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Original Paper

Electricity Trading in a Successive Oligopoly Market: A Social Welfare Comparison between the Generation and Retail Sectors' Liberalization

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Abstract

This study models the electricity industry as a successive Cournot oligopoly market to compare the market performance between the generation and retail sectors' liberalization. We show that, assuming identical fixed costs on free entry into both generation and retail sectors, liberalization of the retail sector can dominate that of the generation sector with regard to social welfare.

Keywords

access price, electricity liberalization, free entry, social welfare, successive oligopoly

1. Introduction

In spite of a vast body of literature on the electricity market, there is scant attention on "vertical" structure, which is one of the significant properties of the market. However, the worldwide wave of liberalization in electricity markets has changed the traditional market structure, and economists are required to analyze the market under a more powerful lens. It is proper to analyze the market using the successive oligopoly theory. (Note 1)

In the vertical structure of an electricity market, the suppliers are mainly composed of three vertical sectors: generators, distributors, and retailers. As economics textbooks posit, incumbent firms with operations in all three sectors have long maintained their positions as regional monopolists owing to the principle of natural monopolization. However, by removing the distribution sector from the incumbent and establishing a network sector, liberalization enables potential generation and retail firms to enter the market freely. The network sector passes electricity received from the generation firms to the retail firms, and receives payment in the form of access charge/price from the retail firms (Figure 1). In other words, under liberalization, the electricity market should be analyzed as a successive oligopoly market, in addition to the traditional one-tier market. (Note 2)

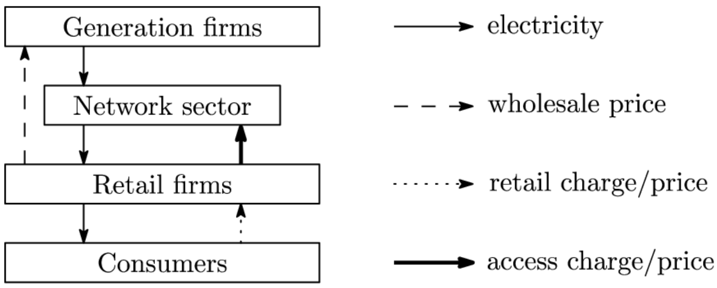

Figure 1. The Vertical Structure in the Electricity Market

This study undertakes an equilibrium analysis in the electricity market as a successive oligopoly and compares the market performance between the generation sector's liberalization and the retail sector's liberalization, which is a new field of research in the related literature. (Note 3) This study boldly regards liberalization as free entry to obtain simple and clear results.

The rest of this paper is organized as follows. In section 2, we introduce the models of the two types of liberalization for the generation sector and the retail sector. In section 3, we discuss the results. The last section concludes.

2. The Model

2.1 Liberalization of the Generation Sector

An important property of electricity-supplying structures is that the network sector, (Note 4) which lies between the generation and the retail sectors, usually receives the access price (Note 5) from the retail firms. Based on this principle, we construct the multiple-stage game as follows. In the first stage, the network sector determines the access price. In the second stage, (potential) generation firms observe know the access price and determine whether to enter the upstream market. In the third stage, the generation firm entrants compete in quantity. In the last stage, the retail firms, whose number is given, compete in quantity. Consumers buy the good distributed. (Note 6)

The basic model is as follows. The reverse demand is given by $p = A - Q$ where Q is total demand, and A is assumed to be sufficiently large. As for the generation firms, (Note 7) we assume that (i) the number is $m \geq 1$, which is determined endogenously through free entry, (ii) the marginal costs, which are identical among all the firms, are constant $c > 0$, and (iii) potential entrants bear the fixed costs of $k_G > 0$. As for the network sector, its cost function is given by

$$C(Q) = \theta Q + F \tag{1}$$

where θ indicates the constant marginal costs for distributing electricity, and F indicates the fixed costs. As for retail firms, we assume that (i) n firms exist and (ii) each of them receives retail price p from consumers and pays access price a, and wholesale price w to the network sector. Furthermore, we assume that retail firms bear no fixed costs.

Note that w is determined such that total quantity of generation equals total quantity of retail supply. In other words, in equilibrium, w satisfies

$$\sum_{i=1}^{m} x_i = \sum_{j=1}^{n} q_j \tag{2}$$

where x_i and q_j indicate the quantity of electricity generated by firm i and the quantity sold by retail firm j, respectively.

Now, we solve the game by backward induction. In the retail firms' competition stage, firm j's profit function is denoted as $\pi_{R_j} = (p - w - a)q_j$. From the First-Order Conditions (FOCs) and the symmetry, we obtain the equilibrium quantity in this stage as follows:

$$q(a, w) = \frac{A - a - w}{n+1} \tag{3}$$

Here, transforming (2) into $\sum_i x_i = nq$ from the symmetry and substituting (3) into the right-hand side of it, we obtain the equilibrium wholesale price in this stage:

$$w(a, X) = A - a - \frac{n+1}{n}\sum_{i=1}^{m} x_i \tag{4}$$

Next, we consider the third stage. Substituting (4) into the generation firm i's profit function, $\pi_{G_i} = (w - c)x_i$, and using the FOCs and the symmetry, we obtain

$$x(a, m) = \frac{n(A - a - c)}{(n+1)(m+1)} \tag{5}$$

Using (5), we obtain the equilibrium wholesale price and production as follows:

$$w(a, m) = c + \frac{A - a - c}{m+1} \tag{6}$$

$$q(a, m) = \frac{m(A - a - c)}{(n+1)(m+1)} \tag{7}$$

We turn to the second stage. Substituting (5) and (6) into the profit function of a potential entrant to the generation sector, $\pi_G = (w - c)x - k_G$, and imposing the free-entry condition, (Note 8) $\pi_G = 0$, we obtain the following:

$$m + 1 = (A - a - c)\sqrt{\frac{n}{k_G(n+1)}} \tag{8}$$

Thus, the wholesale price and total demand under the endogenous number, using (8), are described as

$$w = c + \sqrt{\frac{k_G(n+1)}{n}} \quad \text{and} \quad Q(a) = \frac{n}{n+1}(A - a - c) - \sqrt{\frac{k_G n}{n+1}} \tag{9}$$

respectively.

Lastly, we turn to the first stage. As we assume that the network sector is a public firm rather than a private firm, we define its profit function as follows: (Note 10)

$$\Pi_N = \gamma \pi_N + (1-\gamma)W \tag{10}$$

where $\pi_N \equiv (a-\theta)Q - F$, $W \equiv \int_0^Q p(y)dy - (c+\theta)Q - k_G m$, and $\gamma \in [0,1]$ indicate the sector's private profits, social welfare, and the parameter indicating the sector's concern for social welfare, respectively. The extreme examples of γ, $\gamma = 0$ indicate that the sector is a pure public firm while $\gamma = 1$ indicates it is a pure private firm.

Maximizing (10) with respect to a yields the equilibrium access price, $a*$. The main values in equilibrium are as follows:

$$a* = \theta + \frac{\gamma(n+2)-1}{\gamma(n+2)+n} S \tag{11}$$

$$m* = \frac{S}{\gamma(n+2)+n}\sqrt{\frac{n(n+1)}{k_G}} \tag{12}$$

$$Q* = \frac{nS}{\gamma(n+2)+n} \quad \text{or} \quad p* = A - Q* \tag{13}$$

$$W* = \frac{n[2\gamma(n+2)+n]}{2[\gamma(n+2)+n]^2} S^2 \tag{14}$$

where $S \equiv A - c - \theta - \sqrt{k_G(n+1)/n} > 0$. Here, we obtain the following result.

Proposition 1. The network sector earns positive profits if both

1) $F < \dfrac{nS^2}{4(n+1)}$ and

2) either $4(n+1)F - nS^2 + S\sqrt{V} > 0$ or $S\sqrt{V} + nS^2 - 2nF > 0$

are satisfied ($V \equiv n^2 S^2 - 4n(n+1)F$). Otherwise, the network sector earns no profits.

Proof. First, from (11) and (13), the equilibrium profit of the network sector, π_N^*, is described as a function of γ:

$\pi_N^*(\gamma) = -(n+2)^2 F\gamma^2 + n(n+2)(S^2 - 2F)\gamma - nS^2 - n^2 F$.

This concave function can be positive when the first condition holds. Next, denoting γ_1 and γ_2 as the intersections of this function and γ-axis ($\gamma_1 < \gamma_2$), the network sector earns positive profits and either $\gamma_1 < 1$, which leads to the first inequality of the second condition, or $\gamma_2 > 0$, which leads to the second inequality of the second condition, are satisfied.

As an extreme example that applies to Proposition 1, $F = 0$ satisfies both conditions.

2.2 Liberalization of the Retail Sector

This subsection constructs the multiple-stage game as follows. In the first stage, the network sector determines the access price. In the second stage, the generation firm entrants, whose number is given, compete in quantity. In the third stage, the potential retail firms determine whether to enter the market; if they enter, each bears fixed costs k_R. In the last stage, the retail firm entrants compete in quantity. Consumers buy the electricity distributed. We solve this game by backward induction.

The basic assumption is the same as presented in the previous subsection. The solution in the last stage is the same as (3). Here, note that

$$A - a - w > 0 \tag{15}$$

holds because we assume inner solutions. Next, we consider the free entry in the third stage. Substituting (3) into the potential retail entrant's profit function, $\pi_R = (p - a - w)q - k_R$, and solving the free-entry condition, $\pi_R = 0$, we obtain

$$n + 1 = \frac{A - a - w}{\sqrt{k_R}} \tag{16}$$

as the endogenous number of retail firms. Now, since the wholesale price is expressed as (4), substituting (16) into (4) yields

$$(A - a - w)\left(A - a - w - \sqrt{k_R} - \sum_{i=1}^{m} x_i\right) = 0 .$$

From the condition of (15), we obtain

$$w(a, X) = A - a - \sqrt{k_R} - \sum_{i=1}^{m} x_i \tag{17}$$

as the equilibrium wholesale price in this stage.

We turn to the second stage. Substituting (17) into a generation firm's profit function, $\pi_{G_i} = (r - c)x_i$, and imposing FOCs and symmetry, we obtain

$$x(a) = \frac{A - a - c - \sqrt{k_R}}{m + 1} \tag{18}$$

Substituting this equation into (17), we obtain the equilibrium wholesale price in this stage as follows:

$$w(a) = c + \frac{A - a - c - \sqrt{k_R}}{m + 1} \tag{19}$$

Lastly, we turn to the first stage. Following the same procedure as in the previous subsection, we obtain the main values in equilibrium in this game:

$$a^{**} = \theta + \frac{\gamma(m+2)-1}{\gamma(m+2)+m}T \tag{20}$$

$$n^{**} = \frac{mT}{\sqrt{k_R}[\gamma(m+2)+m]} \tag{21}$$

$$Q^{**} = \frac{mT}{\gamma(m+2)+m} \quad \text{or} \quad p^{**} = A - Q^{**} \tag{22}$$

$$W^{**} = \frac{m[2\gamma(m+2)+m]}{2[\gamma(m+2)+m]^2}T^2 \tag{23}$$

where $T \equiv A - c - \theta - \sqrt{k_R} > 0$.

3. Welfare Comparison

Our main interest is which of the retail or generation sector's liberalization yields higher welfare. Since this model holds four kinds of variables, the analysis is not easy. However, in reality, liberalization and technical revolution in generating and retailing will surely create sufficiently low entry costs, and hence, enough large entrants. In other words, as a strong but not impractical assumption, $k_G = k_R$ and $m = n$ can be posited. In this case, the following holds.

Proposition 2. Welfare under the retail sector's liberalization is higher than under the generation sector's liberalization.

Proof. Under the conditions of $m = n = l$, a simple subtraction yields

$$W^{**} - W^{*} = \frac{l[2\gamma(l+2)+l](T-S)(T+S)}{2[\gamma(l+2)+l]^2}.$$

Since all the valuables are non-negative, the term $T - S$ determines the sign. Here, imposing the other condition, $k_G = k_R$, $T - S > 0$ holds.

The logic behind this result is simple. Under the dual conditions for the sunk costs and the number of players, both consumer surplus and producer surplus in retail firms' free entry exceed those in generation firms' free entry, so that social welfare under the former free entry dominates the latter free entry. This result implies that liberalization in the downstream sector, which is close to consumers, improves consumer welfare more strongly than the liberalization in the upstream sector does, which is disrupted by the bottleneck sector.

4. Conclusion

Three directions should refine future study. First, we should generalize the model. For instance, we should review the validity of the assumption behind the second proposition. Second, although we have simply compared the two types of successive oligopoly game, the model structures are different between the two. We must review the methodology for comparing and evaluating dual liberalization.

Lastly, we should provide a detailed overview of the market structure and properties of global electricity markets.

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Notes

Note 1. The early work of successive oligopoly theory dates to Greenhut and Ohta (1979) and Salinger (1988). The model of this study essentially follows the latter.

Note 2. For the properties of a multiple-tier market, see Corbett and Karmarkar (2001).

Note 3. The literature which analysis an electricity industry as a vertical market, see, for instance, Kurakawa (2013) and Oliveira et al. (2013).

Note 4. Note that this study packages the distribution and transmission sectors into one firm for simplicity, although we recognize the complexity of the distribution system. Incidentally, the network sector is not always monopolistic. For the reform of this sector, see Nepal and Foster (2015) and the literature cited therein.

Note 5. We prefer the word "price" to "charge", since we assume deregulated pricing for the market players, including the monopolistic network sector.

Note 6. In this study, we assume these are small consumers, such as households, rather than large, industrial consumers. In addition, we assume that consumers do not supply electricity generated, for example, from solar panels, to the network sector.

Note 7. Throughout the paper, for simplicity, we exclude the vertical integrated firms composed of generation and retail sectors.

Note 8. The seminal work of so-called excess entry theorem goes back to Mankiw and Whinston (1986) and Suzumura and Kiyono (1987). As for the interesting properties of free entry in successive oligopoly markets, so-called insufficient entry theorem, see Ghosh and Morita (2007) and Matsushima (2006).

Note 9. The formulation in (10) follows the traditional modeling in mixed oligopoly. For pioneering works in mixed oligopoly, see Bös (1986, 1991), De Fraja and Delbono (1989), and Matsumura (1998).