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Duopoly competitions with capacity constrained input ☆

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ABSTRACT

This paper focuses on the duopoly substitutability product with an upstream input subjected to capacity constraints. The effects of capacity constraints are captured. Combining competition effect with constraint effect, some interesting conclusions are reached. First, the relationship between capacity constraints and firm size is addressed. We argue that the capacity constraints reduce market size difference and price difference under Cournot. Second, under the Stackelberg case, the existence of solution is proved, and Stackelberg competitions enlarge firm-size difference and price difference if the more efficient firm plays the leading position. When the weaker firm plays the leading position, the conclusions depend on the total capacity. Finally, under the Stackelberg case, when the stronger firm plays the leading position, the firm-size difference and price difference decrease with total input under capacity constraints, which is contrary to the conclusions under Cournot competitions.

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1. Introduction

Capacity constraints exist in many economic activities. For example, doctors and barbers can serve only a limited number of clients because of time constraints. Restaurants have a limited number of tables because of space constraints (Lester, 2011). Moreover, such capacity constraints have crucial effects on firms' strategies, including price, firm size, innovation investment and so on.

Extensive research exists about capacity constraints in economics (Esó et al., 2010)—in the energy field (Veit et al., 2011), in the transportation field (Evans and Schaefer, 2011) and in management. Here, we mainly introduce the related literature about capacity constraints in economics. Cave and Salant (1995) argued the existence of a solution under Cournot with capacity constraints. Esó et al. (2010) discussed the effects of capacity constraints on a firm scale. When the capacity is sufficiently scarce, industry structure is symmetric, and otherwise, it is asymmetric. Lester (2011) addressed the effects of capacity constraints on the relationship between information and price and showed that the conventional conclusion – more information yielding lower price – does not necessarily hold. Genc and Reynolds (2011) showed that capacity constraints may contribute to the market power of generation firms. Arnold and Saliba (2011) addressed the effects of asymmetric capacity constraints on price dispersion. Ishibashi (2008) discussed collusive price leadership in homogeneous good capacity-constrained repeated price competition and argued that all firms obtain (strictly) higher profits if a large firm has an incentive to move early to demonstrate its commitment not to deviate.

As we know, with capacity constraints little research exists addressing the effects of firm position on competition (see in Ishibashi (2008)) although firm position seems quite important to firm strategy. This paper addresses capacity constraints related to firm position in competitions, and the effects of capacity constraints on firm size, price difference and price dispersion are discussed both under the Cournot and Stackelberg situations. This study finds that compared with Stackelberg competitions in which the stronger firm acts as the leading position, Cournot competitions reduce both firm-size difference and price difference. If the capacity is large and binding, when the weaker firm launches the first mover, both the firm-size difference and the price difference are less than that under Cournot. More importantly, if capacity constraints are binding, capacity will be decentralized. As total available capacity increases, capacity will aggregate because as the scarcity of capacity increases, capacity allocation will be more efficient and a firm cannot hoard extra capacity if capacity allocation is effective. In summary, market power yields

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the aggregation effect, while competition owns the decentralization effect for resource or capacity. Two types of effects interact and yield some interesting conclusions.

Compared with existing literature, this paper addresses symmetric capacity constraints, while Arnold and Saliba (2011) addressed the asymmetric situation. This paper considers both the Cournot case and Stackelberg competitions. We focus on price and firm-size differences, while Ishibashi (2008) focused only on the Stackelberg situation. The rest of this paper is organized as follows. The model is established in Section 2. Then, in Section 3, the model is addressed both under Cournot and under Stackelberg, and an example is outlined to illustrate the above theoretic conclusions. Finally, conclusions are provided in Section 4.

2. The model

Consider an industry of two producers with an upstream input and capacity constraints about this input. We formally establish a model of substitutability product under duopoly with capacity constrained input. Denote the two producers to be A and B.

2.1. Demand

For $i \in \{A, B\}$, p_i is the price, and the quantity of production is q_i. Denote $p = (p_A, p_B)$ and $q = (q_A, q_B)$. The utility function is

$$u(p, q) = \alpha(q_A + q_B) - \frac{1}{2}\left[(q_A)^2 + (q_B)^2\right] - p_A q_A - p_B q_B - \gamma q_A q_B. \tag{1}$$

$\alpha > 0$ is a constant, and $\gamma \in [0,1]$. $\alpha > 0$ represents the total market size, and $\gamma \in [0,1]$ stands for the degree of substitutability. $\gamma = 0$ means that two goods are independent, and $\gamma = 1$ indicates perfect substitutes (Liu and Wang, 2011). The inverse demand function, which is the same as that in Liu and Wang (2011), Liu et al. (2011), or Sacco and Schmutzer (2011), is given as follows

$$p_i = \alpha - q_i - \gamma q_j, \tag{2}$$

$i, j \in \{A, B\}$ and $i \neq j$. Note that the inverse demand function is directly induced by the above utility function. Linear price function is employed to simplify the model.[1]

2.2. Producer

There is a unique final good using the unique input with capacity constraints. Denote that the quantity of input is r_i for $i \in \{A, B\}$. $R > 0$ is a constant and represents the total capacity in this industry. Capacity constraints imply $r_A + r_B \leq R$. The production function is stipulated to be a Cobb–Douglas production function as follows

$$q_i = \theta_i r_i, \tag{3}$$

where $\theta_i > 0$ is a constant for firm $i \in \{A, B\}$ and stands for the marginal production. Without loss of generality, we assume that $\theta_A \geq \theta_B$. Denote $\Delta\theta = \theta_A - \theta_B$ to be the efficiency difference.

The cost function of the two firms is mainly determined by the allocation of input under capacity constraints. For $i, j \in \{A, B\}$ and $i \neq j$, the profit function of the two producers is given as follows:

$$\pi_i = p_i q_i - c(r_i), \tag{4}$$

where $c(r_i)$ denotes the costs incurred by consuming r_i in production. The term $p_i q_i$ means the revenue of firm i. The cost function in this work is different from that in Esó et al. (2010). For the above model, the following assumption is made.

Assumption. $c(r_i)$ is continuously convex in r_i. $\frac{dc(r_i)}{dr_i} > 0$ for any r_i and $i \in \{A,B\}$.

The above assumption guarantees the existence and the uniqueness of the solution to the above systems. Eqs. (2)–(3) and (4) jointly imply that π_i is continuous both in r_i and r_j for $i \in \{A,B\}$.

We note that there was some discussion about the capacity allocation mechanism in the interesting paper by Esó et al. (2010), so this paper focuses on downstream competitions and neglects the capacity allocation mechanism. When capacity is scarce enough, similar to Esó et al. (2010), we assume that this capacity allocation mechanism is efficient.

3. Analysis and primary results

Here, the model based on Eqs. (1)–(4) is discussed. For $i, j \in \{A,B\}$ and $i \neq j$, from Eq. (2), (3) and (4), we have the following problems

$$\begin{aligned} &\operatorname*{Max}_{r_i} \pi_i = \theta_i\left(\alpha - \theta_i r_i - \gamma\theta_j r_j\right) r_i - c(r_i), \\ &\text{S.T.} \qquad r_A + r_B \leq R \end{aligned} \tag{5}$$

This model is discussed both in Cournot and the Stackelberg case.

3.1. Cournot case

Two firms compete in quantity. The equilibrium solution is determined by its first order optimal conditions as follows. For $i, j \in \{A, B\}$ and $i \neq j$, we have

$$\theta_i\left(\alpha - \gamma\theta_j r_j\right) - 2\theta_i^2 r_i - \frac{dc(r_i)}{dr_i} - \lambda_i = 0, \tag{6}$$

where $\lambda_i \geq 0$ is the Lagrangian multiplier. If the capacity constraints are not active or $r_A + r_B < R$, we have $\lambda_i = 0$. Otherwise, $r_A + r_B = R$.

Case 1. $r_A + r_B < R$

In this case, $\lambda_A = \lambda_B = 0$ and capacity constraints have no effect on firm strategies. For $i, j \in \{A,B\}$ and $i \neq j$, we therefore have

$$\theta_i\left(\alpha - \gamma\theta_j r_j\right) - 2\theta_i^2 r_i - \frac{dc(r_i)}{dr_i} = 0. \tag{7}$$

Denote the equilibrium solution to be $r^* = (r_A^*, r_B^*)$. Apparently, the equilibrium depends heavily on the cost function. By comparative static analysis, we then have the following conclusion about the equilibrium:

$$\theta_A r_A^* \geq \theta_B r_B^*, \ \ p_A \leq p_B, \quad \frac{\partial r_i}{\partial \gamma} < 0, \frac{\partial r_i}{\partial \theta_j} < 0 \ \text{ and } \ \frac{\partial r_i}{\partial \theta_i} \begin{cases} < 0 & \dfrac{dc(r_i)}{dr_i} < 2\theta_i^2 r_i \\ > 0 & \dfrac{dc(r_i)}{dr_i} > 2\theta_i^2 r_i \end{cases} \ \text{for}$$

$i \in \{A, B\}$. We define firm-size difference as $|\theta_A r_A - \theta_B r_B|$ and price difference as $|p_A - p_B|$. We further define price dispersion as $\eta = \frac{|p_A - p_B|}{p_A + p_B}$, which is also employed in the interesting paper of Samuelson and Zhang (1992). Moreover, we achieve the following:

Proposition 1. For $i, j \in \{A,B\}$ and $i \neq j$, $\gamma \frac{\partial r_i}{\partial \gamma} = \theta_j \frac{\partial r_i}{\partial \theta_j}$. When the capacity is not scarce, given θ_A, the firm-size difference, price difference and price dispersion all decrease with θ_B (or increase with $\Delta\theta$).

Proof. See in Appendix. ■

Remarks. Smaller production efficiency difference $\Delta\theta$ (or larger θ_B) yields more competition, and firm-size difference, price difference

[1] Liu et al. (2011) also used this type of price, while Wang and Yang (2010) employed a two-part price to address firm decisions.

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