Price Wars and Collusion in the Spanish Electricity Market

Natalia Fabra
IDEI, Université de Toulouse

Juan Toro
University of Oxford and centrA

February 2002

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Abstract: We analyze the pattern of pool prices in the Spanish electricity market during 1998 by means of a Time Varying Transition Probabilities Markov switching model. Our purpose is two-fold: firstly, to identify and date the drops in prices that cannot be accounted for by supply nor demand conditions; and secondly, under the assumption that these correspond with reversions to non-cooperative behavior, to identify the trigger variables upon which a collusive equilibrium could be based upon. Our results confirm the hypothesis that two distinct price levels characterize the time series of pool prices, and point to the conclusion that price wars are induced by changes in the major generators' market shares. In turn, this shows that firms' pricing behavior is highly influenced by the way in which the so-called Competition Transition Charges (CTCs) are computed.

JEL No: C22, L13, L94.

Keywords: Electricity Markets, Tacit Collusion, Markov Switching.

Guerras de Precios y Colusión en el Mercado Eléctrico Español[2]

Resumen: En este articulo analizamos la serie de precios en el mercado eléctrico español durante 1998. Para ello, utilizamos un modelo de Markov en el que las probabilidades de cambio de estado dependen del tiempo. El objetivo del análisis es doble: primero, identificar y datar los periodos en los que las caidas de precios no se pueden explicar por condiciones objetivas de oferta y demanda; y segundo, bajo el supuesto de que dicho fenómeno forma parte de una estrategia colusiva, identificar las variables que provocan el comienzo de una guerra de precios. Los resultados empiricos confirman la hipótesis de que la serie de precios se caracteriza for dos estados claramente diferenciados en el nivel de precios. Los cambios en las cuotas de mercado de los generadores dominantes aparecen como la variable más significativa en la determinación del comienzo de las guerras de precios. Por último, nuestro análisis pone de manifiesto que el comportamiento de las empresas se ha visto influido por el cobro de los Costes de Transición a la Competencia.

Clasificación JEL: C22, L13, L94.

Palabras Clave: Mercados Eléctricos, Colusión Tácita, Modelo de Markov.

[1]The authors gratefully acknowledge the financial support provided by *Fundación Empresa Pública*. We are also greateful to Soren Johansen and Massimo Motta for useful comments and suggestions.

[2]Este proyecto de investigación ha sido financiado por la Fundación Empresa Pública. Los autores agradecen a Soren Johansen y Massimo Motta por el apoyo prestado.

1 Introduction

During the last decade a wave of reform has swept across many of the formerly regulated electricity industries.[3] The details differ country by country, but the different processes of reform share some common features. These include the breaking up of the formerly vertically integrated companies - typically monopolies under government regulation-; the unbundling of the products and services required to produce and deliver electricity - 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.

The new form of regulation of the electricity supply industry has given rise to a new set of problems associated with the achievement of efficiency goals. Among these, one of the problems receiving the greatest attention is the issue of market power and its likely effects on allocative efficiency (above marginal cost pricing) and productive efficiency (inefficent dispatch and biased signals on the need for new capacity). While the issue of market power in electricity markets has been broadly studied within static contexts, little attention has been given to its analysis within dynamic models of competition. Recognizing the dynamics of market power is likely to be important in determining its causes and in designing new market rules that reduce the opportunities of manipulation.

In this paper, we attempt to shed light on the empirical analysis of some of the dynamic issues of competition in electricity markets. With this purpose, we analyze the time series of pool prices in the Spanish electricity during its first year of operation, 1998. Unlike other previous analysis, it is not our aim to estimate the extent to which prices have exceeded the levels that would be obtained in a market in which all participants behaved non-strategically.[4] Instead, we exploit the changes in the pattern of prices and firms' market shares to infer firms' ability to exercise market power in a dynamic context.[5] The whole analysis is based on a simple idea: on the one hand, if firms effectively compete in prices, then prices should be equal in different periods in which demand and supply conditions coincide. On the other hand, if firms are alternating between episodes of collusion and price wars, then such a close relationship is broken. This has implications about the observable consequences of collusive behavior. Therefore, even without an estimation of firms' marginal costs, competitive and collusive behavior can be distinguished from the movements in industry prices and firms market shares.

[3]Decentralized electricity markets have been created in Britain, Norway, Sweden, the United States, Australia, Spain, Canada, New Zealand, Colombia, Argentina and Chile, to name but a few.

[4]See Wolak and Patrick (1997), Wolfram(1998, 1999), Borenstein and Bushnell (1999) and Boresntein, Bushnell, Knittel and Wolfram (2001), among others. See Fabra and Harbord (2001) for a review of these works. See also Section 3.2 for more on this.

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

Accordingly, we aim at empirically investigating the existence of price wars in the Spanish electricity market; and at identifying a number of plausible triggers upon which a collusive equilibrium might be based. With these purposes, we propose to model the behavior of the pool price in the Spanish electricity market as an autoregressive Markov switching model in mean with time varying transition probabilities. This process 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.

Our results support the hypothesis that two distinct price levels characterize the time series of prices in the Spanish electricity market during 1998. In the spirit of Green and Porter (1984), we claim that the periods of low prices represent reversions to non-cooperative behavior that are triggered when changes in some of the observable variables resemble a signal of cheating. Furthermore, we find that increases in the major generator's market share appear as a plausible trigger for price wars. As we explain in more detail in the paper, this supports the view that firms' pricing behavior is likely to be highly influenced by the existence of the so-called Competition Transition Charges (CTCs) and the way in which these are computed.

This paper is structured as follows. In section 2 we briefly describe the Spanish electricity industry. In section 3 we survey some of the different theoretical and empirical approaches that have been proposed in the recent literature for analyzing and testing collusion. In section 4 we present the econometric approach and interpret the results in the light of the theoretical predictions. Section 5 of the paper concludes.

2 The Spanish electricity industry

In 1997,[6] 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[7] to one that relied on market forces as a way to find 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.

[6]In 1996, the Ministry of Industry and Energy started to envisage the regulatory change. The preliminary work led to the so-called Protocol for the Establishment of a New Regulation of the Electricity System, which was signed by the Ministry and the electricity generating companies. A year later, the Law 54/97, of November 27th 1997, and the drafts of the European Union Directive for the internal electricity market, led to the creation of the Spanish wholesale electricity market, which started to operate on January the 1st, 1998.

[7]Generators' costs and efficiency rates were audited by the System Operator; according to these audited costs, production was allocated among firms on the basis of least cost despatch; the generating companies were paid some regulated tariffs that were based on some average of their audited costs (the so-called *standard costs*).

The daily market concentrates most of the transactions.[8] 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.[9] 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 supply (consume) at a price no greater (lower) than the SMP. 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 Spanish electricity generation market is highly concentrated.[10] Prior to the regulatory reform of 1997, the industry was consolidated as a four-firm oligopoly, where the two largest participants -Endesa and Iberdrola- controlled almost the 80 percent of total available generating capacity, and the remaining 20 percent was divided between two smaller firms -Unión Fenosa and Hidrocantábrico- and several fringe companies.[11] Furthermore, firms differ in their technology

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

[9]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.

[10]The process of concentration started towards 1988. On the one hand, ENDESA - a public company at that time- adopted an aggressive strategy aimed at controlling some of the several small, regional electricity companies (ERZ (Aragón), ELECTRA DE VIESGO (Cantabria), SALTOS DEL NANSA (Asturias), ENHER (Cataluña), UNELCO (Canarias) and GESA (Baleares)). This process was culminated in 1996 when the government allowed ENDESA to take control over two important companies, Sevillana de Electricidad and FECSA. This merger allowed ENDESA to become the largest firm in the sector, with a 50 per-cent share of total available generating capacity. Since that date, ENDESA has been privatized through public tender offers, and is currently in private hands. On the other hand, a merger between two private companies, IBERDUERO and HIDROLA, led to consolidation of the second largest firm in the sector, IBERDROLA, which would furthermore have the control over a large fraction of the available hydro resources.

[11]Since then, further merger plans have been attempted, but they have all been frustrated, in some instances due to the government's refusal, in others by the firms' decisions themselves. In March 2000, Unión Fenosa wanted to take over Hidrocantábrico (See Tribunal de Defensa de la Competencia (2000); but this concentration was refused by

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)

mixes. These differences give each firm a different market position in each of the relevant time periods. Table 1 summarizes the capacity shares by company and technology in the Spanish electricity market.

2.1 The functioning of the Spanish electricity market during 1998

We will be mainly concerned about two features that characterize the functioning of the Spanish electricity market during 1998. Firstly, the pattern of prices; and secondly, the evolution of firms' market shares (See Figure 1).

Unlike what one would expect, prices do not show any systematic relationship with the evolution of demand. The highest and lowest average monthly prices do not coincide with the months of higher and lower demand, as these are verified, respectively, during November (4.8 PTAS/kWh) and June and May (3.8 PTAS/kWh). One can observe the occurrence of five to six periods (February, May, June, September, October and December), during which average prices fall below 3 PTAS/kWh.[12] We will refer to these phases as price wars, and we will aim at testing their empirical significance, dating them, and identifying some of their possible triggers.

Closely related to the anomalous behavior is prices is the evolution of firms' market shares. The pattern of market shares during 1998 showed abrupt changes, some of which can be partly accounted for by the availability of hydro resources in the system (a great part of which are owned by Iberdrola). During January, 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

the government. In October 2000, Endesa and Iberdrola wanted to merge, but they refused to carry over with their plans after been informed of the conditions imposed by the government (See Tribunal de Defensa de la Competencia (2001)).

[12] Such a price would not allow most of the thermal groups to recoup their marginal costs of production.

to a more steady state, with Endesa's share reaching a 50% of the market as opposed to Iberdrola, whose market share was reduced to the 30% of the market. 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.

The evolution of firms' market shares naturally appears as a possible trigger that might induce changes in the state of prices. Our empirical model will evaluate whether their impact in the transition probabilities from one state of prices to the other was indeed significant. The remaining triggers that we will consider are related to the way in which generators' revenues are computed, which we pass on to discussing in the following subsection.

2.2 The determination of generators' revenues

Mainly, generators have three potential sources of revenues: market revenues, capacity payments, and stranded cost recovery payments.[13]

Firstly, as described in the preceding subsection, 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 (independently of whether they have been actually despatched or not) are entitled to obtain a capacity payment, which is in place to compensate firms for the service they provide to the industry from been available (and which is meant to provide firms with further incentives for capacity investments). The total value of capacity payments resulted in 1998 from applying 1.30 PTAS/kWh to the total volume of power demanded, and is shared among firms on the basis of their availability factors.[14] 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, it is unlikely that these payments will be able to explain the anomalous behavior of the price pattern. We will therefore omit them from our analysis.

And last, the incumbent generators are entitled to earn the so-called Competition Transition Charges (CTC) during a ten-year transition period since the opening of the market. These charges are in place to compensate firms for the value of their stranded investments, which were undertaken through a centralized capacity planning system under the guarantee of cost recovery. The maximum amount of these charges to be paid during the transition period[15] was computed as the difference between the net present value of the revenues that firms were entitled to receive under the old

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

[14]The total capacity payments represented, in 1998, a 22% of their total market revenues.

[15]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.

regulatory regime and firms' expected revenues in the market place, assuming that the competitive price would be equal to 6 PTAS/kWh. The total volume of CTCs is shared among firms on the basis of some pre-determined CTC shares, which were fixed at 51.2% for Endesa, 27.1% for Iberdrola, 12.9% for Unión Fenosa and 5.7% for Hidrocantábrico.

The amount of CTCs to be paid to the whole industry in a particular year is computed as follows: the government fixes the tariff 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 remaining amount is the amount of CTCs to be paid for the whole industry, and is shared among firms on the basis of their predetermined CTC shares.[16]

At the end of every year, the residual amount of each firm's CTCs to be received during the remaining years of the transition period is computed as follows: from the maximum amount of CTC a firm is entitled to, one must extract the amount of CTCs already received and 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.

The existence of CTCs payments and the way in which they are computed have an important effect on firms' pricing behavior. To analyze the effect of the changes in prices on a firm's current year profits, note that an increase in the SMP has a double impact on a firm's current year revenues: on the hand, it will imply higher market revenues, but on the other hand it will lead to lower CTC revenues. The first impact will be stronger the larger a firm's market share, whereas the second effect will be more pronounced the larger a firm's CTC share. Thus, the marginal effect of an increase in SMP on a firm's current year revenues will be positive for those firms whose market share exceeds its CTC share, and negative otherwise.

Furthermore, an increase in the SMP will have an impact on firms' residual CTC payments: if the average price received by a firm exceeds 6 PTAS/kWh, then the residual amount of CTCs to be charged at the end of the transition period will be reduced. From this we can conclude that for a discount factor equal to one (i.e. firms give equal weight to current and future revenues) firms are indifferent about the level of prices, as long as these do not fall on average below 6 PTAS/kWh. As the discount factor falls below one,[17] then the marginal effect of an increase in SMP on a firm's

[16] Note that this implies that the revenues made by the industry as a whole are fixed, independently of the pool price movements: higher (lower) market prices imply higher (lower) market revenues but lower (higher) CTC payments. However, each firm's revenues are not fixed, as these depend on the interplay between its market share and its share of total CTCs entitlements. This will play an important role in our analysis.

[17] Note that changes in the discount factor can be due either to changes in firms' time preferences, or to changes in the perception of the certainty/uncertainty of whether the full amount of CTCs compromised by Law will effectively be paid or not at the end of the transition period. Given that the European Commission was questioning the legality of these payments, it is likely that this uncertainty might have played a role in determining firms' pricing incentives.

expected profits over the transition period will be positive for those firms whose market share exceeds its CTC share, and negative otherwise.

We can conclude that, as long as firms' market shares do not coincide with their CTC shares (as this was indeed the case during 1998) there is a conflict of interest between firms: Endesa, whose market share lies on average (40%) below its CTC share (51.2%) prefers low SMPs; in contrast, Iberdrola, whose market share (30%) lies on average above its CTC share (27.1%), prefers high SMPs.[18] We will investigate whether such a conflict of interest among firms plays any role in triggering price wars.

3 Static versus dynamic market power: a review of the literature

In this paper, we provide an empirical analysis of the pattern of pool prices during 1998 with the aim of distinguishing whether its movements are consistent with firms' competitive behavior or rather, with the dynamic exercise of market power. We thus review some of the insights that can be obtained from the literature and the approaches that have been used in the empirical work.

3.1 Review of the theory

Oligopoly models provide us with a range of static and dynamic pricing models that may explain some of the features that we observe in the Spanish data set.

The most cited static models of bidding behavior in electricity markets are those developed by Green and Newbery (1992) and von der Fehr and Harbord (1993). Using Klemperer and Meyer's (1989)'s supply function approach, Green and Newbery (1992) assumed that generators submit continuously differentiable supply functions to the pool, and that the market equilibrium was the static one-shot supply function equilibrium. The equilibrium solution lies between the price-setting Bertrand equilibrium and the quantity-setting Cournot equilibrium. von der Fehr and Harbord (1993) proposed to model competition in electricity markets as a first-price, sealed-bid, multi-unit auction. They showed that prices are either equal to the marginal cost of the least efficient firm or to the highest admissible price, depending on whether all generators have enough capacity to supply the whole market or on whether the largest generator faces a positive residual demand. Thus, there is no guarantee that the competitive outcome will arise, even in a static equilibrium.

Nevertheless, for our current purposes, the one feature we want to stress is that in these two models prices and demand exhibit a systematic relationship: that is, prices in periods of similar demand and supply conditions, should be roughly the same. These static models are thus not well suited to explain what we observe in the Spanish data: namely, the occurrence of drastic drops in prices that cannot be explained by changes in supply nor demand conditions.

[18] These results are formally derived in the Appendix.

The alternative way to approach this issue is to resort to dynamic models of competition. Both theory and experience suggest that the daily repetition of electricity auctions may 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. In a collusive equilibrium firms earn joint profits which exceed those at the one-shot Nash equilibrium. Even if firms have unilateral incentives to deviate, the threat that deviations will be punished by future aggressive conduct discourages them from breaking the tacit agreement. If future discounting is not heavy enough, the collusive equilibrium can then be sustained as an equilibrium of the infinitely repeated game (Friedman (1977)).

Collusion under certainty markedly differs from collusion under uncertainty. If there is no exogenous source of uncertainty, deviations from the tacitly agreed market shares are perfectly detected, and thus punished. In contrast, punishing behavior is never observed in equilibrium - precisely because the collusive strategy is designed in a way such that deviations never take place. However, as argued by Green and Porter (1984), as long as some amount of imperfect information is introduced into these models, the sustainability of collusion requires periodic reversions to some short-run unprofitable behavior.[19]

Green and Porter (1984) study a model in which demand fluctuations are not directly observable by firms. In this context, firms collude while prices remain high but they revert to Cournot behavior when prices fall below a trigger price; collusion is then restored after a period of intense rivalry. In this model, price wars are not the punishment to secret price cheating, but a device that allows firms to deter deviations when firms cannot distinguish whether a price drop has been generated by secret price cutting or by a negative shock in demand. Abreu, Pierce and Stacchetti (1986) show that the trigger strategies employed in Green and Porter (1984) are optimal in a model that allows for more general strategies.

The Spanish electricity market does not precisely correspond to the Green and Porter's (1984) formulation. Its insights can nevertheless be valuable when applied to our data set, for the following reasons.

The main distinction relates to the information available to firms. In the Spanish electricity market, demand is known to all market participants, so that in contrast to Green and Porter's (1984) formulation, electricity generators can distinguish whether a fall in price is due to a negative shock in demand. Furthermore, during the first half of the 1998, generators knew the production allocated to each of its competitors with one day of delay; this delay was increased up to a month during the second half of the year. Despite this, there are likely to be other sources of uncertainty which induce an inference problem of the same nature as in Green and Porter (1984). Among

[19] As will be discussed in the following subsection, the necessary appearance of this phenomenon if collusion is to take place makes it possible to obtain clear-cut predictions about the presence or absence of collusion.

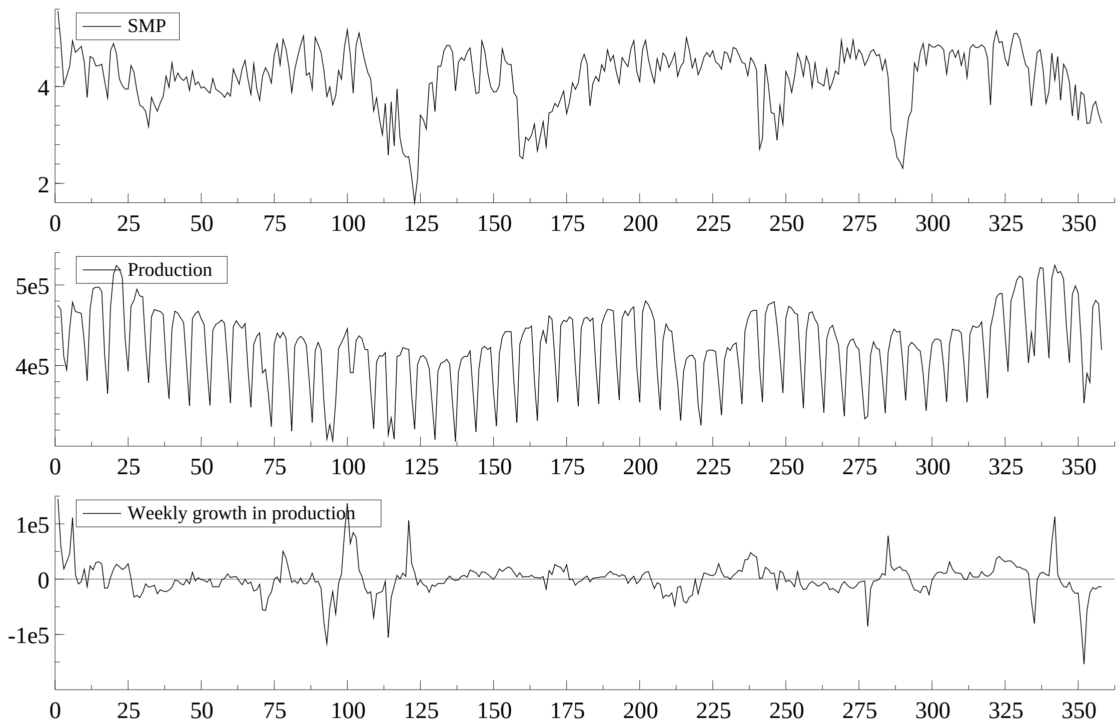

Figure 1: SMP and production

these, one could consider the degree of available capacity by each generator, which is subject to random outages, their maintenance plans, which are not public knowledge, or the availability of hydro resources in the system, which is also subject to random and publicly unknown shocks. This implies that the possible triggers upon which an equilibrium might be based could include several other variables, and not only the market price. Price wars should be triggered when changes in the observable variables resemble the effects that a deviation would have had. Hence, to identify these trigger variables, one should ask the question of which among the observable variables would be the best signal of cheating. We have considered a number of them, and its use is justified in the sections that follow.[20]

3.2 Review of the empirical work

In estimating the degree of market power in the electricity industry, most researchers have relied on the comparison between the actual observed prices and the prices that would result if firms behaved competitively. This is the approach adopted by Wolak and Patrick (1997), Wolfram(1998, 1999)

[20]An additional distinction is that it is more reasonable to think of the electricity generators as setting prices and not quantities. However, the different mode of competition should not alter the nature of the equilibrium.

and Borenstein and Bushnell (1999), to name but a few. However, as predicted by the static oligopoly models, prices would not always be equal to marginal costs but would indeed exceed them in periods of high demand. It is therefore difficult to establish a benchmark with which to asses whether an industry is behaving competitively or not. Furthermore, the comparison of actual prices with marginal cost data does not either provide a complete answer to the question as to whether the underlying bidding behavior is static or rather dynamic. This naturally poses the question as to how the distinction between the static and the dynamic exercise of market power in electricity auctions should be undertaken.

A useful approach to addressing this question is to employ some of the several techniques that have been used to test Green and Porter's (1984) model. As already noted, if firms are alternating between episodes of collusion and price wars then the systematic relationship between prices and demand and supply conditions is broken. The observable consequences of this phenomenon have been exploited by several researchers to distinguish whether firms are involved in some kind of tacit agreement.

Porter (1983) is among the firsts to address the empirical evaluation of price wars as enforcement devices. In line with Green and Porter's (1984) model, Porter (1983) uses a simultaneous equation switching regression model to investigate whether significant switches in firms' pricing behavior took place in the Railroad Joint Executive Committee (JEC).[21] Porter (1983) models the behavioral switches with a Bernoulli distribution and the simultaneous equation switching regression model is estimated using the EM (expectation-maximization algorithm) proposed in Kiefer (1980). His results showed that noncooperative periods lasted on average about ten weeks and that equilibrium prices were 66 % higher in cooperative periods as compared to periods of price wars.

This line of research is further extended in Porter (1985), where the cause of the reversions and the frequency of wars due to entry are investigated. The methodology used to analyze the potential cause of behavioral switches is based on a two steps procedure. In the first step the reversion indicator is estimated on the basis of a simultaneous equation switching regression model. In a second step, a probit model is used where the regressand is the classification of regimes obtained from the estimated indicator. The regressors (cause of the reversions) considered include the Herfindahl Index, the sum of squared deviations of actual from allotted market shares, some measure of the activity of competitors (whether Great Lakes were open to navigation) and lagged values of quantity demanded. Porter (1985) finds that these variables were significant, but reported opposite signs to those predicted by the theory.

The work in Porter (1983, 1985) is reexamined in Ellison (1994). First, he estimates whether switches in suppliers' behavior took place and identifies the period when they occurred. Second,

[21] The JEC was a cartel organized to control freight prices between Chicago and the East Coast. During its existence the cartel dealt with an homogeneous good and entrants were accommodated (see Porter (1983) for further details).

he considers a number of triggers upon which an equilibrium might be based and analyzes the determinants of the transition probabilities from one price phase to the other. His choice of the indicator of price wars is a logistic formulation capable of encompassing some previous specifications used in the literature: independent switch regimes and a Markov structure to the price wars (i.e. a non-cooperative state today is likely to lead to another non-cooperative state tomorrow). Ellison's (1994) results indicate that the degree of collusion was higher than the one reported in Porter (1985), that the regimes were not independently determined and that only one of the triggers considered was significant and contained the same sign as that predicted by theory.

Our specification differs from that used in previous studies. In contrast to Porter (1983), who uses a simultaneous equation switching regression model, we limit our analysis to what we consider to be a supply equation. In the case of the Joint Executive Committee studied by Porter (1983), the elasticity of demand implied a simultaneous relationship between prices and quantities. On the contrary, it is arguably reasonable to say that the demand for electricity is almost perfectly inelastic. In the Spanish electricity market, distributors are responsible for bidding into the pool the demand expressed by their captive, 'non-eligible' consumers, who pay fixed tariffs independently of pool price movements. Eligible consumers are allowed to bid downward sloping demand functions, but in 1998 (and still today) these represented a very small share of total demand (less than 1% in December 1998). Hence, in our case, there is no such a simultaneous relationship between prices and quantities, as the latter are fixed and independent of prices.

Furthermore, in contrast to Ellison (1994), we use a Markov switching model with changing mean and time varying probabilities rather than a Markov switching intercept model with fixed transition probabilities. We show that the fixed transition probabilities model, at least in our data set, reports a lower log-likelihood ratio than the former. We also depart from Ellison (1994) in that we allow for dynamics in our estimated equation for prices considering the lagged dependent variable. 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).

4 The econometric analysis

4.1 The statistical model

In order to model the behavior of the system marginal price in the Spanish electricity market we will consider an autoregressive Markov switching model in mean with time varying transition probabilities. The time varying transition probabilities model (TVTP) can characterize the dynamics of the price behavior better than a fix transition probability model (FTP). Also the TVTP is linked to the notion of time-varying duration in the Markov switching framework. In a FTP the expected duration of a phase of low/high prices would be constant.

The TVTP Markov-switching model of prices, p_t, 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. 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:

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

where p_t is the price in period t, μ_{s_t} is the mean in state s_t, which can either be a collusive state, $s_t = 0$, or a price war state, $s_t = 1$ and x_t are a group of weakly exogenous variables.

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

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

The transition probabilities are given by:

$$\Lambda = \begin{pmatrix} q(z_t) & 1 - p(z_t) \\ 1 - q(z_t) & p(z_t) \end{pmatrix} \tag{1}$$

where z_t are a set of variables that are likely to influence the transition probabilities. In searching for a particular functional form of the transition probabilities, we will use the logistic function:

$$P(S_t = j | S_{t-1} = i, z_t) = \frac{\exp(\lambda_{ij,0} + \lambda_{ij,1} z_t)}{1 + \exp(\lambda_{ij,0} + \lambda_{ij,1} z_t)}, \; i = 1, 0, \; j = 1, 0.$$

We are interested in characterizing the probability of moving into a state of low prices, coming from a state of high prices. This is given by

$$1 - q(z_{t-1}) = P(S_t = 1 | S_{t-1} = 0, z_{t-1}) = 1 - \frac{\exp(\lambda_{00,0} + \lambda_{00,1} z_{t-1})}{1 + \exp(\lambda_{00,0} + \lambda_{00,1} z_{t-1})} \tag{2}$$

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

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

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

and the likelihood function is:

$$
L(\theta) = \sum_{t=1}^{T} \ln f(p_t|p_{t-1}, x_t, z_t; \theta)
$$

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.

4.1.1 Choosing information variables for transition probabilities

A common approach to estimate TVTP models is to use jointly conditional maximum likelihood estimator (MLE) and the filtering methods proposed in Hamilton (1989). The complication of using this method in TVTP models arises because of the presence of additional variables z_t in the unconditional likelihood function. This fact implies that one should jointly estimate the parameters of the p_t and z_t processes. This raises the issue of the conditions that z_t should satisfy in order to use the traditional estimation approach. Filardo (1994) identifies the conditions that need to be accomplished to use Hamilton's (1989) filtering method for estimating fixed transition probability Markov switching models.

The conditional density function is formed by conditioning on the information variables, the exogenous and lagged dependent variables and by integrating the state of the economy. So by maximizing the conditional density function with respect to the given set of observables p_t and x_t, we can expect to obtain consistent estimates. However, in the presence of information variables, further assumptions have to be made on the joint distributional of p_t, x_t and z_t to justify the use of the conditional likelihood instead of maximizing the joint likelihood. Given that only when an appropriate factorization is feasible the likelihood equations from a conditional likelihood are equivalent to the likelihood equations from an unconditional likelihood, the above conditions can be derived from the possibility of factoring the unconditional likelihood into a concentrated likelihood function (see also Engle, Hendry and Richard (1983) for a general discussion on this subject).

If the conditional likelihood f can be written as the product of two factors such as

$$\ln L(\theta) = \max_{\theta_1 \in \Theta} \ln f(p_t | p_{t-1}, x_t, z_t; \theta_1) + \max_{\theta_2 \in \Theta} \ln f(z_t | p_{t-1}, x_t; \theta_2),$$

the parameters of interest can then be inferred from the first factor. We can then justify the use of the conditional MLE together with Hamilton's (1989) filter in the TVTP case. Filardo (1994) shows the need of sufficient conditions to justify conditional MLE in the TVTP case. He proves that the information variables that govern time-variation in the transition probabilities must be conditionally uncorrelated with the state of the Markov process.

These conditions raise a practical issue when choosing the information variables that influence the switching probabilities. More specifically, the former variables should be uncorrelated with contemporaneous states in order to obtain consistent and normally distributed estimators. In some cases, contemporaneous z_t can be used as information variables if it can be justified on the basis of the economic model. This is our claim when we make the choice of our information variables. Because of the very nature of the trigger-variables, these should be conditionally uncorrelated with the price states (given the current prices) and the conditional likelihood would deliver consistent estimates.

4.2 The data

The data used contains daily observations on the hourly System Marginal Price, the hourly final price,[22] the hourly demand in the system, the daily production by technology-type, and the daily market shares and revenues obtained by each generator. The time span goes from the 1^{st} of January 1998 until the 31^{st} of December 1998. From these set of variables we will construct some new trigger-variables or information variables for transition probabilities, which are likely to induce change in price states.

We will thereby distinguish between two types of variables: exogenous variables, x_t and trigger-variables, z_t. The latter are assumed to influence the transition probabilities from one state to the other. Because these trigger-variables are likely to impact with a lag on the probabilities in the transition probabilities, we will used lags of z_t.[23]

[22]The final price includes the daily market price (SMP), the costs resulting from the process of solving technical constraints, the costs from the ancillary services market, the intraday market price, the capacity payment, the costs from the technical operation processes, plus the surplus or deficit accruing from the international contracts signed by the System Operator.

[23]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.

4.3 The exogenous variables

We will consider the following exogenous variables (x_t): the log of production at period t ($Prod_t$), the log of the amount of hydro at period t ($Hydro_t$), the log of electricity imported by REE (REE_t), deterministic seasonals for days of the week ($WeekDum_t$), and a Sunday dummy ($SundDum_t$).

4.4 The trigger variables

Among the trigger-variables that attempt to capture a plausible trigger in a cartel that switches to a price war we will consider the following:

The variable $BigShare_t$ is intended to capture a plausible trigger in cartel that switches to a price war regime when a firm obtains a suspiciously high market share.[24] Note that firms cannot perfectly infer whether the increase in a firm's market share is a consequence of deviation, given that it could be due to other variables that are unobservable to firms - such as firms' maintenance plans, firms' random capacity outages, or a large fraction of run of the river in the system (which firms cannot control for). $BigShare_t$ is constructed as follows:

$$Bigshare = \max_i (s_{it} - \overline{s}_{it})/\sigma_i^2$$

Let us denote with $Q_{i,t}$ the market production of generator i, $i = 1, 2, 3, 4$ (Endesa, Iberdrola, Unión Fenosa and Hidrocantábrico, respectively), at time t, $t = 1, 2, ..., T$. The log of $Q_{i,t}$ is denoted $q_{i,t}$, and the variance of $q_{i,t}$ is σ_i^2. Then

$$s_{it} = q_{it} - \frac{1}{4}\sum_{j=1}^{4} q_{jt},$$

defines the strength of i's demand, and $\overline{s}_{it}$ is taken to be the average of the same measure over the previous two weeks.

An alternative trigger is the one captured by the variable $ResidShareEndesa_t$, which represents Endesa's market share, where the relevant market is taken to be the joint production of Endesa and Iberdrola.[25] Formally, it is constructed as follows:

$$ResidShareEndesa_t = \frac{Q_{END,t}}{Q_{END,t} + Q_{IB,t}}.$$

The reliance on this variable rests on the assumption that only the two major competitors -Endesa and Iberdrola- act as strategic players. The smaller firms -Unión Fenosa and Hidrocantábrico- are assumed to be non-strategic, price-taking players, which sell their available capacities at the

[24] This variable has been proposed in Ellison (1994).

[25] Therefore, $[1 - ResidShareEndesa_t]$ represents Iberdrola's market share over the residual market.

price set by the strategic players.[26] Accordingly, changes in one of the smaller firms' market shares should not trigger reversions to non-cooperative behavior, as these are assumed not to participate in the collusive agreement (i.e. collusion is partial). Or equivalently, changes in one of the strategic firms' market shares which are due to changes in the smaller firms' market shares should neither trigger the start of price wars.

A natural trigger to consider is the difference between the current price and an average of last periods' prices. This trigger is captured by the variable $DevPricePrevious_t$, where we have distinguished the price differences between weekdays and weekend days that arise due to the seasonal demand component are taken into account. For each day of the week we calculate the price average over the last two weeks considering only weekdays. We then define:

$$\overline{p}_t^w = \frac{1}{k}\sum_{j=0}^{k} p_{t-j}^w,\ k = 10$$

and compute

$$DevPricePrevious_t^w = p_t^w - \overline{p}_t^w$$

We calculate the same measure for prices corresponding to weekend days by taking the prices for each day of the weekend, p_t^{wend}, and calculating its average over the previous week, $\overline{p}_t^{wend}$.[27] Accordingly, we define:

$$DevPricePrevious_t^{wend} = p_t^{wend} - \overline{p}_t^{wend}$$

The last two trigger variables considered aim at capturing the effects induced by the CTCs payments. As already noted in Subsection 2.2, changes in the SMP have an impact on firms' CTCs recovery payments. If the average price received by a firm exceeds 6 PTAS/kWh, or if a firm's average revenues exceed the one that it would have received with an average market price of 6 PTAS/kWh, then the total amount of CTCs to be charged at the end of the transition period will be reduced. If firms give a higher weight to the current than to the future years' revenues, then Endesa, whose average market share lies below its CTC share prefers higher prices than Iberdrola, whose market share is above its CTC share. If firms observe a large disparity between the market price and the guaranteed price of 6 PTAS/kWh, or if their revenues differ from their guaranteed revenues, then they may infer that a deviation from the collusive regime has taken place and revert to the non-collusive outcome.

[26] This approach is common in the literature. See Borenstein and Bushnell (1999) and Wolfram (1998, 1999). As Wolfram (1999) has shown, the incentives to bid high are decreasing in firm's size, given that the smaller a firm's inframarginal capacity, the smaller the benefits of bidding high are compared to the risks of not been despatched.

[27] For instance, for a sunday the weekly average would be the average between the previous day's price (Saturday) and the previous weekend day (previous Sunday).

These possible triggers are captured by the variables $DevPrice_t$ and $DevRevenues_t^i$. $DevPrice_t$ is constructed as the difference between the average final price over the previous k periods (two weeks) and the price used to compute the CCT payments, 6 PTA/Kwh. Thus

$$DevPrice_t = \frac{1}{k}\sum_{j=0}^{k} p_{t-j} - 6, \ k = 14$$

$DevRevenues_t^i$ is defined as the average deviation of a firms' revenues from its guaranteed revenues over the two previous weeks.

$$DevRevenues_t^i = \frac{1}{k}\sum_{j=0}^{k} \left(REV_{t-j}^i - Prod_{t-j}^i * 6\right)$$

where $i = Endesa,\ Iberdrola$ and $k = 14$.

Table 2 gives summary statistics for the trigger-variables and Figure 2 plots these time series. These are plots of the variables in levels, except for $DevRevenues_t^i$, which are normalized by dividing them by 10000.

As can be observed from the Figure, the trigger variable $BigShare_t$ tends to be more volatile in the first part of the year. The highest values are obtained for the third week of January, first week of February and second week of May. Over the second part of the year, the first week of September and the two first weeks of October register values that are above the mean of this second part of the year. $ResidShareEndesa_t$ and, symmetrically $ResidShareIb_t$, have important shifts in the second half of February and third week of June, with two small shifts taking place in the second part of the year in September and October. The series of $DevPrice_t$ depicts important drops below their mean in the third week of May, second week of June, third week of September and last week of October. A similar behavior is followed by $DevRevenuesEndesa_t$ and $DevRevenuesIberdrola_t$. On the other hand, $DevRevenuesIberdrola_t$ has a drop in the first week of February that coincides with an upward shift in the series of $DevRevenuesEndesa_t$. Last, $DevPricePrevious_t$ has important downward spikes in the last week of April, second week of June and third week of October.

The table of summary statistics confirms the visual analysis of Figure 2. $BigShare_t$ is characterized by a big variance, with the maximum value being as high as 90. The maximum value of $ResidShareEndesa_t$ reaches the 65% of the relevant market, and its smallest values goes as low as 38 %, corresponding to the first part of the year. The last four variables, $DevPrice_t$, $DevPricePrevious_t$, $DevRevenuesEndesa_t$ and $DevRevenuesIberdrola_t$, are characterized by a large volatility; however, from its maximum and minimum values one sees that, whereas the volatility of $DevPricePrevious_t$ is present all along the year, the volatility of $DevPrice_t$, $DevRevenuesEndesa_t$ and $DevRevenuesIberdrola_t$ is induced by only a few important drops.

4.5 The empirical results and their interpretation

The statistical model for the system marginal price(SMP) is given by:

$$\begin{aligned} smp_t - \mu_{s_t} &= \rho(smp_{t-1} - \mu_{s_{t-1}}) + \beta_1 Prod_t + \beta_2 Hydro_t + \beta_3 REE_t + \\ &+ \beta_4 WeekDum_t + \beta_5 SundDum_t + \varepsilon_t \end{aligned} \tag{3}$$

with $\varepsilon_t \sim N(0, \sigma)$ and

$$\mu_{s_t} = \mu_0(1 - s_t) + \mu_1 s_t$$

$$s_t = 1, 0$$

where smp_t is the log of SMP_t. The stochastic process on S_t can be summarized by the transition matrix:

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

$$\Lambda = \begin{pmatrix} q(z_{t-1}) & 1 - p(z_{t-1}) \\ 1 - q(z_{t-1}) & p(z_{t-1}) \end{pmatrix}$$

We will consider six different models that differ in the variables that are used as triggers, z_{t-1}. The different models are labelled from 1 to 6, corresponding respectively to the use of $BigShare_t$, $ResidShareEndesa_t$, $DevPrice_t$, $DevPricePrevious_t$, $DevRevenuesEndesa_t$ and $DevRevenuesIberdrola_t$. All variables will enter as deviations from the mean, except for $DevRevenues_t^i$ that will be normalized by dividing them by 10000.

Estimates are computed by numerically maximizing the conditional likelihood. Table 3 reports results for our set of models under analysis. Table 5 reports a summary 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 heteroscedasticity, as well as a Chi-square test for normality. Their corresponding p-values are reported in the first, second and fifth row, respectively. The skewness and excess kurtosis of the predicted residuals for each model are reported in the third and fourth rows, respectively. Based on a likelihood criterium, the best model is Model 4 (where the trigger variable is $DevPricePrevious_t$), where the mean of the low and high smp_t states are respectively 1.12 and 1.41.

The signs of the coefficients associated with the exogenous variables are as expected. The coefficient associated with $Prod_t$, β_1, is positive: as demand increases more expensive technology units are needed to cover demand, and this leads to an increase in prices. Given that demand during Sundays is much lower than during the remaining days of the week, this same reason

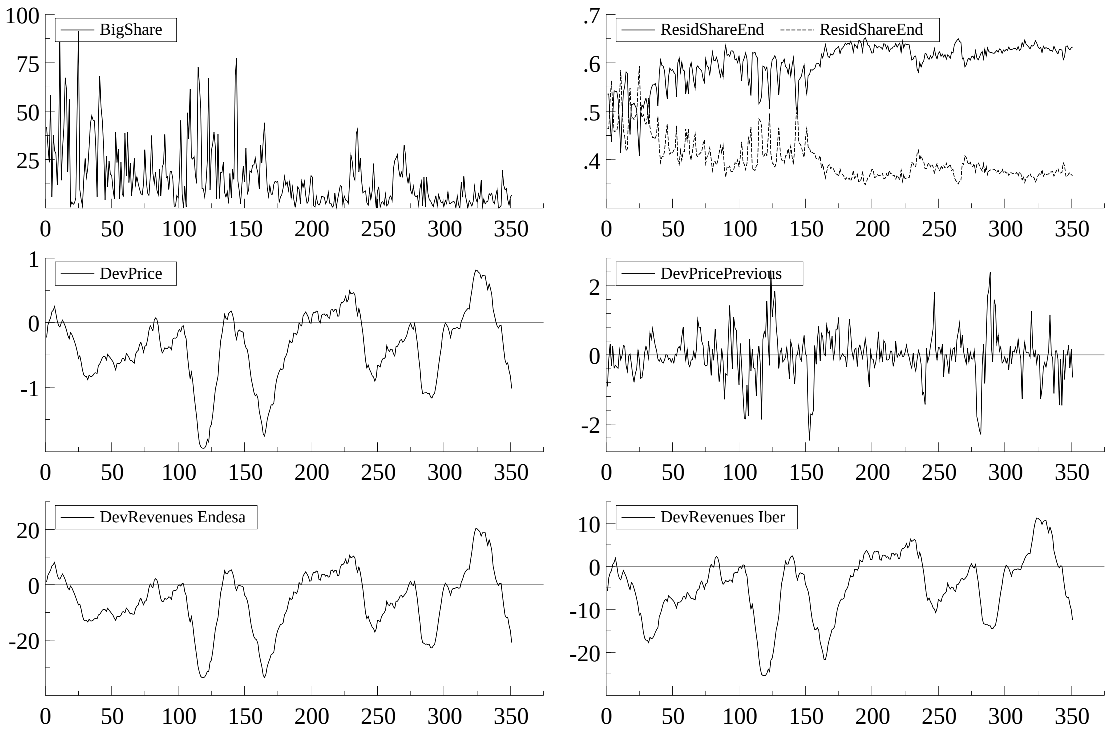

Figure 2: Trigger-variables

underlies the fact that the coefficient associated with the weekly dummies, β_4, and that associated with the Sunday dummy, β_5, are positive and negative, respectively. The coefficient associated with $Hydro_t$, 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 SMP should be. And last, the coefficient associated with REE_t, 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.[28]

Table 3 presents enough evidence to support the hypothesis that two distinct price levels characterize the time series of the daily system marginal price (SMP) in the Spanish electricity market during 1998. 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 SMP (collusive phase), given the technology and demand information embodied in equation (3).

Table 3 also lists the estimated transition probabilities for the trigger-variables. All of the points

[28]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.

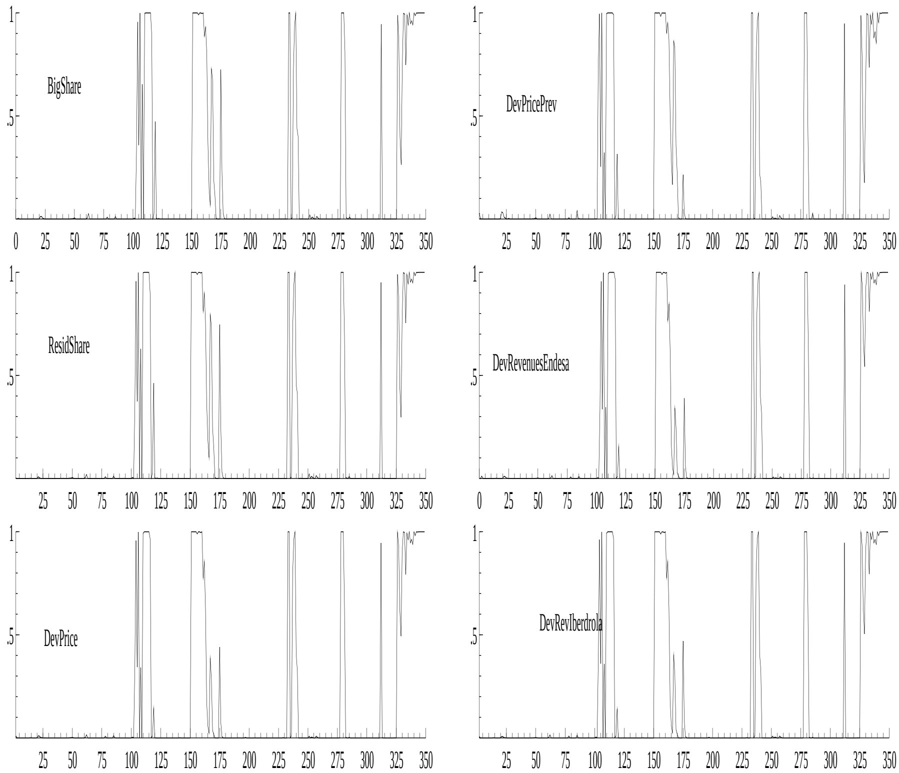

Figure 3: Smooth probabilities of being in low price regime

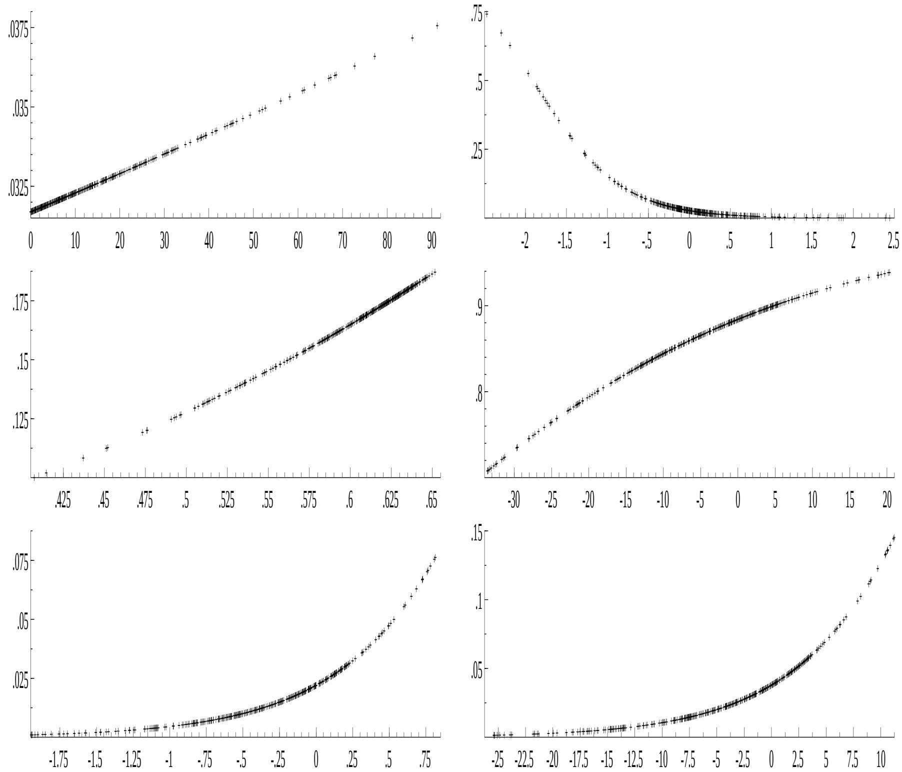

Figure 4: Relationship between transition probabilities and trigger-variables for $Bigshare_{t-1}$, $ResidShareEnd_{t-1}$, $DevPrice_{t-1}$, $DevPricePrevious_{t-1}$, $DevRevenuesEndesa_{t-1}$ and $DevRevenuesIberdrola_{t-1}$: The first plot in the left hand side shows the cross plot of $P(S_t = 1|S_{t-1} = 0, Bigshare_{t-1})$ with $Bigshare_{t-1}$, the second plot in the left hand side shows shows the cross plot of $P(S_t = 1|S_{t-1} = 0, ResidShareEnd_{t-1})$ with $ResidShareEnd_{t-1}$ and the third plot in the left hand side shows the cross plot of $P(S_t = 1|S_{t-1} = 0, DevPrice_{t-1})$ with $DevPrice_{t-1}$. In the right hand side the first plot shows the cross plot of $P(S_t = 1|S_{t-1} = 0, DevPricePrevious_{t-1})$ with $DevPricePrevious_{t-1}$, the second plot in the right hand side shows the cross plot of $P(S_t = 1|S_{t-1} = 0, DevRevenuesEndesa_{t-1})$ with $DevRevenuesEndesa_{t-1}$ and the third plot in the right hand side shows the cross plot of $P(S_t = 1|S_{t-1} = 0, DevRevenuesIberdrola_{t-1})$ with $DevRevenuesIberdrola_{t-1}$

estimates are statistically significant at the 5 % level.

4.5.1 The dating of price wars

Figure 3 plots the smooth probabilities of being in a low state of prices for each of the six models under analysis. The state probabilities plotted in Figure 3 can be used to date the periods of price wars. The smooth probabilities are able to clearly identify the periods of low prices and all trigger-variables tend to identify similar regime phases. 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 will assign that observation to a given regime according to the highest filtered probability, i.e. $\Pr(s_t = 1 \mid Y_t) < 0.5$ and $\Pr(s_{t+1} = 1 \mid Y_t) > 0.5$. 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 dating of price wars is reported in Table 4. The average duration of a price war ranges from slightly less than five days to almost six days.

4.5.2 The triggers of price wars

For the parametrization of the transition probability,

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

the test for the non influence of the trigger-variables in the process for the transition probabilities is a test for $\lambda_{00,1} = 0$. 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 $\chi^2(2)$. The results for the FTP model indicated a value for the likelihood of 361.09.[29] The p-values resulting from this test are reported in the last row of Table 5. The hypothesis of a FTP is rejected at the 10% except for Model 5, where we only get a slight rejection. These results show that the TVTP model is preferred to the FTP model and there is further information in the trigger-variables in order to explain the transition dynamics from low to high price states.

The state of high price is state 0, and the state of low price is state 1 and the transition probabilities are given by the matrix defined in (1). The nature of the news contained in z_{t-1} can be obtained from the movements in $[1 - q(z_{t-1})]$. In order to quantify the effect of a variation of z_{t-1} in the transition probability $[1 - q(z_{t-1})]$, we would be interested in calculating the marginal effect of z_{t-1} in the transition of moving from a high state of price to a low state of prices, evaluated

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

Table 2: Summary Statistics:Information variables for transition probabilities

	Mean	Variance	Min	Max
BigShare	14.793	15.766	0.00000	91.243
ResidShare Endesa	0.59447	0.047618	0.38151	0.65160
DevPrice	-0.35601	0.54750	-1.9459	0.81417
DevPricePrevious	0.069496	0.87991	-2.4714	5.7947
DevRevenues Endesa	-5.2944	10.845	-33.599	20.341
DevRevenues Ib	-4.4669	7.4421	-25.391	11.222

at the average ($\overline{z}_{t-1}$). That is,

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

We could also consider the average marginal effect given by:

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

Table 6 summarizes the marginal effect of the trigger-variables in the transition probability $[1 - q(z_{t-1})]$. This is complemented with Figures 4 which depict the cross plots of $P(S_t = 1|S_{t-1} = 0, z_{t-1})$ with each of the six triggers considered. As can be viewed from these figures, the sign of the slope of the cross plots does not change, and coincides with the signs of the marginal effects reported in Table 6.

The sign of the marginal effects coincide with those expected by the theory. First, increases in $BigShare_{t-1}$ or in $ResidShareEnd_{t-1}$ lead to a higher probability of entering into a price war phase. The positive sign of the marginal effect of $ResidShareEnd_{t-1}$ is highly illustrative. An increase in Endesa's market share over the residual market can be produced for either one of the following two reasons: first, because of a more aggressive bidding behavior by Endesa or by a less aggressive bidding behavior of Iberdrola. As discussed in Subsection 2.2, this coincides with firms' incentives once the existence of stranded cost recovery payments is accounted for. Thus the movements in $ResidShareEnd_{t-1}$ represent a good signal for cheating on theoretical grounds, and this is supported by the data.

Furthermore, the fact that the marginal effect of $ResidShareEnd_{t-1}$ is much greater than that associated with $BigShare_{t-1}$ points to the conclusion that the collusive game is played among Endesa and Iberdrola, i.e. the assumption that only the big generators act strategically seems to be corroborated by the empirical results. If this is the case, then changes in $BigShare_{t-1}$ could be associated, for instance, to Unión Fenosa and Hidrocantábrico's maintenance plans or random capacity outages. As these should not trigger a reversion to non-cooperative behavior, they should increase the probability of entering into a price war by only a small amount, as it is indeed verified by the empirical results.

Table 3: Parameters Estimates of TVTP models for the Spanish Electricty SMP

	Model 1 $BigShare_t$	Model 2 $ResidShareEndesa_t$	Model 3 $DevPrice_t$	Model 4 $DevPricePrevious_t$	Model 5 $DevRevenuesEndesa_t$	Model 6 $DevRevenuesIberdrola_t$
log-lik	363.834	363.67305	364.112	365.562	364.420	364.510
ρ	0.50613	0.50388	0.49593	0.50208	0.49556	0.49599
	0.00228	0.0022918	0.00238	0.00212	0.00238	0.00237
β_1	0.06635	0.066648	0.07472	0.06335	0.07484	0.07420
	0.00298	0.0029745	0.00304	0.00301	0.00304	0.00305
β_2	-0.04518	-0.04530	-0.04729	-0.04685	-0.04731	-0.04717
	0.00054	0.00054	0.00055	0.00056	0.00055	0.00055
β_3	0.14073	0.14212	0.14348	0.14037	0.14358	0.14347
	0.00084	0.00085	0.00086	0.00080	0.00086	0.00086
β_4	0.03545	0.03393	0.03394	0.03773	0.03397	0.03399
	0.00075	0.00075	0.00076	0.00075	0.00076	0.00076
β_5	-0.03799	-0.03886	-0.04117	-0.04166	-0.04114	-0.04116
	0.00087	0.00087	0.00088	0.00087	0.000888	0.00088
μ_0	1.4193	1.4219	1.4231	1.4167	1.4231	1.4230
	0.00133	0.00132	0.00132	0.00131	0.001319	0.00132
μ_1	1.1270	1.1303	1.1273	1.1221	1.1273	1.1273
	0.00163	0.00161	0.00159	0.00159	0.001597	0.00159
$\lambda_{00,0}$	1.8892	1.6854	1.8636	2.3911	2.0318	2.0637
	0.02482	0.02293	0.02443	0.03633	0.028478	0.03010
$\lambda_{11,0}$	3.4195	3.4107	3.7933	3.5914	3.3647	3.2348
	0.01874	0.01898	0.02698	0.02273	0.020520	0.01985
$\lambda_{00,1}$	-0.04287	23.208	0.63663	0.86124	0.034152	0.04739
	0.00110	0.64282	0.03242	0.02644	0.001691	0.00246
$\lambda_{11,1}$	-0.00192	-2.9807	-1.5951	1.8784	-0.082671	-0.13030
	0.00113	0.44304	0.05081	0.05169	0.002436	0.00377
σ	0.00523	0.00523	0.00534	0.00524	0.005346	0.00534
	2.27e-005	2.30e-005	2.36e-005	2.26e-005	2.36e-005	2.35e-005

Table 4: Dating of Price Wars in the Spanish Electricity Market

Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
$BigShare_t$	$ResidShareEndesa_t$	$DevPrice_t$	$DevPricePrevious_t$	$DevRevenuesEndesa_t$	$DevRevenuesIberdrola_t$
			04/28/1998-4/29/1998		
05/05/1998-05/11/1998	05/05/1998-05/11/1998	05/05/1998-05/11/1998	05/05/1998-05/11/1998	05/05/1998-05/11/1998	05/05/1998-05/11/1998
06/15/1998-06/27/1998	06/15/1998-06/27/1998	06/15/1998-06/27/1998	06/15/1998-6/28/1998	06/15/1998-6/27/1998	06/15/1998-6/27/1998
07/01/1998-07/02/1998	07/01/1998-07/02/1998		07/1/1998-07/02/1998		
09/05/1998-09/06/1998	09/05/1998-09/06/1998	09/05/1998-09/06/1998	09/05/1998-09/06/1998	09/05/1998-09/06/1998	09/05/1998-09/06/1998
09/09/1998-09/11/1998	09/09/1998-09/11/1998	09/09/1998-09/11/1998	09/09/1998-09/11/1998	09/09/1998-09/11/1998	09/09/1998-09/11/1998
10/20/1998-10/23/1998	10/20/1998-10/23/1998	10/20/1998-10/23/1998	10/20/1998-10/22/1998	10/20/1998-10/23/1998	10/20/1998-10/23/1998
12/07/1998-12/08/1998	12/07/1998-12/08/1998	12/07/1998-12/9/1998	12/07/1998-12/08/1998		
12/11/1998-12/30/1998	12/11/1998-12/30/1998	12/11/1998-12/30/1998	12/11/1998-12/30/1998	12/07/1998-12/30/1998	12/07/1998-12/30/1998

Table 5: Specification tests

	Model 1 $BigShare_t$	Model 2 $ResidShareEndesa_t$	Model 3 $DevPrice_t$	Model 4 $DevPricePrevious_t$	Model 5 $DevRevenuesEndesa_t$	Model 6 $DevRevenuesIberdrola_t$
Error Autocorrelation	0.393	0.344	0.414	0.718	0.408	0.413
ARCH	0.474	0.436	0.359	0.419	0.372	0.343
Skewness	0.038	0.023	-0.004	0.012	-0.007	-0.002
Excess Kurtosis	0.027	0.042	0.002	0.032	0.000	0.005
Normality	0.884	0.884	0.951	0.908	0.953	0.948
Likelihood Test	0.064	0.075	0.048	0.011	0.035	0.032

Table 6: Marginal effect of the trigger variables on the transition probabilities

Trigger Variable	$\frac{\partial P(S_t=1\|S_{t-1}=0,\overline{z}_{t-1})}{\partial z_t}$	$\frac{1}{T}\sum_{i=1}^{T}\frac{\partial P(S_t=1\|S_{t-1}=0,z_{i-1})}{\partial z_{i-1}}$
Bigshare	6.08e-005	6.08e-005
ResidShareEnd	0.4092	0.40988
DevPrice	0.0195	0.02639
DevPricePrevious	-0.0507	-0.07747
DevRevenues Endesa	0.0017	0.00236
DevRevenues Iberdrola	0.0026	0.00378

It would be interesting to verify the relationship between $ResidShareEnd_{t-1}$ and the disparity between firms' market shares with respect to their CTC shares. As discussed in Subsection 2.2, firms' conflict of interests is more pronounced the greater this disparity is. Accordingly, changes in $ResidShareEnd_{t-1}$ would be a better signal for cheating the larger the difference between firms' market shares and their allocated CTC shares is; the associated transition probability should therefore be greater. However, with only six price wars occurring during the whole year, we would have few data to work with if we divided the whole sample into sub-samples.

Table 6 and Figure 4 show that an increase in $DevPricePrevious_{t-1}$ decreases the probability of entering into a price war phase, i.e., the lower p_{t-1} is as compared to the average price over the last periods, the more likely it is that a price war will be triggered. From Figure 4, note however that this probability is almost zero when $DevPricePrevious_{t-1}$ takes positive values. That is, it is as if firms interpreted that deviations should only involve price undercutting, and not raising the prices over the tacitly agreed level. Relating this to our previous discussion, one could conjecture that an increase in Endesa's residual share coupled with a reduction in prices is a good signal of cheating; i.e. what triggers a price war is the fear that Endesa might be attempting to reduce market prices in order to increase its CTC revenues.

And last, an increase in either $DevPrice_{t-1}$ or $DevRevenues^{i}_{t-1}$, $i = Endesa, Iberdorla$, lead to a higher probability of entering into a price war phase. Again, this coincides with the prediction that Endesa is better off with lower SMPs, whereas the reverse is true for Iberdrola. An increase in the market price and in firms' revenues over the guaranteed amount could be due to Iberdrola's attempts to raise prices, and thus, be a good signal from cheating. Furthermore, the larger these price or revenue differences are, the less costly it is to enter into a price war, given that firms would recoup the loss in market revenues through the resulting higher value of the CTCs payments.

5 Conclusions

We have analyzed the series of pool prices in the Spanish electricity market during 1998 by means of a Time Varying Transition Probabilities Markov switching model. The aim has been to identify whether firms have competed effectively or whether they have been engaged in some kind of tacit agreement. In the spirit of Green and Porter (1984), we have exploited the movements in industry prices and firms' market shares to distinguishing 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 establishing 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 changes in one of the observable variables resemble the effects that a deviation would have had. Hence, we have considered some of the variables that could be a good sign of cheating, and have evaluated whether these influenced indeed the probability of triggering a price war. The triggers that we have analyzed appear to be significant and report the same signs as those predicted by the theory. Interestingly enough, we have found that increases in the major generator's market share, coupled with reductions in the market price, 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 the major generator might attempt to reduce market prices in order to increase its CTC revenues. 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 too far the idea 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. What we observe should then be interpreted more as an adjustment or learning process, rather than as a series of abortive states to sustain collusion.[30]

[30] 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 constantly changing as market rules are modified and as other firms modify their behavior."*

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)). In our view however, if this were the case, there should be no reason to observe such a persistence in each 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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Appendix: CTCs payments

In this Appendix we formally analyze the effects that the CTCs payments have on firms' bidding incentives.

Let T denote the regulated tariff paid by consumers; and let $\sum_{t=1}^{T} p_t Q_t$ represent the total cost incurred by the distribution companies in their market transactions, where p_t is the average final price and Q_t is the total quantity traded in period t. Thus, the amount of CTCs paid to the whole industry is given by $\left[T - \sum_{t=1}^{T} p_t Q_t\right]$; this amount is to be shared among firms on the basis of their predetermined CTC shares, θ_i for firm i, with $\sum_{i=1}^{4} \theta_i = 1$. Let q_{it} be firm i's production in period t. Firm i's total revenues in a given year (i.e. the sum between its market and CTCs revenues) can therefore be expressed as

$$\pi_i = \underbrace{\sum_{t=1}^{356} p_t q_{it}}_{\text{Market revenues}} + \underbrace{\left[T - \sum_{t=1}^{356} p_t Q_t\right] \theta_i}_{\text{CTC revenues}}$$

Firm i's revenues can also be expressed in terms of firm i's market share in period t, $s_{it} = \frac{q_{it}}{Q_t}$,

$$\pi_i = \sum_{t=1}^{356} p_t \left[s_{it} - \theta_i\right] Q_t + T\theta_i$$

Summing across all firms (with $\sum_{i=1}^{4} s_{it} = \sum_{i=1}^{4} \theta_i = 1$), note that the whole industry revenues during the current year are fixed at T.

In order to analyze the marginal effect of price changes on firm i's current year profits, let us compute

$$\frac{\partial \pi_i}{\partial p_t} = \left[s_{it} - \theta_i\right] Q_t$$

Thus the marginal effect of price changes on firm i's current year profits is positive (negative) whenever firm i's market share exceeds its CTC share.

At the end of 1998, the residual amount of each firm's CTCs to be received during the remaining years of the transition period, CTC_i, is computed as follows: from the maximum amount of CTCs the firm is entitled to, say $\theta_i CTC$, one must extract the amount of CTCs already received, $\left[T - \sum_{t=1}^{356} p_t Q_t\right] \theta_i$, and the difference between the market revenues that such a firm has received during that year and the revenues that it would have received if the final price had been 6 PTAS/kWh. Thereby,

$$CTC_i = \theta_i CTC - \left[T - \sum_{t=1}^{356} p_t Q_t\right] \theta_i - \max\left\{0, \sum_{t=1}^{356} \left[p_t - 6\right] q_{it}\right\}$$

Again, this can be expressed in terms of the relationship between firm i's market share and CTC share. If we let R_i denote the portion of the residual amount of CTCs which is independent of pool prices, $\theta_i [CTC - T] + \sum_{t=1}^{356} 6q_{it}$, and $\widetilde{p}$ denote the average pool price, then

$$CTC_i = \begin{cases} R_i - \sum_{t=1}^{356} p_t [s_{it} - \theta_i] Q_t & \text{if} \quad \widetilde{p} > 6 \\ R_i & \text{if} \quad \widetilde{p} \leq 6 \end{cases}$$

Summing across all firms, note that the whole industry revenues during the transition period are independent of pool price movements, $CTC + \sum 6Q_t$, as long as the average price does not fall below 6 PTAS/kWh, and they are lower than that level otherwise.

To analyze the marginal effect of the changes in prices on firm i's residual CTC payments, let us compute

$$\frac{\partial CTC_i}{\partial p_t} = \begin{cases} -[s_{it} - \theta_i] Q_t & \text{if} \quad \widetilde{p} \geq 6 \\ 0 & \text{if} \quad \widetilde{p} < 6 \end{cases}$$

Note that if the average price received by firm i exceeds 6 PTAS/kWh, then the residual amount of CTCs to be charged at the end of the transition period will be reduced, and that this reduction is a function of the difference between firm i's market share and CTC share.

With this, we can analyze the marginal effect of increases in price on firm i's present discounted of revenues during the transition period,

$$\frac{\partial \Pi_i}{\partial p_t} = \frac{\partial \pi_i}{\partial p_t} + \frac{\delta - \delta^\tau}{1 - \delta} \frac{1}{\tau - 1} \frac{\partial CTC_i}{\partial p_t}$$

where we have assumed that the transition period lasts τ years, and that CTC_i is evenly divided across the remaining $\tau - 1$ years of the transition period. Note that the expected market revenues to be earned during the remaining years drop out since these are not affected by changes in p_t. Substituting

$$\frac{\partial \Pi_i}{\partial p_t} = \begin{cases} [s_{it} - \theta_i] Q_t \left[1 - \frac{\delta - \delta^\tau}{1 - \delta} \frac{1}{\tau - 1}\right] & \text{if} \quad \widetilde{p} \geq 6 \\ [s_{it} - \theta_i] Q_t & \text{if} \quad \widetilde{p} < 6 \end{cases}$$

From this we can conclude that:

Conjecture 1 *If $\delta = 1$, i.e. firms give equal weight to current and future revenues, then firms are indifferent about the level of prices as long as $\widetilde{p} \geq 6$. However, if $\delta < 1$, firms are faced with a conflict of interest about the level of prices: if $s_{it} < \theta_i$ and $s_{jt} > \theta_j$, $i \neq j$, firm i prefers lower prices than firm j.*

Conjecture 2 *The convergence between firms' market shares towards their allocated CTC shares alleviates firms' conflict of interest. On the contrary, a reduction in firms' discount factors (e.g. due to an increase in regulatory uncertainty) enhances firms' conflict of interest.*