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A Quantity-Setting Mixed Duopoly with Inventory Investment as a Coordination Device

Kazuhiro Ohnishi

Osaka University and Institute for Basic Economic Science, Japan
E-mail: ohnishi@e.people.or.jp

This paper examines a two-period mixed market model in which a welfare-maximizing public firm and a profit-maximizing private firm can use inventory investment as a strategic device. It is then demonstrated that the equilibrium in the second period coincides with the Stackelberg solution where the private firm is the leader, and at equilibrium, both social welfare and the private firm's profit are higher than in the game without inventory.

Key Words: Mixed duopoly; Public firm; Private firm; Inventory investment.
JEL Classification Numbers: C72, D21, H42, L13, L32.

1. INTRODUCTION

As is well known, mixed oligopolies are common in developed and developing countries as well as in former communist countries. Public firms compete with private firms in many industries, such as telecommunications, railways, airlines, broadcasting, tobacco, banking, education, electricity, home loans, health care, life insurance and shipbuilding.

Following the early work of Merrill and Schneider (1966), the analysis of mixed market models that incorporate welfare-maximizing public firms has received significant attention in recent years.[1] Cremer, Marchand and Thisse (1991) examine a mixed oligopoly in which firms choose product characteristics. Mujumdar and Pal (1998) examine taxation in a mixed duopoly. Delbono and Denicolò (1993) and Poyago-Theotoky (1998) investigate mixed models with R&D.[2] Willner (1994) and Wen and Sasaki (2001) construct mixed models in which firms choose capacity. Bárcena-

[1]For excellent surveys, see, for instance, Bös (1986, 2001), Vickers and Yarrow (1988), Cremer, Marchand and Thisse (1989) and Nett (1993).

[2]Malerba (1993) reports that in Italy, during the 1960s through to the 1980s, there were two public firms in the top five R&D investors.

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Ruiz and Garzón (2003) consider a mixed model in which a private firm and a public firm merge or one of them acquires the other. Pal (1998) examines a Stackelberg-type sequential-move mixed oligopoly with a single homogeneous product, and Matsumura (2003) examines a Stackelberg mixed duopoly where a public firm competes against a foreign private firm. White (1996) analyses the effects of domestic production subsidies in a mixed oligopoly regarding privatization and efficiency, and Anderson, de Palma and Thisse (1997) consider a mixed oligopoly with product differentiation that privatizes a public firm.[3] In addition, Fershtman (1990), George and La Manna (1996), Matsumura (1998), Fujiwara (2007) and Lu and Poddar (2007) study the partial privatization of public firms. There are many further studies, such as Nett (1994), Fjell and Pal (1996), Fjell and Heywood (2002), Nishimori and Ogawa (2002), Bárcena-Ruiz (2007), Ohnishi (2008) and Fernández-Ruiz (2009). However, there are few mixed market models in which inventories as a strategic device are used.

Therefore, we study a two-period mixed market model in which a welfare-maximizing public firm and a profit-maximizing private firm are allowed to use inventory investment as a strategic device. We discuss the equilibrium of the quantity-setting mixed duopoly model with inventory investment as a strategic device. We then demonstrate that the equilibrium in the second period coincides with the Stackelberg solution where the private firm is the leader, and at equilibrium, social welfare and the private firm's profit both are higher than in the game without inventory.

Matsumura (1999) examine multi-period private market models with inventories as a strategic device and shows that two-period competition is insufficient to make private firms collusive.

On the other hand, we demonstrate that inventories are used by public and private firms to deter deviations from an implicitly collusive arrangement.

The remainder of this paper is organized as follows. In Section 2, we describe the model. Section 3 gives supplementary explanations of the model. Section 4 analyses the equilibrium of the model. Section 5 concludes the paper. All proofs are given in the appendix.

2. THE MODEL

Let us consider a mixed duopoly model with one social-welfare-maximizing public firm (firm 0) and one profit-maximizing private firm (firm 1), producing perfectly substitutable goods. In the remainder of this paper, sub-

[3]For empirical studies, see, for example, Pinto, Belka and Krajewski (1993), Estrin et al. (1995), Iatridis and Hopps (1998), Jones (1998), Iatridis (2000) and Jones and Mygind (2000).

scripts 0 and 1 refer to firms 0 and 1, respectively, and superscripts 1 and 2 refer to periods 1 and 2, respectively. In addition, when i and j are used to refer to firms in an expression, they should be understood to refer to 0 and 1 with $i \neq j$. There is no possibility of entry or exit. The demand and cost conditions that firms face remain unchanged over time. The price of each period is determined by $P(S^t)$, where $S^t = \sum_{i=0}^{1} s_i^t$ is the aggregate sales of each period. We assume that $P' < 0$ and $P'' \leq 0$.

The game runs as follows. In the first period, each firm simultaneously and independently chooses its first-period production $q_i^1 \in [0, \infty)$ and its first-period sales $s_i^1 \in [0, q_i^1]$. Firm i's inventory I_i^1 becomes $q_i^1 - s_i^1$. At the end of the first period, each firm knows the behaviour of the other firm. In the second period, each firm simultaneously and independently chooses its second-period production $q_i^2 \in [0, \infty)$. At the end of the second period, each firm sells $s_i^2 = I_i^1 + q_i^2$ and holds no inventory. For notational simplicity, we consider the game without discounting.

Since $\sum_{t=1}^{2} q_i^t = \sum_{t=1}^{2} s_i^t$, firm i's profits are

$$\prod_i = \sum_{t=1}^{2} [P(S^t)s_i^t - c_i q_i^t] = \sum_{t=1}^{2} [P(S^t)s_i^t - c_i s_i^t], \tag{1}$$

where c_i denotes firm i's constant cost. We assume that firm 0 is less efficient than firm 1, i.e. $c_0 > c_1$.[4] We define

$$\pi_i^t \equiv P(S^t)s_i^t - c_i s_i^t. \tag{2}$$

Since $\sum_{t=1}^{2} q_i^t = \sum_{t=1}^{2} s_i^t$, social welfares are

$$W = \sum_{t=1}^{2} \left[\int_0^{S^t} P(x)dx - c_0 q_0^t - c_1 q_1^t \right] = \sum_{t=1}^{2} \left[\int_0^{S^t} P(x)dx - c_0 s_0^t - c_1 s_1^t \right]. \tag{3}$$

We define

$$w^t \equiv \int_0^{S^t} P(x)dx - c_0 s_0^t - c_1 s_1^t. \tag{4}$$

[4] This assumption is justified in Gunderson (1979) and Nett (1993, 1994) and is often used in literature studying mixed markets. See, for instance, George and La Manna (1996), Mujumdar and Pal (1998), Pal (1998), Nishimori and Ogawa (2002), Matsumura (2003), Ohnishi (2008) and Fernández-Ruiz (2009). Let us assume that firm 0 is equally or more efficient than firm 1. In this case, since firm 0, which is interested in social welfare, has a higher incentive to underbid an opponent's price than firm 1 would have, firm 0 chooses q_0^1 and s_0^1 such that price equals marginal cost. Therefore, firm 1 has no incentive to operate in the market, and firm 0 supplies the entire market, resulting in a social-welfare-maximizing public monopoly. This assumption is made to eliminate such a trivial solution.

We analyse the subgame perfect Nash equilibrium of the mixed duopoly model.

3. SUPPLEMENTARY EXPLANATIONS

In this section, we will give supplementary explanations of the model described in the previous section. First, we derive firm 0's reaction functions from (4). In the first period, since there is no inventory available, firm 0's reaction function is defined by

$$R_0^1(s_1^1) = \arg\max_{\{s_0^1 \geq 0\}} \left[\int_0^{S^1} P(x)dx - c_0 s_0^1 - c_1 s_1^1 \right]. \tag{5}$$

In the second period, firm 0's reaction function without inventory is defined by

$$R_0^2(s_1^2) = \arg\max_{\{s_0^2 \geq 0\}} \left[\int_0^{S^2} P(x)dx - c_0 s_0^2 - c_1 s_1^2 \right], \tag{6}$$

and thus its best response is shown as follows:

$$\overline{R_0}^2(s_1^2) = \begin{cases} R_0^2(s_1^2) & \text{if } s_0^2 > I_0^1, \\ I_0^1 & \text{if } s_0^2 = I_0^1. \end{cases} \tag{7}$$

When the inventory is zero, the first-order condition for firm 0 is

$$P - c_0 = 0. \tag{8}$$

Furthermore, we have

$$R_0^{t\,\prime}(s_1^t) = -\frac{P'}{P'}. \tag{9}$$

In the first period, the slope of the reaction function of firm 0 is -1. In the second period, the slope of the reaction function of firm 0 is -1 for $s_0^2 > I_0^1$, and it is zero for $s_0^2 = I_0^1$.

Second, we derive firm 1's reaction functions from (2). In the first period, since there is no inventory available, firm 1's reaction function is defined by

$$R_1^1(s_0^1) = \arg\max_{\{s_1^1 \geq 0\}} [P(S^1)s_1^1 - c_1 s_1^1]. \tag{10}$$

In the second period, firm 1's reaction function without inventory is defined by

$$R_1^2(s_0^2) = \arg\max_{\{s_1^2 \geq 0\}} [P(S^2)s_1^2 - c_1 s_1^2], \tag{11}$$

and thus its best response is shown as follows:

$$\overline{R_1}^2(s_0^2) = \begin{cases} R_1^2(s_0^2) & \text{if } s_1^2 > I_1^1, \\ I_1^1 & \text{if } s_1^2 = I_1^1. \end{cases} \tag{12}$$

When the inventory is zero, the first-order condition for firm 1 is

$$P' s_1^t + P - c_1 = 0. \tag{13}$$

Furthermore, we have

$$R_1^{t\,\prime}(s_0^t) = -\frac{P'' s_1^t + P'}{P'' s_1^t + 2P'}. \tag{14}$$

In the first period, the slope of the reaction function of firm 1 is larger than -1 and further smaller than zero. In the second period, the slope of the reaction function of firm 1 is larger than -1 and further smaller than zero for $s_1^2 > I_1^1$, and it is zero for $s_1^2 = I_1^1$. From (9) and (14), we see that each firm treats s_i^t as strategic substitutes.[5]

Third, we state the Cournot Nash equilibrium of the mixed market model. In each period, each firm selects s_i^t simultaneously and independently. Firm 0 maximizes social welfare with respect to s_0^t given s_1^t, while firm 1 maximizes its profit with respect to s_1^t given s_0^t. A Cournot Nash equilibrium is a pair $(s_0^{t^*}, s_1^{t^*})$ of sales levels where each firm maximizes its objective given the other firm's sales. Firm i's optimal sales are nonincreasing in firm j's sales. From (5)-(14), there exists a unique Cournot Nash equilibrium in each period.[6]

Fourth, we consider Stackelberg games. If firm 0 is the Stackelberg leader, then firm 0 selects s_0^t, and firm 1 selects s_1^t after observing s_0^t. Firm 0 maximizes social welfare $w^t(s_0^t, R_1^t(s_0^t))$ with respect to s_0^t. On the other hand, if firm 1 is the Stackelberg leader, then it maximizes its profit $\pi_1^t(s_1^t, R_0^t(s_1^t))$ with respect to s_1^t. We present the following lemma:

LEMMA 1.
(i) Firm 0's Stakelberg leader sales are lower than its Cournot sales without inventory.
(ii) Firm 1's Stakelberg leader sales are higher than its Cournot sales without inventory.

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[5] The concept of strategic substitutability is due to Bulow, Geanakoplos and Klemperer (1985).
[6] Friedman (1977) details the existence and uniqueness of equilibria in private market models.

Lemma 1 (i) means that firm 0 prefers sales lower than its Cournot sales without inventory. On the other hand, Lemma 1 (ii) means that firm 1 prefers sales higher than its Cournot sales without inventory.

4. EQUILIBRIUM

In this section, we analyse the effects of inventory investment in the mixed duopoly model. To compute the subgame perfect Nash equilibrium, the game is solved by backward induction. First, we consider the behaviour of each firm in the second period, given I_i^1 and I_j^1. It is thought that the equilibrium of the second period is decided by the levels of I_i^1 and I_j^1. We present the following lemma:

LEMMA 2.
(i) If $(I_i^1, I_j^1) \leq (N_i, N_j)$*, then* $(s_i^2, s_j^2) = (N_i, N_j)$.
(ii) If $I_i^1 \geq N_i$*, then* $s_i^2 = I_i^1$.
(iii) If $I_i^1 \leq N_i$ *and* $I_j^1 > N_j$*, then* $s_i^2 = \max\{R_i^2(I_j^1), I_i^1\}$.

The intuition behind Lemma 2 is as follows. If each firm has no inventory, then the equilibrium in the second period is at $(s_i^2, s_j^2) = (N_i, N_j)$. Furthermore, from (7) and (12), we see that if $(I_i^1, I_j^1) \leq (N_i, N_j)$, then the equilibrium is at $(s_i^2, s_j^2) = (N_i, N_j)$.

In the first period, firm i chooses $I_i^1 = q_i^1 - s_i^1$. Since there is no depreciation on I_i^1, firm i cannot choose $s_i^2 < I_i^1$ in the second period. If $(I_i^1, I_j^1) > (N_i, N_j)$, then (N_i, N_j) is not an equilibrium, and hence firm i chooses $s_i^2 = I_i^1$.

If $I_j^1 > N_j$, then we have that $s_j^2 = I_j^1$. From (7) and (12), we see that firm i chooses $s_i^2 = R_i^2(I_j^1)$ if $I_i^1 \leq R_i^2(I_j^1)$, and firm i chooses $s_i^2 = I_i^1$ otherwise.

We can now present the following proposition:

PROPOSITION 1. *In the second period of the mixed duopoly model, there exists an equilibrium that coincides with the Stackelberg solution where firm 1 is the leader. At equilibrium, both social welfare and firm 1's profit are higher than in the game without inventory.*

The intuition behind Proposition 1 is as follows. Lemma 1 states that firm 0's Stakelberg leader sales are lower than its Cournot sales without inventory. That is, firm 0 prefers sales lower than its Cournot sales without inventory. On the other hand, Lemma 2 states that firm 1's Stakelberg leader sales are higher than its Cournot sales without inventory. That is, firm 1 prefers sales higher than its Cournot sales without inventory. These yield collusive outcome in the second period. As a result, we see that the introduction of inventory investment into the analysis of mixed market competition with public and private firms is profitable for the firms.

Next, we consider the first period of the mixed duopoly model. From above discussion, we can see how I_0^1 and I_1^1 affect the equilibrium sales in the second period. Each firm chooses its production and sales in the first period considering the strategic effect of inventories. Proposition 1 shows that in the second period of the mixed duopoly model, there exists an equilibrium that coincides with the Stackelberg solution where firm 1 is the leader. Our equilibrium concept is the subgame perfect equilibrium and all information in the model is common knowledge. Hence, in the first period, firm 1 can choose the inventory level associated with its second-period Stackelberg leader solution.

The equilibrium of the first period is described by the following proposition:

Proposition 2. *In the first period of the mixed duopoly model, the equilibrium coincides with the Cournot Nash solution without inventory* (N_0, N_1).

The intuition behind Proposition 2 is as follows. There is no inventory available in the first period, and further s_i^1 does not affect s_i^2 and s_j^2. Since each firm's payoff decreases by deviating from the Cournot Nash solution, it has no incentive to do so, and therefore the equilibrium is at (N_0, N_1).

5. CONCLUDING REMARKS

We have studied the equilibrium of a two-period mixed market model in which a welfare-maximizing public firm and a profit-maximizing private firm can use inventory investment as a strategic device. We have then demonstrated that the equilibrium in the second period coincides with the Stackelberg solution where the private firm is the leader, and at equilibrium, social welfare and the private firm's profit both are higher than in the game without inventory. We have shown that the public and private firms can form an implicit self-enforceable cartel that restricts their sales. As a result, we have found that the introduction of inventory investment into the analysis of mixed market competition with public and private firms is profitable for the firms.

In this paper, we assume that in the second period, total quantities of each firm are shipped to the market; that is, no inventory is held. However, in the second period, if each firm is allowed to hold inventories, then it cannot change its reaction function because inventories do not function as a commitment device. Since each firm's payoff decreases by deviating from the Cournot Nash solution without inventory, it has no incentive to do so. Hence, the equilibrium of the second period becomes the Cournot Nash solution without inventory.

There are many studies dealing with mixed market models that incorporate welfare-maximizing public firms. We will pursue further research on these studies in the future.

APPENDIX

Proof of Lemma 1

(i) If firm 0 is the Stackelberg leader, then it maximizes social welfare $w^t(s_0^t, R_1^t(s_0^t))$ with respect to s_0^t. Therefore, firm 0's Stackelberg leader sales satisfy the first-order condition:

$$\frac{\partial w^t}{\partial s_0^t} + \frac{\partial w^t}{\partial s_1^t}\frac{\partial R_1^t}{\partial s_0^t} = 0, \tag{A.1}$$

where $\frac{\partial w^t}{\partial s_1^t} = P - c_1$ is positive from (9) and $c_0 > c_1 > 0$, while $\frac{\partial R_1^t}{\partial s_0^t}$ is negative from (10), (11) and (14). To satisfy (A.1), $\frac{\partial w^t}{\partial s_0^t}$ must be positive, and thus (i) follows.

(ii) If firm 1 is the Stackelberg leader, then it maximizes its profit $\pi_1^t(s_1^t, R_0^t(s_1^t))$ with respect to s_1^t. Therefore, firm 1's Stackelberg leader sales satisfy the first-order condition:

$$\frac{\partial \pi_1^t}{\partial s_1^t} + \frac{\partial \pi_1^t}{\partial s_0^t}\frac{\partial R_0^t}{\partial s_1^t} = 0, \tag{A.2}$$

where $\frac{\partial \pi_1^t}{\partial s_0^t} = P' s_1^t$ is negative from $P' < 0$, and $\frac{\partial R_0^t}{\partial s_1^t}$ is also negative from (5), (6) and (9). To satisfy (A.2), $\frac{\partial \pi_1^t}{partial s_1^t}$ must be negative, and thus (ii) follows. ▮

Proof of Lemma 2

The proof is very similar to the proofs of Lemmas 1-3 in Matsumura (1999), and will be omitted. ▮

Proof of Proposition 1

From Lemma 2, firm i's sales in the second period are as follows:

$$s_i^2 = \begin{cases} I_i^1 & \text{if } I_i^1 \geq N_i \\ \max\{I_i^1, R_i(I_j^1)\} & \text{if } I_j^1 \geq N_j \\ N_i & \text{if } I_i^1 < N_i \text{ and } I_j^1 < N_j \end{cases} \tag{A.3}$$

We consider optimal sales in the second period. Lemma 1 (i) states that firm 0's Stakelberg leader sales are lower than its Cournot sales without inventory. Let w^2 be assumed to be continuous and concave in s_0^2. Hence, firm 0 never chooses $I_0^1 > N_0$. However, firm 0 prefers $I_1^1 > N_1$ above all others because of strategic substitutes. Lemma 1 (ii) states that firm 1's Stakelberg leader sales are higher than its Cournot sales without inventory. Let π_1^2 be assumed to be continuous and concave in s_1^2. The further a point on R_0 gets from firm 1's Stackelberg leader point, the more social welfare decreases. Hence, firm 1 prefers $I_1^1 > N_1$ above all others.

From (A.3), we see that the equilibrium outcome in the second period is decided by the value of I_i^1. Our equilibrium concept is the subgame perfect equilibrium and all information in the model is common knowledge. Firm 1 chooses $\overline{I_1}^1 (= \overline{q_1}^1 - N_1)$ associated with its second-period Stackelberg leader solution. Thus, the proposition follows. ∎

Proof of Proposition 2

Since s_i^1 does not affect s_i^2 and s_j^2, s_i^1 has no strategic value. Thus, the result follows easily from (5) and (10). ∎

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