A Supply Function Competition Model for the Spanish Wholesale Electricity Market.*

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October 15, 2005

Abstract

We model the Spanish wholesale market as a multiplant linear supply function competition model. According to the theory, the larger generators should have supply curves for each plant which are to the left of the supply curves of plants owned by smaller generators. We test this prediction for fuel plants using data from the Spanish Market Operator (OMEL) from May 2001 to December 2003. Our results indicate that the prediction of the model holds.

JEL: L11, L13, L51

Keywords: supply function competition, electricity market

*Financial support from Ministerio de Ciencia y Tecnología (BEC2003-02084), UPV (9/UPV 00035.321-13560/2001), BBVA and IVIE is gratefully acknowledged. We thank Jorge de la Cruz for his very helpful research assistance, and seminar participants at the IDEI Conference on Competition and Coordination in the Electricity Industry (Toulouse), Universidad Autónoma de Barcelona and Universidad de Alicante for their comments and suggestions. We are especially indebted to Eva Ferreira, M. Cruz Loyo and Enrique Pastor for their invaluable help.

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1 Introduction

In the context of European deregulation, the Spanish pool for electricity (day-ahead market) started its operations in January 1998.[1] The market is characterized by a high concentration index together with an inelastic demand. Two companies, Endesa (EN) and Iberdrola (IB), own most of the generating capacity, while Union Fenosa (UF) and Hidrocantabrico (HC) are smaller competitors; all are private companies and each owns nuclear, thermal and hydroelectric plants. Since 2002 there has been entry on a small scale (ENEL, Repsol and Gas Natural, among others).

In this paper we study the observed behavior at the electricity auction of firms with high market shares and compare it to that of small firms. To interpret any observed differences in bidding behavior, we model the outcome of the pool as a supply function equilibrium. The supply function of a large operator at the pool is obtained by aggregating the supply functions of each generating plant under its control. If the size of the generator were irrelevant, a generating plant would bid at the pool independently of whether it belongs to a large operator or to a small firm, and thus the supply function of a larger operator would coincide with the supply curve obtained as the sum of the supply functions of similar plants under the control of small firms. However, we would expect production units to take into account their effect on other production plants under the same ownership and respond to their incentive to restrict output and raise prices (i.e. a supply curve more to the left).

Our purpose is to detect and measure any difference in bidding behavior between larger and smaller generators. For the comparison of bid behavior, we choose fuel plants of similar capacities and ages, and compare their bids for the same auction (same day and same time) so that demand and cost conditions are the same. Thus, any systematic difference in their plant supply functions could be attributed to the generator's size. After observing this different behavior in terms of supply curves at the pool, we measure the impact on equilibrium prices.

The paper is organized as follows. Section 2 presents the supply function equilibrium model, where we show that in equilibrium a plant owned by a larger generator has a supply function which is to the left of the supply curve of a plant owned by a smaller generator. The rest of the paper presents the empirical results for the Spanish pool. Our main findings are that the two larger operators consistently submit supply curves for fuel plants which are to the left of the corresponding supply curves of smaller generators. Section 5 concludes.

[1] See Appendix 1 for a brief description of market rules

2 A supply function equilibrium model

In this section we represent strategic interaction in the electricity market through a supply function equilibrium model,[2] where each generator decides a supply curve for each of the plants it owns. The supply curve of a generator is then obtained as the sum of the supply curves of all its individual plants.

We analyze the equilibrium behavior of generators of different sizes. In our model the participants in the generation market own different numbers of production units: a generator with m plants (generator 1), a generator with k plants (generator 2) and a third generator with only one plant (generator 3). We assume $m \geq k > 1$. The cost function for each plant is quadratic:

$$C(q_{ij}) = \frac{1}{2} c q_{ij}^2 \tag{1}$$

where q_{ij} denotes electricity produced by plant j owned by generator i. The choice of a linear marginal cost is frequent because it allows the solution to the system of differential equations to be found more easily. Green and Newbery (1992) use quadratic marginal cost, which requires numerical solution of differential equations.[3] All plants are assumed identical. Demand function is linear:

$$D_t = a_t - b p_t + u_t \tag{2}$$

where u_t is a random error with zero mean and p_t denotes price at period t. Note that the slope of the demand function b is assumed to be independent of time, while the intercept a_t may vary over time. The Spanish electricity auction is a uniform price auction; thus, all buyers (sellers) whose offer has been accepted pay (receive) the marginal price for the electricity required (supplied) in their offer. Firms are assumed to be risk neutral and therefore they maximize their expected payoff.

Each plant's bid at the auction is represented here as a continuous supply function. The problem for generator 1, with m plants, is to decide the supply curve for each plant j at each period t, $q_{1j}^t(p_t)$, such that it maximizes expected profits:

$$\max_{q_{1j}^t(p_t)} \qquad p_t \sum_{j=1}^{m} q_{1j}^t(p_t) - \sum_{j=1}^{m} C(q_{1j}^t(p_t)) \qquad \text{for } \ \mathrm{j} = 1, ...m$$

[2]See Klemperer and Meyer (1989), Green and Newbery (1992), Green (1996), Baldick, Grant and Kahn (2000), and Bolle (1992). Other authors have analyzed the electricity market as Cournot competition (see Borenstein and Bushnel, 1997) or as a sealed-bid, multiple-unit, private-value auction (see Wolfram, 1999, von der Fehr and Harbord, 1993, and García-Díaz and Marín, 2003). For a further discussion of the advantages of the supply function equilibrium model over Cournot, see Baldick, Grant and Kahn (2000).

[3]See also Laussel (1992).

Since all plants are identical, $q_i^t(p_t)$ denotes the supply curve of any plant belonging to generator i. Substituting (1) and (2) in the profits expression we have:

$$\max_{q_{1j}^t(p_t)} \qquad p_t \left[a_t - bp_t - kq_2^t(p_t) - q_3^t(p_t)\right] - \frac{1}{2}c\sum_{j=1}^{m}\left[a_t - bp_t - kq_2^t(p_t) - q_3^t(p_t) - (m-1)q_{1j}^t(p_t)\right]^2$$

$$\text{for} \quad j = 1, ...m$$

The first order conditions for generator 1 are:

$$p_t\left[-b - k\frac{dq_2^t(p_t)}{dp_t} - \frac{dq_3^t(p_t)}{dp_t}\right] + mq_1^t(p_t) - cmq_1^t(p_t)\left[-b - k\frac{dq_2^t(p_t)}{dp_t} - \frac{dq_3^t(p_t)}{dp_t} - (m-1)\frac{dq_1^t(p_t)}{dp_t}\right] = 0$$

We look for solutions of the form:[4]

$$q_i^t(p_t) = A_i + B_i p_t \qquad\qquad i = 1, 2, 3$$

and obtain:

$$A_1 = A_2 = A_3 = 0$$

$$B_1 = \frac{b + kB_2 + B_3}{m + cm\left[b + kB_2 + B_3 + (m-1)B_1\right]}$$

$$B_2 = \frac{b + mB_1 + B_3}{k + ck\left[b + mB_1 + B_3 + (k-1)B_2\right]} \tag{3}$$

$$B_3 = \frac{b + mB_1 + kB_2}{1 + c\left[b + mB_1 + kB2\right]}$$

[4] When the support of the demand uncertainty is unbounded the linear equilibrium is unique, but in general there will be multiple equilibria. See Klemperer and Meyer (1989) and Laussel (1992).

Solving the system we get the equilibrium values $B_1(b,c,m,k)$, $B_2(b,c,m,k)$, $B_3(b,c,m,k)$, as functions of the parameters of the model, and thus the equilibrium supply curve for each plant.[5] Since we are assuming that b and c are constant over time, the slope of the supply function is also constant over time. The main result of this section, which will be tested later on, is the following:

Proposition 1 *Large generators submit plant supply curves which are to the left of the plant supply curves of small generators:*

$$B_1(b,c,m,k) \leq B_2(b,c,m,k) < B_3(b,c,m,k)$$

The result can be checked from the expressions for B_1, B_2 and B_3 in (3). A generator with a large number of plants has to take into account the effect of a plant's bid on the price received by its other plants. Therefore, to maximize total profits, each plant restricts output, i.e., it offers a lower amount at each price, or asks for a higher price for each energy volume. Since all production units have the same technology, the different positions of the supply curves are due only to the size of the generators. Increasing output (moving the supply curve to the right) has a negative effect on all the other plants' profits. A larger generator would internalize these effects and therefore choose for each plant a supply curve with a higher slope (lower B).

The aggregate supply function is:

$$S_t = Bp_t + \varepsilon_t \tag{4}$$

where $B = (mB_1 + kB_2 + B_3)$ and ε_t is an error term with zero mean.

Matching aggregate demand and aggregate supply (equations 2 and 4) we obtain the equilibrium price and energy traded $p_t = \frac{a_t}{B+b} + \frac{u_t - \varepsilon_t}{B+b}$ and $q_t = \frac{Ba_t}{B+b} + \frac{Bu_t + b\varepsilon_t}{B+b}$. Note that q_t and p_t are higher in high demand periods (high a_t) and are affected by demand and supply errors (u_t and ε_t, respectively).

2.1 Impact of differences in supply curves on prices

From Proposition 1 we would expect a larger generator to instruct its plants to restrict output, submitting supply curves to the left. The difference in supply curves will be measured by its impact on market clearing prices. For that purpose, we use as a benchmark a multiplant generator which behaves as the sum of independent firms.

Definition 1 *A **Synthetic Firm** is a multiplant firm where each production unit maximizes its profits.*

[5] When the cost function in (1) includes a linear term $d_i q_i$, the supply function has a non-zero intercept.

Note that in a synthetic firm total profits are not maximized, since the effect of each plant's supply curve on other plants under the same ownership is not taken into account.

In our analysis of the pool equilibrium, we replace generator 1's behavior by synthetic generator 1's: Each plant in synthetic generator 1 maximizes profits individually and as a result this synthetic supply function equilibrium is given by;

$$B_1^s = \frac{b + kB_2 + B_3 + (m-1)B_1^s}{1 + c\left[b + kB_2 + B_3 + (m-1)B_1^s\right]}$$

$$B_2 = \frac{b + mB_1^s + B_3}{k + ck\left[b + mB_1^s + B_3 + (k-1)B_2\right]} \tag{5}$$

$$B_3 = \frac{b + mB_1^s + kB_2}{1 + c\left[b + mB_1 + kB2\right]}$$

where superscript s denotes that the firm is synthetic. Solving this system we obtain $B_1^s = B_3 > B_2$. The equality between B_1^s and B_3 is not surprising: synthetic generator 1's plants are maximizing individual profits hence they behave exactly as the single-plant generator 3 does. It is worth noting that the equilibrium values for B_3 and B_2 are different from before, since generators 2 and 3 react to the behavior of generator 1.

Denote by $p_B(a_t)$ the expected equilibrium price at the pool when firms submit supply curves given by system (3) and by $p_{B^{1^s}}(a_t)$ the expected equilibrium price with supply curves given by system (5), i.e. when the slope of the aggregate supply function is $B^{1^s} = (mB_1^s + kB_2 + B_3)$. The impact of generator 1 on prices is $p_B(a_t) - p_{B^{1^s}}(a_t)$.

In the linear model,

$$p_B(a_t) = \frac{a_t}{B + b} \tag{6}$$

and

$$p_{B^{1^s}}(a_t) = \frac{a_t}{B^{1^s} + b} \tag{7}$$

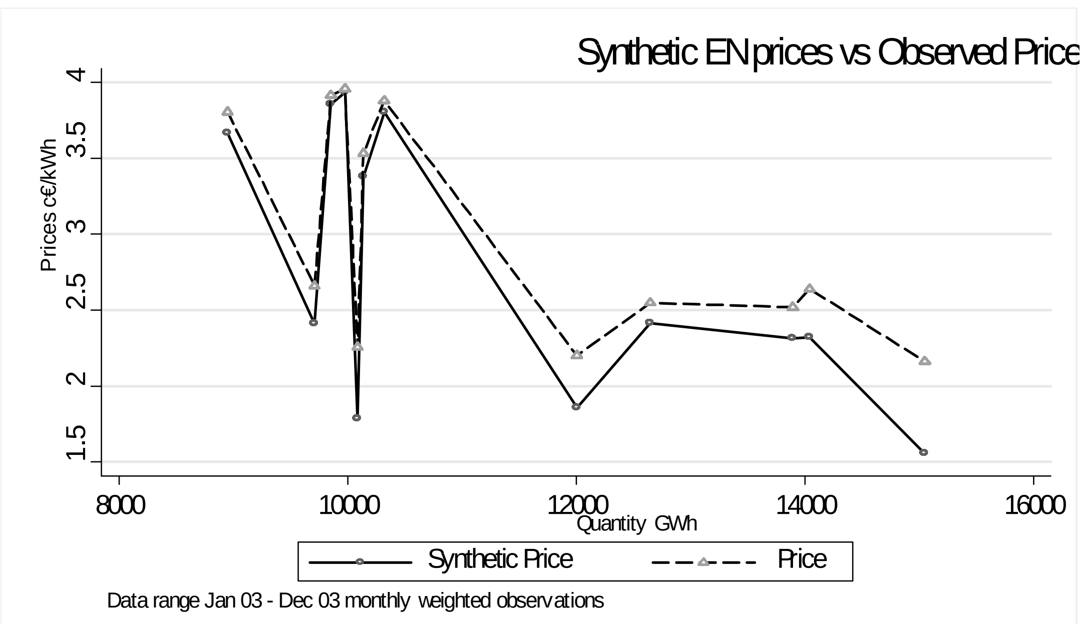
Similarly, the impact on prices of generator 2 is $p_B(a_t) - p_{B^{2^s}}(a_t)$, with $B^{2^s} = (mB_1 + kB_2^s + B_3)$.

The impact of firm 3 is zero by definition since $B_3^s = B_3$. When the number of plants tends to infinity then B_1^s tends to $\frac{1}{c}$, that is, each firm submits its marginal cost function at the pool (see Appendix 2).

3 Empirical implementation

In this section we test for differences in the supply curves submitted by firms of different sizes. In the model described in section 2 we assume that all plants have the same technology. To approximate these conditions as closely as possible in our empirical implementation we will consider only one class of plants: fuel thermal plants.[6] The reference point is the bidding behavior in the pool of small generators. Larger generators are likely to present bids for each plant that maximize overall profits for the firm. At the same auction, there are small generators with plants of similar characteristics. We approximate the competitive behavior for a larger generator using the bids at the same auction of small generators. The two largest generators in the Spanish wholesale market are Endesa (EN) and Iberdrola (IB). We build a "Synthetic Endesa" (EN^s) and a "Synthetic Iberdrola" (IB^s). Then we compare the prices obtained before and after replacing the supply functions of the firms by the supply curves of the synthetic firms.

Figures 1 and 2 present such a comparison for EN and IB, respectively, for the year 2003. On the horizontal axis we represent monthly quantities traded in the market. Observations are sorted from smallest to biggest. On the vertical axis we represent the monthly weighted average synthetic prices and observed prices. Note that the observed average price is consistently higher than the synthetic price for both generators.



[6] Nuclear production is unlikely to be used strategically and hydro units are less homogeneous than oil-fired plants. Coal-burning plants are subject to other incentives despite purely strategic ones (see Ciarreta and Espinosa (2005)).

Figure 1

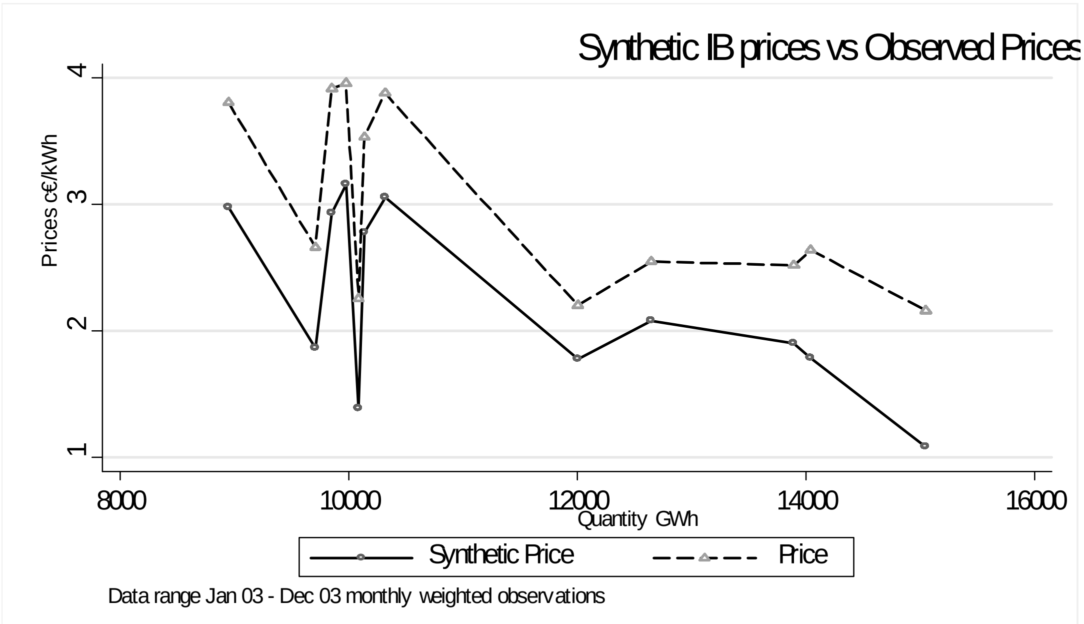


Figure 2

In the previous section we obtained the observed price for the linear model as a function of demand and supply parameters as well as demand and supply random errors: $p_t = p_B(a_t) + \frac{u_t - \varepsilon_t}{B+b}$. These prices are obtained empirically by simply crossing demand D_t and supply S_t. Then we use UF, HC's and other small generators' oil-fired production plants to build the synthetic Endesa (EN^s) and the synthetic Iberdrola (IB^s). For each oil-fired plant owned by a large generator, plant L, we find a plant with a similar capacity owned by a small generator, plant S. We compute a capacity coefficient dividing the capacity of plant L by the capacity of plant S: $\frac{K_L}{K_S}$. We multiply the quantities in the bid by firm S by the coefficient $\frac{K_L}{K_S}$, so as to get a 'scaled bid'. Plant L's bid is then replaced by the 'scaled bid' by plant S. The bid so obtained is called the *synthetic bid* for plant L.

Repeating this procedure for all the oil-fired plants owned by a large generator we get its synthetic fuel supply curve. Here we describe the test for the largest generator EN. The same procedure is then applied to the second generator IB.

We obtain the equilibrium price when EN's supply is replaced by its synthetic supply: $p_t^{EN^s}$. In the linear model these synthetic prices are:

$$p_t^{EN^s} = p_{B^{EN^s}}(a_t) + \frac{u_t - \mu_t}{B^{EN^s} + b}$$

where μ_t are random error terms with zero mean. If the bidding behavior of EN and the small generators were the same, then $B^{EN^s} = B$ and therefore the time series $p_t^{EN^s}$ and p_t would only differ in the realization of random errors with zero mean.

Under the alternative hypothesis, large generators restrict output, as shown in Proposition 1, so that $B^{EN^s} < B$, which implies that we should expect positive values for the differences:

$$p_t - p_t^{EN^s} = p_B(a_t) - p_{B^{EN^s}}(a_t) + \left(\frac{u_t - \varepsilon_t}{B + b} - \frac{u_t - \mu_t}{B^{EN^s} + b} \right). \qquad (8)$$

Our empirical test is based on that implication of the model, although it does not depend on the specific functional form of demand and supply schedules. Under the null hypothesis p_t and $p_t^{EN^s}$ will only differ in the realization of a random error, while under the alternative, p_t, $p_t^{EN^s}$ will show a systematic difference which is a function of the demand level a_t; in particular, $p_t > p_t^{EN^s}$, as the theory predicts that larger generators submit supply curves more to the left.

We test for differences in the means of the two series of prices. We use the t-test to determine whether the two datasets differ significantly. Because the test is performed under very general conditions, it is interesting to control for the size of the demand. Therefore we also perform a test for differences between the conditional means $E\left[p_t \backslash a_t\right]$, and $E\left[p_t^{EN^s} \backslash a_t\right]$ or, in other words, we test whether the functions $p_B(a_t)$ and $p_{B^{EN^s}}(a_t)$ are identical or not (see Appendix 4).[7]

4 Data and results

The data consist of hourly demand and supply bids for each agent and for each generation plant and demand agent in the day-ahead wholesale electricity market from May 2001 to December 2003.[8] There are a total of 23400 hours, 5880 between May 2001 and December 2001, and 8760 hours in 2002 and 2003.

The installed capacity of oil-fired plants is 8262 MW. Five companies own the plants, EN (32.2%), IB (38.6%), UF (9.3%), HC (10.7%) and VI (9.1%). Considering all capacity total market shares are: EN 35.06%, IB 35.49%, UF 12.21%, HC 4.75% and VI 4.3%. As a competitive benchmark we use the bidding behavior of oil-fired plants under the ownership of the two smallest companies which own some fuel capacity, that is HC and VI. Note that the two larger firms also have most of the fuel capacity generation, and that the three smaller firms have similar fuel capacities (although UF's overall market share is higher). To make bid comparisons we use plants of similar capacity and age bidding at the same hourly auction. We exclude plants with shared ownership (in fact there is only one such plant). Appendix 5 presents the list of plants and synthetic plants (Table 4) and a detailed description of how they were chosen.

[7] See Hall and Hart (1990) and Ferreira and Stute (2003).

[8] We do not consider the energy traded in the intra-day market, which amounts to less than 5% of the energy traded in the day-ahead market.

With these data, we compute the following prices: the market clearing prices, $\{p_t\}$, and the synthetic prices obtained by replacing EN's, IB's and UF's bids by their synthetic firm bids, $\{p_t^{EN^S}\}$, $\{p_t^{IB^S}\}$ and $\{p_t^{UF^S}\}$.

The supply bids at the auction sometimes include restrictions that may be binding.[9] When that is the case, those bids are not included in the final assignment by the market operator, OMEL. Since these restrictions cannot be replicated for the synthetic bids we decided to ignore them. This sometimes causes our market clearing prices to be lower than the price made public by the market operator. Since the complex conditions on the supply bids are ignored for both the real and the synthetic plants, there is no reason to think that this procedure is introducing any bias.

On the other hand, the market operator sometimes rejects demand bids at a high price because they are unfeasible given the capacity restrictions of the interconnections with neighboring countries. In such cases there is a rationing procedure to assign the interconnection capacity between bidders. This reduction on demand sometimes causes our market clearing price to be higher than the price published by OMEL. Again, these capacity limits are ignored for both the synthetic firms and the actual ones so no bias is introduced.

Table 1 summarizes the results for the null hypothesis of equal bidding behavior between larger and small generators for each of the large firms.

Table 1: Differences in oil-fired bid behavior for EN, IB and UF

	Test of means			**Test of Ferreira-Stute**		
Period	$\overline{P}-\overline{P}^{EN^s}$	$\overline{P}-\overline{P}^{IB^s}$	$\overline{P}-\overline{P}^{UF^s}$	T^{EN^s}	T^{IB^s}	T^{UF^s}
$2001-2003$	0.986 (0.005)	0.646 (0.003)	0.159 (0.001)	10.69***	5.74***	7.94***
2001	0.908 (0.011)	0.901 (0.009)	0.195 (0.003)	7.46***	4.87***	7.42***
2002	0.558 (0.009)	0.364 (0.004)	0.154 (0.004)	9.97***	7.38***	5.63***
2003	1.131 (0.007)	0.756 (0.006)	0.141 (0.003)	5.19***	5.32***	8.12***

Prices are measured in c€/kWh. Standard errors into brackets.
*** Significant at 1% level

The statistical results allow us to reject the hypothesis that large and small generators have the same oil-fired bidding behavior. In fact, we can conclude that plants owned by large generators have

[9] A 'complex offer' may include indivisibility conditions (for the first block in the bid), a minimum revenue condition, load gradient conditions and scheduled stop conditions.

restricted output by bidding plant supply curves to the left of those owned by small generators. In other words, higher market concentration is associated with higher prices. This empirical result is also consistent with other theoretical models. In Appendix 3 we show that a linear Cournot model would have the same implication.

We also consider possible differences in bidding behavior between small generators. UF could be included among the small generators since its market share (12.21%) and its impact on equilibrium prices is lower, as can be seen in Table 1.We build the synthetic supply curves for the three firms. Thus "Synthetic HC" (HC^S) is built using plants from either UF or VI, "Synthetic UF" (UF^S) is built using plants from either HC or VI, and "Synthetic VI" (VI^S) is built with plants from UF and HC. Results are summarized in Table 2.

Table 2: Differences in oil-fired bid behavior for UF, HC and VI
Test of Mean Differences for Small Firms

	Test of Means			**Test of Ferreira-Stute**		
Period	$\overline{P}-\overline{P}^{UF^s}$	$\overline{P}-\overline{P}^{HC^s}$	$\overline{P}-\overline{P}^{VI^s}$	T^{UF^s}	T^{HC^s}	T^{VI^s}
$2001-2003$	0.159 (0.001)	-1.01 (0.027)	-0.453 (0.009)	4.94^{***}	-2.58^{***}	$-1.452***$
2001	0.195 (0.003)	-0.412 (0.037)		7.42^{***}	-1.42	
2002	0.154 (0.004)	-1.12 (0.055)	-0.719 (0.019)	5.63^{***}	-5.05^{***}	$-4.625***$
2003	0.141 (0.003)	-1.301 (0.039)	-0.482 (0.017)	8.12^{***}	-5.12^{***}	$-4.115***$

Prices are measured in c€/MWh. Standard errors in brackets.
*** Significant at 1% level

As Table 2 indicates HC's bids are lower on average than UF's, as the theory predicts since UF's overall market share is 12.21% as compared to the 4.75% of HC. The smallest firm, VI, presents the lowest average bids. With this procedure we measure bid behavior differences between firms, so that when the competitive benchmark changes, the measured impact on equilibrium prices of larger generators also changes. To see the effect of including UF's plants in the competitive benchmark, we present in Table 3 the impact of IB and EN on equilibrium prices when the reference point is the behavior of UF, HC and VI oil-fired plants.

Table 3: Differences in oil-fired bid behavior for EN and IB				
	Test of means		Test of Ferreira-Stute	
Period	$\overline{P} - \overline{P}^{EN^s}$	$\overline{P} - \overline{P}^{IB^s}$	T^{EN^s}	T^{IB^s}
2001 − 2003	0.239 (0.003)	0.497 (0.003)	4.33***	3.08***
2001	0.648 (0.008)	0.780 (0.009)	6.31***	4.87***
2002	0.117 (0.003)	0.2 (0.039)	2.59**	5.17***
2003	0.086 (0.002)	0.604 (0.005)	2.84**	6.2***

Prices are measured in c€/kWh. Standard errors in brackets.

*** Significant at 1% level

** Significant at 5% level

The results in Table 3 reveal the same qualitative results: The two largest generators, EN and IB, present bids for oil-fired plants that are consistently higher than the bids for similar plants owned by UF, HC and VI. The quantitative results, however, are sensitive to whether or not UF's plants are considered in building the synthetic firms. Comparing Table 2 and Table 3 we observe that our measure of EN's impact on prices is lower than IB's on Table 3, while the opposite is true in Table 1. This is due to the fact that UF's plants are closer in capacity and age to EN's plants so that they are used more often to generate EN^S; in the case of IB, the other two small firms have more similar plants so that UF is used less often to generate IB^S. This has introduced a bias in the results presented in Table 3: The impact of EN on equilibrium prices is underestimated because the competitive benchmark used contains a firm with non-negligible market power. In this respect, it is worth noting that for the procedure to provide a good measure of the impact on prices, it would be necessary, on the one hand, for the firms in entering the competitive benchmark to have a low market share and, on the other hand, for the firms in the benchmark to own plants of similar technical characteristics.

5 Conclusion

In this paper we have modeled the outcome of the pool as a supply function equilibrium and tested whether the bidding behavior of large generators differs from that of small generators. For that purpose we have designed a procedure for comparing the bidding behavior of different generators. The procedure is based on the definition of a synthetic firm. To construct the synthetic firm for each large generator, we delimit a set of firms with the following conditions: They are small generators, so that their market power can be considered negligible, and they own plants technically similar to those of large generators (capacity and age). The bidding behavior of this set of firms is then set as a competitive benchmark. We use this procedure to compare the supply bids of oil-fired plants in the Spanish pool. Our empirical results indicate that the total size of the generator affects the bid of a oil-fired plant: Larger generators restrict output and drive prices up, as the theory predicts.

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Appendix 1. The pool

The day-ahead market for electricity works as follows. Before 11:00 a.m., qualified buyers and sellers of electricity present their offers for the following day. Each day is divided into 24 hourly periods.

Sellers in the pool present bids consisting of up to 25 different prices and the corresponding energy quantities for each of the 24 periods and for each generating unit they own; the prices must be increasing.[10] If no restriction is included in the offer this is called a 'simple offer'. A seller may also present a 'complex offer' which may include indivisibility conditions, a minimum revenue condition, production capacity variation (load gradient conditions) and scheduled stop conditions. The pool administrator consolidates the sales bids for each hourly period to generate an aggregate supply curve.

Qualified buyers in the pool present offers.[11] Purchase bids state a quantity and a price of a power block and there can be as many as 25 power purchasing blocks for the same purchasing unit, with different prices for each block; the prices must be decreasing. The pool administrator constructs an aggregate demand with these offers.

In a session of the daily market the pool administrator combines these offers matching demand and supply for each of the 24 hourly periods and determines the equilibrium price for each period (the system marginal price) and the amount traded. This matching is called the *base daily operating schedule (PBF).* After the *base daily operating schedule* is settled, the pool administrator evaluates the technical feasibility of the assignment; if the required technical restrictions are met then the program is feasible; if not, some previously accepted offers are eliminated and others included to obtain the *provisional feasible daily schedule (PVP).* The *final feasible daily schedule (PVD)* is obtained taking into account the ancillary services assignment procedure.

[10] According to the Electricity Market Activity Rules, p. 6, generators "shall be required to submit electric power sale bids to the market operator for each of the production units they own for each and every one of the hourly scheduling periods." There is an exception to this rule when the production unit has a bilateral contract which, due to its characteristics, is excluded from the bidding system.

[11] From January 1st 2003, all buyers of electricity are considered qualified buyers. Before that date qualified buyers were those with consumption greater than or equal to 1 GWh per year. The required consumption has decreased over time from 5GWh (December 1998) to 3GWh (April 1999), to 2GWh (July 1999) and to 1 GWh (October 1999).

Appendix 2. Competitive limit

We show that when the number of plants tends to infinity and all generators are synthetic firms, the linear solution of the supply curve equilibrium tends to the competitive solution, i. e. each firm bids its marginal cost function.

The supply function equilibrium when all generators are synthetic firms is given by:

$$B_1^s = \frac{b + kB_2^s + B_3 + (m-1)B_1^s}{1 + c\left[b + kB_2^s + B_3 + (m-1)B_1^s\right]}$$

$$B_2^s = \frac{b + mB_1^s + B_3 + (k-1)B_2^s}{1 + c\left[b + mB_1^s + B_3 + (k-1)B_2^s\right]}$$

$$B_3 = \frac{b + mB_1^s + kB_2^s}{1 + c\left[b + mB_1^s + kB_2^s\right]}$$

The solution is:

$$B_1^s = B_2^s = B_3 = \frac{(m+k) - 1 - cb + \sqrt{(1 + cb - m - k)^2 + 4cb(m+k)}}{2c(m+k)}$$

Hence,

$$\lim_{(m+k)\to\infty} \frac{(m+k) - 1 - cb + \sqrt{(1 + cb - m - k)^2 + 4cb(m+k)}}{2c(m+k)} = \frac{1}{c}$$

Thus, at the limit the supply curve for each plant is $p = cq$, which coincides with the marginal cost curve $C'(q) = cq$.

Appendix 3. Cournot competition

A linear Cournot competition model would also predict a different behavior for large and small generators. From profit maximization for each firm we obtain the following reaction functions: $q_1 = \frac{a-kq_2-q_3}{2m+bc}$; $q_2 = \frac{a-mq_1-q_3}{2k+bc}$; $q_3 = \frac{a-mq_1-kq_2}{2+bc}$.

Solving the system:

$$q_1 = \frac{a\left(b^2c^2 + bc + kbc + k\right)}{Z}$$
$$q_2 = \frac{a\left(b^2c^2 + bc + bcm + m\right)}{Z}$$
$$q_3 = \frac{a\left(b^2c^2 + kbc + bcm + km\right)}{Z}$$

where $Z = b^3c^3 + 2b^2c^2\left(1 + k + m\right) + 3bc\left(k + m + km\right) + 4km$. From these expressions it can be seen that the output for each plant is such that:

$$q_1 \leq q_2 < q_3$$

Appendix 4. Test of conditional means. Ferreira-Stute (2003)

Define $M_t = p_t - p_t^{EN^s}$, then

$$\alpha_n(x) = \frac{\sum_{t=1}^{n} M_t I\left(a_t \leq x\right)}{n^{\frac{1}{2}}}$$

$$\tau_n^2 = \frac{\sum_{t=1}^{n} (M_t - \overline{M})^2}{n}$$

The statistic is:

$$T = \frac{\sup_x \alpha_n\left(x\right)}{\tau_n}$$

under H_o:

$$\sup_x \alpha_n \rightarrow \sup_{0 \leq u \leq \tau^2} B(u) = \tau \sup_{0 \leq u \leq 1} B(u)$$

where B is a Brownian motion. Furthermore, we have that

$$P[\sup_{0 \leq u \leq 1} B(u) \leq \delta] = 2\Phi(\delta) - 1$$

where $\Phi(\delta)$ is the distribution function of the normal distribution. Thus,

$$P[T \leq \delta] \rightarrow 2\Phi(\delta) - 1$$

We compute the T statistic for several tests, and present the results in Tables 1, 2 and 3. In our model a_t is a measure of intensity of demand at each hour t. As an index for demand level we choose for each t the energy demanded at prices 18c€/KWh or above (the horizontal segment of the aggregate demand schedule).

Appendix 5. Fuel plants

We summarize some characteristics of the plants under study. Column 1 is the name of the plant (code in brackets), column 2 is the starting date of operation, column 3 is the power of each generating unit and column 4 is the owner. Column 5 represents the synthetic plant used under the selection procedure.

There has been no entry of new oil-fired plants during the period under study. Only ALG has changed ownership; until January 2002 it belonged to EN, since then it has belonged to VI. The total number of oil-fired units bidding in the day-ahead market is 29. We have excluded ACE1 and ACE2 from Table 4 because they are the only plants with shared ownership (IB 50% and UF 50%), and are neither used to build a synthetic plant nor synthesized.

For the construction of a synthetic firm for a large generator, plants are selected taking into account capacity and age. When for whatever reason there is no bid by the selected plant (maintenance, breakdown, etc) then the second best match is chosen (in brackets in the last column).

Table 4. The oil-fired plants				
Plant Code	**Age**	**Power (MW)**	**Ownership**	**Synthetic Plant (Alternate)**
ABO1	1974	351	HC	SBO2 (SBO1; 2001) (ALG1; 2002, 2003)
ABO2	1985	536	HC	SBO2 (SBO1; 2001) (ALG1; 2002, 2003)
ADR1	1973	335	EN	ABO1 (SBO2)
ADR2	1973	335	EN	ABO1 (SBO2)
ADR3	1973	335	EN	ABO1 (SBO2)
ALG1	1970	211	EN(2001) VI(2002,2003)	SBO1 (SBO2)
ALG2	1975	542	EN(2001) VI(2002,2003)	SBO2 (ABO2)
BDL1	1967	172	EN	SBO1 (SBO2; 2001) (ALG1; 2002, 2003)
BDL2	1967	172	EN	SBO1 (SBO2; 2001) (ALG1; 2002, 2003)
BES1	1967	145	EN	SBO1 (SBO2; 2001) (ALG1; 2002, 2003)
BES2	1972	294	EN	SBO2 (ABO1)
COL1	1961	70	EN	SBO1 (SBO2; 2001) (ALG1; 2002, 2003)
COL2	1964	144	EN	SBO1 (SBO2; 2001) (ALG1; 2002, 2003)
COL3	1968	155	EN	SBO1 (SBO2; 2001) (ALG1; 2002, 2003)
CTN1	1972	542	IB	ABO2 (ABO2; 2001) (ALG2; 2002, 2003)
CTN2	1973	542	IB	ABO2 (ABO2; 2001) (ALG2; 2002, 2003)
ESC1	1956	70	IB	SBO1 (SBO2; 2001) (ALG1; 2002, 2003)
ESC2	1957	70	IB	SBO1 (SBO2; 2001) (ALG1; 2002, 2003)
ESC3	1957	140	IB	SBO1 (SBO2; 2001) (ALG1; 2002, 2003)
ESC4	1966	289	IB	SBO2 (ABO1)
ESC5	1968	289	IB	SBO2 (ABO1)
FOI1	1980	502	EN	ABO2 (ABO1; 2001) (ALG2; 2002, 2003)
SBO1	1972	115	UF	ABO2 (ABO1; 2001) (ALG1; 2002, 2003)
SBO2	1975	341	UF	ABO1 (ABO2)
STC1	1969	378	IB	ABO1 (SBO2)
STC2	1972	542	IB	ABO2 (ABO1; 2001) (ALG2; 2002, 2003)
STC3	1972	17	IB	ABO1 (SBO2; 2001) (ALG1; 2002, 2003)