The Competitive Role of the Transmission System in Price-regulated Power Industries *

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Abstract

This note shows how the transmission system can enhance competition in price-regulated power industries, thus extending earlier findings reported in the literature for deregulated industries. In the context of a two-technology, price-regulated power industry, we show that the interconnection of two markets initially supplied by a different monopoly reduces market power and raises welfare. We also show that the capacity of the transmission line plays a key role in determining whether market equilibrium lies closer to competition or monopoly.

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1. Introduction

This note shows how the transmission system can enhance competition in price-regulated power industries, thus extending earlier findings reported in the literature for deregulated industries. The pro-competition effect of the transmission system operates differently in each case, however. While in deregulated industries it can result in less distorted prices, in price-regulated industries it can lead to more efficient generation portfolios. The paper thus fills a gap in the literature which could be useful to policymakers in countries that have regulated power industries.

We model an industry with two technologies (peaking and baseload), facing inelastic demand, in which an independent system operator dispatches the generating plants so as to minimize total operation cost and sets prices on peak-load criteria (see Boiteux, 1960 and Crew *et al*., 1995). Variants of this regulatory scheme are used in several Latin American countries, including Chile, Dominican Republic, Nicaragua, Panama and Peru. In this setting, producers can exercise market power by reducing the share of baseload plants in the generation portfolio compared to the optimal solution (Arellano and Serra, 2005).

We show that interconnection reduces market power and raises welfare. Then we prove that previous results by Borenstein et al (2000) for deregulated power markets also hold in the price-regulated case. In particular, we show that a transmission line connecting two symmetric markets each supplied by a single firm has a pro-competition effect even when it is not actually used. It is also shown that the line must have a minimum capacity for Cournot competition between both firms to be the outcome; otherwise one of the local monopolies may find it profitable to restrict its production in order to congest the transmission line and thus be able to behave as a monopolist in the residual local market. However, as Borenstein et al (2000) show, even a congested transmission line has a pro-competition effect, because the resultant composition of the generating portfolio is less distorted than without transmission.

At first sight, construction of a line that will not be used might seem socially wasteful, since local monopolies can be efficiently regulated. Regulation is widely acknowledged to be a poor substitute for competition, however; and, in this case it would have to go further than usual, not only setting tariffs and making it compulsory to provide the service, but also specifying the composition of the generating portfolio to be used. Furthermore, not only does the transmission system play the role of "competition facilitator," it also performs energy transportation and backup functions that may justify its construction.

The literature also analyzes how transmission rights change the incentives to exercise market power. Oren et al (1995) argue that the owners of link-based transmission rights face perverse investment incentives because they can benefit by degrading the link or by limiting transmission expansion. Joskow and Tirole (2000) show that the possession of transmission rights by a genco in the energy-importing region enhances its market power by giving it an additional reason to restrict total output. Hogendorn (2003) finds that in the long run both gencos and the transmission company have incentives to keep the transmission system congested.

Léautier (2000), using a model involving price competition, shows that even when generators receive transmission payments, they will not always be willing to pay for an optimal transmission expansion, since they may be better off keeping the rents arising from the exercise of local market power. In our model, reductions of transmission capacity below the minimum level that makes it profitable for a firm to behave as a Cournot duopolist increases the generator's profits. So, if generation companies had to decide on transmission capacity they would try to keep it at a minimum.

The rest of this paper is organized as follows. Section 2 develops the spaceless market equilibrium under different competitive assumptions. Section 3 analyzes how interconnection between two isolated markets reduces market power. Section 4 determines the minimum transmission capacity needed for full market integration. The last section concludes.

2. Spaceless market equilibrium

Our model involves a two-technology, linear-cost generating industry, where "*b*" denotes the baseload 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, $i=b,p$. Hence $f_b > f_p$ and $c_b < c_p$. Gencos are free to choose their technology mix, but, once installed, an independent system operator dispatches the plants in strict merit order.

Demand is assumed to be inelastic, and is represented by a continuously differentiable load curve denoted by $q(t)$, which designates consumption at the t-th highest consumption hour. Finally, we assume that plants are always available to produce at full capacity and can adjust their production level instantaneously and without cost.[1]

2.1 The perfect competition solution

As demand is inelastic, welfare maximization implies minimizing the total cost of the electric power system. Given the assumptions made, the optimization problem can be formalized as follows:

$$\min_{k_b, k_p} \left\{ f_b k_b + f_p k_p + c_p \int_0^{t(k_b)} (q(t) - k_b)\,dt + c_b k_b t(k_b) + c_b \int_{t(k_b)}^{T} q(t)\,dt \right\}$$
$$s.t.: \quad k_b + k_p \geq q^M \tag{1}$$

where $t(\cdot)$ denotes the inverse of the load curve, q^M the peak demand, k_b and k_p the installed capacity of baseload and peaking plants, respectively, and T the number of hours in the year. Thus $t(0)=T$ and $t(q^M)=0$. This specification of the problem assumes optimal use of installed capacity. In fact, between hours $t(k_b)$ and T, demand is met by baseload plants, since installed capacity renders this feasible and it is cheaper than using peaking plants. Between hours 0 and $t(k_b)$, peaking plants generate the residual demand that baseload plants cannot supply (see Figure 1). Thus $t(k_b)$ shows the number of hours during which consumers pay a higher energy price. Denoting by λ the Lagrange Multiplier of the capacity constraint, the Kuhn-Tucker conditions for the optimization problem as stated above are:

[1] This excludes hydroelectric plants which are limited by the amount of water accumulated in the reservoir.

$$f_b - t(k_b)\Delta c - \lambda \geq 0 \qquad k_b(f_b - t(k_b)\Delta c - \lambda) = 0$$
$$f_p - \lambda \geq 0 \qquad k_p(f_p - \lambda) = 0 \tag{2}$$

where $\Delta f = f_b - f_p$ and $\Delta c = c_p - c_b$, with both Δc and Δf positive, given the assumptions. Since the objective function is convex, the Kuhn Tucker conditions are necessary and sufficient for optimality. Hence assuming that both types of plants are installed in the optimal solution, the optimal baseload capacity k_b^* satisfies the condition $t(k_b^*) = \Delta f / \Delta c$. If $\Delta f / \Delta c > T$ then only peaking plants are installed in the optimal solution and $k_b^* = 0$. If t^* represents the time for which peaking plants operate in the optimal solution, i.e. $t^* = t(k_b^*)$, then:

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

As is well known, peak-load pricing, which consists of an energy charge equal to the marginal operating cost of the most expensive plant in operation plus a peak consumption capacity charge equal to the per-unit investment cost of peaking plants, leads a decentralized system with these characteristics to the optimal solution.

2.2 Monopoly solution

We now assume that energy is supplied by a single genco.[2] Given that peak-load pricing is used to set prices, the monopolist's profit when the baseload capacity is k_b, is given by:

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

Then $\pi'(0) = T\Delta c - \Delta f > 0$ and, recalling (3), $\pi'(k_b^*) = k_b^* t'(k_b^*)\Delta c < 0$. Since we assumed function t to be continuously differentiable, it follows that function π' is continuous. Consequently there is at least one $k_b^m \in (0, k_b^*)$ satisfying the condition $\pi'(k_b^m) = 0$. To simplify the analysis we also assume that π is strictly concave,[3] in which case there is only one solution that maximizes the monopolist's profit. This involves a larger share of peaking technology than the competitive solution (see Figure 1).

Despite both services (energy and power) being priced at marginal cost, the monopolist exercises market power by distorting the composition of the generation portfolio, thereby obtaining rents equal to $\Delta c k_b^m (t^m - t^*) > 0$, where t^m denotes the number of hours in which peaking plants operating in the monopoly solution, i.e. $t^m = t(k_b^m)$. This strategy results in consumers paying the higher energy price for a longer period of time (t^m instead of t*) and hence a smaller consumer surplus. Producer rents do not compensate for the reduction in

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[2] Alternatively, it may be assumed that there is a baseload technology monopoly, but a competitive bid with peaking technology.

consumer surplus, so society as a whole is worse off. The change in social welfare is given by:

$$\Delta W = -\Delta c \int_{t^*}^{\hat{t}} (q(t) - q(\hat{t}))dt < 0 \qquad (6)$$

3. Market Equilibrium with Transmission

We now extend the model to analyze the interconnection of two initially isolated markets (A and B). To focus exclusively on the competition effect, we assume that both markets have the same load curve *q(t)* and that a monopolist supplies each one. A transmission line is built connecting the two markets, with sufficient capacity to ensure that the line suffers no congestion. We further assume that gencos do not have to pay to use the transmission line and that there are no transmission losses (these assumptions are justified later). This is equivalent to a single market in which the two gencos compete.

We assume Cournot-type behavior, in which each generating company maximizes its profit by taking its rival's installed baseload capacity as given. Note that the peaking technology capacity to be installed is not relevant to agents' decisions since peaking technology plants always break even. Given the symmetry of the problem, we can assume that each producer sells half of its production in each market, so the producer located in market *j* solves the following problem:

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[3] The profit function is strictly concave if and only if $2t'(k_b) + k_b t''(k_b) < 0$.

$$\underset{k_b^j}{Max}\left\{\Delta c\, k_b^j\, t\left(\frac{k_b^j + k_b^l}{2}\right) - \Delta f\, k_b^j\right\} \qquad j,l = A,B,\ j \neq l \tag{7}$$

where k_b^j denotes its choice of installed baseload technology capacity. The first-order condition is:

$$t\left(\frac{k_b^j + k_b^l}{2}\right) = t^* - t'\left(\frac{k_b^j + k_b^l}{2}\right)\frac{k_b^j}{2} \tag{8}$$

The concavity of function π ensures that the objective function of the minimization problem (7) is concave, and hence has a unique Cournot solution k_b^j. We define k_b^c as each market's baseload installed capacity in the Cournot equilibrium. By symmetry, $k_b^c = k_b^A = k_b^B$. Hence the market equilibrium condition is:

$$t(k_b^c) = t^* - \frac{1}{2}t'(k_b^c)\,k_b^c \tag{9}$$

In addition $k_b^c > k_b^m$ and $t^c < t^m$ where $t^c = t(k_b^c)$. As a result of interconnection of the two systems and the ensuing Cournot competition, the baseload installed capacity chosen by producers lies between the monopoly and optimal solutions. Hence the competition engendered by the transmission line reduces the local market power that was exercised by each genco before interconnection. Consumers in each locality benefit because their total energy expenditure decreases by

$$\Delta c \int_{t^c}^{t^m} q(t)dt\,. \tag{10}$$

Interconnection reduces each genco's rents by:

$$\pi^c - \pi^m = -\Delta f\,(k_b^c - k_b^m) \quad + \quad \Delta c\,(k_b^c t^c - k_b^m t^m) < 0 \tag{11}$$

Thus the pro-competition effect of the transmission system changes social welfare by

$$\Delta W = 2\Delta c\left[(k_b^c - k_b^m)(t^c - t^*) + \int_{t^c}^{t^m} (q(t) - k_b^m)dt \right] > 0 \tag{12}$$

Construction of the transmission line will be socially profitable if and only if the social benefit exceeds the cost of building and operating the line. Note also that, since $k_b^A = k_b^B = k_b^c$, the line does not actually carry energy from one market to another; the transmission line thus reduces the market power of local monopolies without being used. This would make our assumption that gencos do not pay for the transmission line seem reasonable, for it would be unrealistic to expect them to finance a line that (a) they do not use and (b) reduces their profits. The foregoing results can be easily extended to a Cournot oligopoly with *n* firms operating in each demand center.

4. The minimum transmission capacity for market integration

The fact that the transmission line remains unused does not mean that any level of transmission capacity will suffice to produce the pro-competitive effect. Indeed, our analysis assumed that the line remained uncongested. We adapt the Borenstein et al (2000) methodology to estimate the smallest capacity K^{ℓ} that the line must have to force gencos to behave as if both markets were fully integrated. The minimum capacity K^{ℓ} is such that the profit obtained by a local monopoly when it passively accepts imports from the other (i.e. it does not attempt to export energy itself), is equal to the profit obtained in the Cournot solution. The problem faced by the genco when it behaves as a monopolist in the residual local market is:

$$\underset{k_b}{Max}\{\Delta c k_b t(k_b + K) - \Delta f k_b\} \qquad (13)$$

where $K > 0$ is the capacity of the transmission line. The optimal solution $k_b(K)$ therefore satisfies:

$$t(k_b(K) + K) = \left(t^* - t'(k_b(K) + K)k_b(K)\right) \qquad (14)$$

It follows from equation (14) that if $K = k_b^c / 2$, then the residual monopolist's solution is $k_b(k_b^c / 2) = k_b^c / 2$. In this case the baseload capacity that supplies the local market is the same as in the Cournot solution, and consequently $t\left(k_b(k_b^c / 2) + k_b^c / 2\right) = t^c$. Note that the firm located in the other market is willing to supply this baseload capacity as the high energy price will last for t^c hours. Hence if $K = k_b^c / 2$ and the local monopolist behaves as a residual monopolist, it obtains half the profits that it would obtain in the Cournot integrated solution as it chooses not to participate in the other market. In contrast, $K=0$ results in the unrestricted monopoly solution.

Since $\pi(K)$ is a decreasing function of K, $k_b^c / 2$ is an upper bound for K^ℓ. Thus K^ℓ is in the range (0, $k_b^c / 2$). Imposing a more stringent condition, such that $k_b t''(k_b) + t'(k_b) \leq 0$, ensures that $-1 \leq \partial k_b(K) / \partial K \leq 0$, which in turn implies that $k_b^c > k_b(K^\ell) + K^\ell > k_b^m$ and $t^c < t(k_b(K^\ell)+K^\ell) < t^m$. Thus when the transmission capacity is K^ℓ and the local firm behaves as a residual monopolist, the peaking technology will operate for a length of time longer than t^c. This ensures that the genco located in the other market will install baseload plants to export energy.

Even though the share of baseload technology in the local generating portfolio decreases with imports (k_b decreases with K), total baseload capacity serving the local market is larger than in the monopoly solution (k_b+K increases with K). As a result, the efficiency loss in the local market is smaller than in the unrestricted monopoly solution because the aggregate share of baseload technology is larger once energy imports are included.

When the transmission capacity K satisfies $0<K<K^\ell$, the local genco behaves like a residual monopolist. Previous results ensure that $k_b(K) + K > k_b^m$ and $t(k_b(K)+K) < t^m$.

Hence, in this situation the efficiency loss in the residual monopolist's market is smaller than in the unrestricted monopoly solution.

5. Final comments

The transmission system plays a pro-competition role in the power industry by restraining the market power that producers can exert in their local markets. Our analysis shows that the results reported in the literature regarding the role of the transmission system in enhancing competition in the generating sector are not exclusive to deregulated power industries. They are also valid when producers are forced to exert market power through the composition of their generating portfolios—the only variable they can freely control in a situation of mandatory merit-order dispatching and peak-load pricing. In both regulatory settings, the pro-competition effect of the transmission line depends on its capacity.

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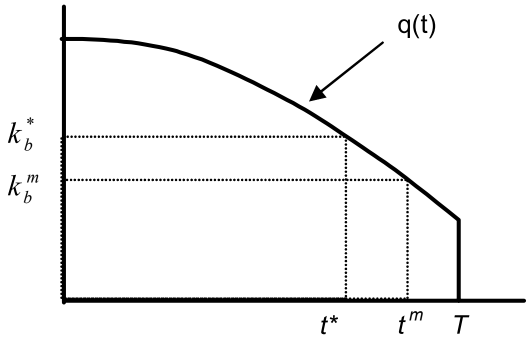
Figure 1

Composition of the Generation Portfolio :

Optimal and Monopoly Solution.



Mathematical Appendix

The optimization problem solved by the independent system operator can be formalized as follows:

$$\underset{k_b,k_p}{Min}\left\{f_b k_b + f_p k_p + c_p \int_0^{t(k_b)} (q(t)-k_b)dt + c_b k_b t(k_b) + c_b \int_{t(k_b)}^{T} q(t)dt\right\}$$

$$s.t.: \quad k_b + k_p \geq q^M \qquad (1)$$

Denoting by λ the Lagrange Multiplier of the capacity constraint and assuming that the optimal solution includes both types of plants, the Kuhn-Tucker conditions become:

$$f_b - t(k_b)\Delta c - \lambda = 0 \quad and \quad f_p - \lambda = 0$$

Hence the optimal baseload capacity k_b^* satisfies the condition $t(k_b^*) = \Delta f / \Delta c$. However if $\Delta f / \Delta c > T$, then the optimal generation portfolio cannot include baseload plants. In this case the optimal solution is $k_p^* = q^M$ and $k_b^* = 0$. It is easy to verify that this condition satisfies the Kuhn Tucker conditions; and it also can be shown that the solutions $k_p^* = 0$ and $k_b^* = q^M$ do not. So, denoting the time that the peaking plants operate in the optimal solution by $t^* = t(k_b^*)$ gives:

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

In what follows, we make the simplifying assumption that the optimal solution includes baseload plants, so $t^* = \Delta f / \Delta c$.

The monopolist's profit when its baseload capacity is k_b is given by:

$$\pi(k_b) = \Delta c k_b t(k_b) - \Delta f k_b \qquad (4)$$

Thus

$$\pi'(k_b) = (k_b t'(k_b) + t(k_b))\Delta c - \Delta f = (k_b t'(k_b) + t(k_b) - t^*)\Delta c \qquad (4.a)$$

and

$$\pi''(k_b) = (2t'(k_b) + k_b t''(k_b))\Delta c \qquad (4.b)$$

The profit function is therefore concave if and only if $2t'(k_b) + k_b t''(k_b) \leq 0$.

When the two initially isolated symmetric markets (A and B) are interconnected, the producer located in market *j* maximizes its profits $\pi_j(k_b^j, k_b^l)$ by choosing its baseload capacity k_b^j, taking its rival's capacity k_b^l as given. The optimization problem is therefore:

$$\underset{k_b^j}{Max}\, \pi_j(k_b^j, k_b^l) = \underset{k_b^j}{Max}\left\{ \Delta c\, k_b^j\, t\left(\frac{k_b^j + k_b^l}{2}\right) - \Delta f\, k_b^j \right\} \qquad j, l = A, B,\ j \neq l \qquad (7)$$

The first order condition of the objective function is

$$t\left(\frac{k_b^j + k_b^l}{2}\right)\Delta c + k_b^j t'\left(\frac{k_b^j + k_b^l}{2}\right)\frac{\Delta c}{2} - \Delta f \qquad (7.a)$$

and the second derivative is:

$$t'\left(\frac{k_b^j + k_b^l}{2}\right)\Delta c + k_b^j t''\left(\frac{k_b^j + k_b^l}{2}\right)\frac{\Delta c}{4} \qquad (7.b)$$

The concavity of function π implies that the objective function of the maximization problem (7) is also concave. Therefore, there is one and only one solution k_b^j to that optimization problem, given by equation (8).

$$t\left(\frac{k_b^j + k_b^l}{2}\right) = t^* - t'\left(\frac{k_b^j + k_b^l}{2}\right)\frac{k_b^j}{2} \tag{8}$$

Finally we analyze how the monopolist's choice of k_b changes with the capacity of the transmission line *(K)*. In this case, the monopolist in the residual local market chooses $k_b(K)$ such that:

$$t(k_b(K) + K) = \left(t^* - t'(k_b(K) + K)k_b(K)\right) \tag{14}$$

The implicit derivative of (14) results in:

$$\left[2t'\left(k_b(K) + K\right) + k_b(K)t''\left(k_b(K) + K\right)\right]\left(\frac{\partial k_b}{\partial K} + 1\right) - t'\left(k_b(K) + K\right) = 0 \tag{14.a}$$

The concavity of function π guarantees that the left hand bracket is negative, so $\partial k_b^j / \partial k_b^l \geq -1$. We can also rewrite (14.a) as

$$\left[2t'\left(k_b(K) + K\right) + k_b(K)t''\left(k_b(K) + K\right)\right]\frac{\partial k_b}{\partial K} + \left[t'\left(k_b(K) + K\right) + k_b(K)t''\left(k_b(K) + K\right)\right] = 0 \tag{14.b}$$

We assume $t'(k_b) + k_b t''(k_b) \leq 0$, which ensures that the right hand bracket is negative.[4]

Therefore, $-1 \leq \partial k_b / \partial K \leq 0$; a rise in K reduces k_b but by a smaller amount.

[4] Note that this assumption implies concavity of the profit function.