Technology Choice under Stackelberg Duopoly*

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Abstract

This paper investigates how affects the timing of firms' output decision on their technology choice and the social desirability by extending Cournot duopoly model of Mills and Smith (1996) to Stackelberg duopoly one as follows: In the first stage, the firms choose its production technology *simultaneously*. In the second stage, given the technologies chosen in the first stage, the firms choose its output *sequentially*. Main conclusions we obtain are as follows: [i] Heterogeneity of technologies tends to occur under Stackelberg duopoly as compared with Cournot duopoly. [ii] Heterogeneity of technology is not necessarily socially desirable under Stackelberg duopoly, although it is always socially desirable under Cournot duopoly. [iii] Suppose that the follower firm uses the technology with lower marginal cost and higher fixed cost solely. Then, it tends to earn more profit than the leader firm.

1. Introduction

There are many literatures to investigate firms' technology choice under imperfect competition. Mills and Smith (1996) is one of the representative papers. They constructed a two-stage duopoly model in which *ex ante* identical firms choose the technology used simultaneously in the first stage and compete *à la* Cournot in the second stage. In their model, firms face a technology choice between two alternative production technologies as follows; a technology with a low marginal cost and a high fixed cost, and one with a high marginal cost and a low fixed cost.[1] Following Elberfeld and Götz (2002), we refer the former technology as a *large-scale* technology and the latter one as a *small-scale* technology. Mills and Smith (1996) showed that excessive choice of both the large-scale and the small-scale technology may occur from the viewpoint of social welfare, and that heterogeneity, which means that the firms choose different technologies, is always socially desirable. Elberfeld (2003) extended the duopoly model of Mills and Smith (1996) to the oligopoly model and suggested that there is a strong tendency towards excessive choice of the large-scale technology if more than two firms are active in the market. He also showed that there is no systematic relationship between heterogeneity and social welfare although heterogeneity may occur in the oligopoly model.[2]

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In these studies, firms choose its output *simultaneously*. However, firms do not necessarily make its decision simultaneously. For example, firms may decide its output *sequentially*, i.e. they compete *à la* Stackelberg. In this paper, using Stackelberg model, we investigate how affects the timing of firms' output decision on the technology choice and the social desirability.

We simply extend Cournot model of Mills and Smith (1996) to Stackelberg one as follows: In the first stage, the firms choose its production technology *simultaneously*. In the second stage, given the technologies chosen in the first stage, the firms choose its output *sequentially*, that is they compete *à la* Stackelberg.

Main conclusions we obtain are as follows: [i] Heterogeneity of technologies tends to occur under Stackelberg duopoly as compared with Cournot duopoly. [ii] Heterogeneity of technology is not necessarily socially desirable under Stackelberg duopoly, although it is always socially desirable under Cournot duopoly. [iii] Suppose that the follower firm uses technology L solely. Then, it tends to earn more profit than the leader firm.

Remainder of this paper is organized as follows: Section 2 presents the model. Section 3 solves the game and obtains firms' technology choice in the equilibrium. Section 4 examines whether firms' technology choice is desirable from the viewpoint of social welfare. Section 5 concludes the paper.

2. Model

Consider an economy with two firms, denoted firm 1 and firm 2 respectively, which produce a homogenous good. The market demand function is given by

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

where p is the price of the market, both a and b are the positive constants, and Q is the quantity demanded in the market. The firms are identical *ex ante*, but they face a choice of alternative production technologies. The available technologies are characterized by a combination $(c,\ F)$ of a constant marginal cost c and a fixed cost F. For simplicity, we assume two types of technologies: a *large-scale* technology $(c_L,\ F_L)$ and the *small-scale* technology $(c_S,\ F_S)$, and that $a/3>c_S>c_L=0$ and $F_L>F_S=0$. We refer these technologies as technology L and technology S respectively. Each firm chooses its technology k and output q_i in order to maximize its profits, which is given by

$$\pi_{ik}=p(Q)q_i-c_{ik}q_i-F_{ik},\ \ i=1,2 \text{ and } k=L,S. \tag{2}$$

The following two-stage game is considered: In the first stage, the firms choose its production technology *simultaneously*. In the second stage, given the technologies chosen in the first stage, the firms choose its output *sequentially*, that is they compete *à la* Stackelberg. We assume that firm 1 (firm 2) is the leader (the follower) throughout the paper.

Table 1 : Firms' Output under Each Technology Combination

Follower Firm 2 / Leader Firm 1	Technology S	Technology L
Technology S	$\frac{1-c}{2}, \frac{1-c}{4}$	$\frac{1-2c}{2}, \frac{1+2c}{4}$
Technology L	$\frac{1+c}{2}, \frac{1-3c}{4}$	$\frac{1}{2}, \frac{1}{4}$

Note that we assume that $a=1$, $b=1$, and $c_s=c$ for simplicity.

Table 2 : Firms' Profit under Each Technology Combination

Follower Firm 2 / Leader Firm 1	Technology S	Technology L
Technology S	$\frac{(1-c)^2}{8}, \frac{(1-c)^2}{16}$	$\frac{(1-2c)^2}{8}, \frac{(1+2c)^2}{16}-F$
Technology L	$\frac{(1+c)^2}{8}-F, \frac{(1-3c)^2}{16}$	$\frac{1}{8}-F, \frac{1}{16}-F$

Note that we assume that $a=1$, $b=1$, $c_s=c$, and $F_L=F$ for simplicity.

3. Technology Choice

We use a backward induction as a solution concept. In the second stage, the follower firm 2 chooses its output q_2, given the leader firm 1's output. From (1) and (2), the best response function of firm 2 is given by

$$R_2(q_{1k})=\frac{a-c_{2k}}{2b}-\frac{1}{2}q_{1k},\quad k=L,S. \tag{3}$$

Taking into account, $R_2(q_{1k})$, the leader firm 1 chooses its output q_1. From (1) through (3), the output of leader firm 1 with technology k is

$$q_{1k}=\frac{a-2c_{1k}+c_{2k}}{2b}. \tag{4}$$

From (1) through (4), we can calculate each firm's output and profit under each technology combination as shown in Tables 1 and 2. From Tables 1 and 2, we have following results[3]:

Lemma 1 : *Suppose that c is given.*

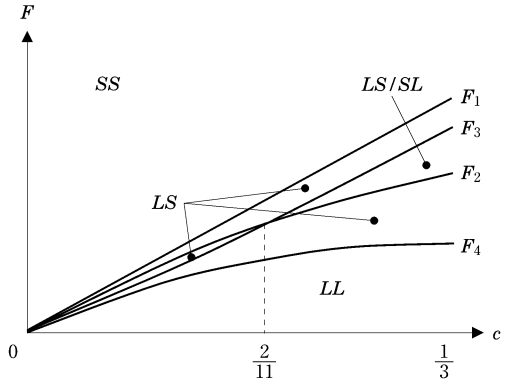
(i) *The leader firm chooses technology S irrespective of the follower firm's technology choice if $F>F_1$.*

(ii) *The leader firm chooses technology L irrespective of the follower firm's technology choice if $F<F_2$.*

(iii) *The leader firm chooses different technology from the follower firm's one if $F_1>F>F_2$.*

Both F_1 and F_2 are critical values for the leader firm 1's technology decision, where $F_1=\frac{c}{2}$ and $F_2=\frac{(1-c)c}{2}$.

Figure 1 : Firms' Technology Choice



Lemma 2: *Suppose that c is given.*

(i) *The follower firm chooses technology S irrespective of the leader firm's technology choice if* $F>F_3$.

(ii) *The follower firm chooses technology L irrespective of the leader firm's technology choice if* $F<F_4$.

(iii) *The follower firm chooses different technology from the leader firm's one if* $F_3>F>F_4$.

Both F_3 and F_4 are critical values for the follower firm 2's technology decision, where $F_3=\frac{3c(2+c)}{16}$ and $F_4=\frac{3c(2-3c)}{16}$.

From Lemmas 1 and 2, we obtain

Proposition 1: *Each firm chooses its technology as follows*:

(i) *Both firms choose technology S if* $F>F_1$.

(ii) *Both firms choose technology L if* $F<F_4$.

(iii) *The leader Firm chooses technology L while the follower firm chooses technology S if* $F_1>F>F_3$ or $F_2>F>F_4$.

(iv) *Firms choose different technologies if* $F_3>F>F_2$.

Proposition 1 states that multiple equilibria do not necessarily arise when firms choose different technologies under Stackelberg duopoly. This result is contrast to that in Mills and Smith (1996), which considered technology choice in the Cournot duopoly model. They showed that multiple equilibria always arise when firms choose different technologies. Intuition behind Proposition 1 is as follows: The leader firm produces more output than the follower firm when the firms use the same technology. Thus, given c and F, the effects of marginal cost reduction, which is derived by choosing technology L, are large for the leader as compared with the follower. Therefore, the leader firm tends to adopt technology L as compared with the follower firm when the firms choose the different technologies under Stackelberg competition. Figure 1 shows these results.

Table 3 : Social Welfare under Each Technology Combination

	W	CS	PS
SS	$\frac{15}{32}(1-c)^2$	$\frac{9}{32}(1-c)^2$	$\frac{3}{16}(1-c)^2$
LS	$\frac{1}{32}(23c^2-10c+15)-F$	$\frac{1}{32}(3-c)^2$	$\frac{1}{16}(11c^2-2c+3)-F$
SL	$\frac{1}{32}(28c^2-20c+15)-F$	$\frac{1}{32}(3-2c)^2$	$\frac{1}{16}(12c^2-4c+3)-F$
LL	$\frac{15}{32}-2F$	$\frac{9}{32}$	$\frac{3}{16}-2F$

Note that LS represents the technology combination where the leader (follower) firm chooses technology L (S).

Now, let us consider how affects the timing of output decision on the existence of heterogeneity. As shown in Mills and Smith (1996), when the firms compete *à la* Cournot, they choose different technologies if $4c/9>F>4c(1-c)/9$ in our model. Proposition 1 states that firms choose different technologies under Stackelberg duopoly if $F_1>F>F_4$. From Lemmas 1 and 2, $F_1>4c/9$ and $4c(1-c)/9>F_4$. We obtain

Proposition 2

Heterogeneity of technologies tends to occur under Stackelberg duopoly as compared with Cournot duopoly.

4. Welfare Analysis

In this section, we investigate whether the equilibrium technology choice is desirable from the viewpoint of social welfare, defined as the sum of consumer surplus and producer surplus:

$$W_{k_1k_2}=CS+PS=\frac{1}{2}Q^2+\pi_{1k}+\pi_{2k}. \tag{5}$$

Note that subscript k_1 (k_2) represents the leader (follower) firm's technology. From (5), Tables 1 and 2, we can calculate social welfare under each technology combination as shown in Table 3. From Table 3, we have following results:

Proposition 3 : *Socially desirable technology choice is as follows*:

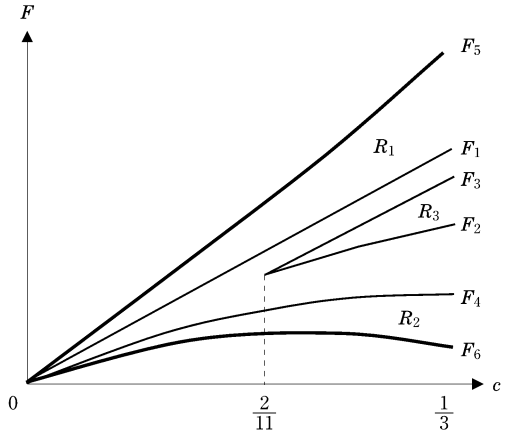
(i) SS *if* $F>F_5$.

(ii) LS *if* $F_5>F>F_6$.

(iii) LL *if* $F_6>F$.

Note that LS represents the technology combination where the leader (follower) firm chooses technology $L(S)$, and that $F_5=\frac{1}{8}c(5+2c)$ and $F_6=\frac{1}{32}c(10-23c)$.

Figure 2 : Social Desirability of Technology Choice



Proposition 3 indicates that adoption of technology L by the leader firm is socially desirable when heterogeneity of technologies arises. In other words, unilateral adoption of technology L by the follower (that is SL) is *never* desirable from the viewpoint of social welfare.

Now, let us investigate the social desirability of equilibrium technology choice. From Propositions 1 and 3, we obtain:

Proposition 4 : *Socially undesirable technology choice may occurs when LS is desirable from the viewpoint of social welfare as follows:*

(i) *No firms choose technology L in region* R_1.

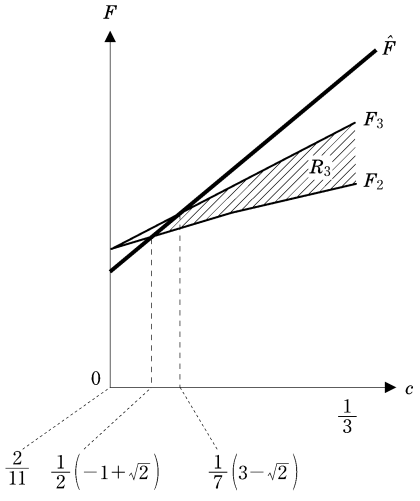
(ii) *Both firms choose technology L in region* R_2.

(iii) *The follower firm may choose technology L solely in region* R_3.

As shown in Mills and Smith (1996), equilibria tend to have too little heterogeneity from the viewpoint of social welfare even when the firms compete *à la* Stackelberg. However, we should note that heterogeneity of technology is *not necessarily* socially desirable under Stackelberg duopoly, although it is *always* socially desirable under Cournot duopoly. Intuitions behind Propositions 3 and 4 are as follows: As mentioned above, the leader firm can enjoy the effect of marginal cost reduction by adoption of technology L more than the follower firm because the leader firm produces more output than the follower firm if they use same technology. Consumer surplus is increasing function of total output. Producer surplus under technology combination LS is greater than that under SL due to the marginal cost reduction effect. Therefore, it is socially desirable for the leader to use technology L when the heterogeneity is desirable.

Finally, we investigate whether the leader firm earns more profit than the follower firm under any technology combination. When the firms use same technology, the leader firm earns more profit than the follower firm obviously. When the leader firm uses technology L solely in the equilibrium, it of course earns more profit than the follower firm. Suppose that

Figure 3 : Heterogeneity and Profitability



the leader (follower) firm uses technology S (L) in the equilibrium. From Table 2, the follower firm earns more profit than the leader one if $F<\dfrac{-4c^2+12c-1}{16}\equiv\widehat{F}$. From here, we obtain :

Proposition 5 : *Suppose that* $F_3>F>F_2$ *and that the follower firm chooses technolog* L *solely. Then, it earns more profit than the leader firm if* $F<\widehat{F}$.

Intuition behind Proposition 5 is as follows : When the follower firm uses technology L solely, it always produces more output than the leader firm.[4] This is because the effect of marginal cost reduction with technology L dominates that from disadvantage as Stackelberg follower. Then, the follower firm can earn more profit than the leader firm by adopting technology L unless the marginal cost reduction effect is not so small against fixed cost.[5] Figure 3 shows this result. In the shaded region, the follower firm earns more profit than the leader firm by choosing technology L unilaterally. Therefore, when heterogeneity of technologies arises and the follower firm chooses technology L solely the follower firm is very likely to earm more profit than leader firm. In other cases, the leader firm earns more profit than the follower firm.

5. Concluding Remark

This paper extends Cournot model of Mills and Smith (1996) to Stackelberg one in order to investigate how affect the timing of output decision on the technology choice as well as its desirability from the viewpoint of social welfare. In the first stage, the firms choose its production technology *simultaneously*. In the second stage, given the technologies chosen in the first stage, the firms choose its output *sequentially*. We assume that there are two avail-

able technologies: *large-scale* technology L and *small-scale* technology S for simplicity. Main conclusions we obtain are as follows: [i] Heterogeneity of technologies tends to occur under Stackelberg duopoly as compared with Cournot duopoly. [ii] Heterogeneity of technology is not necessarily socially desirable under Stackelberg duopoly, although it is always socially desirable under Cournot duopoly. [iii] Suppose that the follower firm uses technology L solely. Then, it tends to earn more profit than the leader firm.

In this paper, we assume that the firms choose its technology simultaneously although they choose output sequentially. Therefore, it may be worthwhile to investigate under sequential technology choice. Another possible direction for future research is to extend oligopoly model with sequential move as Elberfeld (2003) did.

References

Elberfeld, W. (2003), "A Note on Technology Choice, Firm Heterogeneity and Welfare", *International Journal of Industrial Organization*, vol. 21, pp. 593-605.

Elberfeld, W., and Götz, G. (2002), "Market Size, Technology Choice, and Market Structure", *German Economic Review*, vol. 3(1), pp. 25-41.

Elberfeld, W., and Nti, K. O. (2004), "Oligopolistic Competition and New Technology Adoption under Uncertainty", *Journal of Economics*, vol. 82(2), pp. 105-121.

Götz, G. (2005), "Market Size, Technology Choice, and the Existence of Free-Entry Equilibrium", *Journal of Institutional and Theoretical Economics*, vol. 161, pp. 503-521.

Mills, D. E., and Smith, W. (1996), "It Pays to be Different: Endogenous Heterogeneity of Firms in an Oligopoly", *International Journal of Industrial Organization*, vol. 14, pp. 317-329.

Note

1) Precisely, they assumed that firms choose technology from continuous technology set, and showed that firms choose only the extreme production technologies if the technology set is insufficient convex.

2) Mills and Smith (1996) and Elberfeld (2003) regarded choice of large-scale technology as cost-reducing investment and analyzed which technology is chosen, and whether market select efficient industry structure. Therefore, excess choice of large (small) - scale technology corresponds to overinvestment (underinvestment) in their analysis. Elberfeld and Götz (2002) considered similar issues under monopolistic competition. Götz (2005) considered technology choice in a free-entry Cournot model and discusses about the (non) existence problem. Elberfeld and Nti (2004) examined technology choice under ex ante uncertainty about variable cost.

3) Proofs are available upon request from the author.

4) From Table 2, the follower produces more output than the leader if $c>1/6$. This condition is always satisfied in this situation from Proposition 1 (iv).

5) Suppose that $F_3>F>F_2$. The condition $F<\widehat{F}$ is always satisfied if $c>\frac{1}{7}(3-\sqrt{2})$, and may be satisfied if $c>\frac{1}{2}(-1+\sqrt{2})$.