Strategic policy for product R&D with symmetric costs

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Abstract. In this paper I examine strategic policy for product R&D in an international duopoly where domestic and foreign firms are identical. It is shown that strategic R&D policy is described by a subsidy schedule contingent on firms' quality choices. Unilateral policy enables its domestic firm to produce a high-quality product, making equilibrium outcome unique. With two active governments, in equilibrium they implement different subsidy schedules. Two equilibrium outcomes exist, which are identical except for the identity of the countries. Thus, both countries have an equal chance to become the high-quality exporter. Both Bertrand and Cournot cases are examined. JEL classification: F12, F13

Politique stratégique pour le R&D dans le développement de nouveaux produits quand les coûts sont symétriques. Ce mémoire examine la politique stratégique pour le R&D dans le développement de produits nouveaux dans un duopole international où les entreprises domestique et étrangère sont identiques. On montre que cette politique est décrite par cédules de subventions qui dépendent des choix du niveau de qualité des entreprises. Une politique unilatérale permet à l'entreprise domestique de manufacturer un produit de haute qualité – ce qui engendre des résultats d'équilibre uniques. Si deux gouvernements sont actifs, en équilibre, ils mettent en place des cédules de subventions différentes. Deux résultats d'équilibre existent qui sont identiques sauf pour l'identité des pays. Donc les deux pays ont une chance égale de devenir l'exportateur du produit de haute qualité. On examine les cas de figure à la Bertrand et à la Cournot.

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1. Introduction

In high-technology industries, firms engage in research and development (R&D) activities to gain competitive edge over rivals through development of new products, quality improvements of existing products, and cost reduction innovations. There are many examples of governments using policy to affect R&D. For example, in the consumer electronics industry, Japanese firms' research on high-definition television (HDTV) in the 1980s has been heavily supported by subsidies (Tyson 1993). European firms' research on HDTV has also been supported by national governments' subsidies as well as by European Community cooperative programs (Yoffie and Gomes-Casseres 1994). In the semiconductor industry, both the U.S. and the Japanese governments actively supported their domestic firms' R&D on the dynamic random access memory (DRAM) chips (Flamm 1996).

Why do the governments have an incentive to use policies targeted at R&D in high-technology industries? In the strategic trade policy literature, Spencer and Brander (1983) show that the government has a unilateral incentive to subsidize R&D. The R&D in their case is aimed at reducing production costs, which is called *process R&D*. The development of new products and improvements in product quality are known as *product R&D* and are distinguished from process R&D.[1] Because of the difference between the two types of R&D, Spencer and Brander's results do not explain why governments use policy for product R&D. More recently, Park (2001) and Zhou, Spencer, and Vertinsky (2002) have shown that the government has a strategic incentive to use policy to affect product R&D. It is interesting that the government will subsidize or tax R&D, depending on the nature of market competition and on the position of the domestic firm in the ordering of product quality. In both of these two papers, however, the authors examine only the case where the quality ordering is exogenously given due to a large technology gap between firms. Their analysis thus applies only to the competition between industrial and developing countries. Since in many cases the competition involving product R&D takes place between industrial countries that have similar technology, their results are not enough to explain R&D policy for product R&D.

In this paper, I examine strategic policy for product R&D when firms have access to the same technology. I use a model of duopolistic competition under vertical differentiation.[2] Recently, Aoki and Prusa (1997) and Aoki (2003) have characterized simultaneous and sequential quality choices by two identical firms in an unregulated market. In this paper I extend their analysis to an international duopoly of a third-market model.

1 For difference between process and product R&D, see, for example, Beath, Katsoulacos, and Ulph (1987) and Symeonidis (2003).

2 For the vertically differentiated oligopoly, see Gabszewicz and Thisse (1979) and Shaked and Sutton (1982, 1983).

The main results are as follows. Unlike Spencer and Brander (1983), the unilateral policy is not a uniform subsidy. It takes a form of subsidy schedule that is contingent on firms' quality choices, involving various subsidy rates. While the government commits to the subsidy schedule in stage 1 of the game, the actual subsidy rate is determined when firms choose their product qualities in stage 2. Since there exist multiple equilibria in the unregulated market, the strategic policy not only confers a strategic advantage on the domestic firm but also makes the preferred equilibrium unique. A sufficiently large R&D subsidy is required for the second task.[3] The unilateral policy enables the firm in the policy-active country to produce a high quality product. Moreover, when the two governments are active, in equilibrium the two governments implement different subsidy schedules. There are two equilibrium outcomes that are identical except for the identity of the countries. Each country has an equal chance to become the high-quality exporter.

The results in this paper concerning the conditions under which R&D should be taxed or subsidized are essentially the same as those in Park (2001) and Zhou, Spencer, and Vertinsky (2002). However, there is a difference in the nature of equilibrium, because the assumption of symmetric costs makes the identity of the countries indeterminate.[4] In this paper I show that an asymmetric result is derived from symmetric countries. Moreover, the strategic policy in Park and Zhou et al. is based on the predetermined quality ordering. It is hence designed only to confer a strategic advantage on the domestic firm, given the quality ordering. In this paper the strategic policy is designed for both the equilibrium selection and the strategic advantage. The quality ordering is hence endogenously determined.

The rest of the paper proceeds as follows. In section 2 I set up the model. In section 3 I examine strategic R&D policy in the case where the final stage is Bertrand competition. In section 4 I analyse strategic R&D policy under Cournot competition. Section 5 concludes.

2. The model

The model is a three-stage, third-market trade model. There are two firms: Home and foreign, competing in a third market. Either only the home government is active or both the home and the foreign governments are active. In stage 1 the policy-active government(s) (simultaneously) set(s) R&D policy; in stage 2 firms simultaneously choose the quality of their products; and in stage 3 firms compete in either prices or quantities. The solution is the subgame perfect Nash equilibrium (SPNE).

3 The equilibrium-eliminating role of R&D subsidy is similar to what Herguera and Lutz (1997) show in the context of leapfrogging. The main difference is that an R&D subsidy is used to eliminate a *possible* equilibrium rather than to switch from a realized equilibrium to another.

4 There are also some differences in results and in assumptions as to functional forms for costs and so on. Park and Zhou et al. also address some issues that are not analysed in this paper. For example, Park considers export policy together with R&D policy, and Zhou et al. consider jointly optimal policy.

In the third market there is a continuum of consumers indexed by θ, which is uniformly distributed on [0, 1] with density one. The parameter θ represents a consumer's marginal willingness to pay for quality. Each consumer buys either one unit of the vertically differentiated good or nothing. Consumer θ's utility is given by $u = \theta q - p$ if he buys one unit of a product of quality $q \in [0, \infty)$ at price $p \in [0, \infty)$ and zero if he buys nothing.[5]

The home and foreign firms are identical in that each firm offers a single product and has the same cost function of product R&D. The marginal production cost is assumed to be invariant with respect to both quality and quantity.[6] For simplicity, I let it be zero.[7] The cost of product R&D is given by $C(q) = kq^2$, where $k > 0$ is an efficiency parameter.

3. Strategic R&D policy under Bertrand Competition

3.1. Firm behaviour

In this section, I examine the case where the final stage is Bertrand competition. I first examine the competition in stages 2 and 3. The results in stage 3 and in stage 2 of the unregulated market are basically drawn from Aoki and Prusa (1997). The home firm's equilibrium revenue in stage 3 is given by

$$R^b(q, q^*) = \begin{cases} \frac{4q^2(q-q^*)}{(4q-q^*)^2}, & \text{if } q > q^* \\ \frac{q^*q(q^*-q)}{(4q^*-q)^2}, & \text{if } q < q^*, \end{cases} \tag{1}$$

where q and q^* are, respectively, product qualities of the home and the foreign firms. Foreign variables are indicated by an asterisk ($*$). Note that $R^b(q, q^*)$ has a jump discontinuity at $q = q^*$. The home firm's profits are given by $\Pi^b(q, q^*; s) = R^b(q, q^*) - (1 - s)C(q)$, where $s < 1$ is an R&D subsidy from the home government.[8]

In stage 2, the home firm's quality best-response is given by $B(q^*; s) = q^H(q^*; s)$ if $q^* \leq \hat{q}^*(s)$ and $B(q^*; s) = q^L(q^*; s)$ if $q^* \geq \hat{q}^*(s)$, where $q^H(q^*; s)$ and $q^L(q^*; s)$ satisfy the first-order condition with $q^L(q^*; s) \leq q^* \leq q^H(q^*; s)$ and $\hat{q}^*(s)$ satisfies $\Pi^b(q^H(\hat{q}^*; s), \hat{q}^*(s); s) = \Pi^b(q^L(\hat{q}^*; s), \hat{q}^*(s); s)$.[9] The properties of $B(q^*; s)$ are as follows:

5 The use of this utility function is common to the literature. See, for example, Mussa and Rosen (1978).

6 This is a standard assumption in the literature. See, for example, Shaked and Sutton (1982, 1983).

7 In the literature, this is a common assumption. However, Toshimitsu and Jinji (2003) point out that this assumption may reduce the generality of the model.

8 A negative s means an R&D tax. R&D policy may take the form of subsidy schedule, involving various subsidy rates.

9 It means that the home firm is indifferent between $q^H(q^*; s)$ and $q^L(q^*; s)$ when the foreign firm's quality is $\hat{q}^*(s)$. Since $\partial^2 R^b(q, q^*)/\partial q^2 < 0$ and $C'' > 0$, the second-order condition is satisfied. The foreign firm's quality best-response, $q^* = B^*(q; s^*)$, is defined in the same way as that of the home firm.

LEMMA 1. *(1) $B(q^*; s) \neq q^*$, $\forall q^*$; (2) $B(q^*; s)$ is discontinuous at $q^* = \hat{q}^*(s)$; (3) $dB(q^*; s)/dq^* > 0$, $\forall q^* \neq \hat{q}^*(s)$; (4) $dB(q^*; s)/ds > 0$; and (5) $d\hat{q}^*/ds > 0$.*

(Proofs of lemmas and propositions are available from the author upon request.)

The third property implies that qualities are *strategic complements* in the terminology of Bulow, Geanakoplis, and Klemperer (1985) for both the higher- and lower-quality products.

In the unregulated market two pure-strategy Nash equilibria (NEs) exist in stage 2 (Aoki and Prusa 1997).[10] The equilibrium quality pair is given by $(q_N, q_N^*) = \{(q_N^H, q_N^L), (q_N^L, q_N^H)\}$, where $q_N^H > q_N^L$. The situation is depicted in figure 1. In the figure the solid lines of $B(q^*; s)$ (resp., $B^*(q)$) are the home (resp., foreign) firm's quality best-response in the unregulated market. $B(q^*; s)$ (resp. $B^*(q)$) is discontinuous at $\hat{q}^*$ (resp. $\hat{q}$). The iso-profit curves of the home and foreign firms are drawn, respectively, as π and π^*. The two NEs are given by the intersections of $B(q^*; s)$ and $B^*(q)$ at E_1 and E_2. In equilibrium, firms choose distinct qualities because they can earn positive profits by doing so.[11] The high-quality producer earns higher profits.[12] Moreover, if one firm can choose quality before the rival, the leader chooses a higher quality than the rival. The quality chosen by the leader, however, is *lower* than that of the high-quality product in the simultaneous R&D game (Aoki and Prusa 1997).[13] The Stackelberg leader point for the home firm is S in figure 1.

3.2. *Unilaterally optimal R&D policy*

Here I examine the unilateral R&D policy used by the home government. In stage 1 the home government chooses s to maximize home welfare, which is simply the home firm's profits less the cost of the subsidy to taxpayers: $W(s) = \Pi^b(q_N(s), q^*_N(s)) - sC(q_N(s)) = R^b(q_N(s), q^*_N(s)) - C(q_N(s))$.[14] The unilaterally optimal R&D policy is to allow the home firm to credibly choose the quality the Stackelberg leader would choose.

PROPOSITION 1. *When firms compete in prices in stage 3, the unilaterally optimal R&D policy for the home government is to implement the following subsidy schedule*:

10 In general, there also exists at least one non-degenerated mixed-strategy equilibrium. The following analysis, however, covers only pure-strategy equilibria.
11 This is a well-known result. See Shaked and Sutton (1982, 1983) and Mussa and Rosen (1978).
12 This is one of the stylized results in the vertical differentiation literature. See Lehmann-Grube (1997).
13 The leader earns higher profits by committing to a lower quality, because cost savings from the reduced quality is more than enough to compensate for the loss in revenue resulting from the intensified price competition by the reduced quality.
14 For simplicity, I assume that the opportunity cost of a dollar public funds is equal to one.

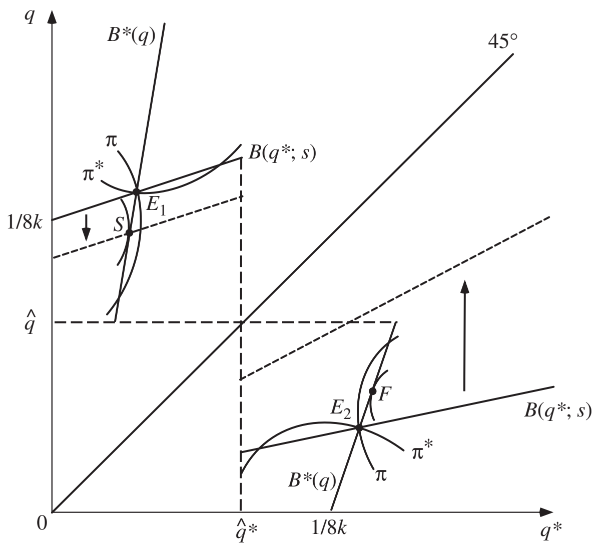

FIGURE 1 Bertrand competition: Nash equilibria and the unilateral policy

$$s\begin{cases} = \hat{s} < 0, & \textit{if } q > q^* \textit{ and } q^* < \hat{q}^* \\ = \underline{s} > 0, & \textit{if } q < q^* \textit{ and } q^* > \hat{q}^* \\ < \hat{s}, & \textit{if } q < q^* \textit{ and } q^* < \hat{q}^* \\ < \underline{s}, & \textit{if } q > q^* \textit{ and } q^* > \hat{q}^*, \end{cases} \tag{2}$$

where $\hat{s} \equiv \arg\max_s \{W(s)|q^* = B^*(q), q > q^*\}$ *and* $\underline{s}$ *eliminates the equilibrium in* $q < q^*$.

The unilaterally optimal policy is a subsidy schedule that is contingent on firms' quality choices. The schedule involves both tax and subsidy. While the home government commits to the schedule in stage 1, the actual subsidy rate is determined when firms decide their product qualities in stage 2.[15] In the subsidy schedule, an R&D tax, $\hat{s} < 0$, confers a strategic advantage on the home firm when it is the high-quality producer.[16] The R&D tax makes the home firm's commitment to the quality that the Stackelberg leader would choose credible. Because of the multiple equilibria in stage 2, the home government has to eliminate the equilibrium where the home firm is the lower-quality producer, making the Stackelberg leader point a

15 When the policy is an incentive scheme, s depends on q and q^*. Firms take this into account when they choose qualities in stage 2. However, since s does not respond to a marginal change in q or q^*, the standard analysis of SPNE is valid.

16 Park (2001) and Zhou, Spencer, and Vertinsky (2002) have shown the same qualitative result. An R&D tax is rarely seen in the real world. This may be because spillover effect of R&D is taken into account. Spillover effect raises the optimal subsidy rate.

unique equilibrium in stage 2. Since the equilibrium in $q < q^*$ can be eliminated by a sufficiently large R&D subsidy, $\underline{s} > 0$ is included in the subsidy schedule.[17] The purpose of the other elements in the schedule is to leave the switching point $\hat{q}^*$ unchanged.

Figure 1 shows how the unilateral policy works. The dotted lines are the home firm's quality best-response with policy. An R&D tax $\hat{s}$ shifts down $B(q^*; s)$ in the region of $q > q^*$ and $q^* < \hat{q}^*$. A sufficiently large subsidy $\underline{s}$ shifts up $B(q^*; s)$ in the region of $q < q^*$ and $q^* > \hat{q}^*$, so that there is no intersection between $B(q^*; s)$ and $B^*(q)$ in $q < q^*$. The effects of the subsidies for $q < q^* < \hat{q}^*$ and $q > q^* > \hat{q}^*$ are not seen in figure 1, because these elements affect the undrawn parts of $q^H(q^*; s)$ and $q^L(q^*; s)$. The unique NE is at S, which is the Stackelberg leader point. The unique equilibrium outcome is that an R&D tax is imposed on the home firm, which produces a high-quality product.

This result sharply contrasts with that in Spencer and Brander (1983). The difference arises from the fact that the process R&D in their case does not produce multiple equilibria. Thus, in order to lead the domestic firm to the Stackelberg leader point, the strategic R&D policy is designed only for giving a strategic advantage to the domestic firm.

3.3. *Two active governments*

I now examine strategic R&D policy when both of the two governments are active. In stage 1 each government simultaneously sets R&D policy, taking the rival's R&D policy as given. As in the unilateral case, strategic R&D policy is characterized by subsidy schedule. Then there exist two classes of NEs in stage 1:

LEMMA 2. *In stage 1, the following combination of subsidy schedules is one class of NEs*:

$$s \begin{cases} = \hat{s}_N < 0, & \text{if } q > q^* \text{ and } q^* < \hat{q}^* \\ = \underline{s}_N > 0, & \text{if } q < q^* \text{ and } q^* > \hat{q}^* \\ < \hat{s}_N, & \text{if } q < q^* \text{ and } q^* < \hat{q}^* \\ < \underline{s}_N, & \text{if } q > q^* \text{ and } q^* > \hat{q}^* \end{cases} \tag{3}$$

$$s^* \begin{cases} = \hat{s}^*_N > 0, & \text{if } q > q^* \text{ and } q > \hat{q} \\ = \underline{s}^*_N, & \text{if } q < q^* \text{ and } q < \hat{q} \\ < \hat{s}^*_N, & \text{if } q < q^* \text{ and } q > \hat{q} \\ < \underline{s}^*_N, & \text{if } q > q^* \text{ and } q < \hat{q}, \end{cases} \tag{4}$$

where $\hat{s}_N \equiv \arg\max_s \{W(s, s^*) \mid q^* = B^*(q; \hat{s}^*_N),\ q > q^*\}, \hat{s}^*_N \equiv \arg\max_{s^*} \{W^*(s, s^*) \mid q = B(q^*; \hat{s}_N), q > q^*\}$, and $\underline{s}_N$ *and* $\underline{s}^*_N$ *jointly eliminate the*

17 Note that $\underline{s}$ is not uniquely determined.

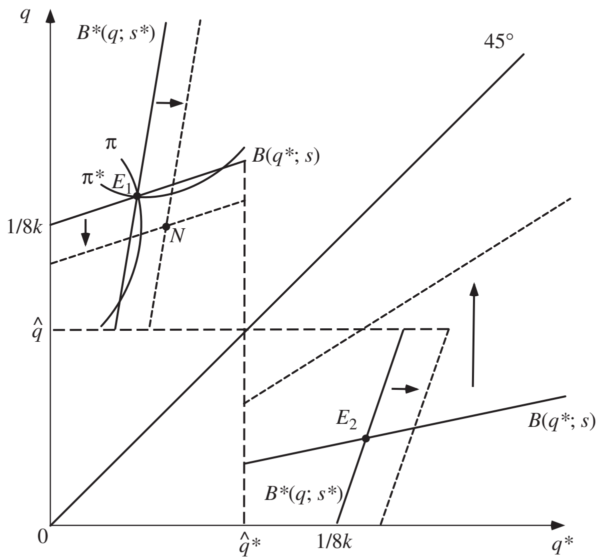

FIGURE 2 Bertrand competition: Two active governments

equilibrium, where $q < q^*$. There is another class of NEs, where s and s^* (and q and q^*) are switched in the previous case.

The subsidy schedule of the home government (3) is qualitatively similar to (2) in the unilateral case. The schedule involves both tax and subsidy. In the subsidy schedule of the foreign government (4), on the other hand, an R&D subsidy, $\hat{s}_N^* > 0$, gives a strategic advantage to the foreign firm when it is the low-quality producer.[18] An R&D subsidy or tax, $\underline{s}_N^*$, ensures no equilibrium in $q < q^*$. The rest of the elements in (4) leave the switching point, $\hat{q}$, unchanged. Since some of the elements in the subsidy schedules are not uniquely determined, there are many NEs that produce the same outcome.

Figure 2 shows effects of the policies in the case where the home government implements (3) and the foreign government implements (4). The solid lines correspond to the firms' quality best-response curves in the unregulated market and the dotted lines are those with two active governments. In the region of $q > q^*$, $B(q^*; s)$ shifts down, owing to an R&D tax, and $B^*(q; s^*)$ shifts to the right, owing to an R&D subsidy. $B(q^*; s)$ and $B^*(q; s^*)$ in $q < q^*$ move, owing to $\underline{s}_N$ and $\underline{s}_N^*$, so that there is no intersection in this region.[19] The unique equilibrium in this case is at N in figure 2.

18 The same qualitative result is shown by Park (2001) and Zhou, Spencer, and Vertinsky (2002).
19 The movements of the two curves are not unique, and one typical example is drawn in the figure.

This result implies that the governments do not battle to become the high-quality exporter. The reason is that if the rival provides a very high subsidy, choosing a higher quality is no longer attractive. While the government could make its domestic firm the high-quality producer by providing a counter-subsidy, social welfare would be higher when a low-quality product is produced. Thus, such a policy is not an equilibrium strategy. The situation is analogous to the 'battle of the sexes,' a well-known game,[20] in the sense that there are two equilibrium outcomes, one in which one player obtains a higher payoff and one in which the other player obtains a higher payoff. The interests of the two players conflict. Each player has an equal chance to obtain a higher payoff.

Given the NEs in stage 1, the SPNEs in the entire game are as follows:

PROPOSITION 2. *When firms compete in prices in stage 3, there are two SPNE outcomes, which are identical except for the identity of the countries. In these SPNEs, the two governments implement the policy schedules that are specified in lemma 2.*

There are two SPNE outcomes, one in which the home country is the high-quality exporter and one in which the foreign country is the high-quality exporter. There are many SPNEs that produce each outcome. In one SPNE outcome, where the home firm is the high-quality producer, the home government taxes R&D of the home firm and the foreign government subsidizes R&D of the foreign firm. Another SPNE outcome is obtained by switching the two countries. The quality ordering is hence endogenously determined, and both countries have an equal chance to become the high-quality exporter.

4. Strategic R&D policy under Cournot competition

I now turn to the case where firms compete in quantities in stage 3. The results in stage 3 and in stage 2 of the unregulated market are basically drawn from Aoki (2003). The home firm's equilibrium revenue in stage 3 is given by

$$R^c(q, q^*) = \begin{cases} \frac{q(2q-q^*)^2}{(4q-q^*)^2}, & \text{if } q > q^* \\ \frac{q(q^*)^2}{(4q^*-q)^2}, & \text{if } q < q^*. \end{cases} \tag{5}$$

The home firm's profits are given by $\Pi^c\,(q, q^*; s) = R^c(q, q^*) - (1-s)C(q)$ and its quality best-response is defined as $\tilde{B}(q^*; s) = \tilde{q}^H(q^*; s)$ if $q^* \le \tilde{q}^*(s)$ and $\tilde{B}(q^*; s) = \tilde{q}^L(q^*; s)$ if $q^* \ge \tilde{q}^*(s)$, where $\tilde{q}^L(q^*; s) \le q^* \le \tilde{q}^H(q^*; s)$ and $\tilde{q}^*(s)$ satisfies $\Pi^c\,(\tilde{q}^H(\tilde{q}^*; s), \tilde{q}^*(s); s) = \Pi^c\,(\tilde{q}^L(\tilde{q}^*; s), \tilde{q}^*(s); s)$.[21] The properties of $\tilde{B}(q^*; s)$ are as follows:

20 As for the battle of the sexes, see, for example, Fudenberg and Tirole (1991).

21 The foreign firm's quality best-response, $q^* = \tilde{B}^*(q; s^*)$, is defined in the same way as that of the home firm.

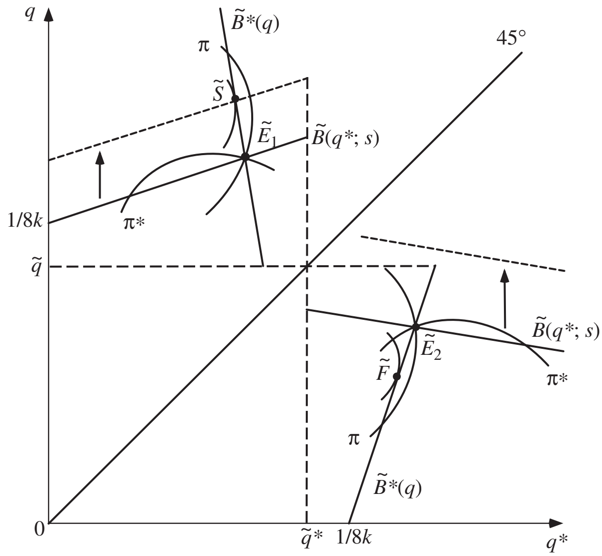

FIGURE 3 Cournot competition: Nash equilibria and the unilateral policy

LEMMA 3. *(1)* $\tilde{B}(q^*; s) \neq q^*, \forall q^*$; *(2)* $\tilde{B}(q^*; s)$ *is discontinuous at* $q^* = \tilde{q}^*(s)$; *(3)* $d\tilde{B}(q^*; s)/dq^* >$ *(resp.,* $<$*)* 0 *for* $q^* \leq$ *(resp.,* $\geq$*)* $\tilde{q}^*(s)$; *and (4)* $d\tilde{B}(q^*; s)/ds > 0$.

The third property implies that qualities are *strategic complements* for the higher-quality product and *strategic substitutes* for the lower-quality product.

As in the Bertrand case, two pure-strategy NEs exist in stage 2 of the unregulated market. The NE quality pair is given by $(\tilde{q}_N, \tilde{q}_N^*) = \{(\tilde{q}_N^H, \tilde{q}_N^L), (\tilde{q}_N^L, \tilde{q}_N^H)\}$, where $\tilde{q}_N^H > \tilde{q}_N^L$. The situation is depicted in figure 3. The solid lines of $\tilde{B}(q^*; s)$ (resp., $\tilde{B}^*(q)$) are the home (resp., foreign) firm's quality best-response in the unregulated market. The two NEs are at $\tilde{E}_1$ and $\tilde{E}_2$. The high-quality producer earns higher profits than the rival in equilibrium. Thus, the Stackelberg leader would choose a higher quality than the rival. Unlike the Bertrand case, the quality chosen by the leader is *higher* than that of the high-quality product in the simultaneous R&D game. This is because the follower responds to an increase in the leader's product quality by *decreasing* its own quality. An increase in the leader's revenue due to the greater product differentiation is higher than an increase in its product R&D costs. The Stackelberg leader point for the home firm is $\tilde{S}$ in figure 3.

As in the Bertrand case, the unilaterally optimal policy is to allow the home firm to credibly commit to the Stackelberg leader point.

PROPOSITION 3. *When firms compete in quantities in stage 3, the unilaterally optimal R&D policy for the home government is to implement the following subsidy schedule*:

$$s\begin{cases} = \tilde{s} > 0, & \text{if } q > q^* \text{ and } q^* < \tilde{q}^* \\ = \underline{s}' > 0, & \text{if } q < q^* \text{ and } q^* > \tilde{q}^* \\ < \tilde{s}, & \text{if } q < q^* \text{ and } q^* < \tilde{q}^* \\ < \underline{s}', & \text{if } q > q^* \text{ and } q^* > \tilde{q}^*, \end{cases} \tag{6}$$

where $\tilde{s} \equiv \arg\max_s \{W^c(s) \mid q^* = \tilde{B}^*(q),\ q > q^*\}$ *and* $\underline{s}'$ *eliminates the equilibrium in* $q < q^*$

The major difference from the Bertrand case is that an R&D subsidy $\tilde{s} > 0$, rather than a tax, is included in the schedule to give a strategic advantage to the home firm when it is the high-quality producer.[22] This is because committing to a higher quality than the NE level of quality improves social welfare of the high-quality exporting country. As in the Bertrand case, an R&D subsidy $\underline{s}' > 0$ is involved to eliminate the equilibrium where $q < q^*$. Under the conditions I assume in this paper, $\underline{s}'$ must be higher than $\tilde{s}$.

Figure 3 shows the effect of the unilateral policy. The dotted lines are the home firm's quality best-response with policy. An R&D subsidy $\tilde{s}$ shifts up $\tilde{B}(q^*; s)$ in the region of $q > \tilde{q}^*$ and $q^* < \tilde{q}^*$. A sufficiently large subsidy $\underline{s}'$ shifts up $\tilde{B}(q^*; s)$ in the region of $q < q^*$ and $q^* > \tilde{q}^*$, so that there is no intersection between the two curves in $q < q^*$. The unique NE is at $\tilde{S}$, the Stackelberg leader point for the home firm.

Consider, now, the case in which both the home and the foreign governments are active. As in the Bertrand case, there are two classes of NEs in stage 1:

LEMMA 4. *In stage 1, the following combination of subsidy schedules is one class of NEs*:

$$s\begin{cases} = \tilde{s}_N > 0, & \text{if } q > q^* \text{ and } q^* < \tilde{q}^* \\ = \underline{s}'_N > 0, & \text{if } q < q^* \text{ and } q^* > \tilde{q}^* \\ < \tilde{s}_N, & \text{if } q < q^* \text{ and } q^* < \tilde{q}^* \\ < \underline{s}'_N, & \text{if } q > q^* \text{ and } q^* > \tilde{q}^* \end{cases} \tag{7}$$

$$s^*\begin{cases} = \tilde{s}^*_N < 0, & \text{if } q > q^* \text{ and } q > \tilde{q} \\ = \underline{s}^{*\prime}_N, & \text{if } q < q^* \text{ and } q < \tilde{q} \\ < \tilde{s}^*_N, & \text{if } q < q^* \text{ and } q > \tilde{q} \\ < \underline{s}^{*\prime}_N, & \text{if } q > q^* \text{ and } q < \tilde{q}, \end{cases} \tag{8}$$

where $\tilde{s}_N \equiv \arg\max_s \{W^c(s, s^*) \mid q^* = \tilde{B}^*(q; \tilde{s}^*_N), q > q^*\}, \tilde{s}^*_N \equiv \arg\max_{s^*} \{W^{*c}(s, s^*) \mid q = \tilde{B}(q^*; \tilde{s}_N), q > q^*\}$, *and* $\underline{s}'_N$ *and* $\underline{s}^{*\prime}_N$ *jointly eliminate the equilibrium where* $q < q^*$. *There is another class of NEs where* s *and* s^* *(and* q *and* q^**) are switched in the previous case.*

22 The same qualitative result is shown by Park (2001) and Zhou, Spencer, and Vertinsky (2002).

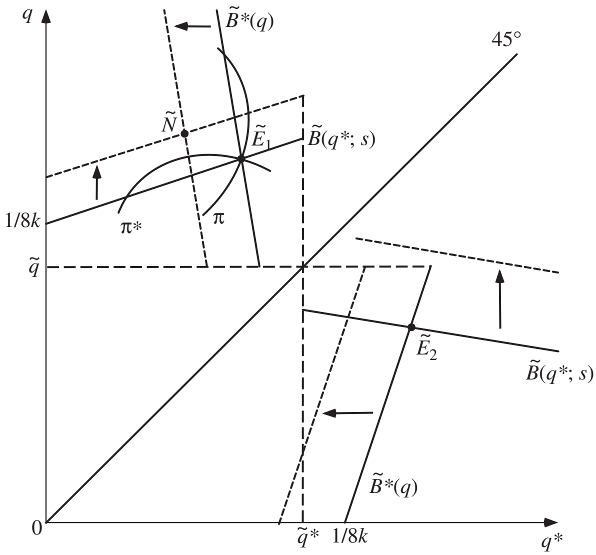

FIGURE 4 Cournot competition: Two active governments

The main difference from the Bertrand case is that a positive R&D subsidy $\tilde{s}_N > 0$ confers a strategic advantage on the high-quality producer, while an R&D tax $\tilde{s}_N^* < 0$ does so on the low-quality producer.[23]

Figure 4 shows how the policies work with two active governments. In the figure, the case where the home government implements (7) and the foreign government implements (8) is depicted. The solid lines are the firms' quality best-response curves in the unregulated market and the dotted lines are those with two active governments. In $q > q^*$, $\tilde{B}(q^*; s)$ shifts up due to an R&D subsidy and $\tilde{B}^*(q; s^*)$ shifts to the left, owing to an R&D tax. The two quality best-response curves in $q < q^*$ move, owing to $\underline{s}'_N$ and $\underline{s}^{*\prime}_N$, so that there is no intersection in this region.[24] The unique equilibrium in this case is at $\tilde{N}$.

Given the NEs in stage 1, SPNEs in the entire game are as follows:

PROPOSITION 4. *When firms compete in quantities in stage 3, there are two SPNE outcomes, which are identical except for the identity of the countries. In these SPNEs, the two governments implement the policy schedules that are specified in lemma 4.*

There are two SPNE outcomes, one in which the home country is the high-quality exporter and one in which the foreign country is the high-quality

23 This result is qualitatively the same as that shown by Park (2001) and Zhou, Spencer, and Vertinsky (2002).

24 The movements of the two curves are not unique, and one typical example is drawn in figure 4.

exporter. In the first outcome, the home government subsidizes R&D of the home firm and the foreign government taxes R&D of the foreign firm. The second outcome is obtained by switching the two countries.

5. Conclusions

This paper has examined strategic policy targeted at product R&D. It shows that the strategic policy for product R&D with symmetric firms is described by a subsidy schedule, or an incentive scheme, that is contingent on firms' quality choices. The elements of the subsidy schedule are different, depending on the nature of market competition. If only one country is policy active, the unilateral policy enables its domestic firm to become the high-quality producer. If both countries are policy active, there exist two equilibrium outcomes, which are identical, except for the identity of the countries. Thus, both countries have an equal chance to become the high-quality exporter.

An implication of the analysis is that asymmetric results can be derived from identical countries with policy active governments. It is often observed that countries with similar technology produce products with distinct qualities and trade with each other. This is so-called 'vertical intra-industry trade.'[25] The result in this paper provides an alternative explanation for such a phenomenon. The result, however, involves indeterminacy, and hence accident or history matters for the realization of the equilibrium outcome. Another implication is that the government has an incentive to implement R&D policy in the form of incentive schemes. Research grants for firms' product R&D and budgets of publicly funded R&D projects normally vary with sector, goal, and other factors. This can be interpreted as an example of the government's implementing R&D policy based on incentive schemes. The results in this paper provide a rationale for such policy conduct.

The results in this paper are not restricted to the case of perfectly symmetric firms. They also hold for the case of asymmetric firms with low degree of asymmetry. Although Park (2001) and Zhou, Spencer, and Vertinsky (2002) have examined the case of asymmetric firms, their results hold only for the case of sufficiently high degree of asymmetry. Moreover, although I employed a specific functional form for the cost function, most of the qualitative results will hold for more general cost functions, such as one used by Zhou et al.

For the future research, I suggest some extensions of the analysis. First, it will be interesting to introduce uncertainty, because in the real world, product R&D normally involves some uncertainty and it may have some important policy implications. Second, it may also be interesting to extend to a dynamic analysis since dynamic aspects of R&D are sometimes emphasized in the literature. Third, as an extension of the third-market trade framework, it

25 As for empirical evidence of vertical intra-industry trade, see, for example, Greenaway, Hine, and Miller (1995).

may yield some interesting results to introduce domestic consumption in each policy-active country or to consider trade between the home and foreign countries.

References

Aoki, Reiko (2003) 'Effect of credible quality investment with Bertrand and Cournot competition,' *Economic Theory* 21, 653–72

Aoki, Reiko, and Thomas J. Prusa (1997) 'Sequential versus simultaneous choice with endogenous quality,' *International Journal of Industrial Organization* 15, 103–21

Beath, John, Yannis Katsoulacos, and David Ulph (1987) 'Sequential product innovation and industry evolution,' *Economic Journal* 97(Supplement), 32–43

Bulow, Jeremy I., John D. Geanakoplis, and Paul D. Klemperer (1985) 'Multimarket oligopoly: strategic substitutes and complements,' *Journal of Political Economy* 93, 488–511

Flamm, Kenneth (1996) *Mismanaged Trade? Strategic Policy and the Semiconductor Industry* (Washington, DC: Brookings Institution Press)

Fudenberg, Drew, and Jean Tirole (1991) *Game Theory* (Cambridge, MA: MIT Press)

Gabszewicz, Jean Jaskold, and Jacques-François Thisse (1979) 'Price competition, quality and income disparities,' *Journal of Economic Theory* 20, 340–59

Greenaway, David, Robert Hine, and Chris Milner (1995) 'Vertical and horizontal intra-industry trade: a cross industry analysis for the United Kingdom,' *Economic Journal* 105: 1505–18

Herguera, Iñigo, and Stefan Lutz (1997) 'International leapfrogging and subsidies,' Centre for Economic Policy Research Discussion Paper No. 1606

Jinji, Naoto (2001) 'Essays on product quality and strategic policies in open economies,' PhD dissertation, University of British Columbia

Lehmann-Grube, Ulrich (1997) 'Strategic choice of quality when quality is costly: the persistence of the high–quality advantage,' *Rand Journal of Economics* 28, 372–84

Mussa, Michael, and Sherwin Rosen (1978) 'Monopoly and product quality,' *Journal of Economic Theory* 18, 301–17

Park, Jee-Hyeong (2001) 'Strategic R&D policy under vertically differentiated oligopoly,' *Canadian Journal of Economics* 34, 967–87

Shaked, Avner, and John Sutton (1982) 'Relaxing price competition through product differentiation,' *Review of Economic Studies* 49, 3–13

—(1983) 'Natural oligopolies,' *Econometrica* 51, 1469–83

Spencer, Barbara J., and James A. Brander (1983) 'International R&D rivalry and industrial strategy,' *Review of Economic Studies* 50, 707–22

Symeonidis, George (2003) 'Comparing Cournot and Bertrand equilibria in a differentiated duopoly with product R&D,' *International Journal of Industrial Organization* 21, 39–55

Toshimitsu, Tsuyoshi, and Naoto Jinji (2003) 'Strategic trade policy with endogenous choice of quality and asymmetric costs: a comment,' mimeo, Kwansei Gakuin University, Nishinomiya, Japan

Tyson, Laura D'Andrea (1993) *Who's Bashing Whom? Trade Conflict in High-Technology Industries* (Washington, DC: Institute for International Economics)

Yoffie, David B., and Benjamin Gommes-Casseres (1994) *International Trade and Competition: Cases and Notes in Strategy and Management*, 2nd ed. (New York: McGraw–Hill)

Zhou, Dongsheng, Barbara J. Spencer, and Ilan Vertinsky (2002) 'Strategic trade policy with endogenous choice of quality and asymmetric costs,' *Journal of International Economics* 56, 205–32