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OPTIMAL R&D POLICY AND ENDOGENOUS QUALITY CHOICE

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Abstract

In a quality-differentiated duopoly where (i) quality is endogenously chosen before production, (ii) fixed costs are increasing and convex in quality, and (iii) variable production costs are insubstantial, an R&D subsidy for the firm producing a high-quality product improves social welfare, irrespective of whether the ensuing product-market competition is Bertrand or Cournot, while an R&D subsidy for the firm producing a low-quality product improves social welfare only if Bertrand, and not if Cournot.

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1. Introduction

In high-technology industries, such as automobiles, computers, consumer electronics, and others, the firms engage in Research and Development (R&D, hereafter) activities to develop new products and improve product qualities, i.e., product R&D. Since oligopolistic competition prevails in such industries, the firms invest strategically in product R&D. In that case, socially optimal product qualities are not necessarily chosen by an individual firm. But there are many cases where governments have used various policy measures to affect R&D activities. In particular, R&D subsidies and government-sponsored research projects have been popular in Japan and European countries.

A micro-theoretic rationale for subsidising R&D investments to improve product quality is that the social benefit of the resulting quality improvement is higher than the incremental profit it generates, as only the former, and not the latter takes the increase in consumers' surplus into account. From a socially optimal point of view, such R&D should be motivated by more than the firm's profit incentives. A natural yet non-trivial question springs from this observation: what if there are multiple firms competing in a vertically differentiated product oligopoly? Assuming that policy measures can be tailored to subsidize or tax each firm separately, should a firm producing a high-quality product (a higher quality firm, hereafter) be subsidized or taxed? What about a firm producing a low-quality product (a lower quality firm, hereafter)?

Although there are many theoretical models addressing process R&D activities, we know a few works analyzing the economic implications of product R&D activities under imperfect competition, e.g., Symeonidis (2003). There are a few papers closely related to ours: Lahiri and Ono (1999) and Zhou et al. (2002). First, Lahiri and Ono have examined the structure of optimal R&D taxes-cum-subsidies, by considering endogenous R&D investments by Cournot duopolists with an initial cost differential. In their model, R&D investments reduce the marginal costs of production, i.e., process R&D. Lahiri and Ono have found that under Cournot competition in a homogenous product market, the firm with a lower (higher) primary marginal cost invests more (less, respectively) in process R&D and thus takes the larger (smaller, respectively) market share; that the government should subsidize the larger firm with lower marginal initial costs and tax the smaller firm with higher marginal initial costs in order to maximize social welfare. Their conclusion implies that the distribution of output and profits among the firms under Cournot competition is an essential factor in the maximization of social welfare. In other words, helping an efficient firm and eliminating an inefficient firm eventually leads to increases in consumer surplus and producer surplus (Lahiri and Ono, 1988).

Second, using a standard vertically differentiated product model, Zhou et al. (2002) have examined the implications of a 'strategic trade policy' targeted at investments in quality improvements of exported products. It is assumed in their model that the firm producing a higher (lower) quality product locates in a (less, respectively) developed country, and that the two firms compete in a third country's market. Zhou et al. have shown that under Bertrand (Cournot) competition, the developed country's government should tax (subsidize, respectively) the higher quality firm, while the less developed country's government should subsidize (tax, respectively) the lower quality firm.

We will present a standard version of vertically differentiated product models, where (i) quality is endogenously chosen before production, (ii) fixed costs are increasing and convex in quality, and (iii) variable production costs are insubstantial. Based on that model, we will examine optimal subsidy/tax policies applied to R&D investments in quality improvements in a concentrated industry where Bertrand or Cournot product-market competition prevails.

As mentioned above, Zhou et al. (2002) has discussed the optimal R&D policy in the context of international rivalry. That context implies that the purpose of a government is to maximize the net profit of each country's firm. In other words, they mainly focus on the international distribution of profits in order to interpret the implications of a 'strategic trade policy'. As will be shown below, we will also address the R&D policy to maximize net producer surplus, i.e., aggregate profit. We agree with the results of Zhou et al. as to the jointly optimal policies. In addition, we will analyze optimal R&D policies to maximize net consumer surplus and to social surplus.

We will mainly derive the following results: First, regardless of the mode of competition, maximizing net consumer surplus calls for R&D subsidies for the firms, if the government's burden of the subsidies is sufficiently small. Intuitively, this is because R&D subsidies increase the qualities and/or the quantities demanded. Second, the R&D policy of maximizing net producer surplus leads to an increase in quality difference and thus to reduction of the degree of competition in the market. Hence, under Bertrand (Cournot) competition, subsidizing (taxing, respectively) the higher quality firm and taxing the lower quality firm result in increased aggregate profit. But such a policy does not necessarily increase the profit of an individual firm. Third, from a viewpoint of the maximization of social welfare, subsidizing the higher quality firm is always optimal. On the other hand, the socially optimal policy for the lower quality firm depends on the mode of competition. That is, under Bertrand (Cournot) competition, subsidizing (taxing, respectively) the lower quality firm results in increased social welfare.

The rest of this paper is organized as follows. In Section 2 we will set up our model, presenting the structure of consumer preferences and cost functions underlying the model of a quality-differentiated duopoly. In Section 3 we will analyze endogenous quality choice and the effects of R&D subsidies, and then show optimal R&D policies. We will first investigate the issues under Bertrand competition and then under Cournot competition. Finally, in Section 4 we will summarize our results and present some related issues.

2. The model

We use a version of the standard quality differentiation model presented by Mussa and Rosen (1978), Shaked and Sutton (1982, 1983), and others. There exists a continuum of consumers whose types are indexed by θ, $\theta \in [0, 1]$, and associated with a utility function, $u(\theta, q)$. Consumer θ is assumed to purchase either one or zero units of a quality-differentiated product. Let q designate quality, which is modeled as a unidimensional variable, $q \in [0, \infty)$. To simplify, we assume that the continuum of consumers is uniformly distributed with density one, and that the utility function of consumer θ is $u(\theta, q) = \theta q$. That is, consumer θ is willing to pay up to θq dollars for one unit of the product. Hence his/her surplus is expressed as

$$V(\theta, q, P) = \theta q - P. \tag{1}$$

P is the price of the product. If consumer θ does not purchase any product, his/her surplus is zero.

We concentrate on an industry in which each of two firms offers a single variant of a quality-differentiated product. There are two qualities observed in the market: a higher quality, q_1, and a lower quality, q_2, $q_1 > q_2$. In what follows, we assume that firm 1 (2) produces a higher (lower, respectively) quality product.

Let us consider the marginal consumer indexed by θ_{1m} who has the same surplus, regardless of whether that consumer purchases either the higher quality product or the lower quality product. Based on (1), we have $\theta q_1 - P_1 = \theta q_2 - P_2$. The index of the marginal consumer is

$$\theta_{1m} = (P_1 - P_2)/(q_1 - q_2). \tag{2}$$

Similarly, the marginal consumer, indexed by θ_{2m}, who wants to buy either the lower quality product or none, has index

$$\theta_{2m} = P_2/q_2. \tag{3}$$

The demand for the higher (lower) quality product is expressed by x_1 (x_2, respectively). Taking into account (2) and (3), the demand for the higher and lower quality products can be shown as

$$x_1 = 1 - \theta_{1m} = 1 - (P_1 - P_2)/(q_1 - q_2), \tag{4.1}$$

$$x_2 = \theta_{1m} - \theta_{2m} = (P_1 - P_2)/(q_1 - q_2) - P_2/q_2. \tag{4.2}$$

For the analysis below, we let X $(= 1 - \theta_{2m})$ be the size of the quality-differentiated product market. The market size means the number of consumers who purchase some version of the quality-differentiated products.

In view of (4.1) and (4.2), the corresponding inverse demand functions are

$$P_1 = q_1 (1 - x_1) - q_2 x_2, \tag{5.1}$$

$$P_2 = q_2 (1 - x_1 - x_2). \tag{5.2}$$

Following the standard assumption in the literature of a vertical product differentiation (e.g., Aoki and Prusa, 1996; Ronnen, 1991; Shaked and Sutton, 1982, 1983; Zhou et al., 2002), we assume that a fixed cost depends on quality

$$F_i = F_i\,(q_i);\ F_i(0) = \partial F_i(0)/\partial q_i = 0;\ \partial F_i(q_i)/\partial q_i > 0 \text{ and } \partial^2 F_i(q_i)/\partial q_i^2 > 0 \text{ for } q_i > 0;$$

$$\lim_{q_i \to \infty} \partial F_i(q_i)/\partial q_i = \infty;\ \partial^3 F_i(q_i)/\partial q_i^3 \geq 0,\ i = 1, 2. \tag{6}$$

In order to focus on investment decisions to improve quality, we let variable costs of production be zero. This assumption implies that the costs of quality improvement have already been expended in the stage of product-market competition.

3. Endogenous quality choice and R&D policy

In this section, we analyze endogenous quality choice and R&D subsidy/tax policies. We present a three-stage game: In the first stage, the government sets a firm-specific R&D subsidy/tax rate; in the second stage, the two firms simultaneously choose the quality level, given the government's R&D policy; and in the third stage, the two firms compete in price, or in quantity, given their qualities and the policy. We derive a subgame perfect equilibrium by backward induction.

3.1. Price-quality competition case

3.1.1. Endogenous quality choice and effect of R&D subsidy on quality

Since the derivation of the Bertrand-Nash equilibrium in the product market is generally known and straightforward, we present the equilibrium outcomes in which the two firms compete in price at the final stage:

$$P_1^B = 2q_1 (q_1 - q_2)/D, \tag{7.1}$$

$$P_2^B = q_2 (q_1 - q_2)/D, \tag{7.2}$$

$$x_1^B = 2q_1/D, \tag{8.1}$$

$$x_2^B = q_1/D, \tag{8.2}$$

where superscript B denotes Bertrand competition and $D = 4q_1 - q_2 > 0.$

The two firms' revenues as functions of quality are

$$R_1^B(q_1, q_2) = 4(q_1)^2 (q_1 - q_2)/D^2, \tag{9.1}$$

$$R_2^B(q_1, q_2) = q_1q_2(q_1 - q_2)/D^2. \tag{9.2}$$

Aoki and Prusa (1997, lemma 2), Zhou et al. (2002), and others have already shown the properties of the revenue functions. The first order derivatives have signs: $\partial R_1^B/\partial q_1 > 0$, $\partial R_1^B/\partial q_2 < 0$, $\partial R_2^B/\partial q_2 > (\leq)\ 0 \longleftrightarrow q_1 > (\leq)\ (7/4)q_2$, and $\partial R_2^B/\partial q_1 > 0.$ In what follows, we assume $q_1 > (7/4)q_2$. Further, the second order derivatives have signs: $\partial^2 R_1^B/\partial q_1^2 < 0$, $\partial^2 R_1^B/\partial q_1\partial q_2 = -(q_1/q_2)(\partial^2 R_1^B/\partial q_1^2) > 0$, $\partial^2 R_2^B/\partial q_2^2 < 0$, and $\partial^2 R_2^B/\partial q_2\partial q_1 = -(q_2/q_1)(\partial^2 R_2^B/\partial q_2^2) > 0.$ The positive cross partial derivative, $\partial^2 R_i^B/\partial q_i\partial q_j > 0,$ implies that qualities are strategic complements.

We consider the determination of quality at the second stage. Let us define s_i as the portion of the cost of investments in quality covered by an R&D subsidy to firm i for $i = 1, 2$. Assuming $s_i < 1$, with $s_i < 0$ corresponding to an R&D tax, the two firms face a strictly positive investment cost, with the profits for firm i given by

$\Pi_i^B(q_i, q_j, s_i) = R_i^B(q_i, q_j) - (1 - s_i)F_i(q_i), i \neq j, i, j = 1, 2.$ The first order condition to maximize the profit of firm i is

$$\partial \Pi_i^B(q_i, q_j, s_i)/\partial q_i = \partial R_i^B(q_i, q_j)/\partial q_i - (1 - s_i)\partial F_i(q_i)/\partial q_i = 0, i \neq j, i, j = 1, 2. \qquad (10)$$

Taking into account the properties of the fixed costs and of the revenue functions, the second order and stability conditions are satisfied. The reaction function of firm i is expressed as $q_i^B = q_i^B(q_j, s_1, s_2), i \neq j, i, j = 1, 2.$ The reaction curves of the two firms are upward sloping in quality space. Furthermore, the second order and stability conditions ensure that the lower quality firm has a steeper reaction curve than the higher quality firm and thus that the curves cross at a unique Nash equilibrium in quality space, i.e., (q_1^B, q_2^B).

We now examine the effects of R&D subsidies. Totally differentiating (10) for $i = 1$ and 2, we obtain the effects of subsidizing the higher and lower quality firm on qualities

$$dq_1^B/ds_1 = -(\partial F_1/\partial q_1)(\partial^2 \Pi_2^B/\partial q_2^2)/\Delta^B > 0, \qquad (11.1)$$

$$dq_2^B/ds_1 = (\partial F_1/\partial q_1)(\partial^2 \Pi_2^B/\partial q_2 \partial q_1)/\Delta^B > 0, \qquad (11.2)$$

$$dq_1^B/ds_2 = (\partial F_2/\partial q_2)(\partial^2 \Pi_1^B/\partial q_1 \partial q_2)/\Delta^B > 0, \qquad (12.1)$$

$$dq_2^B/ds_2 = -(\partial F_2/\partial q_2)(\partial^2 \Pi_1^B/\partial q_1^2)/\Delta^B > 0, \qquad (12.2)$$

where

$$\Delta^B = (1-s_1)(\partial^2 F_1/\partial q_1^2)(1-s_2)(\partial^2 F_2/\partial q_2^2) - (1-s_1)(\partial^2 F_1/\partial q_1^2)(\partial^2 R_2^B/\partial q_2^2)$$
$$- (1-s_2)(\partial^2 F_2/\partial q_2^2)(\partial^2 R_1^B/\partial q_1^2) > 0.$$

Taking into account (8.1), (8.2), (11.1), (11.2), (12.1) and (12.2), the effects of subsidizing the higher and lower quality firm on quantities demanded are

$$dx_1^B/ds_1 = -(x_1^B/D)\Lambda_1^B < 0, \qquad (13.1)$$

$$dx_2^B/ds_1 = -(x_2^B/D)\Lambda_1^B < 0, \qquad (13.2)$$

$$dx_1^B/ds_2 = (x_1^B/D)\Lambda_2^B > 0, \qquad (14.1)$$

$$dx_2^B/ds_2 = (x_2^B/D)\Lambda_2^B > 0, \qquad (14.2)$$

where

$$\Lambda_1^B = (\partial F_1/\partial q_1)(1-s_2)(\partial^2 F_2/\partial q_2^2)(q_2^B/q_1^B)/\Delta^B > 0,$$

$\Lambda_2^B = (\partial F_2/\partial q_2)(1-s_1)(\partial^2 F_1/\partial q_1^2)/\Delta^B > 0.$

Thus, let us summarize the results derived above as follows:

Proposition 1. (1) *With Bertrand duopoly, R&D subsidies increase the two qualities.*

(2) *With Bertrand duopoly, an R&D subsidy for the higher (lower) quality firm decreases (increases, respectively) the quantities demanded of the two firms.*

(3) *With Bertrand duopoly, an R&D subsidy for the higher (lower) quality firm decreases (increases, respectively) the market size.*

First, the economic intuition behind Proposition 1 (1) is clear. Since an R&D subsidy for a firm reduces the burden of investment costs, the firm has an incentive to raise its quality level. Hence an increase in the firm's quality raises the other firm's quality due to the strategic complement relationship. Second, subsidizing the higher (lower) quality firm increases (reduces, respectively) the difference in qualities, q_1^B/q_2^B. Proposition 1 (2) is because in the case of subsidizing the higher (lower) quality firm, the two firms' quality levels being farther apart (close) reduce (promote, respectively) the severity of price competition. Third, Proposition 1 (3) is obvious, taking into account Proposition 1 (2).

3.1.2. Optimal R&D policy

Let us begin with the analysis of the effects of R&D subsidies on consumer surplus and find the consumer-oriented R&D policy to maximize net total consumer surplus. Second, we will examine the effects of R&D subsidies on profits and producer surplus, and then present the producer-oriented R&D policy to maximize net producer surplus, i.e., aggregate profit. Third, we will show the optimal R&D policy to maximize social surplus.

First, total consumer surplus is the sum of the surplus of those who purchase the higher quality product, CS_1, and of those who purchase the lower quality product,

CS_2. Taking into account (1), (2) and (3), we derive

$$CS_1 = (1 - \theta_{1m})(q_1\theta_{1A} - P_1),$$

$$CS_2 = (\theta_{1m} - \theta_{2m})(q_2\theta_{2A} - P_2),$$

where $\theta_{1A} = (1 + \theta_{1m})/2 = 1 - (x_1/2)$ and $\theta_{2A} = (\theta_{1m} + \theta_{2m})/2 = 1 - x_1 - (x_2/2)$. θ_{1A} (θ_{2A}) is the index of the average consumer who purchases the higher (lower, respectively) quality product. Substituting (5.1) and (5.2) into the equations above can be rewritten as

$$CS_1 = x_1\{q_1(x_1/2) + q_2x_2\}, \tag{15.1}$$

$$CS_2 = x_2\{q_2(x_2/2)\}. \tag{15.2}$$

Under Bertrand competition, based on (8.1) and (8.2), the total consumer surplus, CS^B, is expressed as

$$CS^B = CS_1{}^B + CS_2{}^B = (X^B)^2(4q_1{}^B + 5q_2{}^B)/18. \tag{16}$$

Differentiating (16) with respect to s_1, we obtain the effect of subsidizing the higher quality firm on the total consumer surplus

$$sgn\ (dCS^B/ds_1) = sgn\ \{2(8q_1{}^{B2} - 6q_1{}^Bq_2{}^B - 5q_2{}^{B2})/[q_1{}^B(28q_1{}^B + 5q_2{}^B)] + \Gamma_2{}^B\},$$

where $\Gamma_2{}^B = (dq_2{}^B/ds_1)/(dq_1{}^B/ds_1) = -(\partial^2\Pi_2{}^B/\partial q_2\partial q_1)/(\partial^2\Pi_2{}^B/\partial q_2{}^2) = \partial q_2{}^B(q_1)/\partial q_1 < 1.$ Since the two qualities are assumed to be so far apart, $q_1{}^B \geq (7/4)\ q_2{}^B$, the effect on the total consumer surplus is positive. This is because the benefit of the increased qualities more than outweighs the cost of the decreased market size.

Moreover, in view of Proposition 1, since the subsidy increases the qualities and quantities demanded of the two firms, it increases each consumer surplus and thus total consumer surplus.

We suppose that the purpose of the government is to maximize net total consumer surplus: $GC^B(s_1,\ s_2) = CS^B - (s_1F_1 + s_2F_2)$. Given s_2, the first order condition with respect to s_1 to maximize GC^B is

$$\begin{aligned} dGC^B/ds_1 = \{&(\partial CS^B/\partial q_1)(dq_1{}^B/ds_1) + (\partial CS^B/\partial q_2)(dq_2{}^B/ds_1)\} - F_1 \\ &- s_1(\partial F_1/\partial q_1)(dq_1{}^B/ds_1) - s_2\,(\partial F_2/\partial q_2)(dq_2{}^B/ds_1) = 0. \end{aligned} \tag{17.1}$$

Similarly, given s_1, that condition with respect to s_2 is

$$dGC^B/ds_2 = \{(\partial CS^B/\partial q_1)(dq_1{}^B/ds_2) + (\partial CS^B/\partial q_2)(dq_2{}^B/ds_2)\} - F_2$$
$$- s_1(\partial F_1/\partial q_1)(dq_1{}^B/ds_2) - s_2(\partial F_2/\partial q_2)(dq_2{}^B/ds_2) = 0. \tag{17.2}$$

Thus the maximizing net total consumer surplus policy satisfies

$$s_1{}^{B*} = \Phi_1{}^B/\{(\partial F_1/\partial q_1)\Omega^B\}, \tag{18.1}$$

$$s_2{}^{B*} = \Phi_2{}^B/\{(\partial F_2/\partial q_2)\Omega^B\}, \tag{18.2}$$

where

$$\Omega^B = (dq_1{}^B/ds_1)(dq_2{}^B/ds_2)\{1 - \Gamma_1{}^B\Gamma_2{}^B\} > 0,$$

$$\Gamma_1{}^B = (dq_1{}^B/ds_2)/(dq_2{}^B/ds_2) = -(\partial^2\Pi_1/\partial q_1\partial q_2)/(\partial^2\Pi_1/\partial q_1{}^2) = \partial q_1{}^B(q_2)/\partial q_2 > 0,$$

$$\Phi_1{}^B = (\partial CS^B/\partial q_1)\Omega^B - \{F_1(dq_2{}^B/ds_2) - F_2(dq_2{}^B/ds_1)\},$$

$$\Phi_2{}^B = (\partial CS^B/\partial q_2)\Omega^B - \{F_2(dq_1{}^B/ds_1) - F_1(dq_1{}^B/ds_2)\}.$$

The effect of an increase in quality of the higher quality firm on the net total consumer surplus is $\partial CS^B/\partial q_1 = \{4(x_1{}^B)^2/(q_1{}^B D)\}\{[q_1{}^B - (5/4)q_2{}^B](2q_1{}^B + q_2{}^B)\}$. That effect is positive by the assumption, i.e., $q_1{}^B > (7/4)q_2{}^B$. Also, the effect of an increase in quality of the lower quality firm is always positive: $\partial CS/\partial q_2 = \{(x_2{}^B)^2/(2D)\}(28q_1{}^B + 5q_2{}^B) > 0$. Furthermore, the second term of $\Phi_i{}^B$, $i = 1, 2,$ implies the government's burden of R&D subsidies, which is of ambiguous sign. We thus present the following proposition:

Proposition 2. *With Bertrand duopoly, in order to maximize net total consumer surplus, the government should subsidize the two firms if the government's burden of R&D subsidies is sufficiently small.*

Second, let us examine the effect of an R&D subsidy on the two firms' profits. The effects of subsidizing the higher quality firm are

$$d\Pi_1{}^B/ds_1 = (\partial R_1{}^B/\partial q_2)(dq_2{}^B/ds_1) + F_1, \tag{19.1}$$

$$d\Pi_2{}^B/ds_1 = (\partial R_2{}^B/\partial q_1)(dq_1{}^B/ds_1) > 0. \tag{19.2}$$

When the lower quality firm increases its quality, the higher quality firm has an incentive to raise its quality since maintaining quality differentiation prevents price competition from intensifying. Hence an increase in quality of the lower quality firm reduces the higher quality firm's revenue. But the R&D subsidy directly increases the higher quality firm's profit. Thus, that effect is of ambiguous sign. On the other hand, when the higher quality firm increases its quality, an increase in quality of the higher quality firm relaxes price competition. In addition, an increase in quality of the lower quality firm expands the demand for its product. Since the lower quality firm has an incentive to raise its quality level at a rate of less than one for one, compared to the higher quality firm's quality increase, quality is a strategic complement for the lower quality firm as well. Hence an increase in quality of the higher quality firm increases the lower quality firm's revenue. Thus the effect on the lower quality firm is of positive sign.

Similarly, the effects of subsidizing the lower quality firm on the profits of the two firms are

$$d\Pi_1^B/ds_2 = (\partial R_1^B/\partial q_2)(dq_2{}^B/ds_2) < 0, \tag{20.1}$$

$$d\Pi_2^B/ds_2 = (\partial R_2^B/\partial q_1)(dq_1^B/ds_2) + F_2 > 0, \tag{20.2}$$

which are true.

Moreover, let us analyze the effects of R&D subsidies on producer surplus, which can be written as: $PS^B\,(s_1,\ s_2) = \Pi_1^B + \Pi_2^B.$ Taking into account (19.1) and (19.2), we obtain the effect of subsidizing the higher quality firm on producer surplus

$$dPS^B/ds_1 = \{(\partial R_1^B/\partial q_2)\Gamma_2^B + (\partial R_2^B/\partial q_1)\}(dq_1^B/ds_1) + F_1. \tag{21.1}$$

As to the first term of RHS in (21.1), we have the following relationship:

$$(\partial R_1^B/\partial q_2)\Gamma_2^B + (\partial R_2^B/\partial q_1) > (<)\ 0 \longleftrightarrow (q_2{}^B/2q_1^B)^2 > (<)\ \Gamma_2^B.$$

If $(q_2{}^B/2q_1^B)^2 \geq \Gamma_2^B$, that effect is positive. Otherwise, the effect of subsidizing the higher quality firm on producer surplus is of ambiguous sign. Also, the effect of subsidizing the lower quality firm on producer surplus is

$$dPS^B/ds_2 = \{(\partial R_1^B/\partial q_2) + (\partial R_2^B/\partial q_1)\Gamma_1^B\}(dq_2{}^B/ds_2) + F_2. \tag{21.2}$$

Since the first term of RHS in (21.2) is negative, the effect on producer surplus is of ambiguous sign.

It has often been said that the Japanese government's industrial policies are producer-oriented, and tend to be more oriented to large companies, but never to the benefit of consumers. Based on the analysis above, we present the R&D policy to maximize net producer surplus, i.e., aggregate profit. We suppose that the government has the following purpose function: $GP^B(s_1, s_2) = PS^B - (s_1F_1 + s_2F_2) = R_1^B - F_1 + R_2^B - F_2$, where the opportunity cost of a dollar of public funds is assumed to be equal to one. Given s_2, the first order condition to maximize GP^B with respect to s_1 is

$$dGP^B/ds_1 = -s_1(\partial F_1/\partial q_1)(dq_1^B/ds_1) + (\partial R_1^B/\partial q_2)(dq_2^B/ds_1)$$
$$- s_2(\partial F_2/\partial q_2)(dq_2^B/ds_1) + (\partial R_2^B/\partial q_1)(dq_1^B/ds_1) = 0. \quad (22.1)$$

Similarly, given s_1, that condition to maximize GP^B with respect to s_2 is

$$dGP^B/ds_2 = -s_1(\partial F_1/\partial q_1)(dq_1^B/ds_2) + (\partial R_1^B/\partial q_2)(dq_2^B/ds_2)$$
$$- s_2(\partial F_2/\partial q_2)(dq_2^B/ds_2) + (\partial R_2^B/\partial q_1)(dq_1^B/ds_2) = 0. \quad (22.2)$$

From (22.1) and (22.2), we find that the R&D subsidy-cum-tax policy to maximize net producer surplus, s_1^{B**}, s_2^{B**}, satisfies

$$s_1^{B**} = (\partial R_2^B/\partial q_1)/(\partial F_1/\partial q_1) > 0, \quad (23.1)$$

$$s_2^{B**} = (\partial R_1^B/\partial q_2)/(\partial F_2/\partial q_2) < 0. \quad (23.2)$$

Therefore, we have the following proposition:

Proposition 3. *With Bertrand duopoly, in order to maximize net producer surplus, the government should subsidize the higher quality firm and tax the lower quality firm.*

Such a discriminatory R&D policy extends the difference in the qualities of the two firms. In turn, an increase in the difference relaxes price competition and thus increases aggregate profit. But it reminds us that the taxation reduces the total consumer surplus and the lower quality firm's profit.

Third, we are in a position to show an optimal R&D policy to maximize social surplus. Let us define social surplus as follows:

$$W^B (s_1, s_2) = CS^B + PS^B - s_1F_1 - s_2F_2$$

$$= U_1^B - F_1 + U_2^B - F_2, \tag{24}$$

where $U_1^B = q_1^B\theta_{1A}\ x_1^B$ and $U_2^B = q_2^B\theta_{2A}\ x_2^B$. $U_1^B\,(U_2^B)$ is the total utility of all consumers purchasing the higher (lower, respectively) quality product.

Given s_2, the first order condition to maximize social surplus with respect to s_1 is

$$dW^B/ds_1 = \{\partial U_1^B/\partial q_1 + \partial U_2^B/\partial q_1 - \partial F_1/\partial q_1\}(dq_1^B/ds_1)$$

$$+ \{\partial U_1^B/\partial q_2 + \partial U_2^B/\partial q_2 - \partial F_2/\partial q_2\}(dq_2^B/ds_1) = 0.$$

The equation above can be rewritten as

$$dW^B/ds_1 = \{\Sigma_1^B - s_1(\partial F_1/\partial q_1)\}(dq_1^B/ds_1) + \{\Sigma_2^B - s_2\,(\partial F_2/\partial q_2)\}(dq_2^B/ds_1) = 0, \tag{25.1}$$

where

$$\Sigma_1^B = \partial U_1^B/\partial q_1 + \partial U_2^B/\partial q_1 - \partial R_1^B/\partial q_1 > 0,$$

$$\Sigma_2^B = \partial U_1^B/\partial q_2 + \partial U_2^B/\partial q_2 - \partial R_2^B/\partial q_2 > 0.$$

Similarly, given s_1, the first order condition with respect to s_2 is

$$dW^B/ds_2 = \{\Sigma_1^B - s_1(\partial F_1/\partial q_1)\}(dq_1^B/ds_2) + \{\Sigma_2^B - s_2(\partial F_2/\partial q_2)\}(dq_2^B/ds_2) = 0. \tag{25.2}$$

From (25.1) and (25.2), we find that the optimal R&D policy to maximize social surplus, s_1^{B***}, s_2^{B***}, satisfies

$$s_1^{B***} = \Sigma_1^B/(\partial F_1/\partial q_1) > 0, \tag{26.1}$$

$$s_2^{B***} = \Sigma_2^B/(\partial F_2/\partial q_2) > 0. \tag{26.2}$$

We thus summarize as follows:

Proposition 4. *With Bertrand duopoly, subsidizing the two firms is socially optimal.*

Σ_i^B is the difference between the marginal utility of consumers purchasing the product of firm i and the marginal revenue of firm i. The positive sign of Σ_i^B in the equations above implies that the quality level chosen by each firm in the unregulated market is too low from the viewpoint of social optimality. Thus, the government ought to subsidize the two firms in order to promote the R&D

investments to improve qualities.

3.2. Quantity-Quality Competition Case

3.2.1. Endogenous quality choice and effect of R&D subsidy on quality

We address the case of Cournot competition in which the two firms choose quantities in the final stage after committing to qualities in the second stage. It is well known in the literature of strategic trade and industrial policy that if firms compete in quantities rather than in prices, the optimal policy may be reversed. We present the Cournot-Nash equilibrium outcomes in the final stage:

$$x_1^C = (2q_1 - q_2)/D, \tag{27.1}$$

$$x_2^C = q_1/D, \tag{27.2}$$

$$P_1^C = q_1 x_1^C, \tag{28.1}$$

$$P_2^C = q_2 x_2^C, \tag{28.2}$$

where superscript C denotes Cournot competition.

The two firms' revenues as functions of quality are

$$R_1^C(q_1, q_2) = q_1(2q_1 - q_2)/D^2, \tag{29.1}$$

$$R_2^C(q_1, q_2) = q_1 q_2/D^2. \tag{29.2}$$

The first order derivatives have signs: $\partial R_i^C/\partial q_i > 0$, $\partial R_i^C/\partial q_j < 0$, $i \neq j$, $i, j = 1, 2$. Furthermore, the second order derivatives have signs: $\partial^2 R_1^C/\partial q_1^2 < 0$, $\partial^2 R_1^C/\partial q_1 \partial q_2 = -(q_1/q_2)(\partial^2 R_1^C/\partial q_1^2) > 0$, $\partial^2 R_2^C/\partial q_2^2 > 0$, and $\partial^2 R_2^C/\partial q_2 \partial q_1 = -(q_2/q_1)(\partial^C R_2^C/\partial q_2^2) < 0$. The negative cross partial derivative, $\partial^2 R_2^C/\partial q_2 \partial q_1 < 0$, implies that quality is a strategic substitute for the lower quality firm. The higher quality increase has a negative effect on the lower quality firm's revenue. Since the lower quality firm can make this negative effect smaller by decreasing its own quality, it has an incentive to do so even if the reduction in its own quality has a direct negative effect on its own revenue. Thus, together with cost savings from reduced quality, the lower quality firm can increase its own profit by reducing its quality in response to an increase in its rival's quality.

The two firms face a strictly positive investment cost, with profits for firm i given by $\Pi_i^C(q_i, q_j, s_i) = R_i^C(q_i, q_j) - (1 - s_i)F_i(q_i), i \neq j, i, j = 1, 2.$ The first order condition to maximize the profit of firm i is

$$\partial\Pi_i^C(q_i, q_j, s_i)/\partial q_i = \partial R_i^C(q_i, q_j)/\partial q_i - (1 - s_i)\partial F_i(q_i)/\partial q_i = 0, i \neq j, i, j = 1, 2. \quad (30)$$

Based on the properties of the fixed costs and of the revenue functions, the second order and stability conditions are satisfied. The reaction function of firm i can be expressed as $q_i^C = q_i^C(q_j, s_1, s_2), i \neq j, i, j = 1, 2.$ The reaction curve of the higher (lower) quality firm is upward (downward, respectively) sloping in quality space. Moreover, the second order and stability conditions ensure that the curves cross at a unique Nash equilibrium in quality space, i.e., (q_1^C, q_2^C)

We show the effects of R&D subsidies. Totally differentiating (30) for $i = 1$ and 2, we derive the effects of subsidizing the higher and lower quality firm on qualities:

$$dq_1^C/ds_1 = -(\partial F_1/\partial q_1)(\partial^2\Pi_2^C/\partial q_2^2)/\Delta^C > 0, \quad (31.1)$$

$$dq_2^C/ds_1 = (\partial F_1/\partial q_1)(\partial^2\Pi_2^C/\partial q_2\partial q_1)/\Delta^C < 0, \quad (31.2)$$

$$dq_1^C/ds_2 = (\partial F_2/\partial q_2)(\partial^2\Pi_1^C/\partial q_1\partial q_2)/\Delta^C > 0, \quad (32.1)$$

$$dq_2^C/ds_2 = -(\partial F_2/\partial q_2)(\partial^2\Pi_1^C/\partial q_1^2)/\Delta^C > 0, \quad (32.2)$$

where

$$\Delta^C = (1-s_1)(\partial^2F_1/\partial q_1^2)(1-s_2)(\partial^2F_2/\partial q_2^2) - (1-s_1)(\partial^2F_1/\partial q_1^2)(\partial^2R_2^C/\partial q_2^2)$$
$$- (1-s_2)(\partial^2F_2/\partial q_2^2)(\partial^2R_1^C/\partial q_1^2) > 0.$$

Based on (27.1), (27.2), (31.1), (31.2), (32.1), and (32.2), we obtain the effects of subsidizing the higher and lower quality firm on output

$$dx_1^C/ds_1 = (2x_1^C/D)\Lambda_1^C > 0, \quad (33.1)$$

$$dx_2^C/ds_1 = -(x_2^C/D)\Lambda_1^C < 0, \quad (33.2)$$

$$dx_1^C/ds_2 = -(2x_1^C/D)\Lambda_2^C < 0, \quad (34.1)$$

$$dx_2^C/ds_2 = (x_2^C/D)\Lambda_2^C > 0, \quad (34.2)$$

where

$\Lambda_1^C = (\partial F_1/\partial q_1)(1-s_2)(\partial^2 F_2/\partial q_2^2)(q_2^C/q_1^C)/\Delta^C > 0,$

$\Lambda_2^C = (\partial F_2/\partial q_2)(1-s_1)(\partial^2 F_1/\partial q_1^2)/\Delta^C > 0.$

Moreover, in view of (33.1), (33.2), (34.1), and (34.2), we present the effect of the R&D subsidies on the number of consumers in the quality-differentiated market, i.e., the market size, X^C:

$$dX^C/ds_1 = (x_2^C/D)\Lambda_1^C > 0, \tag{35.1}$$

$$dX^C/ds_2 = (x_2^C/D)\Lambda_2^C < 0. \tag{35.2}$$

Let us summarize the various results derived above as follows:

Proposition 5. (1.1) *With Cournot duopoly, an R&D subsidy for the higher quality firm increases its quality, while it reduces the quality of the lower quality firm;* (1.2) *With Cournot duopoly, an R&D subsidy for the lower quality firm increases the qualities of the two firms.*

(2) *With Cournot duopoly, an R&D subsidy for one firm increases its output, while it reduces the other's output.*

(3) *With Cournot duopoly, an R&D subsidy for the higher (lower) quality firm increases (decreases, respectively) the market size.*

First, the economic intuition of Proposition 5 (1.1) is as follows. In general, since subsidizing a firm reduces the burden of investment costs, the firm has an incentive to raise its quality level. The increase in quality of the higher quality firm reduces the quality of the lower quality firm by the strategic substitute relationship. On the other hand, Proposition 5 (1.2) is obvious, taking into account the strategic complement relationship. Second, the intuition for Proposition 5 (2) is as follows. Since the quality improvement provided by the R&D subsidy directly expands the demand, the subsidized firm has an incentive to increase its output. In addition, the increase in the output reduces that of the other firm by the strategic substitute relationship under Cournot competition. Third, in view of (27.1) and

(27.2), the higher quality firm has a larger market share than the lower quality firm. The increase in the output of the higher quality firm by the R&D subsidy more than compensates for the decrease in that of the lower quality firm. As a result, the size of the quality-differentiated product market increases. On the other hand, in the case of the R&D subsidy for the lower quality firm, the reverse is the case for the market size.

3.1.2. Optimal R&D policy

First, we analyze the effects of R&D subsidies on consumer surplus. Taking into account (15.1), (15.2), (27.1), and (27.2), we obtain

$$CS_1^C = (x_1^C)^2(q_1^C/2)\{(2q_1^C + q_2^C)/(2q_1^C - q_2^C)\}, \tag{36.1}$$

$$CS_2^C = (x_2^C)^2(q_2^C/2). \tag{36.2}$$

Thus, the total consumer surplus is

$$CS^C = CS_1^C + CS_2^C = (X^C)^2(q_1^C/2)\{(4q_1^{C2} + q_1^C q_2^C - q_2^{C2})/(3q_1^C - q_2^C)^2\}.$$

In view of (31.1), (31.2), and (35.1), the R&D subsidy for the higher quality firm increases its quality and the market size, while it reduces the quality of the lower quality firm. In fact, differentiating (36.1) with respect to s_1 yields

$$sgn\ (dCS_1^C/ds_1) = sgn\ \{\Gamma_2^C + (16q_1^{C3} - 12q_1^{C2}q_2^C + 4q_1^C q_2^{C2} + q_2^{C3})/[8q_1^{2C}(q_1^C - q_2^C)]\},$$

where $\Gamma_2^C = (dq_2^C/ds_1)/(dq_1^C/ds_1) = -(\partial^2\Pi_2^C/\partial q_2\partial q_1)/(\partial^2\Pi_2^C/\partial q_2^2) = dq_2^C(q_1)/dq_1 < 0.$ The equation above shows that if the absolute value of Γ_2^C is sufficiently small, the R&D subsidy for the higher quality firm increases CS_1^C. Otherwise, the effect is of ambiguous sign. Furthermore, since that subsidy reduces the quality and quantity of the lower quality firm, it decreases CS_2^C. Thus, the effect of subsidizing the higher quality firm on the total consumer surplus is of ambiguous sign.

On the other hand, in a view of (32.1), (32.2), and (35.2), the R&D subsidy for the lower quality firm improves the qualities, although it reduces the market size. In that case, the positive effect of quality improvement more than outweighs the negative effect of market size reduction. As a result, such a subsidy for the lower quality firm increases total consumer surplus.

By the same way as in the analysis of the price-quality competition case, with respect to R&D policy to maximize net total consumer surplus, we can derive the same results as in (18.1) and (18.2). Hence the effects of an increase in quality on total consumer surplus are positive: $\partial CS^C/\partial q_i > 0,\ i = 1,\ 2.$ We thus have the following proposition:

Proposition 6. *With Cournot duopoly, in order to maximize net total consumer surplus, the government should subsidize the two firms if the government's burden of R&D subsidies is sufficiently small.*

In view of Propositions 2 and 6, regardless of the mode of competition, R&D subsidies for the two firms increase the qualities and/or the number of consumers purchasing the products. In turn, these effects are likely to result in an increased net total consumer surplus.

Second, we show the effects of R&D subsidies on the two firms' profits. The effects of subsidizing the higher quality firm on the profits are

$$d\Pi_1^C/ds_1 = (\partial R_1^C/\partial q_2)(dq_2^C/ds_1) + F_1 > 0, \tag{37.1}$$

$$d\Pi_2^C/ds_1 = (\partial R_2^C/\partial q_1)(dq_1^C/ds_1) < 0, \tag{37.2}$$

which are true. Also, the effects of subsidizing the lower quality firm are

$$d\Pi_1^C/ds_2 = (\partial R_1^C/\partial q_2)(dq_2^C/ds_2) < 0, \tag{38.1}$$

$$d\Pi_2^C/ds_2 = (\partial R_2^C/\partial q_1)(dq_1^C/ds_2) + F_2. \tag{38.2}$$

The effect of such a subsidy on the higher quality firm's profit is negative. But, since the first term of RHS in (38.2) is negative, that effect is of ambiguous sign.

We address the effects of R&D subsidies on producer surplus, which is expressed as: $PS^C\,(s_1,\ s_2) = \Pi_1^C + \Pi_2^C.$ The effect of subsidizing the higher quality firm on producer surplus is

$$dPS^C/ds_1 = \{(\partial R_1^C/\partial q_2)\Gamma_2^C + (\partial R_2^C/\partial q_1)\}(dq_1^C/ds_1) + F_1. \tag{39.1}$$

As to the first term of RHS in (39.1), we derive the following relationship:

$$(\partial R_1^C/\partial q_2)\Gamma_2^C + (\partial R_2^C/\partial q_1) > (<)\ 0 \longleftrightarrow -\Gamma_2^C > (<)\ q_2^{C2}/\{2q_1^C(2q_1^C - q_2^C)\}.$$

If the absolute value of Γ_2^C is relatively large, subsidizing the higher quality firm increases producer surplus. Otherwise, that effect is of ambiguous sign. Similarly, the effect of subsidizing the lower quality firm is

$$dPS^C/ds_2 = \{(\partial R_1^C/\partial q_2) + (\partial R_2^C/\partial q_1)\Gamma_1^C\}(dq_2^C/ds_2) + F_2, \tag{39.2}$$

where $\Gamma_1^C = (dq_1^C/ds_2)/(dq_2^C/ds_2) = -(\partial^2\Pi_1^C/\partial q_1\partial q_2)/(\partial^2\Pi_1^C/\partial q_1^2) = dq_1^C(q_2)/dq_2 > 0.$ Since the first term of RHS in (39.2) is negative, that effect is of ambiguous sign.

Let us consider the producer-oriented R&D policy to maximize aggregate profit: $GP^C(s_1, s_2) = PS^C - (s_1F_1 + s_2F_2) = R_1^C - F_1 + R_2^C - F_2.$ Given s_2, the first order condition to maximize GP^C with respect to s_1 is

$$\begin{aligned} dGP^C/ds_1 = &- s_1(\partial F_1/\partial q_1)(dq_1^C/ds_1) + (\partial R_1^C/\partial q_2)(dq_2^C/ds_1) \\ &- s_2(\partial F_2/\partial q_2)(dq_2^C/ds_1) + (\partial R_2^C/\partial q_1)(dq_1^C/ds_1) = 0. \end{aligned} \tag{40.1}$$

Similarly, given s_1, that condition to maximize GP^C with respect to s_2 is

$$\begin{aligned} dGP^C/ds_2 = &- s_1(\partial F_1/\partial q_1)(dq_1^C/ds_2) + (\partial R_1^C/\partial q_2)(dq_2^C/ds_2) \\ &- s_2(\partial F_2/\partial q_2)(dq_2^C/ds_2) + (\partial R_2^C/\partial q_1)(dq_1^C/ds_2) = 0. \end{aligned} \tag{40.2}$$

From (40.1) and (40.2), the R&D policy to maximize net producer surplus, s_1^{C**}, s_2^{C**}, satisfies

$$s_1^{C**} = (\partial R_2^C/\partial q_1)/(\partial F_1/\partial q_1) < 0, \tag{41.1}$$

$$s_2^{C**} = (\partial R_1^C/\partial q_2)/(\partial F_2/\partial q_2) < 0. \tag{41.2}$$

Therefore, we have the following proposition:

Proposition 7. *With Cournot duopoly, in order to maximize net producer surplus, the government should tax the two firms.*

The intuition behind Proposition 7 is as follows. A decrease in quality of one firm increases the other's revenue and saves fixed costs. Since the R&D taxation upon the two firms leads them to reduce their qualities, it results in higher profits, and thus in increased aggregate profit. In that case, however, such an R&D tax policy likely harms the benefits of all consumers in the market.

Third, we should analyze an optimal R&D policy to maximize social surplus. By the same process used in the price-quality competition case, the social surplus is

$$W^C(s_1, s_2) = CS_1^C + CS_2^C + PS^C - s_1F_1 - s_2F_2$$

$$= U_1^C - F_1 + U_2^C - F_2,$$

where $U_1^C = q_1^C\theta_{1A}\, x_1^C$, and $U_2^C = q_2^C\theta_{2A}\, x_2^C$.

Given s_2, the first order condition to maximize W^C with respect to s_1 is

$$dW^C/ds_1 = \{\Sigma_1^C - s_1(\partial F_1/\partial q_1)\}(dq_1^C/ds_1) + \{\Sigma_2^C - s_2\,(\partial F_2/\partial q_2)\}(dq_2^C/ds_1) = 0, \quad (42.1)$$

where

$$\Sigma_1^C = \partial U_1^C/\partial q_1 + \partial U_2^C/\partial q_1 - \partial R_1^C/\partial q_1 > 0,$$

$$\Sigma_2^C = \partial U_1^C/\partial q_2 + \partial U_2^C/\partial q_2 - \partial R_2^C/\partial q_2 < 0.$$

Similarly, the first order condition with respect to s_2 is

$$dW^C/ds_2 = \{\Sigma_1^C - s_1(\partial F_1/\partial q_1)\}(dq_1^C/ds_2) + \{\Sigma_2^C - s_2(\partial F_2/\partial q_2)\}(dq_2^C/ds_2) = 0. \quad (42.2)$$

Based on (42.1) and (42.2), the optimal R&D tax-cum-subsidy policy to maximize social welfare, s_1^{C***}, s_2^{C***}, satisfies

$$s_1^{C***} = \Sigma_1^C/(\partial F_1/\partial q_1) > 0, \quad (43.1)$$

$$s_2^{C***} = \Sigma_2^C/(\partial F_2/\partial q_2) < 0. \quad (43.2)$$

We thus present the following proposition:

Proposition 8. *With Cournot duopoly, the socially optimal R&D policy is to subsidize the higher quality firm and to tax the lower quality firm.*

The positive sign of Σ_1^C implies that the quality level chosen by the higher quality firm in the unregulated market is too low from the viewpoint of social optimality. On the other hand, the negative sign of Σ_2^C shows that the quality level chosen by the lower quality firm in the unregulated market is too high form the viewpoint of social optimality. These results mean that since the qualities of the two firms are closer than are socially optimal, excess competition in the Cournot market prevails. The government intervenes in order to relieve the competition in the market. That is, the combination of a tax upon the lower quality firm and a subsidy for the higher quality firm leads to quality upgrading of the higher quality firm and to quality downgrading of the lower quality firm. In turn, this increases the higher quality firm's market share, while it reduces the lower quality firm's share. Since these changes increase total welfare under Cournot product-market competition, such a *discriminatory* policy is optimal from the viewpoint of maximizing social surplus.

4. Conclusions

In this paper, based on the model of a quality-differentiated duopoly with endogenous quality choice, we have discussed the implications of subsidy/tax policies targeted at R&D investments to improve product qualities in the cases of Bertrand and Cournot duopoly.

We have shown that the effects of R&D subsidies on qualities and quantities demanded depend on the firm's strategic relationship in the quality decision.

Moreover, we have presented the R&D policies to maximize (i) net total consumer surplus, (ii) net producer surplus, i.e., aggregate profit, and (iii) social surplus:

(i) Regardless of the mode of competition, the R&D policy to maximize net consumer surplus is to subsidize the two firms, if the government's burden of the subsidies is sufficiently small.

(ii) Under Bertrand competition, the R&D policy to maximize net producer surplus is to subsidize the higher quality firm and tax the lower quality firm. On the other hand, under Cournot competition, R&D taxation upon the two firms increases net producer surplus.

(iii) Under Bertrand competition, subsidizing the two firms is socially optimal. On the other hand, under Cournot competition, subsidizing the higher quality firm and taxing the lower quality firm is socially optimal.

We should refer to some remaining issues related to our results. First, the qualitative difference between Bertrand and Cournot cases inevitably implies that the same policy (tax or subsidy) may be useful in one case while harmful in the other. Given that it is in general empirically difficult to discern whether an industry is a Bertrand oligopoly or a Cournot oligopoly, what sort of "selective" policy measure can be recommended? We should investigate such a policy measure that automatically operates differently depending upon whether the industry is Bertrand or Cournot, e.g., a subsidy with the "string" that the subsidized firm conforms to a price ceiling. Second, when the supposedly "optimal" policy affects firms' quality choices, even if the said policy is social *welfare* efficient, it does not always make all consumers *Pareto better-off.* For example, under Cournot competition, the socially optimal tax-cum-subsidy policy harms the benefits of the consumers who purchase the lower quality product. In that case, is there any "moral" concern that the utility transfer caused by such a policy might be "regressive", that is, those consumers with low willingness to pay for quality – who tend to be low in income – are made worse off in exchange for utility improvement of richer peers? Third, related to the issues above, a discriminatory firm-specific policy is assumed in this paper. But the socially optimal policy under Cournot duopoly reduces the profit of the lower quality firm, while it increases that of the higher quality firm. Hence the owners and/or the stockholders of the lower quality firm might protest that policy using various political ways. Under such a political pressure, the government may be obliged to apply the same policy to all firms. In future research, we will address the case of a uniform R&D policy.

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