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A model of market power in electricity industries subject to peak load pricing ☆

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Abstract

This paper studies the exercise of market power in price-regulated electricity industries under peak-load pricing and merit order dispatching, but where investment decisions are taken by independent generating companies. Within this context, we show that producers can exercise market power by under-investing in base-load capacity, compared to the welfare-maximizing configuration. We also show that when there is free entry with an exogenous fixed entry cost that is later sunk, more intense competition results in higher welfare but fewer firms.

JEL Classification: L94; L51

Keywords: Electricity; Market power; Peak-load pricing

1. Introduction

This paper analyzes the exercise of market power in electricity markets subject to peak-load pricing (see e.g. Boiteux, 1960; Crew et al., 1995 for a detailed survey) and centralized dispatching based on merit order, but where investment decisions are taken by independent generating companies. This regulatory scheme is frequent among those countries that have privatized their power systems but where full competition might seem impractical at the outset. In fact, it approximates the regulatory framework introduced by chile in 1981, and subsequently by other Latin American countries, such as Peru, Nicaragua, Panama and Dominican Republic.

In this setting, the only variable that firms are able to control is the composition of their generating portfolios. For simplicity, we assume that only two generating technologies are available: peaking and base-load, where the former has a lower per unit capacity cost but a higher unit operating cost. Hence, producers' strategic variable is investment in base-load capacity. Demand, which is assumed to be inelastic, is summarized by a load curve that reflects hourly demand during a whole year. In this context, market power is better measured by the length of time for which peaking technology plants operate over and above the welfare-maximizing solution.

Within this framework, we show that even where prices are set equal to marginal costs, producers can still exercise market power by altering the composition of their generating portfolios; generators can earn rents by increasing the share of peaking technology in the generating portfolio beyond its welfare-maximizing level. This strategy raises the average price paid by consumers, since the peaking technology sets the energy price for a longer period, while the capacity charge remains unchanged. We also show that when the number of firms is fixed, then the more intense is competition the higher is social welfare. Lastly, we consider free entry with an exogenous fixed entry cost that is later

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sunk. In this context, we show that the more intense the competition, the lower the average price paid by consumers, and therefore the larger each firm's sales must be for them to break even. Thus, since demand is assumed to be inelastic, more intense competition results in higher welfare but fewer firms.

Recent years have seen a boom in papers that study market power issues in the electricity sector, motivated by the wave of deregulation that has spread throughout the world with varying degrees of success and by recent experiences of the exercise of market power by generation companies—California being the most notable case in point. This literature has mainly focused on short-term decisions, taking existing capacity as given. Examples of this type of approach are Andersson and Bergman (1995), Borenstein and Bushnell (1999), Bushnell (2003), Green and Newbery (1992), Halseth (1998), Joskow and Kahn (2002) and Von der Fehr and Harbord (1993). They show that market power can be exercised more freely when the capacity of rivals is exhausted. As a result, the market equilibrium is allocatively inefficient, as the price paid by consumers is higher than marginal cost in the relevant periods.

Our paper is closer to Von der Fehr and Harbord (1997) and Castro-Rodriguez et al. (2001). These authors analyze capacity investment decisions in decentralized oligopolistic industries. They model firms' decision as a two-stage game. During the first stage, firms decide on how much capacity to install, while in the second they compete to supply energy. Their main finding is, assuming that generators are forced to bid at marginal operating cost, that de-regulated markets under-invest in capacity. Moreover they show that under-investment is always in base-load capacity. Though these results are similar to ours, there are some modeling differences. These authors consider a standard demand subject to random shocks. In turn, we depict demand as a load curve to reflect the fact that in electric systems supply must match demand in real time, but we do so at the cost of assuming a price-inelastic demand.[1]

2. The basic model

We assume a two-technology, linear-cost generating industry, where b denotes the base-load technology and p the peaking technology. In addition, c_i denotes the operating cost per unit and f_i the capacity cost per unit, for technology i, $i = b,p$. Both technologies are efficient. Hence $f_b > f_p$ and $c_b < c_p$. Demand, which is assumed to be inelastic, is summarized in a load curve $q(\ )$ which is assumed to be continuously differentiable, where $q(t)$ designates consumption at the t-th highest consumption hour. Lastly, we assume that (i) plants are always available to produce at full capacity and can adjust their production level instantaneously and costlessly;[2] (ii) plant startup costs can be neglected; and (iii) no failures occur. On this set of assumptions, the problem of minimizing the total cost of the electric power system is formalized as follows:

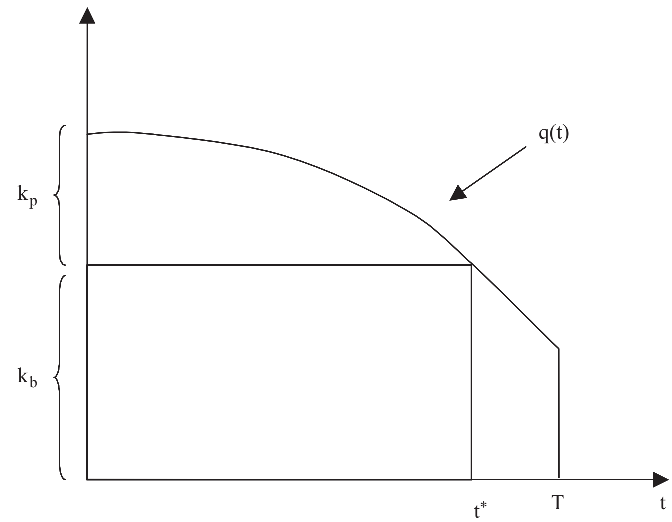

Fig. 1. Optimal composition of the generating portfolio.

$$\underset{k_b}{Min}\ C(k_b) = \underset{k_b}{Min}\left\{ f_b k_b + f_p(q^M - k_b) + c_p \int_0^{t(k_b)} (q(t) - k_b)\,\mathrm{d}t + c_b k_b t(k_b) + c_b \int_{t(k_b)}^{T} q(t)\,\mathrm{d}t \right\}, \tag{1}$$

where q^M designates maximum system's demand, k_i the installed capacity of type i technology, T the number of hours in a year and $t(\cdot)$ denotes the inverse of the load curve. Since the load curve $q(t)$ has a negative slope, $t' < 0$. The formalization of the problem assumes optimal use of installed capacity (see Fig. 1). Indeed, installed capacity equals maximum demand, and peaking plants are dispatched only when base-load plants are operating at full capacity. In fact, between hours $t(k_b)$ and T, demand is met by base-load plants only, since installed capacity renders this feasible. Between hours 0 and $t(k_b)$, peaking plants generate the demand unmet by base-load plants. Thus, in what follows, $t(k_b)$ will stand for the number of hours in which peaking plants operate.

Differentiating $C(k_b)$ gives

$$C'(k_b) = \left(\frac{\Delta f}{\Delta c} - t(k_b)\right)\Delta c, \tag{2}$$

where $\Delta f = f_b – f_p$ and $\Delta c = c_p – c_b$. Since $C(k)$ is a convex function, the optimal solution is characterized by the

[1] The literature that examines investment distortions introduced by the regulation goes back at least to the seminal work of Averch-Johnson (1962).

[2] This excludes hydroelectric plants, which are limited by water accumulated in the reservoir.

condition:

$$t^* = Min\left(\frac{\Delta f}{\Delta c}, T\right) \tag{3}$$

and the generating portfolio that minimizes the overall system cost is $k_b^* = q(t^*)$ and $k_p^* = q^M - k_b^*$. When $t^* = T$, only peaking plants are set up.

Peak-load pricing consists of an energy charge equal to the per unit operating cost of the plant with highest operating cost being dispatched at any instant (i.e. the marginal plant) and a capacity charge equal to the marginal cost of increasing capacity, where the latter corresponds to the per unit capacity cost of the peaking technology. The capacity charge applies only to consumption at peak demand. Then, assuming that an independent operator dispatches generating plants in strict merit order, peak-load pricing will lead a decentralized competitive system to the optimal solution. When the price of energy is c_b, only base-load plants are willing to produce, whereas at price c_p, both types of plants are willing to produce. Moreover, under perfect competition the configuration of the generation portfolio is optimal. Base-load capacity will be installed up to the point where rents are dissipated, which happens when peaking plants operate for t^* hours.

Next, we show that the industry could generate rents by altering the composition of its generating portfolio compared to the welfare-maximizing solution. Since peaking plants never obtain rents, for any level of base-load installed capacity (k_b) the industry's profits are given by:

$$\pi(k_b) = k_b t(k_b)\Delta c - k_b \Delta f \tag{4}$$

with

$$\pi'(k_b) = t(k_b)\Delta c + k_b t'(k_b)\Delta c - \Delta f. \tag{5}$$

Since $t' < 0$, $\pi'(k_b^*) = k_b^* t'(k_b^*)\Delta c < 0$. Hence, although prices are set equal to marginal costs and merit order dispatch is mandatory, there is a range in which reducing the share of base-load plants in the generating portfolio ($k_b < k_b^*$) increases profits. Also note that $\pi'(0) = T\Delta c - \Delta f > 0$. As the function t is assumed to be continuously differentiable, it follows that function π' is continuous. Consequently there is at least one $k_b \in (0, k_b^*)$ satisfying the optimality condition $\pi'(k_b) = 0$. To simplify analysis we further assume that the profit function π is strictly concave; hence there is only one solution to $\pi'(k_b) = 0$.

Turning to consumers, their payments are given by:

$$P(k_b) = c_p \int_0^{t(k_b)} q(t)\,\mathrm{d}t + c_b \int_{t(k_b)}^{T} q(t)\,\mathrm{d}t + f_p q^M. \tag{6}$$

Hence

$$P'(k_b) = k_b t'(k_b)\Delta c < 0. \tag{7}$$

Thus a higher share of peaking technology in the generating portfolio always results in larger consumer payments. Moreover, consumers' losses outweigh the gains made by generating companies, thereby reducing social welfare. In fact, $C'(k_b) = (P'(k_b) - \pi'(k_b)) < 0$ when $k_b < k_b^*$.

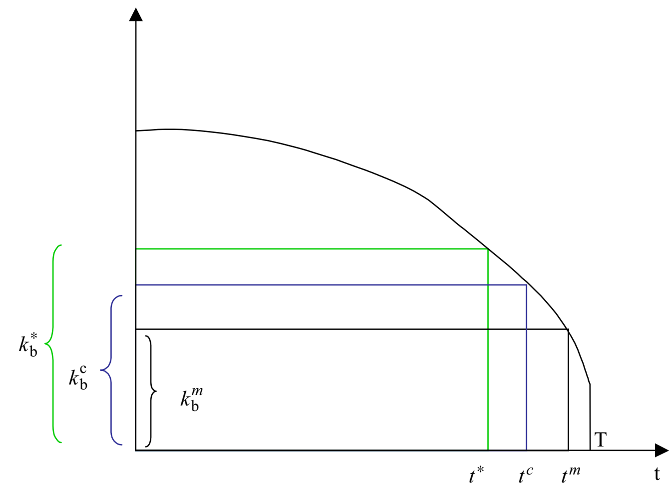

Fig. 2. Composition of the generating portfolio under different competition regimes.

3. Imperfect competition with no entry

In this section, we analyze market equilibrium when the number of firms is given. As before, we assume mandatory dispatching by an independent operator who minimizes total operating cost and applies peak-load pricing.[3] This ensures that generators are willing to satisfy demand since peaking plants always break even.[4] In this context, the only decision left to generation companies concerns the composition of their generating portfolios.

3.1. Monopoly

The solution that maximizes the monopolist's profits satisfies the condition $\pi'(k_b) = 0$. Recalling that $t(k)$ is the inverse of $q(t)$, rearranging Eq. (5) gives:

$$t^m = \frac{e_q^m}{1 + e_q^m}\frac{\Delta f}{\Delta c} = \frac{e_q^m}{1 + e_q^m} t^* \tag{8}$$

where t^m denotes the number of hours that peaking technology plants are dispatched and $e_q{}^m$ the elasticity of function $q(t)$ with respect to t, assessed at t^m. As shown in the appendix, the strict concavity of the profit function π ensures that $t^m \in (t^*, T)$, i.e. that peaking technology plants set the price of energy for a longer period of time under monopoly than under perfect competition. Hence $k_b^m < k_b^*$ and $k_p^m > k_p^*$, where $k_b^m = q(t^m)$ and $k_p^m = q^M - k_b^m$ (see Fig. 2). Accordingly, the monopolist's generating portfolio has a smaller share of base-load technology than the welfare-maximizing pattern.

[3] We assume that strategic withholding of base-load capacity is precluded.

[4] Thus only the number of firms with access to base-load technology needs to be fixed.

3.2. Cournot oligopoly

Let us now assume that there are n generating companies, all of which have access to both technologies. We assume Cournot competition, i.e. each generating company chooses its base-load installed capacity, taking its rivals' base-load installed capacities as given. Hence the profit maximization problem of firm j is

$$\underset{k_b^j}{Max}\{\Delta c k_b^j\, t(k_b) - \Delta f\, k_b^j\}, \tag{9}$$

where k_b^j denotes the choice of base-load installed capacity by firm j; and, as before, k_b denotes the system's base-load total installed capacity. Each generating company's first-order condition is

$$t(k_b) + t'(k_b)k_b^j - t^* = 0. \tag{10}$$

Assuming that firms are symmetric, $k_b^j = k_b/n$, so (10) can be rewritten as

$$t(k_b)\left[1 + \frac{1}{ne_q(t(k_b))}\right] = t^*. \tag{11}$$

Therefore, peaking plants operate between $t = 0$ and $t^c(n)$, where

$$t^c(n) = \frac{n\,e_q^c(t^c(n))}{1 + n\,e_q^c(t^c(n))}t^* \tag{12}$$

and $e_q{}^c(n)$ is the elasticity of function $q(t)$ assessed at $t^c(n)$. In the appendix, we show that the strict concavity of the profit function ensures that $t^c(n) \in (t^*, t^m)$ and that $t^c(n)$ is decreasing in n. Consequently, $t^* < t^c(n) < t^c(n-1) < t^m$ (see Fig. 2), and $k_b^* > k_b^c(n) > k_b^c(n-1) > k_b^m$, where $k_b^c(n) = q(t^c(n))$. Thus, the larger the number of firms, the larger the share of base-load plants in the generation portfolio and the smaller the generating companies' market power.

3.3. General case

In this section, we analyze equilibria for different levels of market power. In a price-regulated power industry, the natural measure of the exercise of market power would be the length of time that peaking technology plants operate beyond their operational time in the welfare-maximizing solution. Hence, by analogy to the Lerner index, the market power index in this setting would be:

$$\frac{t - t^*}{t} = -\frac{\theta}{e_q(t)}, \tag{13}$$

where t is the length of time for which the peaking technology plants operate and θ is the relevant conduct parameter. Since having a higher share of base-load plants in the generating portfolio compared to the welfare-maximizing configuration results in losses, we can assume that $t \geqslant t^*$ without loss of generality. Hence $0 \leqslant \theta \leqslant 1$, with $\theta = 0$ for perfect competition, $\theta = 1$ for perfect collusion (or monopoly) and $\theta = 1/n$ for the Cournot oligopoly with n symmetric firms.[5] Rearranging Eq. (13) leads to,

$$t(\theta) = \frac{e_q(t(\theta))}{e_q(t(\theta)) + \theta}t^* \tag{14}$$

The strict concavity of the profit function ensures that $t(\theta)$ is a decreasing function of θ, so the more market power is exercised by generators, the larger is the share of peaking technology plants in the generating portfolio and the longer is their operating time.

To analyze the effect of industry structure on the equilibrium, it is convenient to rewrite the conduct parameter used in Eq. (14) in terms of n and g where $\theta = 1/(gn)$. Hence, g is a measure of the intensity of competition, which ranges from $1/n$ (perfect collusion) to infinity (perfect competition). Eq. (14) may therefore be rewritten as

$$t(gn) = \frac{e_q(t(gn))gn}{1 + e_q(t(gn))gn}t^*. \tag{15}$$

In the appendix we show that, assuming the function π to be strictly concave, and for a given intensity of competition g, the larger the number of firms n in the industry, the less distorted is the composition of the generating portfolio, except for the polar cases of perfect collusion and perfect competition.

Assuming that every entrant incurs an entry cost σ, the system's total cost function is given by

$$C(t,n) = f_b q(t) + (q^M - q(t))f_p + c_p\int_0^t (q(s) - q(t))\,\mathrm{d}s + c_b t q(t) + c_b\int_t^T q(s)\,\mathrm{d}s + n\sigma. \tag{16}$$

Increasing the number of firms has two opposite effects on total cost and therefore may not be necessary socially desirable. To see this, note that

$$\frac{\partial C(t,n)}{\partial n} = -q'(t)\Delta c(t - t^*)\frac{\mathrm{d}t}{\mathrm{d}n} + \sigma. \tag{17}$$

It is not clear whether the cost reduction resulting from less market power compensates for the entry cost that must be incurred by each entrant.

4. Equilibrium with free entry

Next we analyze free entry, following Sutton (1996) in assuming a fixed cost σ that is sunk once entry occurs. Market equilibrium may then be formulated as a two-stage game. In the first stage, the entry decision is taken with perfect foresight regarding the intensity of competition g in the next stage; while at the second stage competition occurs between the firms that have entered the market. The result of the latter stage is the equilibrium described in Section 3.

[5] Notice the similarity of Eq. (13) to the traditional imperfect competition models' Lerner Index, given by (Price − Marginal Cost)/Price = $-\hat{\theta}/e_p$ where e_p is price elasticity of demand and $\hat{\theta}$ is the relevant conduct parameter such that $0 \leqslant \hat{\theta} \leqslant 1$, with $\hat{\theta} = 1$ corresponding to monopoly, $\hat{\theta} = 0$ to perfect competition, and $\hat{\theta} = 1/n$ to Cournot with n symmetric firms (see Bresnahan, 1989).

The relation between the distortion of the generating portfolio and the number of firms (Eq. (15)) is plotted as line TT in Fig. 3. Moreover, for any industry structure, an increase in the intensity of competition reduces market power and thus moves the curve TT downwards. A homothetic expansion of demand, i.e. one that increases each hour's demand in the same proportion, does not change the TT curve.

Assuming symmetric firms and recalling Eq. (4), the zero-profit condition that results from free entry is given by

$$n^{FE} = \frac{\pi(q(t))}{\sigma}. \tag{18}$$

As in this model the exercise of market power is measured by the length of time that peaking technology plants operate beyond their operational time in the welfare-maximizing solution, π is an increasing function of $t-t^*$ in the relevant range. Therefore, the zero-profit condition (18) is plotted by the upward sloping curve *FEC* in Fig. 3. Either a reduction in the entry cost σ or a homothetic expansion of demand shifts the *FEC* curve downwards.

Equilibrium with free entry is represented by the intersection of curves TT and FEC in Fig. 3, and formally obtained from the joint solution of Eqs. (15) and (18). An increase in the intensity of competition thus reduces both market power (peaking plants operate a shorter period of time) and the number of firms. The more intense the competition, the larger each firm's sales must be for them to break even, and consequently the smaller the number of firms that can coexist in the industry (recall that demand is inelastic). It follows from this result that more intense competition leads to higher welfare as the average price paid by consumers is lower and firms' profits remain nil.

Lastly a rise in the entry cost results in a more concentrated industry and in greater exercise of market power; a homothetic expansion of demand has opposite effects.

5. Final comments

This paper adapts the traditional analysis of imperfect competition to a power industry with centralized dispatch based on merit order and subject to peak-load pricing. Our results show that even when prices are set equal to marginal costs, generators can obtain rents by increasing the share of peaking technology in the generation portfolio above the welfare-maximizing level. This strategy raises the average price paid by consumers, since the peaking technology sets the energy price for a longer period, while the capacity charge remains unchanged. When the number of plants is fixed, the more intense is competition the less market power is exercised and the higher is social welfare. Lastly, we show that with free entry, more intense competition results in higher welfare and fewer firms.

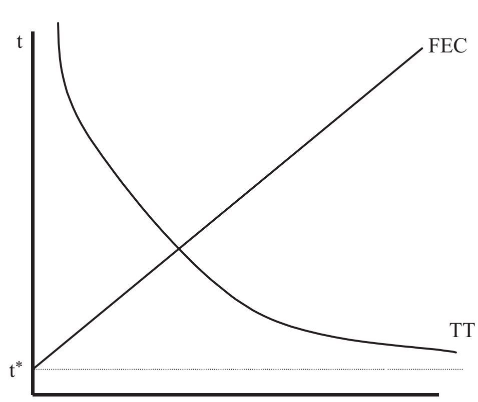

Fig. 3. TT and FEC curves.

Our treatment of the intensity of competition is quite abstract. However, since in the context of this paper, producers make their investment decision in an initial stage, with later production and pricing decisions emulating price competition, our belief is that Cournot competition is the most likely outcome. Therefore the policies that could force generators to behave more competitively need to be understood. It is interesting to note that, in this model, contracts would play a similar role as in the context of traditional imperfect competition models, for which it has been shown that the more contracted a producer is, the less incentive to exercise market power because a smaller portion of its revenues comes from the spot market. The natural sequel to this research would be to extend the formal model to include a previous stage in which contracts are signed and then capacities are chosen.

Since we assume that plants can permanently generate at full capacity, the model is only valid for thermal power industries. A further line of research should consider an industry with a mixed hydro-thermal portfolio and thus extend the model to include the possibility of shifting water from one period to another.

Appendix

For simplicity we rewrite the profit maximization problem (4) as a function of the time t that peaking plants are operational, i.e.

$$\pi(t) = tq(t)\Delta c - q(t)\Delta f. \tag{A.1}$$

Thus

$$\frac{d\pi(t)}{dt} = q(t)\Delta c + q'(t)(t - t^*)\Delta c \tag{A.2}$$

and

$$\frac{d^2\pi(t)}{dt^2} = 2q'(t)\Delta c + q''(t)(t - t^*)\Delta c \tag{A.3}$$

Noting that in the profit maximizing solution $t - t^* = -q(t)/q'(t)$, the strict concavity condition for the profit function π may be written as

$$q''(t) < -\frac{2q'(t)}{t - t^*} = \frac{2(q'(t))^2}{q(t)} \quad t^* \leqslant t \leqslant T. \tag{A.4}$$

We next show that condition (A.4) guarantees that the time for which peaking plants operate diminishes with either the number of firms or the intensity of competition. Consider the solution to equation

$$t(ng) = \frac{e_q(t(ng))ng}{1 + e_q(t(ng))ng} t^*. \tag{A.5}$$

Defining $x = ng$, the above equation can be rewritten as

$$t(x) + x(t(x) - t^*)e_q(t(x)) = 0. \tag{A.6}$$

To simplify notation $t(x)$ will be denoted t. To see how t depends on x we differentiate the Eq. (A.6):

$$(1 + x(t - t^*)e'_q(t) + xe_q(t))t' + e_q(t)(t - t^*) = 0 \tag{A.7}$$

Hence $t'(x)$ is negative if and only if

$$1 + x(t - t^*)e'_q(t) + xe_q(t) < 0 \tag{A.8}$$

Thus if the above condition is satisfied, the time for which peaking plants operate diminishes with either the number of firms or the intensity of competition. Next we show that condition (A.4) implies (A.8). In fact,

$$e'_q(t) = \frac{tq''(t)}{q(t)} + \frac{q'(t)}{q(t)} - \frac{q'(t)^2 t}{q(t)^2}. \tag{A.9}$$

Hence condition (A.8) becomes:

$$-\frac{q''(t)}{q'(t)} + \frac{2q'(t)}{q(t)} + \frac{1 - x}{xt} < 0 \tag{A.10}$$

or

$$q''(t) < \frac{2(q'(t))^2}{q(t)} + q'(t)\frac{1 - x}{xt} \tag{A11}$$

Since $g \in [1/n, \infty]$, $x > 1$, and therefore condition (A.4) guarantees that (A.8) always holds.

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