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Capacity Investment and Mixed Duopoly with State-Owned and Labor-Managed Firms

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We examine the behaviors of one state-owned welfare-maximizing firm and one labor-managed income-per-worker-maximizing firm in a two-stage mixed market model with capacity investment as a strategic instrument. In the first stage, each firm independently decides whether or not to install capacity. This capacity may subsequently be increased, but cannot be decreased. Hence, the firm's capital cost changes from a variable cost to a fixed cost. In the second stage, each firm independently chooses its actual output. We show the equilibrium of the mixed model.

Key Words: Capacity investment; State-owned firm; Labor-managed firm.
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1. INTRODUCTION

The analysis of mixed market models that incorporate state-owned welfare-maximizing public firms is widely performed by many economists.[1] Delbono and Denicolò (1993) investigate a mixed duopoly with R&D in which a welfare-maximizing firm and a profit-maximizing firm compete and show that each firm invests less in R&D than in a profit-maximizing duopoly and this enhances social welfare. Mujumdar and Pal (1998) consider a mixed duopoly, with a welfare-maximizing firm and a profit-maximizing firm, producing a homogeneous commodity and find that an increase in tax (ad valorem or specific) does not change total output, but increases the output of the welfare-maximizing firm and the tax revenue. Pal (1998) analyzes the subgame perfect Nash equilibrium of a mixed market, where the firms first choose the timing for selecting their quantities, and finds that the results are strikingly different from those obtained in a corresponding

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

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oligopoly with all profit maximizing firms. Matsumura and Matsushima (2003) investigate the sequential choice of location in a mixed duopoly, where a welfare-maximizing firm competes against a profit-maximizing firm and consider the effect of price regulation. They find that the welfare-maximizing firm should become the follower (leader) if a price regulation is (is not) imposed. There are many excellent further studies such as Cremer, Marchand, and Thisse (1991), Nett (1994), Willner (1994), Fjell and Pal (1996), George and La Manna (1996), White (1996), Pal and White (1998), Poyago-Theotoky (1998), Wen and Sasaki (2001), and Matsumura (2003).

Furthermore, the study of labor-managed income-per-worker-maximizing firms is very famous and has been studied by a lot of economists.[2] In Mai and Hwang (1989), Horowitz (1991), Okuguchi (1991), and Sakai (1993), the labor-managed firm and the profit-maximizing firm each decide only how much output to produce or how much labor to employ. Cremer and Crémer (1992) extend their analyses to the case in which the firms decide both the employment level and the capital stock simultaneously and show that the labor-managed firm produces less output than the profit-maximizing firm in a two-stage Cournot duopoly regime. However, Futagami and Okamura (1996) show that in a three-stage Cournot duopoly regime with capital strategic interaction, the labor-managed firm could invest more capital and produce more than the profit-maximizing firm does. Delbono and Rossini (1992) examine a one-shot Cournot game with a labor-managed firm and a profit-maximizing firm and show that there exists a unique duopoly equilibrium. Lambertini and Rossini (1998) show that in a two-stage Cournot duopoly model with capital strategic interaction, the labor-managed firm always over-invests while the profit-maximizing firm always under-invests. Lambertini (2001) investigates the nature of the equilibria arising under spatial differentiation in a duopoly model where at least one firm maximizes value added per worker and shows that if firms' objectives differ, there exists a subgame perfect equilibrium in pure strategies, which is possibly characterized by asymmetric locations. There are many excellent further studies such as Svejnar (1982), Law and Stewart (1983), Drago and Turnbull (1992), Stewart (1992), Askildsen and Ireland (1993), and Neary and Ulph (1997).

We consider capacity investment as a strategic instrument that creates kinks in reaction curves. The possibility of firms using excess capacity as a strategic instrument in duopolistic competition has been examined by many economists.[3] For example, this idea is presented in a two-stage model

[2]The pioneering work on a theoretical model of a labor-managed firm is conducted by Ward (1958). See also Ireland and Law (1982), Stephan (1982), and Bonin and Putterman (1987) for excellent surveys.

[3]See Tirole (1988) and Gilbert (1989) for excellent surveys of strategic capacity investment.

by Dixit (1980). He shows that an incumbent installing excess capacity in the first stage is able to deter the entry of a potential entrant in the second stage. Ware (1984) examines the three-stage model in which an incumbent installs capacity in the first stage, an entrant installs capacity in the second stage, and a quantity equilibrium is established in the third stage. Ware concludes that although his three-stage equilibrium is qualitatively similar to Dixit's two-stage equilibrium, it differs in that the strategic advantage available to the first mover is lessened. Poddar (2003) examines a two-stage model of strategic entry deterrence (a la Dixit 1980) under demand uncertainty and shows that to improve its strategic position in the product market competition an incumbent will choose a level of capacity that may remain idle in a low state of demand. These studies are models with profit-maximizing firms and do not examine in the presence of labor-managed firms.

Some studies include labor-managed firms. For example, Zhang (1993) and Haruna (1996) apply Dixit (1980) and Bulow, Geanakoplos, and Klemperer (1985a) frameworks of entry deterrence to labor-managed industries and show that labor-managed incumbents have greater incentive to hold excess capacity to deter entry than corresponding profit-maximizing incumbents. Furthermore, Stewart (1991) explores strategic entry interactions between the profit-maximizing firm and the labor-managed firm using a framework suggested by Dixit (1980).

We examine the behaviors of one state-owned welfare-maximizing firm and one labor-managed income-per-worker-maximizing firm in a two-stage mixed market model with capacity investment as a strategic instrument. We consider the following situation. In the first stage, the state-owned firm and the labor-managed firm each independently decide whether or not to invest capacity. This capacity may subsequently be increased, but cannot be decreased. Hence, the firm's capacity cost changes from a variable cost to a fixed cost. In the second stage, each firm independently chooses its actual output. We show the equilibrium of the quantity-setting mixed model.

This paper is organized as follows. In Section 2, we formulate the model. Section 3 gives supplementary explanations of the model. Section 4 discusses the equilibrium of the model. Section 5 concludes the paper. Finally, the Appendix provides formal proofs.

2. THE MODEL

Let us consider a market with one state-owned welfare-maximizing firm (firm S) and one labor-managed income-per-worker-maximizing firm (firm L), producing a single homogeneous good. For the remainder of this paper, when i and j are used to refer to firms in an expression, they should be understood to refer to S and L with $i \neq j$. There is no possibility of entry or exit. The size of the market is represented by a linear inverse demand function

$$p = a - Q, \tag{1}$$

where $Q = q_S + q_L$ and $a > Q$.

The two stages of the model run as follows. In the first stage, each firm independently decides whether or not to install capacity $k_i > 0$. Neither firm can reduce or dispose of capacity. At the end of the first stage, each firm observes the other firm's actions. In the second stage, each firm independently chooses its actual output $q_i > 0$.

Firm i's profit is given by

$$\pi_i(q_i, q_i^*) = \begin{cases} pq_i - m_i q_i - f_i & \text{if } q_i > k_i, \\ pq_i - (m_i - r_i)q_i - r_i k_i - f_i & \text{if } q_i \leq k_i, \end{cases} \tag{2}$$

where $m_i > 0$ denotes the total cost for each unit of output, $r_i \in (0, m_i)$ the capacity cost for each unit of output, and $f_i > 0$ the fixed cost. If firm i produces output q_i within the limit of the capacity it has installed (i.e., $q_i \leq k_i$), then its marginal cost is $m_i - r_i$ because its capacity cost is sunk as a fixed cost. On the other hand, if firm i wishes to produce $q_i > k_i$ in the second stage, then it must acquire additional capacity to match its output in the second stage, and its marginal cost rises to m_i. That is, if capacity is expended as a flow simultaneously with production, then its cost is not sunk. Thus, each firm's marginal cost exhibits a discontinuity at $q_i = k_i$. We assume that firm S is less efficient than firm L in wage cost and other costs, i.e., $m_S > m_L$ and $m_S - r_S > m_L - r_L$.[4]

The objective of firm S is to maximize social welfare (W), which is defined as the sum of the consumer surplus and total profits of the firms:

$$W = \frac{1}{2}Q^2 + \pi_S + \pi_L. \tag{3}$$

Firm L's income per worker is given by

$$V_L(q_L, q_L^*) = \begin{cases} \dfrac{pq_L - m_L q_L - f_L}{l_L} & \text{if } q_L > k_L, \\ \dfrac{pq_L - (m_L - r_L)q_L - f_L k_L - f_L}{l_L} & \text{if } q_L \leq k_L, \end{cases} \tag{4}$$

[4]This assumption is justified in Gunderson (1979), Cremer, Marchand, and Thisse (1989), 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), and Matsumura (2003). If firm S is more efficient than or equally as efficient as firm L, then firm S supplies the entire market, resulting in a social-welfare-maximizing public monopoly. This assumption is made to eliminate such a trivial solution.

where $l_L \geq 0$ is the quantity of labor utilized. We consider the following production function:

$$q_L = \sqrt{l_L}. \tag{5}$$

From (4) and (5), we can write the objective function of firm L as

$$V_L(q_L, q_L^*) = \begin{cases} \dfrac{pq_L - m_L q_L - f_L}{q_L^2} & \text{if } q_L > k_L, \\ \dfrac{pq_L - (m_L - r_L)q_L - r_L k_L - f_L}{q_L^2} & \text{if } q_L \leq k_L. \end{cases} \tag{6}$$

In this paper, we will discuss the subgame perfect Nash equilibrium of this quantity-setting mixed market model.

3. SUPPLEMENTARY EXPLANATIONS

In this section, we give supplementary explanations of the model formulated in the previous section. First, we derive both firms' reaction functions in quantities. Firm S's best reaction function is

$$R_S = \begin{cases} a - m_S - q_L & \text{if } q_S > k_S, \\ k_S & \text{if } q_S = k_S, \\ a - m_S + r_S - q_L & \text{if } q_S < k_S, \end{cases} \tag{7}$$

and firm L's best reaction function is

$$R_L = \begin{cases} \dfrac{2f_L}{a - m_L - q_S} & \text{if } q_L > k_L, \\ k_L & \text{if } q_L = k_L, \\ \dfrac{2(r_L k_L + f_L)}{a - m_L + r_L - q_S} & \text{if } q_L < k_L. \end{cases} \tag{8}$$

From (7) and (8), we see that firm S treats quantities as strategic substitutes, while firm L treats quantities as strategic complements.[5]

Second, we present the following lemmas.

LEMMA 1. *Firm i's optimal output is larger when it installs k_i than when it does not.*

LEMMA 2. *If firm i installs k_i and an equilibrium is achieved, then in equilibrium $q_i = k_i$.*

[5]The concept of strategic substitutability/complementarity is due to Bulow, Geanakoplos, and Klemperer (1985b).

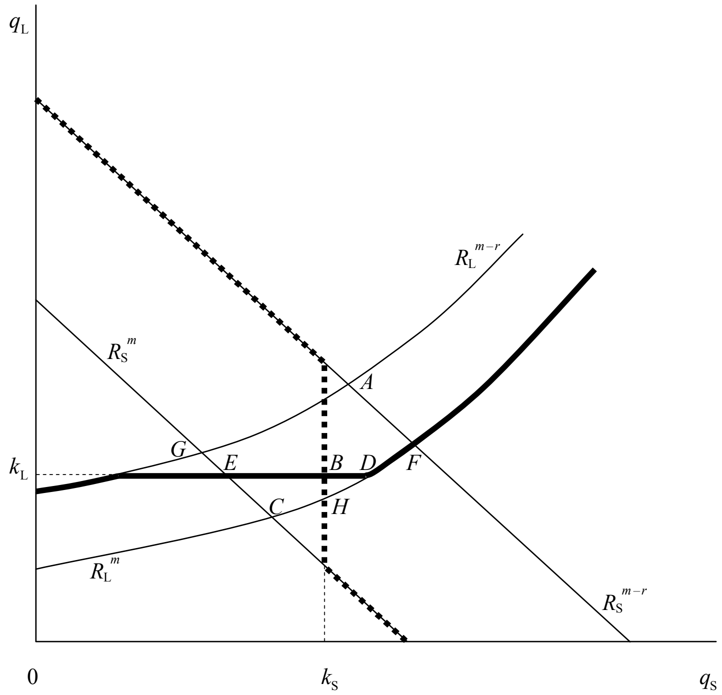
These lemmas provide characterizations of capacity investment as a strategic instrument. Lemma 1 means that if firm i installs capacity in advance of production, then its optimum output increases. Lemma 2 means that in equilibrium firm i does not install extra capacity.

Third, we consider firm i's Stackelberg leader output. Firm i selects q_i, and firm j selects q_j after observing q_i. That is, firm S maximizes social welfare $W(q_S, R_L(q_S))$ with respect to q_S, and firm L maximizes its income per worker $V_L(q_L, R_S(q_L))$ with respect to q_L. We present the following lemma.

LEMMA 3. *Firm i's Stackelberg leader output exceeds its Cournot output.*

Lemma 3 means that firm i has an incentive to increase its output.

FIG. 1. Reaction Curves in the Quantity Space



Fourth, we illustrate both firms' reaction curves, which are drawn in Figure 1. R_i^m is firm i's reaction curve when the marginal cost for output is constantly equal to m_i, and R_i^{m-r} firm i's reaction curve when the marginal cost for output is constantly equal to $m_i - r_i$. Firm S's reaction curve is downward-sloping because of strategic substitutes, while firm L's reaction curve is upward-sloping because of strategic complements. If neither firm installs capacity in the first stage, then the equilibrium occurs at C. If firm S installs k_S, then from (7), firm S's reaction curve becomes the kinked bold broken lines. Furthermore, if firm L installs k_L, then from (8), firm L's reaction curve becomes the kinked bold lines.

4. RESULTS

In this section, we discuss the following three cases:
(i) The case in which only firm S can install capacity in the first stage
(ii) The case in which only firm L can install capacity in the first stage
(iii) The case in which both firms can install capacity in the first stage
We will discuss these cases in order.

(i) The case in which only firm S can install capacity in the first stage

Firm S aims to maximize social welfare. Therefore, it is thought that firm S will install k_S if social welfare increases by doing so, while firm S will not install k_S if social welfare decreases by doing so.

Since firm L does not install capacity in the first stage, its reaction curve is R_L^m drawn in Figure 1. Firm S's investment choice reduces its marginal cost and increases its optimal output (Lemma 1). In Figure 1, if firm S installs k_S, then its reaction curve shifts for $q_S \leq k_S$. The shift size of firm S's reaction curve is decided by the value of r_S. The equilibrium is decided in a Cournot fashion, i.e. the intersection of firm S's and firm L's reaction curves gives us a unique equilibrium. Firm S's unilateral investment solution can occur at the appropriate point of the segment CF. Firm S's Stackelberg leader point is to the right of C on R_L^m (Lemma 3). If H on CF is firm S's Stackelberg leader point, then social welfare is the highest at H on R_L^m. Therefore, firm S chooses capacity corresponding to H in the first stage, and its reaction curve becomes the kinked bold broken lines drawn in Figure 1. Hence, firm S's unilateral investment equilibrium occurs at H.

If firm S's Stackelberg leader point is to the right of F on R_L^m, then the equilibrium cannot occur at that point. In R_L^m, social welfare is the highest at firm S's Stackelberg leader point, and the further the point on R_L^m deviates from its Stackelberg leader point, the more social welfare decreases. Hence, social welfare is the highest at F. Therefore, firm S chooses capacity corresponding to F in the first stage. That is, if F is the highest possible social welfare, then firm S's unilateral investment equilibrium occurs at F.

On the other hand, if neither firm installs capacity in the first stage, then the equilibrium occurs at C. Hence, we can see easily that firm S's unilateral investment solution increases social welfare.

We can now state the following proposition:

PROPOSITION 1. *Suppose that firm S unilaterally installs capacity in the first stage. Then in equilibrium social welfare is higher than in the Cournot game with no capacity installed.*

(ii) The case in which only firm L can install capacity in the first stage

Firm L aims to maximize its income per worker. Therefore, it is thought that firm L will install k_L if its income per worker increases by doing so, while firm L will not install k_L if its income per worker decreases by doing so.

Since firm S does not install capacity in the first stage, its reaction curve is R_S^m drawn in Figure 1. Firm L's investment choice reduces its marginal cost and increases its optimal output (Lemma 1). In Figure 1, if firm L installs k_L, then its reaction curve shifts for $q_L \leq k_L$. The shift size of firm L's reaction curve is decided by the value of r_L. Firm L's unilateral investment solution can occur at the appropriate point of the segment CG. Firm L's Stackelberg leader point is to the left of C on R_S^m (Lemma 3). If E on CG is firm L's Stackelberg leader point, then firm L's income per worker is the highest at E on R_S^m. Therefore, firm L chooses capacity corresponding to E in the first stage, and its reaction curve becomes the kinked bold lines drawn in Figure 1. Hence, firm L's unilateral investment equilibrium occurs at E.

If firm L's Stackelberg leader point is to the left of G on R_S^m, then firm L's income per worker is the highest at G. Therefore, firm L chooses capacity corresponding to G in the first stage. That is, if G is the highest possible income per worker for firm L, then firm L's unilateral investment equilibrium occurs at G.

On the other hand, if neither firm installs capacity in the first stage, then the equilibrium occurs at C. Hence, we can see easily that firm L's unilateral investment solution increases its income per worker.

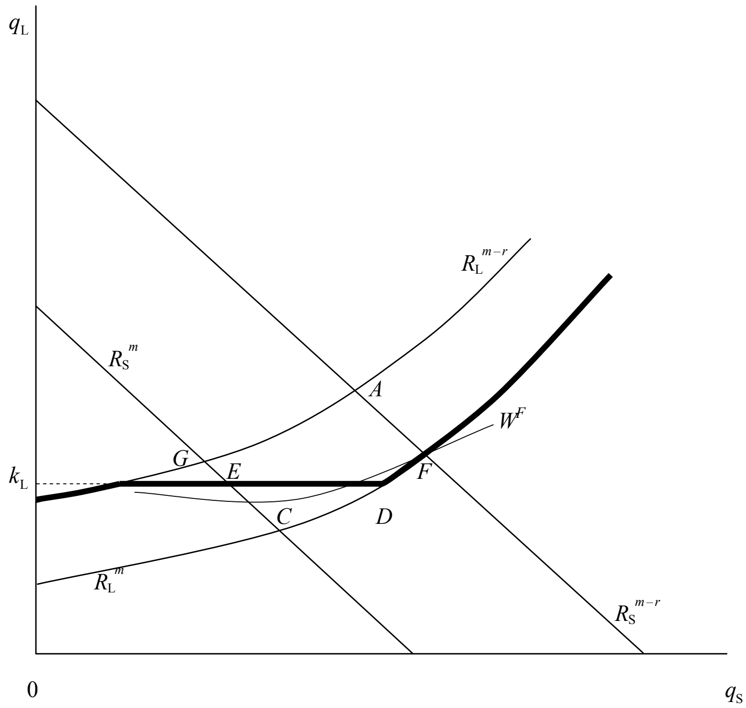
We can now present the following proposition:

PROPOSITION 2. *Suppose that firm L unilaterally installs capacity in the first stage. Then in equilibrium firm L's income per worker is higher than in the Cournot game with no capacity installed.*

(iii) The case in which both firms can install capacity in the first stage

If both firms install k_S and k_L, then the intersection of their reaction curves becomes a point like B drawn in Figure 1. The reaction curve of each firm will then have a flat segment at k_i. Social welfare is higher at E than at B, and firm L's income per worker is higher at H than at B. Therefore, each firm wants to deviate from B. That is, firm S can increase social welfare by reducing k_S, and firm L can increase its income per worker by reducing k_L. Hence, B is not an equilibrium. Furthermore, H is not an equilibrium, because if firm L installs k_L corresponding to H, then firm S wants to deviate from H.

FIG. 2. Equilibrium Outcomes



Now, we consider Figure 2. If firm L installs k_L, then its reaction curve becomes the kinked bold lines. Firm S can effectively select an equilibrium from the feasible segment FDE. W^F is the iso-welfare curve extending through F, and social welfare is higher at E than at F. Because iso-welfare curves are horizontal along R_S^m, firm S will always select E on FDE, unless a more feasible point on the sloping segment FD exists. Even if the latter case holds, firm L will prefer a point on CG to the corresponding point on FD. Our equilibrium concept is subgame perfection and all information in the model is common knowledge. It can always influence each firm to choose such a point with backward induction process. Hence, points on CG, such as E, will be possible equilibria to the quantity-setting model with firm S and firm L.

The main result of this study is given by the following proposition:

Proposition 3. *In the quantity-setting model with firm S and firm L, there exists an equilibrium in which firm L makes a commitment to capacity while firm S does not.*

The intuition behind Proposition 3 is as follows. Proposition 2 states that if firm S does not installs k_S, the best firm L can do is to install k_L. From Figure 1, we can see that if firm L unilaterally installs capacity in the first stage, both social welfare and firm L's income per worker are higher than in the Cournot game with no capacity installed. Proposition 1 states that if firm L does not installs k_L, the best firm S can do is to install k_S. However, firm S's investment choice decreases firm L's income per worker. Therefore, firm L does not want firm S to install k_S.

If firm L installs k_L, then its reaction curve have a flat segment at k_L. Firm S's capacity investment decreases social welfare, and therefore it has no incentive to install k_S. All information in the model is common knowledge. Hence, firm L makes a commitment to capacity while firm S does not.

5. CONCLUDING REMARKS

We have examined the behaviors of one state-owned welfare-maximizing firm and one labor-managed income-per-worker-maximizing firm in a two-stage mixed market model with capacity investment as a strategic instrument.

First, we have shown that if the state-owned firm unilaterally installs capacity in the first stage, then in equilibrium social welfare is higher than in the Cournot game with no capacity installed, and if the labor-managed firm unilaterally installs capacity in the first stage, then in equilibrium the labor-managed firm's income-per-worker is higher than in the Cournot game with no capacity installed. These indicate the effectiveness of capacity investment as a strategic instrument.

Next, we have shown that if each firm can install capacity in the first stage, then there exists an equilibrium in which the labor-maneged firm commits capacity while the state-owned firm does not. This indicates that a state-owned firm unaggressively acting against a labor-managed firm leads to social welfare maximization.

We will pursue further research on mixed market models with state-owned welfare-maximizing and labor-managed income-per-worker-maximizing firms in the future.

APPENDIX

Proof of Lemma 1

First, we prove that firm S's welfare-maximizing output is larger when it installs k_S than when it does not. From (2) and (3), we see that capacity investment will never increase the marginal cost of firm S. The first-order condition for firm S when its marginal cost is m_S is

$$a - q_S - q_L - m_S = 0, \tag{A.1}$$

and the first-order condition for firm S when its marginal cost is $m_S - r_S$ is

$$a - q_S - q_L - m_S + r_S = 0, \tag{A.2}$$

where r_S is positive. To satisfy (A.2), $a - q_S - q_L - m_S$ must be negative. Thus, firm S's optimum output is larger when its marginal cost is $m_S - r_S$ than when its marginal cost is m_S.

Next, we prove that firm L's income-per-worker-maximizing output is larger when it installs k_L than when it does not. From (6), we see that capacity investment will never increase the marginal cost of firm L. The first-order condition for firm L when its marginal cost is m_L is

$$-aq_L + q_S q_L + m_L q_L + 2f_L = 0, \tag{A.3}$$

and the first-order condition for firm L when its marginal cost is $m_L - r_L$ is

$$-aq_L + q_S q_L + m_L q_L + 2f_L - r_L q_L + 2r_L k_L = 0, \tag{A.4}$$

where r_L is positive. Furthermore, from (6), we see that firm L's marginal cost is $m_L - r_L$ if $q_L \leq k_L$. To satisfy (A.4), $-aq_L + q_S q_L + m_L q_L + 2f_L$ must be negative. Thus, firm L's optimum output is larger when its marginal cost is $m_L - r_L$ than when its marginal cost is m_L. ▮

Proof of Lemma 2

First, we prove that if firm S installs k_S, then in equilibrium $q_S = k_S$. Consider the possibility that $q_S < k_S$ in equilibrium. From (2) and (3), when firm S installs k_S, social welfare is

$$\begin{aligned} W &= \frac{1}{2}Q^2 + pq_S - (m_S - r_S)q_S - r_S k_S - f_S + \pi_L \\ &= \frac{1}{2}Q^2 + pq_S - m_S q_S - (k_S - q_S)r_S - f_S + \pi_L. \end{aligned} \tag{A.5}$$

Here, if $q_S < k_S$, firm S installs extra capacity. That is, firm S can increase social welfare by reducing k_S, and the equilibrium point does not change in $q_S \leq k_S$. Hence, $q_S < k_S$ does not result in an equilibrium.

Consider the possibility that $q_S > k_S$ in equilibrium. From (2), we see that firm S's marginal cost is m_S. It is impossible for firm S to change its output in equilibrium because such a strategy is not credible. That is, if $q_S > k_S$, capacity investment does not function as a strategic commitment.

Next, we prove that if firm L installs k_L, then in equilibrium $q_L = k_L$. Consider the possibility that $q_L < k_L$ in equilibrium. From (6), when firm L installs k_L, its income-per-worker is

$$\begin{aligned} V_L &= \frac{pq_L - (m_L - r_L)q_L - r_L k_L - f_L}{q_L^2} \\ &= \frac{pq_L - m_L q_L - (k_L - q_L)r_L - f_L}{q_L^2}. \end{aligned} \tag{A.6}$$

Here, if $q_L < k_L$, firm L installs extra capacity. That is, firm L can increase its income per worker by reducing k_L, and the equilibrium point does not change in $q_L \leq k_L$. Hence, $q_L < k_L$ does not result in an equilibrium.

Consider the possibility that $q_L > k_L$ in equilibrium. From (6), we see that firm L's marginal cost is m_L. It is impossible for firm L to change its output in equilibrium because such a strategy is not credible. That is, if $q_L > k_L$, capacity investment does not function as a strategic commitment. ▮

Proof of Lemma 3

First, we consider firm S's Stackelberg leader output. Firm S selects q_S, and firm L selects q_L after observing q_S. That is, firm S maximizes social welfare $W(q_S, R_L(q_S))$ with respect to q_S. Therefore, firm S's Stackelberg leader output satisfies the first-order condition:

$$a - q_S - q_L - m_S + (a - q_S - q_L - m_L)\left(\frac{2f_L}{(a - m_L - q_S)^2}\right) = 0. \tag{A.7}$$

Here, from $m_S > m_L$, $a - q_S - q_L - m_S$ is negative. Thus, firm S's Stackelberg leader output exceeds its Cournot output.

Next, we consider firm L's Stackelberg leader output. Firm L selects q_L, and firm S selects q_S after observing q_L. That is, firm L maximizes its income per worker $V_L(q_L, R_S(q_L))$ with respect to q_L. Therefore, firm L's Stackelberg leader output satisfies the first-order condition:

$$-aq_L + q_S q_L + m_L q_L + 2f_L + \frac{1}{q_L} = 0 \tag{A.8}$$

To satisfy (A.8), $-aq_L + q_S q_L + m_L q_L + 2f_L$ must be negative. Thus, firm L's Stackelberg leader output exceeds its Cournot output. ▮

Proof of Proposition 1

Lemma 1 shows that firm S's welfare maximizing output is larger when it installs k_S than when it does not. Lemma 3 shows that firm S's Stackelberg leader output exceeds its Cournot output. Furthermore, (3) is continuous and concave. In firm L's reaction curve when its marginal cost is m_L, social welfare is the highest at firm S's Stackelberg leader point, and the further the point on firm L's reaction curve when its marginal cost is m_L gets from firm S's Stackelberg leader point, the more social welfare decreases. Lemma 2 shows that $q_S = k_S$ in equilibrium. Thus, the proposition follows. ▌

Proof of Proposition 2

This is omitted, as it is similar to the proof of Proposition 1. ▌

Proof of Proposition 3

Suppose that each firm installs k_i. Then from (7) and (8), we see that each firm's reaction function has a flat segment at k_i. (3) is continuous and concave. Hence, firm S can increase social welfare by reducing k_S. Firm S maximizes social welfare by reducing k_S to a point of its reaction curve when its marginal cost is m_S. From (7), we see that firm S's capacity investment does not function as a strategic commitment in its reaction curve when its marginal cost is m_S. Reducing k_S also increases firm L's income per worker. Our equilibrium concept is subgame perfection and all information in the model is common knowledge. It can always influence each firm to choose such a point with backward induction process. Thus, the proposition follows. ▌

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