$, which has to be evaluated numerically. This would have increased the amount of calculations in the type of models we use, which are already very computer intensive.

[29] Note that the sign of marginal effect of w_{t-1} on the probability of starting a price war will have the opposite sign as the $\lambda_{00,1}$s.

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

$$\begin{aligned}
f(SMP_t|SMP_{t-1}, w_{t-1}, \mathbf{Z}_t) &= \sum_{s_t=0}^{1}\sum_{s_{t-1}=0}^{1} f(SMP_t, S_t = s_t, S_{t-1} = s_{t-1}|SMP_{t-1}, w_{t-1}, \mathbf{Z}_t) \\
&= \sum_{s_t=0}^{1}\sum_{s_{t-1}=0}^{1} f(SMP_t|S_t = s_t, S_{t-1} = s_{t-1}, SMP_{t-1}, w_{t-1}, \mathbf{Z}_t) \\
P(S_t &= s_t, S_{t-1} = s_{t-1}|SMP_{t-1}, w_{t-1}, \mathbf{Z}_t) \\
&= \sum_{s_t=0}^{1}\sum_{s_{t-1}=0}^{1} f(SMP_t|S_t = s_t, S_{t-1} = s_{t-1}, SMP_{t-1}, w_{t-1}, \mathbf{Z}_t) \\
P(S_t &= s_t|S_{t-1} = s_{t-1}, w_{t-1})P(S_{t-1} = s_{t-1}|w_{t-1})
\end{aligned}$$

and the likelihood function is:

$$L(\theta) = \sum_{t=1}^{T} \ln f(SMP_t|SMP_{t-1},\ \mathbf{Z}_t, w_{t-1}; \theta),$$

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 governing the states.

In order to analyze the pattern of prices in the Spanish electricity market, we will estimate a version of the joint-profit maximizing first order condition (5). Rearranging terms we get,

$$SMP_t = \beta_1 MC_t^{END} + \beta_2 MC_t^{IB} + \beta_3 Q_t^{END} + \beta_4 Q_t^{IB} + \beta_5 Q_t^{R} \tag{9}$$

where $Q_t^R = \left[Q_t - Q_t^{END} - Q_t^{IB}\right]$ is the residual demand not served by the strategic firms (i.e. covered through imports, the production of the non-strategic firms, etc). From the analysis of Section 4, it can be checked that the expected signs of the coefficients should be positive for β_1 and β_2, negative for β_5, and either positive or negative for β_3 and β_4.

In order to formulate Equation (9) as in (6), we express the variables in deviations from their means and allow the mean of prices to fluctuate between two states. Last, we introduce autoregressive dynamics to allow for cross-price effects. This results in our equation of interest,

$$SMP_t - \mu_{S_t} = \rho(SMP_{t-1} - \mu_{S_{t-1}}) + \beta \mathbf{Z}_t + \upsilon_t^s \tag{10}$$

where β is the vector of parameters in the linear part of the model, $\mathbf{Z}_t = [MC_t^{END} - E(MC_t^{END}),\ MC_t^{IB} - E(MC_t^{IB}),\ Q_t^{END} - E(Q_t^{END}),\ Q_t^{IB} - E(Q_t^{IB}),\ Q_t^{R} - E(Q_t^{R})]'$ is the corresponding vector of variables measured in deviations from their means, the term $v_t^s \sim N(0, \sigma_s)$ captures innovations or shocks unmodelled in our supply equation and μ_{S_t} denotes the time varying mean of prices, where S_t denotes the state, with $S_t = 0$ if t is a collusive period (high prices), and $S_t = 1$ if t belongs to a price war (low prices).

Note that there could be three potential sources of endogeneity of the $\mathbf{Z}_t$ variables: the demand not served by the strategic firms, Q_t^R, and the quantities they produce, Q_t^{END} and Q_t^{IB}, are likely to be correlated with innovations in our price equation, (10). In order to address this endogeneity problem we respectively instrument these variables with weekend dummies, the available thermal capacity in the industry, and the demand distributed by Iberdrola (see Table 2 for summary statistics of these variables). These are all valid instruments as they are correlated with the corresponding variables but unrelated with innovations in prices. The weekend dummies capture most of the variation of the demand not served by the strategic firms and they are unrelated with innovations in prices. Moreover, the thermal available capacity should be correlated with Q_t^{END} and uncorrelated with innovations in prices. Last, the amount distributed by Iberdrola should be related to Q_t^{IB} and unrelated with innovations in prices (the amount served by any distributor is independent of wholesale prices as final consumers pay a regulated tariff, set in advance).

5.3 The Results and their Interpretation

In our empirical analysis we consider six different models that differ in the variables that are used as triggers. The different models are labelled from 1 to 6, corresponding to the use of $\Delta Share_{t-1}^{END}$, $\Delta Share_{t-1}^{IB}$, ΔRev_{t-1}^{END}, ΔRev_{t-1}^{IB}, $\Delta\overline{SMP}_{t-1}$ and ΔHHI_{t-1} respectively. Estimates are computed by numerically maximizing the conditional likelihood. [30]

Table 3 reports results for our set of models. The signs of the coefficients associated with the relevant variables are as expected. Increases in the marginal costs of Endesa and Iberdrola induce an increase in prices, as reported by the positive signs of β_1 and β_2. The coefficient of the Endesa's production (β_3) is strongly significant and reports a positive coefficient. The point estimate of the coefficient associated with Iberdrola's production (β_4) reports a negative sign, though a confidence interval constructed at the 5 % level of significance would also include positive values as well as zero. Finally, the demand not served by the two main generators is strongly significant and the negative sign of β_5 is

[30] In the estimation, we have scaled the quantity variables dividing them by 10 000 in order to put all the variables in a similar scale. This is required for the purpose of facilitating the numerical maximization.

Table 3: Parameters Estimates of the TVTP Models

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	$\Delta Share^{END}$	$\Delta Share^{IB}$	ΔRev^{END}	ΔRev^{IB}	$\Delta \overline{SMP}$	ΔHHI
log-lik	27.8975	28.5338	28.4649	28.1910	27.7454	27.6838
ρ	0.5209	0.5217	0.5282	0.5191	0.5173	0.5211
	(0.0455)	(0.0461)	(0.0502)	(0.0441)	(0.0448)	(0.0452)
β_1	0.1207	0.1209	0.1207	0.1234	0.1217	0.1220
	(0.0318)	(0.0317)	(0.0319)	(0.0319)	(0.0317)	(0.0321)
β_2	0.0154	0.0152	0.0153	0.0159	0.0153	0.0156
	(0.0154)	(0.0154)	(0.0156)	(0.0153)	(0.0154)	(0.0155)
β_3	0.0808	0.0803	0.0716	0.0828	0.0816	0.0818
	(0.0299)	(0.0301)	(0.0322)	(0.0293)	(0.0296)	(0.0295)
β_4	-0.0376	-0.0363	-0.0357	-0.0395	-0.0379	-0.0391
	(0.0348)	(0.0347)	(0.0348)	(0.0346)	(0.0345)	(0.0349)
β_5	-0.2004	-0.2017	-0.2026	-0.2056	-0.2019	-0.2027
	(0.0757)	(0.0755)	(0.0759)	(0.0758)	(0.0754)	(0.0765)
μ_0	2.6658	2.6651	2.6643	2.6647	2.6658	2.665
	(0.0231)	(0.0231)	(0.0235)	(0.0228)	(0.0229)	(0.0231)
μ_1	1.9289	1.9255	1.9369	1.9209	1.9260	1.9247
	(0.0512)	(0.0509)	(0.0531)	(0.0508)	(0.0505)	(0.0520)
$\lambda_{11,0}$	3.6185	3.6748	3.6095	3.5963	3.6264	3.6080
	(0.3831)	(0.3948)	(0.3866)	(0.3808)	(0.3800)	(0.3762)
$\lambda_{00,1}$	1.7934	1.8570	1.8977	1.9292	1.7504	1.7757
	(0.4349)	(0.4557)	(0.5048)	(0.4819)	(0.4418)	(0.4401)
$\lambda_{11,1}$	13.0737	12.0412	-1.6093	2.0324	-0.8752	-42.0927
	(14.8481)	(10.2657)	(1.5004)	(3.8287)	(0.8404)	(74.9304)
$\lambda_{11,1}$	10.1408	-9.5191	2.8551	2.9148	-0.1046	-40.45
	(17.4295)	(8.9431)	(2.1643)	(2.6503)	(1.9421)	(92.9327)
σ	0.0373	0.0374	0.0371	0.0373	0.0373	0.0374
	(0.0029)	(0.0029)	(0.0030)	(0.0029)	(0.0029)	(0.0029)

Note: Standard errors are in parenthesis

Table 4: Specification Tests

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	$\Delta Share_{t-1}^{END}$	$\Delta Share_{t-1}^{IB}$	ΔRev_{t-1}^{END}	ΔRev_{t-1}^{IB}	$\Delta\overline{SMP}_{t-1}$	ΔHHI_{t-1}
Error Autocorrelation	0.75738	0.76678	0.74595	0.85982	0.71530	0.73609
ARCH	0.16598	0.17418	0.19316	0.18446	0.18900	0.18635
Normality	0.93584	0.89554	0.92794	0.89832	0.98342	0.98523
Likelihood Test	0.00098	0.00052	0.00055	0.00073	0.00114	0.00121

consistent with the predictions of the model.

Table 3 also presents enough evidence to support the hypothesis that two distinct price levels characterize the time series of prices. The point estimates of the state-dependent means are statistically different and their magnitudes 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 price (collusive phase), given the technology and production information embodied in Equation (10). This result is consistent with Green and Porter's first prediction, namely, that there must be periodic switches in oligopolistic conduct among colluding firms.

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. 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 20.9747.[31] 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% for

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

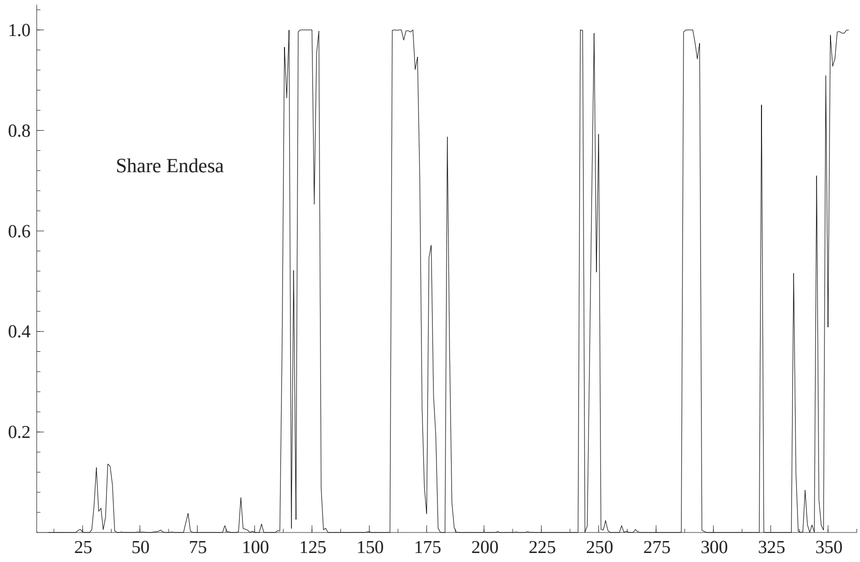

Figure 4: Smooth Probabilities of Being in a Price War in Model 1 (trigger is $\Delta Share^{END}_{t-1}$)

all models. Therefore, our results show that there is further information embodied in the trigger-variables that accounts for the transition dynamics from high to low price states. 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.

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, an F-test for conditional heteroscedasticity of order two, as well as a Chi-square test for normality. Their corresponding p-values are reported in the first, second and third rows, respectively. The different models estimated seem to be a good statistical specification given the diagnostic statistics.

As already mentioned, an important specification issue is whether the data is better described by three rather than two states. Testing for the number of regimes in a Markov switching model is a difficult task, but economic insight can be useful. Given that the over-contracted firm (Endesa) is hurt when prices are high and the under-contracted firm (Iberdrola) is hurt when prices are low, one could conjecture that punishments should be firm specific, leading to three regimes (punishment for Iberdrola, punishment for Endesa and collusive regime) rather than two. However, this possibility is subject to two objections: first, the complexity of such schemes,[32] and second, the fact that the harshest punishment that can be inflicted on both firms involves low prices. From Section 2, recall that the amount of CTC payments earned by a firm cannot exceed the maximum established by Law. This implies that prices below the level that would result in a firm receiving its maximum entitlement would not be compensated by an increase in CTCs.[33]

Figure 4 plots the smooth probabilities of being in a low state of prices for Model 1 (all the models deliver very similar pictures). The classification of the states and the dating of the price wars is done using the smoothed probabilities. At every point in time, we calculate a smoothed probability of being in an given state, and then assign that observation to one of the regimes according to the highest filtered probability, i.e. $P(S_t = 1|S_{t-1} = s_{t-1},\ w_t,\ SMP_t) < 0.5$ and $P(S_t = 1|S_{t-1} = s_{t-1},\ w_t,\ SMP_t) > 0.5$. 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 prices is followed by a state of the same nature.

This definition allows a corresponding dating of price wars in the Spanish electricity market. As can be seen in Table 5, the average duration of a price war ranges from slightly less than five days to almost three weeks.[34] The drops in prices during a price war regime

[32]This parallels Ellison (1994, p.39)'s view that "*if we tried to apply such a theory* [optimal equilibria]*, we would be immediately faced both with the reality that no asymmetric punishments were observed and with the limitations in the amount of data available to identify complex strategies. Even restricting ourselves to symmetric trigger strategies, what is optimal may also be hard to determine without knowing far more details than are available.*"

[33]We have previously discussed the difficulties of testing statistically for the number of regimes. The extension of Hansen's approach to our model seems to be impossible to implement computationally (see Ang and Bekaert (1998)) and is certainly beyond the scope of this paper. Furthermore, it delivers only a bound on the asymptotic distribution of the standardized LR test. The test is conservative, tending to be under-sized in practice and of low power. Having said this, we estimated a three regimes equation for all the models entertained. A LR test of 2 regimes against the alternative of three delivered the following values: 4, 2.01, 3.11, 1.79, 7.75 and 10.05. Where the ordering of the these previous results correspond to the ordering in which the models are presented in the tables. That is, the first value (4) correspond to the LR test of two states against three states for the model with $\Delta Share^{END}_{t-1}$ as trigger, the second value correspond to the LR test of two states against three for the model with $\Delta Share^{IB}_{t-1}$ as trigger, and so on. Even if we use the upper bound suggested in Davies (1977) the null of a two states model cannot be rejected against the alternative of three states for all the models.

[34]The results reported in Table 5 rely on the regime classification obtained using the smooth probabilities of the model where $\Delta Share^{END}_{t-1}$ is the trigger variable. This regime classification hardly changes across

Table 5: Dating of Price Wars, Duration, Depth, and Generators' Mark-ups in the period before a Price War Starts (based on Model 1, trigger $\Delta Share^{END}_{t-1}$)

Dating	Duration (days)	Depth (%)	$Markup^{END}_{t-1}$ (%)	$Markup^{IB}_{t-1}$ (%)
04/05-13/05	10	44.27	-10.18	-31.04
14/06-03/07	20	41.21	8.80	15.95
08/09-12/09	5	18.75	-19.38	-26.77
19/10-26/10	8	34.16	-4.63	-2.02
20/12-30/12	11	21.69	21.11	41.71

with respect to the last collusive period -which we refer to as the *depth* of the price war-, are of great magnitude. On average, prices drop 32% and the highest drops in prices attain values as high as 45 %.

Interesting information can also be gathered concerning firms' mark-ups prior to entering a price war (Table 5) and their average values across the two states (Table 6). Whereas during the collusive phase both firms' mark-ups are positive (which, as already mentioned, shows that firms are not bidding according to their one-shot best responses), during the price war phase Endesa's mark-up becomes negative, as predicted by the model of individual profit maximizing behavior. The behavior of firms' mark-ups in the period that triggers the price war is not homogenous across the different price wars. This seems to suggest that deviations are not taking place (or at least, not always in the same direction). However, this assertion needs to be taken with caution given that the lack of information on firms' actual bids does not allow us to properly identify whether price wars are caused by actual cheating or by changes in the unobservable variables.

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

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

the different models. Further results on the regime classification using other models can be obtained from the authors upon request.

Table 6: Average Markups during Collusive and Price War Periods (based on Model 1, trigger $\Delta Share^{END}_{t-1}$)

	$Markup^{END}$(%)	$Markup^{IB}$ (%)
Collusive Periods	18.27	31.80
Price War Periods	-11.70	4.10

Table 7: Marginal Effects of the Trigger Variables on the Transition Probabilities (based on Model 1, trigger $\Delta Share^{END}_{t-1}$)

Trigger Variable	$\frac{\partial P(S_t=1\|S_{t-1}=0,\bar{z}_{t-1})}{\partial z_{t-1}}$	$\frac{1}{T}\sum_{i=1}^{T}\frac{\partial P(S_t=1\|S_{t-1}=0,z_{t-1})}{\partial z_{t-1}}$
$\Delta Share^{END}_{t-1}$	0.3351	0.3474
$\Delta Share^{IB}_{t-1}$	-0.2937	-0.3153
ΔRev^{END}_{t-1}	0.0422	0.0445
ΔRev^{IB}_{t-1}	-0.0518	-0.0538
$\Delta \overline{SMP}_{t-1}$	0.0222	0.0226
ΔHHI_{t-1}	1.0819	1.1059

and the average marginal effect,

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

This information is provided in Table 7, and it is complemented in Figure 5, which depicts the cross plots of the transition probabilities $P(S_t = 1|S_{t-1} = 0,\ w_{t-1})$ with the trigger variables associated with the changes in firms' market shares and revenues.

The signs of the marginal effects coincide with those predicted by the theory. First, the marginal effects of $\Delta Share^{END}_{t-1}$ and ΔRev^{END}_{t-1} are positive, whereas those of $\Delta Share^{IB}_{t-1}$ and ΔRev^{IB}_{t-1} are negative. That is, increases in Endesa's market share and revenues and reductions in Iberdrola's market share and revenues, increase the probability of entering into a price war phase. The sign of ΔHHI_{t-1} is in agreement with those of $\Delta Share^{END}_{t-1}$ and $\Delta Share^{IB}_{t-1}$, as an increase in Endesa's market share and a reduction in Iberdrola's market share leads to an increase in industry concentration. Last, the positive sign of

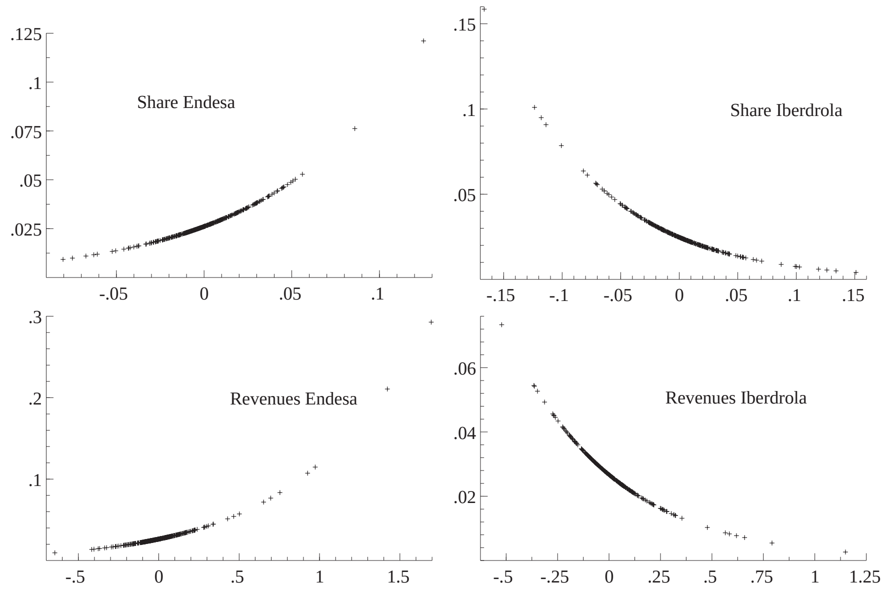

Figure 5: Cross Plots of Trigger Variables and the Probability of Starting a Price War, $P(S_t = 1|S_{t-1} = 0, w_t)$, for $\Delta Share^{END}_{t-1}$, $\Delta Share^{IB}_{t-1}$, ΔRev^{END}_{t-1} and ΔRev^{IB}_{t-1}

$\Delta\overline{SMP}_{t-1}$ is highly meaningful: in contrast to models of collusion among uncontracted firms, we find that an increase in prices with respect to their usually prevailing level increases (rather than decreases) the probability of starting a price war. Given that a price increase is consistent with Iberdrola's one-shot bidding incentives, this seems to suggest that Iberdrola is considered to be the firm most likely to defect from the collusive agreement.[35] These last pieces of evidence support Green and Porter's third prediction, namely, that price wars should be triggered when the observable variables behave *as if* a deviation had taken place.

[35]The recent performance of the Spanish electricity market shows that Iberdrola has decided, in the light of our analysis, to 'defect' forever. In November 2003, Iberdrola proposed to eliminate the CTC payments, even if there was still a residual amount of CTCs to be received. In a newspaper article entitled "The Secret Price War between Endesa and Iberdrola", Mota (2003) writes : *"Why is Iberdrola opposing the CTCs, apparently against such as primary and evident interest as to receive the money that it had been recognized or given by the government?...because it would hurt Endesa more, but above all, because the end of the CTCs would free the market price - now it is capped at 6 PTAS/kWh- in which the Basque generator (Iberdrola) has a larger share than it has on the CTCs."*

6 Conclusions

We have analyzed the dynamic exercise of market power in the Spanish electricity market during 1998 using daily observations on demand, prices and other variables that allow us to obtain accurate marginal costs estimates at the firm level. The Spanish electricity market has interesting institutional features that make this analysis relevant both for public policy, as well as from a methodological perspective.

As in all decentralized electricity markets, trading in the Spanish electricity market takes place through a series of daily auctions. Both theory and experience suggest that the daily repetition of auctions may have a dramatic effect on market performance, as it allows firms to learn to coordinate their strategies and hence compete less aggressively with each other over time, through collusive agreements. However, unlike other markets, collusion in the Spanish electricity market need not result in high price-cost margins. The reason is that the Spanish electricity producers are entitled to earn some regulatory payments, which are computed in a similar fashion as "Contracts for Differences". The theoretical predictions imply that an over-contracted firm may find it in its private interest to reduce prices, as this strategy may lead to an increase in its contract revenues that more than compensates for the reduction in prices. Thus, even in a static context, the value of firms' mark-ups does not provide a precise measure of firms' ability to exercise market power. To overcome this difficulty, our analysis has exploited the movements in prices, firms' market shares and revenues in order to infer firms' ability to exercise market power in a dynamic context.

The performance of the Spanish electricity market during 1998 is not consistent with the predictions of models of individual profit maximizing behavior. In particular, the over-contracted firm should have produced at prices below marginal costs, and the movements in prices should have been fully explained by changes in demand and cost conditions. These observations have led us to conjecture that the Spanish electricity producers may have been engaged in some kind of tacit agreement that has distorted market outcomes from what the theories of individual profit maximizing behavior predict.

The models of collusion under imperfect monitoring, as the ones pioneered by Green and Porter (1984), predict that colluding firms occasionally revert to periods of intense rivalry as a way to enforce collusive outcomes. Our analysis has been designed to test whether these theories provide a consistent explanation for the behavior of prices and firms' market shares in the Spanish electricity market. In order to identify the plausible triggers that firms could be using to support an equilibrium of the Green and Porter type, we have first identified firms' optimal deviations from a model of joint-profit maximizing behavior. This model predicts that price wars should be triggered when the market share and revenues of the under-contracted firm decrease, and those of the over-contracted firm increase. We have tested these predictions empirically by modelling the time series of prices as a Markov switching process in the mean, with time-varying transition probabilities that depend on changes in firms' market shares, revenues, and market prices. The results confirm that the time series of prices is characterized by two distinct price levels, thus giving support to Green and Porter's main prediction. Furthermore, most of the triggers considered appear to be significant and report the same signs as those predicted by the theory. These results offer further support to the claim that the way in which the CTCs 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 possible (although we cannot test it empirically) 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.

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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