Oligopolistic Electrical Market Competition, Stranded Costs and Uncertainty: A Supply Function Approach

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Abstract – In a competitive scenario generation bids are sent by the utilities in order to hedge the operational risks due to uncertain demand, competitors behaviour or other factors. On the other hand, stranded costs payments are an important role in some systems, such as the Spanish one. In this paper, supply function equilibria including stranded costs payments are derived, and their likely effect on the utilities behaviour is focused.
Keywords – Electricity Markets, Stranded Costs, Optimal Bidding, Market Uncertainty, Supply Functions.

I. INTRODUCTION

During the last years, electric systems world wide have turned from being operated in a centralised way to work in a free-market scenario. Utilities make generation bids and receive a price according the established market rules.

There are models which compute the generated power and prices in a deterministic setting [12]. However, it can be proved [8] that the shape of the offer curve (supply function, bids curve) is determined by the operation uncertainty: the utilities decide which supply function to has to be offered trying to hedge their risk with respect to uncertainties in the demand, the competitors behaviour, or other risk factors.

An important component in many systems are the stranded cost payments. The aim of this paper is to extend the Supply Function Theory to accommodate the stranded cost payments. Conclusions will be derived on the likely behaviour of the agents under these circumstances.

This paper contains eight sections organised as follows. Next section describes the structure of the Spanish wholesale electricity market. Section III describes the stranded cost payments in Spain. Section IV reviews the supply function approach extending the analysis to include stranded costs. The theory is applied to an illustrative example in Section V and to a simplified system resembling the Spanish one in Section VI. Finally, conclusions are stated in Section VII.

II. SPANISH WHOLESALE MARKET STRUCTURE

The 1997 Spanish Electricity Act [11] introduces competition in the generation and supply activities. The market operator and the system operator are the authorities that operate these activities.

The market operator receives bids from agents and clears the market according to the *marginal price procedure*. The system operator validates units' schedule considering the electrical system's technical constraints.

The market operator opens on a daily base a generation market that covers approximately 95% of the total business. This market is based on a mandatory regime for units whose installed capacity is above 50 MW. Authorised agents submit bids for each of the next day's 24 hours before 10 a.m.

Bilateral contracts excluding units from the daily market may also take place [11]. Special-regime producers may not submit bids to the daily market [11].

There are simple or complex bids. Simple bids are price-quantity pairs. Complex bids include any of the following conditions: indivisibility of blocks, minimum income, scheduled stop and load gradient.

The matching procedure is a closed one: once a final price has been set, there are no further iterations. At first, a match is find for simple bids. Then, a second match takes into account complex bids and the final hour's price is set.

The market operator submits a base daily operating schedule to the system operator. The base daily operating schedule is composed of the matching results, the schedule of special-regime producers, bilateral contracts notification and the supply-demand pair for each of the grid connection busses [10].

The system operator modifies the base operating schedule to guarantee supply's safety, quality and reliability. A provisional daily viable schedule is obtained following these requirements. Ancillary services added to this provisional schedule constitute the daily viable schedule [4].

Eventually, the market operator publishes at 18.00 hours the final daily operating schedule for the next day.

Spanish two major electricity groups, Endesa and Iberdrola, control approximately 80% of all the electricity that is generated and distributed in Spain. Therefore, the Spanish market can be approximately modelled as a duopolistic one.

III. STRANDED COSTS IN SPAIN (CTCs)

1,629,206 Mptas (9792 M€) of costs involved in the transition to a competitive market system are acknowledged in Act 57/1997. The 10-year Transition to Competition Period may be reduced by the Spanish authorities if market conditions make it advisable. The reasons for the existence of stranded costs, referred to as Costs of the Transition to Competition –CTCs- in Spain, are as follows [1,9]:

1.- Whilst regulated tariffs are based on average costs, perfect competition brings prices to marginal costs. Nowadays, due to new GICC technologies, marginal price is lower than historical average price. This fact would create financial problems for regulated firms.

2.- The Spanish Government has been involved in investment decisions taken by the utilities, for instance, regarding domestically produced coal. Under lower prices, these investments may not be recouped.

Total generation revenues are then bounded in Spain. The model used in this paper [2,5] is one in which a percentage r_i of the annually-set amount of CTC (the total generation income *T* minus the market income *pD)* is distributed to company *i.* Therefore, benefit for firm *i* is:

$$B_i = p \cdot S_i - C_i(S_i) + r_i \cdot \left[T - p \cdot D\right] \quad (1)$$

where p is marginal price, T is the total amount of CTC, S_i the company's supply function, $C_i(S_i)$ is marginal costs and D is demand. Coefficient r will be referred to in this paper as stranded costs ratio.

IV. SUPPLY FUNCTION APPROACH [8]

A supply function (SF) relates the quantity the firm will sell to the price the market will bear. With exogenous uncertainty about market demand a firm has an uncertain residual demand even in equilibrium. So, it has a set of profit-maximizing points, one corresponding to each realization of its residual demand. A supply function can be chosen to coincide with this set of optimal price-quantity pairs. The equilibrium pairs thus obtained are supply function equlibria (SFE). This SF commits the firm in advance of the realization of the uncertainty to achieving its ex post profit-maximizing outcome.

The analysis performed is a static (one-shot) setting. The oligopoly model thus presented better adapts to reality than the single-period Bertrand (fixed price) or Cournot (fixed quantity) models.

It is assumed that demand *D* is a random variable [2,3,5,7,8]. *D* can be modelled by a random variable ε, such that $D = D(p,\varepsilon)$, where *p* is price and *D* is the demand function.

A SF for firm *k* is a function mapping price into a level of output for *k*: $S^k : [0,\infty) \to (-\infty,\infty)$. Firms choose supply functions (SFs) simultaneously, without knowing the realization of ε. After the realization of ε, SFs are implemented by each agent producing at a point $(p^*(\varepsilon), S^k(p^*(\varepsilon)))$ such that demand matches total supply, provided a unique price $p^*(\varepsilon)$ exists. That is,

$$D(p^*(\varepsilon)) = \sum_k S^k(p^*(\varepsilon)).$$

The sequel is for duopolist agents. Demand D is written,

$$S_1(p) + S_2(p) = D(p,\varepsilon) \quad (2)$$

where $S_1(p)$ is the supply function chosen by utility 1 and $S_2(p)$ is chosen by utility 2. ε can be solved from (2) as a function of p,

$$\varepsilon = \varepsilon(S_1(p), S_2(p), p) \quad (3)$$

For known supply functions $S_1(p)$ and $S_2(p)$, total demand *D* and its associated random shock ε are computed following (2) and (3).

Benefit for firm 1 is,

$$B_1 = pS_1 - C_1(S_1) + r_1(T - p \cdot D) \quad (4)$$

Given the competitor's supply function $S_2(p)$ and the market demand D(p,ε), (5) is the maximum benefit condition for utility one.

$$\max_p B_1(p) = p\left[D(p,\varepsilon) - S_2(p)\right] - C_1\left((D(p,\varepsilon) - S_2(p)\right) + r_1\left[T - pD(p,\varepsilon)\right] \quad (5)$$

Solving (5) for each ε yields the optimal price and production level pair for firm 1. The maximizing first order condition is:

$$\frac{\partial B_1}{\partial p} = S_1 + p\left[D' - S_2'\right] - \frac{\partial C_1}{\partial S_1}\left[D' - S_2'\right] - r_1\left[D + pD'\right] = 0 \quad (6)$$

Rearranging (6),

$$S_2'\left[p - \frac{\partial C_1}{\partial S_1}\right] = S_1 + D'p - r_1\left[D + pD'\right] - \frac{\partial C_1}{\partial S_1}D'$$
$$S_2' = \frac{S_1 - r_1\left[D + pD'\right]}{p - \frac{\partial C_1}{\partial S_1}} + D' \quad (7)$$

where comma derivatives refer to variable p, electricity price.

Interchanging subscripts one and two, the coupled differential system (8) is found

$$\frac{\partial S_1(p)}{\partial p} = \frac{S_2(p) - r_2\left[D(p,\varepsilon) + p\dfrac{\partial D(p,\varepsilon)}{\partial p}\right]}{p - \dfrac{\partial C_2}{\partial S_2}} + \frac{\partial D(p,\varepsilon)}{\partial p} \tag{8}$$

$$\frac{\partial S_2(p)}{\partial p} = \frac{S_1(p) - r_1\left[D(p,\varepsilon) + p\dfrac{\partial D(p,\varepsilon)}{\partial p}\right]}{p - \dfrac{\partial C_1}{\partial S_1}} + \frac{\partial D(p,\varepsilon)}{\partial p}$$

Following (2), (8) can be written as

$$\frac{\partial S_1(p)}{\partial p} = \frac{S_2(p) - r_2\left[S_1(p) + S_2(p) + p\left(\dfrac{\partial S_1(p)}{\partial p} + \dfrac{\partial S_2(p)}{\partial p}\right)\right]}{p - \dfrac{\partial C_2}{\partial S_2}} + $$

$$+\frac{\partial S_1(p)}{\partial p} + \frac{\partial S_2(p)}{\partial p} \tag{9}$$

$$\frac{\partial S_2(p)}{\partial p} = \frac{S_1(p) - r_1\left[S_1(p) + S_2(p) + p\left(\dfrac{\partial S_1(p)}{\partial p} + \dfrac{\partial S_2(p)}{\partial p}\right)\right]}{p - \dfrac{\partial C_1}{\partial S_1}} + $$

$$+\frac{\partial S_1(p)}{\partial p} + \frac{\partial S_2(p)}{\partial p}$$

Equations (8) and (9) can be considered as a dynamic system which trajectories are the equilibrium supply functions. Trajectories may be parametrized by their initial conditions, being price analogous to time.

SFs must be upward sloping everywhere on its support [8]. Therefore, initial conditions of (8) which do not yield $\partial S_1 / \partial p > 0$ and $\partial S_2 / \partial p > 0$ are not admissible. Integration can only be meaningfully extended where these conditions apply.

Shock ε computed in (3) must be realistic. Solutions to (9) must only be checked for the realistic ε range $[\underline{\varepsilon}, \overline{\varepsilon}]$. [8] proves that an unbounded ε support ($\varepsilon \in [0, \infty]$) is required to guarantee a single SF pair. For a bounded uncertainty support, a set of admissible SFs may be expected. This means that there is not a single valid game equilibrium.

V. STUDY CASE: LINEAR MARGINAL COSTS

The aim of this section is to study stranded costs payments' influence on SFs when linear marginal costs and demand are considered. This section is an extension of the symmetric linear example presented in [8].

A symmetric study means that duopolists have same marginal costs, market information and generation facilities. Their residual demand is therefore half of the market's. Supply functions for each duopolist are coincident.

Both marginal cost and demand are linear [2,5]. Equation (10) describes demand and marginal cost in this section:

$$C_i{}'(S_i) = m \cdot S_i\,,\; D(p,\varepsilon) = -d \cdot p + \varepsilon = -d \cdot p + 15 \tag{10}$$

The linear coupled system (11) describes this Study Case equations,

$$\frac{dS_1}{dp} = \frac{S_2 - r_2\left[S_1(p) + S_2(p) - d \cdot p\right]}{p - m \cdot S_2} - d$$
$$\frac{dS_2}{dp} = \frac{S_1 - r_1\left[S_1(p) + S_2(p) - d \cdot p\right]}{p - m \cdot S_1} - d \tag{11}$$

SFs are found integrating (11) for appropriate initial conditions. A numerically integration procedure based on Runge-Kutta has been implemented in Matlab [5].

From factible initial pairs, forward and backward integrations are performed. As Runge-Kutta algorithm deals with positive integration variables, the following variable change was performed:

FORWARD: $p = p^* + p0$.
BACKWARD: $p = -p^* + p0$, where p^* increases.

Demand's elasticity is related to *d* coefficient in equation (10). Stranded costs payments shape SFs depending on demand's elasticity.

Subsection V.A. presents SFs with stranded costs payments for a small elasticity demand coefficient *d = 5*. Subsection V.B. presents SFs with stranded costs payments for a more elastic demand coefficient *d = 0.2*.

In addition to SFs, the following figures in this section plot demand D, residual demand D/2 and marginal cost in dotted lines.

A. Linear marginal costs. Small elasticity demand.

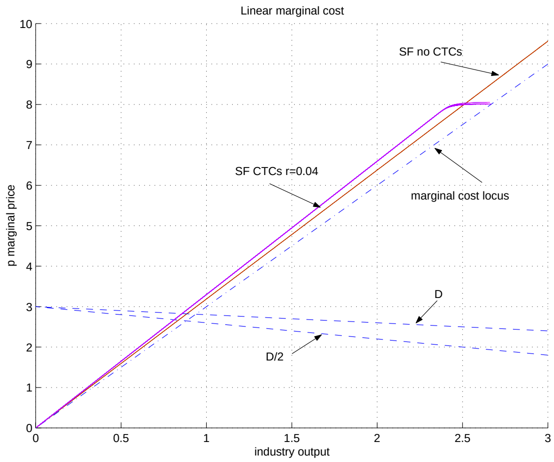
In this subsection, coefficients *m* and *d* in (10) are:

m = 3, d = 5 [8]

Figure 1, figure 2 and figure 3 illustrate the effect of stranded costs payments on optimum bids to a small elasticity demand market.

Figure 1 plots linear SF with no added stranded costs payments (labelled "SF no CTCs") and SFs where this item to revenue has been considered.

Figure 1 shows that stranded costs have an influence on SFs. Small *r* values cause slight deviations from the no-stranded costs SFs.



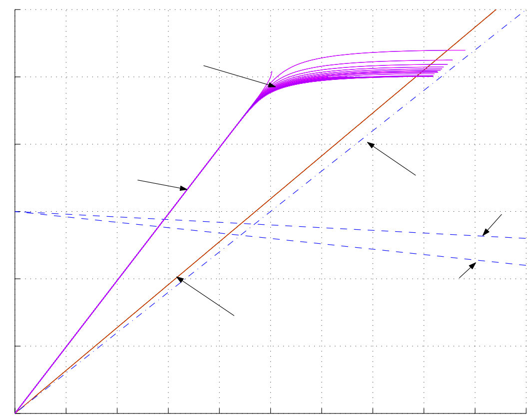


Figure 1. Linear marginal cost. Small elasticity demand. Small *r* effect on SFs.

Figure 3. Linear marginal cost. Small elasticity demand. Regions and overlaps in SFs.

Figure 1 clearly depicts two different regions on SFs: a linear region steeping from the origin and a non-linear flat prices region near the marginal cost locus. This point will be discussed below.

Figure 2 clearly illustrates the influence of the stranded costs payments ratio *r* on SFs. Figure 2 plots 3 sets of SFs for *r* values 0.06, 0.2 and 0.4. These SFs are labelled indicating *r* values. No stranded costs SF is also plotted on the same figure. SFs are integrated for 10 initial equilibrium pairs around (15,3).

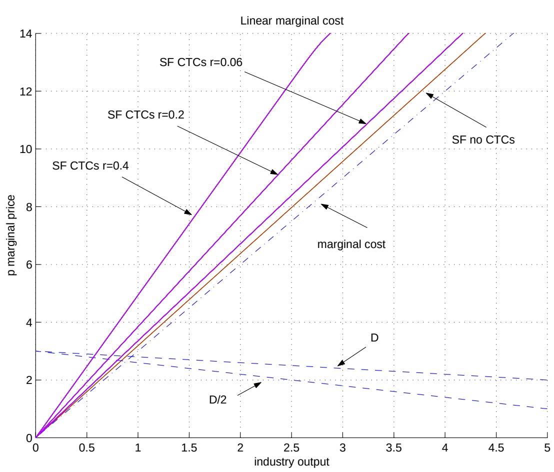


Figure 2. Linear marginal cost. Small elasticity demand. Stranded costs payments ratio *r* effect on SFs.

Figure 2 shows that higher r values produce steeper SFs slopes in the linear region of SFs.

Figure 3 plots a set of SFs where r = 0.4 integrated from a set of valid initial conditions (market equilibria) around (5,1).

If demand shock reduces prices, new SFE will be in the SFs linear region. In this region, stranded costs cause prices to be higher than those corresponding to a scenario without this payments.

Figure 2 and figure 3 show that SFs response to stranded costs payments depends on production's departure from initial market equilibrium. If the final industry output is lower than the pre-shock value, stranded costs increase market clearing prices (in comparison with the no stranded costs' SF).

Conversely, for higher than initial output production levels competition is driven to a Bertrand-like scenario: Figure 3 shows that prices remain flat over an important range of production outputs. If shock ε is large enough, price-quantity pairs will reach the existence boundary locus (marginal cost) [8].

B. Linear marginal costs. Greater demand's elasticity.

In this subsection, coefficients *m* and *d* in (10) are:

$m = 3, d = 0.2$ [8]

Figure 4 and figure 5 illustrate the effect of stranded costs payments on optimum bids to a more elastic demand market.

Figure 4 plots 4 sets of SFs integrated for 4 initial price-quantity pairs. From each of those initial pairs, both SFs with and without stranded costs are integrated. The stranded costs ratio *r* in Figure 4 is 0.06.

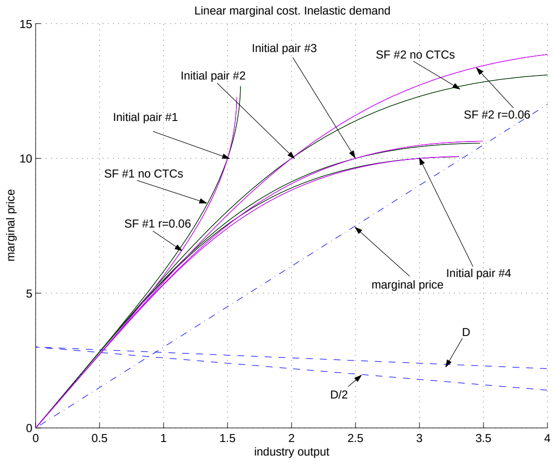


Figure 4. Linear marginal cost. Greater demand's elasticity. Small *r* effect on SFs.

Figure 4 shows that SFs response to stranded costs payments depends on production's departure from initial market equilibrium. If the final industry output is lower than the pre-shock value, stranded costs reduce market clearing prices (in comparison with the no stranded costs' SF).

Conversely, for higher than initial output levels, stranded costs payments increase prices (in comparison with the no stranded costs' SF).

Higher stranded costs ratios *r* produce further prices departures of the no stranded costs market scenario. This effect is illustrated in Figure 5.

Figure 5 plots 3 sets of SFs integrated for 3 initial price-quantity pairs. From each of those initial pairs, both SFs with and without stranded costs are integrated. The stranded costs ratio *r* in Figure 5 is 0.4.

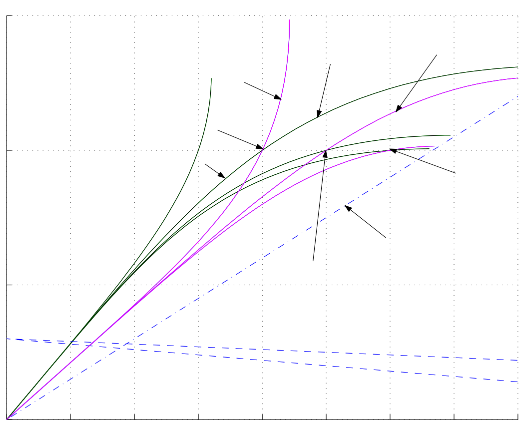


Figure 5. Linear marginal cost. Greater demand's elasticity. Large *r* effect on SFs.

From figure 4 and figure 5 it can be concluded that a higher *r* value moves stranded costs SFs further away from the no stranded costs' SFs.

Figure 5 also shows a linear region in SFs both with and without stranded costs. Higher final output levels than the pre-shock equilibrium one approach competition either to Bertrand's (horizontal SFs) or to Cournot's (vertical SFs) competition models.

VI. STUDY CASE: REALISTIC COST MODEL IN A DUOPOLISTC MARKET WITH STRANDED COSTS

Linear demand D and symmetric firms are assumed. Demand's support is then bounded. In particular, $D(p,\ \varepsilon) = -d \cdot p + \varepsilon = -1000 \cdot p + 20000$. These assumptions proved to model a realistic competition scenario [5].

Both agents cover 80% of the market while other competitors would not bid strategically. Each firm's stranded costs ratio is $r_1 = r_2 = 0.4$.

Figure 6 plots typical Spanish thermal marginal cost vs. power [6]. The marginal costs in this section are those of Figure 6.

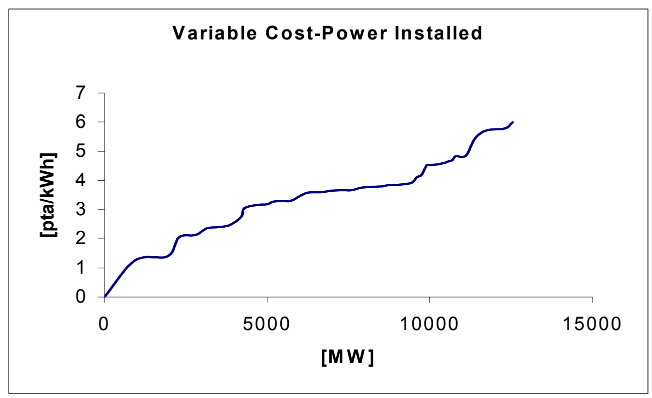


Figure 6. Typical Spanish marginal cost.

The system (12) presents the study case equations.

$$
\begin{aligned}
\frac{\partial S_1(p)}{\partial p} &= \frac{S_2(p) - 0.4 \cdot \left[S_1(p) + S_2(p) - p \cdot d\right]}{p - \dfrac{\partial C_2}{\partial S_2}} - d \\
\frac{\partial S_2(p)}{\partial p} &= \frac{S_1(p) - 0.4 \cdot \left[S_1(p) + S_2(p) - p \cdot d\right]}{p - \dfrac{\partial C_1}{\partial S_1}} - d
\end{aligned}
\qquad (12)
$$

where m = 1000.

SF are computed as in section V. To get positive initial SF derivative values in (12), initial electricity prices for each level of output must be really close to the marginal cost locus. Stranded costs (CTCs) dramatically shrink the subset of valid initial conditions [5].

Figure 7 illustrates stranded costs weight on a realistic market bidding. This figure plots three curves. The lowest curve is the marginal cost locus as plotted in Figure 6. The other curves are two SFs computed for the same initial equilibrium pair (5.5pta/kWh, 11,500MW). The upper SF represents a market with no stranded costs payments. The lower SF (inner curve) represents the duopolistic symmetric case where both agents share 80% of the total stranded costs payments. Marginal price *p* is in pta/kWh.

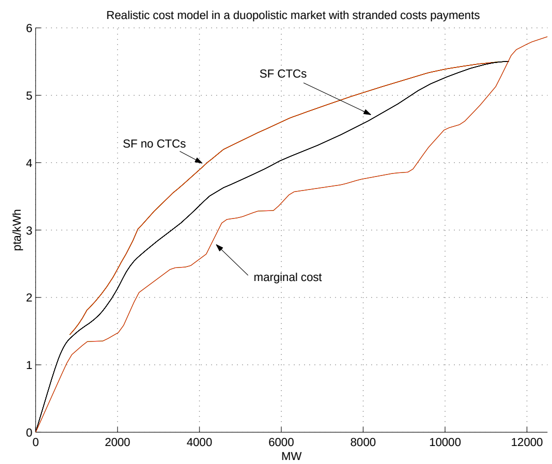


Figure 7. Realistic market cost. Stranded costs effect on SFs

Figure 7 shows that stranded costs payments to duopolistic agents reduce pool prices.

Supply functions where stranded costs have been added exist in the region above the marginal cost locus [8].

VII. CONCLUSIONS

(i) Stranded costs payments effectively shape supply functions.

Stranded costs payments shape SFs. This point has been showed both for a simplified linear marginal cost and demand study case (section V) and for a realistic market scenario (section VI). Thus, stranded costs payments (CTCs) are an effective market regulation scheme.

(ii) Stranded costs payments to duopolistic agents may reduce pool prices.

A realistic market scenario resembling the Spanish duopolistic generation market has been presented in Section VI. Figure 7 illustrates that stranded costs payments reduce pool prices in this scenario.

(iii) Over their common support, different SF do overlap.

There is a SF for each initial price-quantity pair. Demand uncertainty shocks modify power bids. For large enough shocks causing the SFE pairs to move significantly from the initial condition, optimal quantities and prices belonging to different SF do coincide.

VIII. REFERENCES

1. ARRAIZA, J. M. (1998): “Los Costes de Transición a la Competencia”, *Anales de Mecánica y Electricidad*, 75, II, 52-57.
2. BARQUÍN, J., (1998): “Comportamiento de un duopolio eléctrico”, Working Document, *Instituto de Investigación Tecnológica I.I.T.*, May, 1999.
3. BOLLE, F. (1992): “Supply Function Equilibria and the Danger of Tacit Collusion. The Case of Spot Markets for Electricity”, 0140/9883/92/020094-09 © 1992 *Butterworth-Heinemann Ltd.*
4. C.S.N.E., EXTERNAL RELATIONS DEPARTMENT (1998): “Most Frequent Asked Questions on the Spanish Electric Power System”, *C.S.N.E.*, http://www.cne.es, June 1998.
5. DEL CASTILLO, J. I. (1999): “Cálculo de Ofertas en un Mercado Eléctrico Oligopolista”, Degree Dissertation, *Universidad Pontificia Comillas. Escuela Técnica Superior de Ingenieros Industriales ICAI*, May 1999.
6. GARCÍA, J., BARQUÍN, J. (1999): “Strategic Bidding in Deregulated Power Systems”, *13th Power Systems Computation Conference (PSCC '99)*, Norway. June 1999.
7. GREEN, R. J., NEWBERY, D.M. (1992): “Competition in the British Electricity Spot Market”, *Journal of Political Economy*, 100, 5, pp. 929-953.
8. KLEMPERER, P. MEYER, M. (1989): “Supply Functions Equilibria in Oligopoly under Uncertainty”, *Econometrica*, 57, 1243-1277.
9. LASHERAS, M.A. (1998): “Stranded Costs in the Spanish Electricity Industry”, Documento de Trabajo, *Comisión Nacional del Sistema Eléctrico C.S.N.E.* http://www.cne.es, October 1998.
10. MARTÍNEZ CÓRCOLES, F. (1988): “El Mercado de Producción de Energía Eléctrica”, *Anales de Mecánica y Electricidad*, 75, II, 58-73.
11. SPANISH ELECTRIC POWER ACT. *001/98 C.S.N.E.* http://www.cne.es, 1998.
12. VENTOSA, M., RAMOS, A., RIVIER, M. (1999): “Modelling profit maximisation in deregulated power markets by equilibrium constraints”, *Proceedings 13th PSCC Conference*, Norway, Vol.1, pp 231-237, June 1999.