G-COE GLOPE II Working Paper Series

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Working Paper No.20

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Abstract

We establish a three-stage game model of an internationally asymmetric duopoly where a developed country's old firm and a developing country's new firm endogenously decide not only prices (outputs) but also product qualities by product R&D activities, whilst the developing country's government gives an R&D subsidy to its firm. We consider the quality information bias and the asymmetrical reaction between the firms. Then, we examine the firms' product differentiation choices and the government product R&D subsidy decisions in Bertrand and Cournot competition.

I thank Professors Hayne E. Leland, Michihiro Ohyama, Kazuharu Kiyono, Ayano Sato, Kumi Suzuki and Chisato Shibayama for their useful suggestions and comments. I also would like to express my gratitude to the Japanese Ministry of Education, Science and Culture for their financial support.

1. Introduction

It has often been observed recently that new firms from developing countries achieving internationally acceptable product qualities by product R&D enter international markets that are already dominated by well-established old firms from developed countries supplying high quality products, and that developing countries' governments implement a product R&D subsidy policy to support their new firms and help them to survive in international markets. Indeed, even firms from developing countries whose products are inferior in quality to those of incumbent firms from developed countries can make inroads into international markets with lower prices. For example, some firms from China and India have recently competed with firms from Japan and/or the USA in food, apparel, automobiles, electrical industries, and so on. Apparently, in such international markets new entrants and old incumbents compete not only in product prices (or quantities) but also in product qualities.

Practically speaking, it is not always necessary for a new entrant firm to deliberately supply a product superior in quality to that of an incumbent firm. If quality of the entrant good is near to or better than that of the incumbent, the incumbent firm might expect to lose a considerable number of its old customers. The reaction of the incumbent would then be very intense because the entry of the new firm could prove fatal to it. On the other hand, if the entrant's good is very inferior to that of the old firm, the old firm might not react to the entry of the new firm so intensely because the new firm's entry has just a marginal effect on it. Consequently, the optimal quality choice of a new firm from a developing country may be to supply a good whose quality is greatly inferior to that of the old firm. In this paper, we shall investigate such a strategic quality-price (quality-quantity) battle between new and old firms and the optimal R&D subsidy policy of the developing country in an international industry.

When firms endogenously decide product qualities as well as prices (or quantities) they would have incentives to adjust product qualities by product R&D activities, as a matter of course. It is then necessary to establish a model of international oligopoly that installs product R&D activities in order to investigate the quality-price battle (or the quality-quantity battle) between new firms from developing countries and old firms from developed countries.

However, as is well known, not only the original Bertrand and Cournot oligopolistic models but also most of the new Cournot and Bertrand international oligopolistic models originated by Brander and Spencer (1985) and Eaton and Grossman (1986) to discuss intra-industry trade and strategic trade policies have assumed that firms decide only prices (or outputs), given firms' product qualities. Therefore, we shall construct such a model that can examine firms' quality choices as well as price (or quantity) decisions. This implies that though the main purpose of this paper is to investigate the firms' quality-price (quality-quantity) battle and the optimal product R&D subsidy in the sort of international duopoly mentioned above, it will also present a generalized theory of an oligopoly which describes endogenous product differentiation.

As far as I know, there are very few papers analyzing such a quality-price (quality-quantity) battle between old and new firms in an international duopoly, though Park (2001) has presented a model that seems to be similar to the one outlined in this paper.[1] He has built a third-country trade model of an international duopoly where high-tech and low-tech firms respectively produce goods of different qualities through adopting product R&D subsidized by their governments, and export all products to the third country. Accordingly, his model and our model seem to be similar to each other at first glance, but both are quite different from each other in a number of essential features. Park's model has never considered features which are peculiar to international trade involving developed and developing countries. Additionally, it has adopted certain restrictive assumptions such as special types of demand functions derived from a continuum of consumers, no production costs, a large enough asymmetry in firms' product R&D technology and a moderate price difference between high-quality and low-quality goods. The latter two, especially, might be inconsistent with each other. Thus, as is shown in section 6 of this paper, his main propositions lose their generality due to their restrictive assumptions. By contrast, our model not only replaces such restrictive assumptions in his model with more general ones but also introduces economic phenomena of quality information bias and asymmetrical quality reaction that are commonly observed when developing countries export new goods.

The quality information bias is a kind of informational phenomenon about product quality that customers, especially customers who have regularly consumed the high-quality products of incumbent old firms from the developed country, underestimate the quality of goods supplied by new firms from the developing country. Indeed, it is widely observed in many industries that while customers fully estimate the quality of products from developed countries, they underestimate the quality of goods from developing countries (see Chiang and Masson (1988)). This kind of quality bias seems to be very strong for certain goods whose quality is especially important for customers, such as audio sets, musical instruments, and beverages. Once customers formulate such a quality bias for a new firm's good, they do not modify it easily, and thus quality information bias affects (distorts) allotment of the customers' demand between old and new firms for a long time.

The asymmetrical quality reaction between firms is also common in many international industries. For example, in some cases where the quality difference between new and old products is very large, the old firm may be unwilling to vary its quality in response to the new firm's entry. And, in other cases where a change in the old good's quality is technically difficult and/or causes a huge cost increment, the incumbent old firm may not change its quality. In fact, Sony Japan did not vary the quality of its stereo sets when a Chinese audio maker began to export stereo sets, and Nisshin Flour Milling Inc. did not change the quality of its cup noodles in response to new sales of Chinese cup noodles. The old firms reacted to the entry of such new firms by adjusting only their prices (or quantities), and both the old and new firms coexist afterwards in the market through supplying differentiated goods. Hence, in this paper we shall analyze the asymmetrical quality reaction case where the new firm decides both quality and price (output) while the old firm chooses only its price (or quantity) and maintains its quality unchanged, in addition to the symmetrical quality reaction case where both the old and new firms determine qualities and prices (outputs).

Lastly, we suppose that while the developing country's government gives a subsidy to the product R&D activities of its firm, the developed country's government will not adopt any R&D policies because the well-established firm from the developed country can generally afford to bear such costs for R&D activities by itself. Of course, though the developing country's government might also consider some export subsidies in order to support its firm, it cannot adopt them because the new WTO prohibits any export subsidies in principle. Accordingly, nowadays, a product R&D subsidy is regarded as one of the few strategic apparatuses that the developing country can use to reinforce its firm's competitive power in an international market.

The rest of this paper is organized as follows. In section 2, extending a two-stage game model of third-country trade established by Spencer and Brander (1983) and Bagwell and Staiger (1994) that has adopted firms' process R&D, we establish a three-stage game model of third-country trade where the government of a developing country sets its optimal product R&D subsidy in the first stage and then firms from developed and developing countries respectively determine their quality levels through product R&D activities in the second stage and decide their prices (or outputs) in the third stage.[2] We solve such a three-stage game by backward induction. Thus, focusing first on the industry whose product market is under Bertrand price competition, we successively analyze the firms' price decisions in section 3, firms' quality choices in section 4, and the optimal product R&D subsidy set by the developing country's government in section 5. Then, turning our attention to the industry whose product market is under Cournot quantity competition in section 6, we examine firms' quality-output decisions and the optimal product R&D subsidy of the developing country's government and compare the results with those derived in sections 3-5. In section 7, we present some concluding remarks.

2. Assumptions and model

Suppose an international duopoly that consists of two firms producing vertically differentiated (or substitutable) products whose qualities are also the firms' endogenous variables. One of two firms is a well-established old firm from a developed country that has supplied a high quality good (an old good, hereafter) for a long time and already formed its reputation. And the other is a new firm from a developing country that has recently entered the industry with a low quality good (a new good, hereafter) and not yet gained a name for itself. These firms produce differentiated goods in their countries and export all of them to the third country for acquiring rents through a quality-price (or quality-quantity) battle. In our model, not only prices (quantities) but also qualities are the firms' endogenous control variables. While both the firms non-cooperatively determine their products' qualities by engaging in product R&D activities, only the developing country's government gives a product R&D subsidy to its firm. Since the old firm has already made its reputation as a supplier of the high-quality good before the new firm enters the industry, there is a possibility that the new firm might be excluded from the market as a result of a quality-price battle. We, however, focus on the case where both of the firms can yield non-negative profits and thus coexist in the industry.

As regards product quality, Chiang & Masson (1988) have suggested that a good can be said to have higher quality if all buyers prefer it to another good of the same general type, price being equal. However, in the real world even a higher-quality good does not exclude entirely a lower-quality one from the market because there are many various consumers with different incomes and different preferences. So, modifying the Chiang & Masson definition, we adopt the following definition of quality in this paper: a good is said to have higher quality if, at least, a buyer prefers it to another good of the same general type, price being equal. In other words, this definition means that demand for a good increases (decreases) as its quality rises (falls), *ceteris paribus*. Apparently, our definition is a version of vertical differentiation by Chiang & Masson (1988), which means mathematically that demand for a product is a strictly increasing function of its own quality. Furthermore, it is quite natural to suppose, from similar reasoning, that demand for a good is a decreasing function of the quality of its substitutable good.

Thus, considering the characteristic features for differentiated products mentioned above, the demand functions of the new and old goods in the third country are respectively given by

$$x = X(p, p^*) + Q(q, q^*), \quad \text{and} \quad x^* = X^*(p, p^*) + Q^*(\alpha q, q^*), \tag{1}$$

where x is demand for the new good consisting of price-induced demand X depending on prices and quality-induced demand Q depending on qualities, p is price of the new good, q is quality of the new good, α is an index of quality information bias reflecting how the old-good customers assess the new good ($0 \leq \alpha < 1$), and variables with a superscript * denote those of the old firm that are the same as the new firm's, respectively. In (1), we assume, without losing its essence, that only old-good customers have the quality information bias of the new good quality. This reflects a practical presumption that while the old-good customers underestimate the new good because they have few incentives to get information on the new good, the new-good customers appreciate almost exactly the new good because they have a great incentive to gather information about the new good. It should be recognized here that the smaller α is, the larger the quality information bias is. This kind of quality information bias causes not only price distortion but also quality distortion and reduces unfairly the economic welfare of the developing country. This is also one of the reasons why the developing country's government intervenes in the market.

Using subscripts to denote derivatives ($X_p = \dfrac{\partial X}{\partial p}$, $Q^*_{q^*} = \dfrac{\partial Q^*}{\partial q^*}$, $X_{pp^*} = \dfrac{\partial^2 X}{\partial p^* \partial p}$ and so on), we show the ordinary features of the demand functions as follows:

$$X_p < 0,\ X_{p^*} > 0,\ Q_q > 0,\ Q_{q^*} < 0,$$

$$X^*_{p^*} < 0,\ X^*_p > 0,\ Q^*_Z < 0,\ Q^*_{q^*} > 0, \qquad (2)$$

where $Z = \alpha q$ is a substantial quality level of the new good assessed by the old-good customers. Moreover, we also assume that the effects of price and quality on own demand dominate the effects of price and quality on the other demand:

$$0 < X^*_p < -X_p,\ 0 < X_{p^*} < -X^*_{p^*},\quad 0 < -Q^*_Z < Q_q,\ 0 < -Q_{q^*} < Q^*_{q^*}. \quad (3)$$

Since the traditional Bertrand and Cournot models assumed that the quality-induced demands $Q(q, q^*)$ and $Q^*(\alpha q, q^*)$ are always constant, our model would include them as special cases.

Thus, taking into consideration that firms' demand functions are given by (1) respectively, that firms are engaged in product R&D activities and that the developing country's government gives a product R&D subsidy to its firm, the new-good firm's profit from a developing country is

$$\pi = (p-c)\{X(p,p^*)+Q(q,q^*)\} - C(q) + sq\,, \qquad (4)$$

where c is a unit production cost, $C(q)$ is a cost for product R&D activities for achieving good's quality q with features $C'(q) > 0$ and $C''(q) > 0$, and s is a unit quality subsidy (or product R&D subsidy) given by its government. However, since the developed country's government does not give a product R&D subsidy to the old-good firm, the old-good firm's profit is

$$\pi^* = (p^*-c^*)\{X^*(p,p^*)+Q^*(\alpha q,q^*)\} - C^*(q^*)\,. \qquad (5)$$

It is assumed, for simplicity, that there is no spillover of quality technology. The new and old firms respectively decide their qualities and then their prices (or outputs) so as to maximize their profits, given the quality subsidy of the developing country's government. We assume that both of the firms' profits are strictly concave in their prices and qualities, respectively.

On the other hand, since the goods-producing countries in a third-country trade model do not consume any of the goods in question, the economic welfare W of the developing country is defined as

$$W = \pi - sq\,. \qquad (6)$$

Consequently, the developing country's government sets its product R&D subsidy s so as to maximize its welfare W before the firms choose their qualities and prices (or quantities). We also assume that W is strictly concave in a product R&D subsidy s of the developing country.

In this paper the two firms and the developing country's government play a three-stage game. In the first stage the developing country's government sets its quality subsidy so as to maximize the welfare defined as (5). In the second stage the firms respectively determine the optimal quality levels of their goods through product R&D activities so as to maximize their profits, given the quality subsidy set in the first stage and the rival's quality. In this stage we examine two cases separately: the asymmetrical reaction case where, while the new firm from the developing country varies its quality, the old firm from the developed country keeps its quality unchanged; and the symmetrical reaction case where both the old and new firms choose their qualities, respectively. Finally, in the third stage both the firms respectively decide their prices (or outputs) so as to maximize their profits, given the product R&D subsidy set in the first stage, the firms' qualities decided in the second stage, and the rival's price (or output). In order to solve this three-stage game we apply backward induction. The sub-game perfect equilibrium incorporates three stages.

3. Industrial equilibrium and the price battle in the third stage

In the third stage, both the new firm and the old firm decide respectively prices (quantities) so as to maximize profits when the third-country market takes the form of Bertrand price (Cournot quantity) competition. However, we will focus on an international industry under Bertrand price competition for a while, until section 6, in which we analyze an international industry under Cournot quantity competition and compare the results in Bertrand and Cournot competition.

When the third-country market is under price competition, both firms respectively decide their prices so as to maximize their profits in the third stage, which indicates in turn that there is not an asymmetrical reaction case in such a price-decision process. Thus, the Bertrand-Nash equilibrium in the price-selection process of the third stage is characterized by

$$x + pX_p - cX_p = 0, \tag{7-i}$$

$$x^* + p^* X^*_{p*} - c^* X^*_{p*} = 0. \tag{7-ii}$$

where (7-i) and (7-ii) are the first-order conditions of the new firm and the old firm, respectively. We assume, as is adopted in many papers (see Bagwell and Staiger (1994), for example), that the firms' second-order conditions are both satisfied and that own effects of price on marginal profit dominate cross effects:

$$0 < \pi^*_{p^*p} < -\pi^*_{p^*p^*}, \quad 0 < \pi_{pp^*} < -\pi_{pp}. \tag{8-i}$$

Furthermore, we also assume, from similar reasons to (8-i), that effects of price on own marginal profit dominate the effects of price on cross marginal profit:

$$0 < \pi_{pp^*} < -\pi^*_{p^*p^*}, \qquad 0 < \pi^*_{p^*p} < -\pi_{pp}. \tag{8-ii}$$

Of course, it is easily shown that when the demand functions are linear in price, both of (8-i) and (8-ii) always hold under conditions of (3). (8-i) and/or (8-ii) ensures that both firms' reaction curves in the third stage are upward sloping and that the industry equilibrium in the third stage is locally stable.

From (7-i) and (7-ii) we obtain $p = \dfrac{c}{1-\dfrac{1}{\varepsilon}}$ and $p^* = \dfrac{c^*}{1-\dfrac{1}{\varepsilon^*}}$, where ε (ε^*) is a price elasticity of demand of the new (old) firm. This indicates that each firm's price is increasing in its production cost and decreasing in its elasticity, *ceteris paribus*. Generally, production costs are lower in the developing country than in the developed country, but the price elasticity of demand of the new good is considered as larger than that of the old good because demand for the new good is more volatile. Thus, we suppose in this paper that the price of the new good is lower than that of the old good, which means in turn that the quality of the new good is lower than that of the old good because the new firm would perfectly oust the old firm from the market if the opposite case holds.

As is clear from (7-i) and (7-ii), both the firms' prices depend on the product qualities of the two goods as determined through the firms' product R&D activities in the previous stage. Accordingly, from the total differentiation of (7-i) and (7-ii) with respect to p, p^*, and q holding all other variables constant we obtain the effects of a change in the quality of the new firm on the firms' prices (see Appendix I):

$$\frac{\partial p}{\partial q} = \frac{(\alpha Q^*_Z \pi_{pp^*} - Q_q \pi^*_{p^*p^*})}{D}, \tag{9}$$

$$\frac{\partial p^*}{\partial q} = \frac{(Q_q \pi^*_{p^*p} - \alpha Q^*_Z \pi_{pp})}{D}, \tag{10}$$

where $D = \pi_{pp}\pi^*_{p^*p^*} - \pi_{pp^*}\pi^*_{p^*p} > 0$ holds under conditions of (8). Thus, substituting $0 < \alpha < 1$, (3) and (8-ii) into (9), we get $\frac{\partial p}{\partial q} > 0$, which implies that the new-good price is always increasing in its quality, regardless of the degree of quality information bias. In such a case, a new firm which bears the private cost of improving product quality may partially attain a price commensurate with its quality (Chiang & Masson (1988)). Further, it is also obvious that the new-product firm sets its price so as to signal its quality.

On the other hand, the sign of (10) is ambiguous even under $0 < \alpha < 1$, (3) and (8-ii). However, when α is in the neighborhood of zero, it is obvious that $\frac{\partial p^*}{\partial q} > 0$ holds under conditions of (2) and (8-ii). It follows that the critical value α_{QB} of a quality information bias α that makes the numerator of the right side in (10) zero is positive. Therefore, according to the relationships between α_{QB} and α, we divide the degree of quality information bias into three cases and we define that the market faces a large (moderate or small) quality information bias when α is smaller than (equal to or larger than) α_{QB}. Thus, if α_{QB} is equal to or larger than unity, the market always faces a large quality information bias, because $0 < \alpha < 1 \leq \alpha_{QB}$ always holds at industry equilibrium. However, when α_{QB} is smaller than unity the market faces not only a large quality information bias but also a moderate or a small quality information bias because $0 < \alpha_{QB} \leq \alpha < 1$ as well as $0 < \alpha < \alpha_{QB} < 1$ can hold at industry equilibrium.[3] Consequently, substituting the relationships between α_{QB} and α into (10), we have

$$\frac{\partial p^*}{\partial q} \gtreqless 0 \quad \text{as} \quad \alpha \lesseqgtr \alpha_{QB}. \qquad (10)'$$

Now, the above arguments are summarized as

Proposition 1: The price of the new good is always increasing in its quality, regardless of the degree of quality information bias. On the other hand, the old good's price is increasing in (decreasing in or independent of) the new-good quality under a large (small or moderate) quality information bias.

Though it is very common that a rise in quality of the new good raises the new-good price because it increases demand for the new good, it seems to be rather strange that an improvement in the new-good quality may also raise the old-good price. However, such a case is intuitively described as follows. If the third-country market is under a large quality information bias, the old-good firm would suppose that it will not lose many customers even if the new-good firm marginally improves its quality because the quality distance between two goods is still considerable. Thus it raises its price in taking advantage of a rise in the new-good price that stemmed from an increase in the new-good quality. However, if the third-country market is under a small quality information bias, the old-good firm expects that it might lose many of its customers when the new-good firm improves its quality because the quality distance between two goods becomes smaller. It cannot then help cutting its price to mitigate the demand reduction in rivalry with a rise in the new-good quality.

Next, totally differentiating (7-i) and (7-ii) with respect to p, p^* and q^*, we obtain the effects of a change in quality of the old good on prices (see also Appendix II):

$$\frac{\partial p^*}{\partial q^*} = \frac{Q_{q*}\pi^*_{pp*} - Q^*_{q*}\pi_{pp}}{D}, \tag{11}$$

$$\frac{\partial p}{\partial q^*} = \frac{Q^*_{q*}\pi_{pp*} - Q_{q*}\pi^*_{p*p*}}{D}. \tag{12}$$

Hence, by considering (3) and (8-ii) into (11), we easily obtain $\frac{\partial p^*}{\partial q^*} > 0$. However, we cannot judge definitely the sign of (12) under the above assumptions. Thus, we have

Proposition 2: While it is ambiguous whether the price of the new good is increasing or decreasing in the old-good quality, the price of the old good is always increasing in its quality, regardless of the quality information bias.

Furthermore, from (2), (8-i), (9), and (10) we obtain simultaneously

$$\frac{\partial p^*}{\partial q} - \frac{\partial p}{\partial q} = \frac{Q_q(\pi^*_{p^*p^*} + \pi^*_{p^*p}) - \alpha Q^*_Z(\pi_{pp} + \pi_{pp^*})}{D} < 0. \tag{13}$$

It follows that an increase in the new-good quality makes the price battle between two firms more intense, and *vice versa*. Similarly, as regards the effect of a change in the old-good quality on the difference between two goods, (8-i), (2), (11), and (12) combine to give

$$\frac{\partial p^*}{\partial q^*} - \frac{\partial p}{\partial q^*} = \frac{Q_{q^*}(\pi^*_{p^*p^*} + \pi^*_{p^*p}) - Q^*_{q^*}(\pi_{pp} + \pi_{pp^*})}{D} > 0. \tag{14}$$

It follows that a rise in the old-good quality makes the price battle between two firms less intense, and *vice versa*. Consequently, the arguments about (13) and (14) are paraphrased as

Proposition 3: While a rise in the new-good quality makes the price battle between the old and new firms more intense, an increase in the old-good quality makes such a price battle less intense, and *vice versa*.

Propositions 1 and 2 combine to show that while the own effect of a change in the new-good (old-good) quality on the new-good (old-good) price is always positive, the cross effect of a change in the new-good (old-good) quality on the old-good (new-good) price is ambiguous. Furthermore, Proposition 3 shows that the own effect always dominates the cross effect and that the better the new-good (old-good) quality becomes, the more (less) intense the firms' price battle is. It follows that the new firm intentionally supplies a good whose quality is significantly inferior to the old-good quality to avoid an intense price-battle in some cases. This may be one of the reasons why firms from developing countries often enter international markets with lower quality-price products.

Since Park (2001) has adopted very special types of demand functions, he has failed to analyze firms' optimal quality-price choices in the case where the price difference between two goods is too small or too large, as he himself indicates (p. 972). That is a critical defect of a model that aims to analyze firms' quality-price competition because the price difference can be too small or too large when the quality of products changes. However, our model surmounts such a defect by adopting more general demand functions. Therefore, the propositions of the firms' price battle derived in this paper are more robust because they are independent of the price difference between two goods.

4. Industrial equilibrium and the quality battle in the second stage

In this section we investigate the quality battle between two firms in the second stage. However, since the international duopoly in this paper consists of the old firm from a developed country that has dominated the market and the new firm from a developing country that has just recently entered the market, it is especially important to consider that firms' reactions in the quality-selection process are not always symmetrical. Hence, as is already described in section 1, we divide the firms' reaction into two cases: the case of asymmetrical reaction and the case of symmetrical reaction, and we analyze the firms' quality battle in the two reaction cases separately. The asymmetrical reaction case and the symmetrical reaction case are both regarded as typical cases in many industries consisting of old and new firms.

4.1 The case of asymmetrical reaction

The case of asymmetrical reaction is not as special as is often thought. Indeed, even if a new firm enters the market, the incumbent old firm does not vary its quality in some cases (as regards examples, see section 1). Accordingly, it is very common for old firms to cope with the entry of a new firm by changing only its price, and both firms coexist afterward in the market by supplying differentiated products.

In the quality-selection process of the asymmetrical reaction case, while the new firm chooses its quality level so as to maximize its profit, the old firm keeps its quality level set in the pre-game stage unchanged. (As regards the quality-price choice of the old firm in the pre-game stage, see Appendix II). In other words, from a taxonomic point of view, while the new firm's good is a variable-quality commodity, the old firm's product is a constant-quality commodity. Hence, taking (4) and (7-1) into consideration, the industry equilibrium condition in the second stage is given by

$$(p-c)(Q_q + X_{p*}\frac{\partial p^*}{\partial q}) - C'(q) + s = 0. \tag{15}$$

Apparently, (15) is the first-order condition of the new firm in the R&D stage. We assume that the second-order condition of the new firm, i.e., $\pi_{qq} < 0$, holds. Then, q satisfying (15) is the optimal industrial quality level of the new good in the asymmetrical reaction case.

Since the old firm does not change its quality in the asymmetrical reaction case, its product quality is independent of a product R&D subsidy set by the developing country, i.e. $\frac{\partial q^*}{\partial s} = 0$. Therefore, differentiating totally (15) with respect to q and s, given all other variables, and taking account of the second-order condition $\pi_{qq} < 0$, we get the effect of a change in the product R&D subsidy of the developing country on the new firm's quality:

$$\frac{\partial q}{\partial s} = \frac{-1}{\pi_{qq}} > 0. \tag{16}$$

It follows that an increase in the product R&D subsidy by the developing country's government raises the product quality of the new firm, and *vice versa.* This result coincides with our intuition that a rise in a product R&D subsidy given to the new firm would improve the quality of its good in general. Furthermore, since the old firm's quality level is constant in the asymmetrical reaction case, it is immediately obvious that a rise in a product R&D subsidy of the developing country reduces the quality difference between the old and new firms. Consequently, a rise in a product R&D subsidy of the developing country makes the firms' quality battle more intense, and *vice versa*.

4.2 The case of symmetrical relation

The case of symmetrical reaction is also observed widely in the real world. In this case the old firm also changes its product quality in reacting to a quality change of the new firm. Consequently, both the old and new firms compete with each other as if they are equal competitors even though there is a quality information bias in the market. Their goods are both treated as variable-quality commodities from an analytical point of view.

It is assumed that both the new and old firms also act as followers in the quality battle as in the price battle. This implies that the firms respectively decide their qualities q and q^* so as to maximize their profits, given the product R&D subsidy, the rival's quality, and the first-order conditions in the third stage. Then, the Nash equilibrium conditions in the R&D stage are given by

$$(p-c)(Q_q + X_{p^*}\frac{\partial p^*}{\partial q}) \; - C^{'}(q) \; + \; s \; = 0, \qquad (17\text{-i})$$

$$(p^*-c^*)(Q^*_{q^*} + X^*_p\frac{\partial p}{\partial q^*}) \; - C^{*'}(q^*) \; = 0, \qquad (17\text{-ii})$$

where (17-i) and (17-ii) are the first-order conditions of the new and old firms, respectively. It is also assumed that the firms' second-order conditions are both satisfied and that own effects of quality on marginal profit dominate cross effects:

$$0 < \; \pi^*_{q^*q} \; < \; -\pi^*_{q^*q^*}, \quad 0 < \; \pi_{qq^*} \; < \; -\pi_{qq} \,. \qquad (18)$$

It follows that the firms qualities are strategically complementary to each other (see Motta (1993) and Park (2001)), and that the industry equilibrium is locally stable.

The optimal qualities of the two firms at the industry equilibrium are q and q^* that simultaneously satisfy (17-i) and (17-ii), and they depend on the product R&D subsidy s set by the developing country's government. Hence, totally differentiating (17-i) and (17-ii) with respect to q, q^* and s, given all other variables, and taking (18) into consideration, we obtain the effects of a change in the product R&D subsidy on the firms' quality levels (see Appendix III):

$$\frac{\partial q}{\partial s} = \frac{-\pi^*_{q^*q^*}}{\Delta} > 0, \qquad \frac{\partial q^*}{\partial s} = \frac{\pi^*_{q^*q}}{\Delta} > 0, \tag{19}$$

where $\Delta = \pi_{qq}\pi^*_{q^*q^*} - \pi^*_{q^*q}\pi_{qq^*} > 0$. It follows that a rise (cut) in the product R&D subsidy of the developing country raises (reduces) both the quality levels of new and old goods in the symmetrical reaction case when product qualities are strategic complements to each other. Furthermore, (18) and (19) combine to present

$$\frac{\partial q^*}{\partial s} - \frac{\partial q}{\partial s} = \frac{\pi^*_{q^*q} + \pi^*_{q^*q^*}}{\Delta} < 0. \tag{20}$$

This means that the effect of a change in the developing country's product R&D subsidy on the new firm's quality is larger than a similar effect on the old firm's quality. Hence, a rise in the developing country's product R&D subsidy makes the firms' quality battle more intense, and *vice versa.*

Now, the above arguments of the firms' quality choices are summarized as the next proposition:

Proposition 4: While an increase in the product R&D subsidy of the developing country induces more aggressive R&D activities of both firms, which result in the simultaneous improvement of their product qualities, it makes the firms' quality battle more intense, and *vice versa,* regardless of the quality information bias.

Generally speaking, the developing country's government gives its firm a product R&D subsidy to reinforce its firm's competitive power in the international market through inducing an improvement of product quality by its firm. Indeed, it is one of nation's purposes for the developing country to support its new firm that can compete with old firms from developed countries in certain international markets. Proposition 4 demonstrates that the product R&D subsidy is effective in achieving such a wish on the part of the developing country though it simultaneously has an undesirable secondary effect of stimulating the quality battle between the old and new firms.

5. Optimal R&D subsidy implementation in the first stage

In this section, we examine the optimal product R&D subsidy implementation of the developing country in the first stage. Since the developed country does not participate in the product R&D subsidy game, we concentrate on the product R&D subsidy decision of the developing country. As has already been shown, the developing country determines its product R&D subsidy s so as to maximize its welfare W (= π − sq) as given by (6) by expecting firms' behaviors in the second and third stages. It is also necessary in this section, then, to analyze separately the optimal product R&D subsidy choices in the asymmetrical and symmetrical reaction cases, because the firms' reactions in the second stage are different from each other in the two cases.

5.1 The case of asymmetrical reaction

In this case, the old firm keeps its product quality constant in the second stage, though it adjusts its price in the third stage. Therefore, considering that the industry equilibrium conditions in the first and second stages are respectively given by (7-i), (7-ii) and (15) and assuming that W is a strictly concave function of s, the maximization condition of W is $\pi_{p*} \frac{\partial p^*}{\partial q}\frac{\partial q}{\partial s} - s\frac{\partial q}{\partial s} = 0$. The optimal product R&D subsidy of the developing country is then given by

$$s = \pi_{p*} \frac{\partial p^*}{\partial q}. \tag{21}$$

Consequently, applying $(p-c)X_{p*} > 0$ and the Proposition 1 to (21), we obtain the next proposition of the optimal product R&D subsidy:

Proposition 5: The optimal product R&D subsidy set by the developing country in the asymmetrical reaction case is positive, zero, or negative according to whether the industry is under a large, moderate or small quality information bias.

Though this proposition implies that the developing country's government has an incentive to tax or subsidize its firm's product R&D activities according to the degree of the quality information bias in the third-country market, such a relationship between the government incentive and the quality information bias is described intuitively from two standpoints. First, when the third-country market has a small (large) quality information bias, the current quality of the new good is higher (lower) than the level that is regarded as moderate. Hence, the developing country's government has an incentive to tax (subsidize) its firm's product R&D activities in order to achieve the moderate quality of the new good. Furthermore, when the third-country market has a small (large) quality information bias, the new firm is involved in the more (less) intense quality-price battle than the moderate one. Thus, the developing country's government taxes (subsidizes) its firm's product R&D activities in order to mitigate (stimulate) such an intense quality-price battle.

5.2 The case of symmetrical reaction

In this case, the old firm also chooses its price in the third stage and its quality in the second stage, respectively. The industry equilibrium conditions, then, are (7-i) and (7-ii) in the third stage and (17-i) and (17-ii) in the second stage. Thus, considering these industry equilibrium conditions and assuming that W is a strictly concave function of s, the condition for maximizing W is given by

$$\pi_{p^*}\frac{\partial p^*}{\partial q}\frac{\partial q}{\partial s} - s\frac{\partial q}{\partial s} + \pi_{q^*}\frac{\partial q^*}{\partial s} + \pi_{p^*}\frac{\partial p^*}{\partial q^*}\frac{\partial q^*}{\partial s} = 0.$$

Therefore, the optimal product R&D subsidy of the developing country is

$$s = \pi_{p^*} \frac{\partial p^*}{\partial q} - \pi_{p^*} \frac{\partial p^*}{\partial q^*} \frac{\pi^*_{q^*q}}{\pi^*_{q^*q^*}} - \pi_{q^*} \frac{\pi^*_{q^*q}}{\pi^*_{q^*q^*}}. \tag{22}$$

The first term in the right hand side of (22) is positive, zero, or negative according to whether the third-country market has a large, moderate, or small quality information bias, as is shown in the previous subsection. Moreover, taking into consideration $\pi_{p^*} = (p-c)X_{p^*} > 0$, $\pi_{q^*} = (p-c)Q_{q^*} < 0$, $\frac{\partial p^*}{\partial q^*} > 0$ (see (12)) and $\frac{\pi^*_{q^*q}}{\pi^*_{q^*q^*}} < 0$ (see (18)), we know that while the second term is positive, the third term is negative. Accordingly, the sign of (22) is not judged definitely in general. However, since the sign of the first term depends on the degree of quality information bias, we have

Proposition 6: The optimal product R&D subsidy of the developing country in the symmetrical reaction case is larger with a large quality information bias than with a small quality information bias, but its sign is ambiguous, regardless of the quality information bias.

Generally speaking, it seems to be quite natural to suppose that in the symmetrical reaction case where the old firm also joins in the quality battle, the developing country has a strategic incentive to increase its product R&D subsidy in order to reinforce its firm. However, Proposition 6 indicates that such reasoning is not always correct because the developing country prefers the less intense quality battle to the more intense quality battle under certain plausible conditions.[4]

Since Propositions 5 and 6 demonstrate that the developing country has a strategic incentive to tax the product R&D activities of its firm in some circumstances, these are both contrary to Proposition 1 of Park (2001) that the low-tech-firm's government always has a strategic incentive to subsidize the low-tech firm's product R&D activities under Bertrand price competition. This difference between the two papers stems from the fact that our model adopts more realistic and general assumptions with respect to production technology, products' qualities and demand functions.

6. Optimal product R&D subsidy under COURNOT competition

In this section we investigate firms' quality-output decisions and the developing country's product R&D subsidy determination under Cournot quantity competition. Moreover, although it is not the focus of this paper, we reexamine Park's proposition that the sign of the optimal product R&D subsidy under Cournot competition is quite opposite to that under Bertrand price competition. To construct a Cournot industry model, we maintain all the assumptions, notations, and analytical methods adopted in the previous sections. Therefore, the only difference between the Cournot and Bertrand models is that while Bertrand firms determine prices in the third stage, Cournot firms choose outputs in the third stage.

When the third-country market is under Cournot quantity competition, in the third (production) stage the new and old firms respectively determine their outputs so as to maximize their profits defined as (4) and (5), given all other variables and their rival's output. Therefore, the Cournot-Nash equilibrium of the third stage is given by

$$p + xp_x - c = 0, \tag{23-i}$$

$$p^* + x^* p^*_{x^*} - c^* = 0, \tag{23-i}$$

where (23-i) and (23-ii) are the first-order conditions of the new and old firms, respectively. We assume that the firms' second-order conditions are both satisfied and that both firm' reaction functions in the third stage are downward sloping: $\pi_{xx} < \pi_{xx^*} < 0$, $\pi^*_{x^*x^*} < \pi^*_{x^*x} < 0$. Then, since $p_x < 0$, $p^*_{x^*} < 0$ $p_{x^*} < 0$ and $p^*_x < 0$ hold under the features of (3), it is shown from (23-i) and (23-ii) that ($p - c$) and ($p^* - c^*$) are both positive.

Now, totally differentiating (23-i) and (23-ii) with respect to x, x^* and q, given other variables, and considering (2), (3), $0 \leq \alpha < 1$, $\pi_{xx} < \pi_{xx^*} < 0$ and $\pi^*_{x^*x^*} < \pi^*_{x^*x} < 0$, we obtain the effects of a change in the new good quality on firms' outputs:

$$\frac{\partial x}{\partial q} = \frac{(\alpha p^*_{x^*} Q^*_Z \pi_{xx^*} - p_x Q_q \pi^*_{x^*x^*})}{\Theta} < 0, \tag{24}$$

$$\frac{\partial x^*}{\partial q} = \frac{(p_x Q_q \pi^*_{x^*x} - \alpha p^*_{x^*} Q^*_Z \pi_{xx})}{\Theta} > 0, \tag{25}$$

where $\pi_{xx} = 2p_x + xp_{xx}$, $\pi_{xx^*} = p_{x^*} + xp_{xx^*}$, $\pi^*_{x^*x^*} = 2p^*_{x^*} + x^* p^*_{x^*x^*}$, $\pi^*_{x^*x} = p^*_x + x^* p^*_{x^*x}$ and $\Theta = \pi_{xx}\pi_{x^*x^*} - \pi_{xx^*}\pi_{x^*x} > 0$ (see Appendix IV). Similarly, from the total differentiation of (23-i) and (23-ii) with respect to x, x^* and q^* holding all other variables constant we obtain the effects of a change in the old product quality on firms' outputs:

$$\frac{\partial x}{\partial q^*} = \frac{(p^*_{x^*} Q^*_{q^*} \pi_{xx^*} - p_x Q_{q^*} \pi^*_{x^*x^*})}{\Theta} > 0, \tag{26}$$

$$\frac{\partial x^*}{\partial q^*} = \frac{(p_x Q_{q^*} \pi^*_{x^*x} - p^*_{x^*} Q^*_{q^*} \pi_{xx})}{\Theta} < 0. \tag{27}$$

Accordingly, (24), (25), (26) and (27) combine to present the next proposition:

Proposition 7: When the third-country market is under Cournot quantity competition, a rise in the new (old) good quality reduces the new (old) firm's output and raises the old (new) firm's output, and *vice versa.*

This proposition seems to indicate an antithetical result in that while the demand for the new (old) good is increasing in its quality and decreasing in the old (new) good quality as shown by (1), the output (= realized demand) of the new (old) good is decreasing in its quality and increasing in the old (new) good quality at the industry equilibrium. However, such a result is quite plausible because a rise in product quality induces a cost increment. Furthermore, though it shows that signs of the effects of a change in product quality on firms' outputs are all independent of the degree of quality information bias under Cournot quantity competition, this result is also not improbable because quality information may have less significance in firms' quantity decisions than in their quality choices.

Next, we proceed to the quality-selection process in the second stage. While only the new firm decides its quality in the asymmetrical reaction case, both the new and old firms respectively determine their qualities in the symmetrical reaction case.[5] The industry equilibrium condition is then $\pi_q = 0$ in the former case, and the industry equilibrium conditions are given by $\pi_q = 0$ and $\pi^*_{q*} = 0$ in the latter case. It is also assumed here that the firms' second-order conditions and the industry stability conditions are all satisfied as in the previous model. The effects of a change in the product R&D subsidy set by the developing country's government on firms' qualities are then derived by a similar way to that in section 4. Hence, we here omit detailed arguments and simply suggest that we also get (16) in the asymmetrical reaction case and (19) in the symmetrical reaction case, respectively.

In the first stage, the developing country's government sets its product R&D subsidy so as to maximize its welfare. Thus, taking into consideration that the industry equilibrium conditions in the third stage are (23-i) and (23-ii) under Cournot quantity competition, the first-order condition in the first stage is $\pi_{x*}\frac{\partial x^*}{\partial q}\frac{\partial q}{\partial s} - s\frac{\partial q}{\partial s} = 0$ in the asymmetrical reaction case, and it is $\pi_{x*}\frac{\partial x^*}{\partial q}\frac{\partial q}{\partial s} - s\frac{\partial q}{\partial s} + \pi_{q*}\frac{\partial q^*}{\partial s} + \pi_{x*}\frac{\partial x^*}{\partial q^*}\frac{\partial q^*}{\partial s} = 0$ in the symmetrical reaction case. Of course, we also assume that the second-order condition holds in each case. The optimal product R&D subsidy set by the developing country's government is then $s = \pi_{x*}\frac{\partial x^*}{\partial q}$, whilst it is $s = \pi_{x*}\frac{\partial x^*}{\partial q} - \pi_{q*}\frac{\pi^*_{q*q}}{\pi^*_{q*q*}} - \pi_{x*}\frac{\partial x^*}{\partial q^*}\frac{\pi^*_{q*q}}{\pi^*_{q*q*}}$ in the symmetrical reaction case. Consequently, substituting $\frac{\partial x^*}{\partial q} > 0$, $\pi_{x*} = p_{x*}x < 0$, $\pi_{q*} = p_{x*}\frac{\partial x^*}{\partial q^*} > 0$, (19), and (8) into these equations, we easily obtain $s = \pi_{x*}\frac{\partial x^*}{\partial q} < 0$ in the asymmetrical reaction case, but we cannot judge definitely the sign of s in the symmetrical reaction case, because the first term of the right hand side is negative while the latter two are positive. Accordingly, we present

Proposition 8: Under Cournot quantity competition, the optimal product R&D subsidy set by the developing country is negative in the asymmetrical reaction case, whereas its sign can not be judged definitely in the symmetrical reaction case, regardless of the degree of quality information bias.

In other words, this proposition demonstrates that when the third-country market is under Cournot quantity competition, the developing country's government has an incentive to tax its firm's product R&D activities in the asymmetric reaction case, whilst it cannot determine whether to subsidize or tax its firm's product R&D activities in the symmetric reaction case. Therefore, the popular understanding that the optimal product R&D subsidy of the developing country is always positive is also misleading under Cournot quantity competition. Furthermore, Proposition 8, together with Propositions 5 and 6, generalizes Park's deduction that the sign of the optimal product R&D subsidy under Cournot quantity competition is completely symmetrical to that under Bertrand quality competition (p 980), by establishing a more general and realistic trade model of an international duopoly consisting of firms from developed and developing countries.

7. Concluding remarks

In many imperfectly competitive international industries, there coexist certain big firms that supply differentiated goods with different prices. Such industries suggest that even new firms from developing countries producing low-quality products can survive in international markets that have been previously occupied by well-established incumbent firms from developed countries selling high-quality goods, if they set their prices low enough to acquire a base of customers. Hence, for discussing such an industry it is necessary and significant to establish a model of an international oligopoly where firms endogenously determine product qualities as well as prices (outputs) under certain realistic conditions.

In this paper we first established a model of an international duopolistic industry composed of an old firm from a developed country and a new firm from a developing country, both of which endogenously determine not only prices (outputs) but also product qualities by engaging in product R&D activities under a product R&D subsidy from the developing country. We then analyzed the firms' quality-price (quality-quantity) battle and the product R&D subsidy of the developing country. When analyzing these issues we considered certain features which are well-known but peculiar in international industries including firms from developed and developing countries: customers' asymmetrical information on product qualities, firms' asymmetrical reaction in quality choices, and governments' asymmetrical attitude to product R&D subsidies. Thus, several interesting propositions emerge. However, we shall here avoid repeating them and describe some of the economic implications obtained through combining some of them.

It is shown that the strategic effects and the optimal product R&D subsidy of the developing country depend on the form of competition in the third-country market, the slopes of firms' reaction curves in quality and price (output) decisions, the degree of quality information bias and the old firm's reaction type in its quality choice. The last two factors, especially, play significant roles when judging signs of the strategic effects and the optimal level of the product R&D subsidy.

It is also demonstrated that the developing country does not always have an incentive to subsidize its firm's product R&D. The optimal product R&D policy of the developing country is a tax under Cournot competition, but it varies with the degree of the quality information bias under Bertrand competition. In the asymmetrical reaction case, the subsidization of the developing country might jeopardizes its firm's survival, because it induces a more intense price battle under Bertrand quality competition and it definitely reduces the market share of its firm under Cournot quantity competition.

Furthermore, it is indicated that the sign of the optimal R&D subsidy under Bertrand competition is not symmetric to that under Cournot competition. Park (2001) has proved that the signs of the optimal product R&D subsidies in Cournot and Bertrand competition are definitely symmetrical to each other. However, such a symmetrical feature between the R&D subsidies does not hold in our generalized model.

Of course, our model will be extended in several directions. More disadvantages for developing countries and/or a number of uncertain factors will be introduced into the model. Further, the number of firms and/or the form of competition in the market might be also endogenous variables. However, these will be analyzed in future papers.

Appendices

Appendix I. The effects of a change in the product qualities on firms' prices

Totally differentiating (7-i) and (7-ii) with respect to p, p^* and q, we obtain

$$\begin{bmatrix} \pi_{pp} & \pi_{pp*} \\ \pi^*_{p*p} & \pi^*_{p*p*} \end{bmatrix} \begin{bmatrix} \dfrac{\partial p}{\partial q} \\ \dfrac{\partial p^*}{\partial q} \end{bmatrix} = \begin{bmatrix} -Q_q \\ -\alpha Q^*_Z \end{bmatrix},$$

where $\pi_{pp} = 2X_p + pX_{pp} - cX_{pp}$, $\pi_{pp*} = X_{p*} + pX_{pp*} - cX_{pp*}$, $\pi^*_{p*p*} = 2X^*_{p*} + p^*X^*_{p*p*} - c^*X^*_{p*p*} < 0$, and $\pi^*_{p*p} = X^*_p + p^*X^*_{p*p} - c^*X^*_{p*p} > 0$. This gives (9) and (10). Similarly, differentiating totally (7-i) and (7-ii) with respect to p, p^* and q^*, we get

$$\begin{bmatrix} \pi_{pp} & \pi_{pp*} \\ \pi^*_{p*p} & \pi^*_{p*p*} \end{bmatrix} \begin{bmatrix} \dfrac{\partial p}{\partial q^*} \\ \dfrac{\partial p^*}{\partial q^*} \end{bmatrix} = \begin{bmatrix} -Q_{q*} \\ -Q^*_{q*} \end{bmatrix},$$

which presents (12) and (13).

Appendix II. Pre-game Quality-price decisions of the old firm

In the pre-game stage before the new firm enters the industry, the old firm was only a player in the third-country market and acted as a monopoly. Then, it decided its quality q^*_0 and price p^*_0 so as to maximize its profit defined as $\pi^* = (p^* - c^*)\{X^*(p^*) + Q^*(q^*)\} - C^*(q^*)$. Hence, the first-order conditions in the third and second stages were respectively given by $x^* + (p^* - c^*)X^*_{p*} = 0$ and $(p^* - c^*)Q^*_{q*} - C^*_{q*} = 0$. Of course, it is assumed that the second-order condition in each stage held.

Appendix III. The effect of a change in s on the firms' qualities.

Differentiating totally (17-i) and (17-ii) with respect to q, q^* and s gives

$$\begin{bmatrix} \pi_{qq} & \pi_{qq^*} \\ \pi^*_{q^*q} & \pi^*_{q^*q^*} \end{bmatrix} \begin{bmatrix} \dfrac{\partial q}{\partial s} \\ \dfrac{\partial q^*}{\partial s} \end{bmatrix} = \begin{bmatrix} -1 \\ 0 \end{bmatrix}.$$

Then, we obtain (19) under conditions of (18).

Appendix IV. The effects of changes in firms' qualities on their outputs

Totally differentiating (23-i) and (23-ii) with respect to x, x^* and q, we get

$$\begin{bmatrix} \pi_{xx} & \pi_{xx^*} \\ \pi^*_{x^*x} & \pi^*_{x^*x^*} \end{bmatrix} \begin{bmatrix} \dfrac{\partial x}{\partial q} \\ \dfrac{\partial x^*}{\partial q} \end{bmatrix} = \begin{bmatrix} -p_x Q_q \\ -\alpha p^*_{x^*} Q^*_Z \end{bmatrix},$$

where $\pi_{xx} = 2p_x + xp_{xx} < 0$, $\pi_{xx^*} = p_{x^*} + xp_{xx^*} < 0$, $\pi^*_{x^*x^*} = 2p^*_{x^*} + x^* p^*_{x^*x^*} < 0$, and $\pi^*_{x^*x} = p^*_x + x^* p^*_{x^*x} < 0$. Under conditions of (2), (3), $0 \leq \alpha < 1$, $\pi_{xx} < \pi_{xx^*} < 0$, $\pi^*_{x^*x^*} < \pi^*_{x^*x} < 0$, we then have (24) and (25). Similarly, totally differentiating (23-i) and (23-ii) with respect to x, x^* and q^*, we get

$$\begin{bmatrix} \pi_{xx} & \pi_{xx^*} \\ \pi^*_{x^*x} & \pi^*_{x^*x^*} \end{bmatrix} \begin{bmatrix} \dfrac{\partial x}{\partial q} \\ \dfrac{\partial x^*}{\partial q} \end{bmatrix} = \begin{bmatrix} -p_x Q_{q^*} \\ -p^*_{x^*} Q^*_{q^*} \end{bmatrix},$$

Under conditions of (2), (3), $0 \leq \alpha < 1$, $\pi_{xx} < \pi_{xx^*} < 0$, $\pi^*_{x^*x^*} < \pi^*_{x^*x} < 0$, we then have (26) and (27).

Footnotes

1. Motta (1993) has also compared (endogenous) equilibrium qualities under different forms of competition in the market. However, he has not examined the optimal product R&D subsidies.

2. Extending the traditional Cournot and/or Bertrand models, Spencer and Brander (1983) and Bagwell and Staiger (1994) have constructed a third-country trade model of an international duopoly where firms are respectively engaged in process R&D activities and then analyzed firms' price or quantity decisions and the optimal process R&D subsidy policy. However, their models have never considered firms' endogenous determinations of product qualities.

3. As will be shown in section 5, the optimal product R&D subsidy set by the developing country is zero in the asymmetrical reaction case when $\alpha = \alpha_{QB}$ holds. This is the reason why we define the quality information bias at $\alpha = \alpha_{QB}$ as the moderate quality information bias.

4. When the market is under Bertrand price competition, the effect of a change in a product R&D subsidy on the old firm' profit π^* or the developed county welfare W^* is given by

$$\frac{\partial \pi^*}{\partial s} = \frac{\partial W^*}{\partial s} = \alpha Q_Z^* \frac{\partial q}{\partial s} + (p^* - c^*) X_p^* \frac{\partial p}{\partial q}\frac{\partial q}{\partial s} + (p^* - c^*) \frac{\partial p}{\partial q^*}\frac{\partial q^*}{\partial s}.$$

Therefore, the sign of $\frac{\partial \pi^*}{\partial s}$ or $\frac{\partial W^*}{\partial s}$ is ambiguous under the assumptions mentioned above. However, since the value of $\frac{\partial \pi^*}{\partial s}$ without the third term is larger (smaller) than that of $\frac{\partial \pi^*}{\partial s}$ with the third one, the old firm selects the asymmetrical (symmetrical) reaction case.

5. When the market is under Bertrand quantity competition the effect of a change in a product R&D subsidy of the developing country on the old firm's profit from the developed country is expressed as

$$\frac{\partial \pi^*}{\partial s} = \alpha Q_Z^* \frac{\partial q}{\partial s} + \frac{\partial \pi^*}{\partial x}\frac{\partial x}{\partial q}\frac{\partial q}{\partial s} + \frac{\partial \pi^*}{\partial x}\frac{\partial x}{\partial q^*}\frac{\partial q^*}{\partial s}.$$

Thus, if the value of $\frac{\partial \pi^*}{\partial s}$ excluding the third term is larger (smaller) than that of $\frac{\partial \pi^*}{\partial s}$ including the third one, then the old firm also selects the asymmetrical (symmetrical) reaction case endogenously in addition to its product quality and price (output).

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