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Optimal strategic trade policy under asymmetric information

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When cost is private information in the Brander–Spencer model, the home government is confronted by a decision of choosing between two policy options: a menu of policies and a uniform policy. The former induces separation and so reveals the cost information to the foreign competitors. The latter helps the weak firm by concealing the cost information. The main result from this study is that policy menu is preferred to uniform policy under Cournot competition while the opposite occurs under Bertrand competition.

Key words: Strategic trade policy; Assymmetric information
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1. Introduction

As Stegemann (1989, p. 89) has put in a survey article, 'the evidence around us – increasing international economic interdependence, rekindled protectionism, and the increase in policy actions with real or perceived strategic intent – will continually force the economics profession to address the issues that authors of models of strategic trade policy have tried to address'. One of the most influential models of strategic export policy is the well-known Brander–Spencer model (1985), in which it is shown that the home government has a unilateral interest in adopting an export subsidy policy if the home firm competes with a foreign firm in quantities. The central motive for these types of strategic policies is to 'shift profits' from foreign firms to the home country. Subsequently, Eaton and Grossman (1986) demonstrated that the optimal policy is an export tax when the home

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firm competes with a foreign firm in prices. One important implication of these two studies is that the type of optimal strategic export policy is sensitive to many industrial-specific factors such as market conduct. It then becomes clear that lacking the relevant information, the government could very likely adopt the wrong type of policy. Moreover, it is reasonable to expect that policymakers have less information than firms concerning production and markets.

Information is also crucial in determining the appropriate policy. Wong (1990) has shown that if policymakers do not have complete information about the home firm's costs, some export policies could be welfare worsening. In particular, Wong (1990) demonstrated that in the Brander–Spencer model with asymmetric information (about cost), the optimal export subsidy scheme derived from the full information case is no longer incentive compatible in general and may even be detrimental to the home country. The reason is simple. The home firm has an incentive to misreport its cost in order to maximize its subsidy-cum-profit. The production decision is thus distorted (compared with the equilibrium outcome without government intervention) and the distortion could be sufficiently large such that national welfare is reduced to a level lower than that under free trade. However, Wong (1990) did not go any farther to explore incentive-compatible policies.

This paper develops strategic trade policies taking into account the constraints arising from incentive compatibility. We assume that the home firm's marginal cost is private information. Being uninformed, the home government faces two policy options. It can offer a menu of policies or simply a uniform policy. In the case of a policy menu, the home firm makes a selection from the menu, after which another uninformed party, the foreign firm, observes the policy selection. The two firms then compete in a third market for their exports.

The distinguishing feature of this model is that it is a mix of screening and signalling problems. We can divide the game into two stages: the policy stage and the market stage. The former is a screening sub-model in which the uninformed party (government) offers a menu to the informed party (home firm). The latter is a signalling sub-model in which the informed party (home firm) takes an action (policy selection) before it meets another uninformed party (foreign firm).[1] Moreover, the two tasks, screening and signalling, are accomplished in one action – when the home firm makes a selection from the given menu. The home government faces a dilemma because of this. On the one hand, it wants to discern the home firm's type in order to provide export subsidies or taxes for the purpose of profit-shifting. On the other hand, it wishes to have the high-cost firm sending out a low-cost signal under

[1]See Kreps (1990, p. 651) for the conceptual difference between screening and signalling models.

Cournot competition in order to reduce the foreign firm's production, or the low-cost firm signalling a high cost under Bertrand competition to raise the foreign firm's price. In this study we find that under Cournot competition it is optimal for the home government to offer a menu of policies which leads to a separating equilibrium, but under Bertrand competition it is optimal to adopt a uniform policy which results in a pooling equilibrium.

As is well known in the strategic trade literature, the role played by the government is to make the home firm's output expansion credible. In the model with private cost information, we find that there is a second role that the government can play. By offering a separation inducing menu, the government enables the home firm to credibly reveal its true type to its rival.

Recently Brainard and Martimort (1992) and Maggi (1992) also examine the impacts of asymmetric information in the Brander–Spencer model.[2] However, the focus of their papers is somewhat different. Brainard and Martimort (1992) incorporate a cost of raising government funds and Maggi (1992) considers non-linear policies. Neither paper is concerned with the signalling aspect of the design of government policy.

The remainder of the paper is organized as follows. In section 2 we present a model with screening and signalling characteristics when firms compete in a Cournot fashion. A complete analysis of the model is contained in section 3. Section 4 discusses Bertrand competition and gives results contrary to those obtained under Cournot competition. Section 5 concludes the paper.

2. The model

Consider the following situation. Two firms, 1 and 2, who respectively are located in countries 1 and 2, produce homogeneous goods for a third market. Both firms are assumed to produce strictly positive outputs and, unless stated otherwise, compete in a Cournot fashion. The inverse demand function takes the form: $p=a-b(q_1+q_2)$, where $a>0$, $b>0$, p is the price of the product, and q_i the output of firm i, $i=1,2$. Only the government in country 1 is involved in policy intervention.[3]

The information structure is as follows. Firm 1's marginal cost, c, is constant and private information but it is common knowledge that firm 1 is of either high cost, c_H, or low cost, c_L, with $\text{Prob}(c=c_L)=\mu$.[4] Firm 2's marginal cost is assumed known to all parties and equal to zero for simplicity. The reason for this assumption is that in the present setting, even

[2]These papers came to my attention after the initial submission of my paper to this journal.

[3]This supposition is common in the literature on trade policies and is made for simplicity. It can be justified, for instance, if government 2 unilaterally adopts a free trade policy.

[4]Allowing government 1 and firm 2 to have different priors will not change our results as long as these priors are common knowledge.

if there were some uncertainties associated with firm 2's marginal cost, there is no way for firm 2 to signal it. Both government 1 and firm 1 would base their decisions on the expected value. Randomness in firm 2's marginal cost complicates the model without changing the qualitative aspect of the results. In contrast, firm 1 is able to signal its cost through its policy selection.

In the environment described above, we consider the following two-stage, one-shot game. At the beginning of the first stage, called the policy stage, government 1 designs (and commits to) its policy.[5] The government has two options: it can use a uniform policy or a menu of policies.[6] Under the uniform policy regime, the government sets a specific (per unit) export subsidy rate for firm 1 regardless of its type. The alternative possibility, a menu of policies, gives firm 1 a choice as to the policies that will be applied. After the government has announced its menu of policies, firm 1 makes its policy choice. When information-revealing is desirable, a policy menu plays a role in inducing this revelation. Without such policy menus, a simple announcement by firm 1 about its cost is not credible.

The menu approach allows the policy to be conditional on the firm's type. In our setting, each choice on the menu consists of two policies: a specific export subsidy rate and a level of lump-sum tax.[7] If the subsidy rate were the only instrument available to the government, firm 1 would have chosen the highest subsidy rate independently of its type and no information would be revealed.

We confine policy options to linear subsidies, i.e. the subsidy rate does not vary with other informative variables such as output and price. This has the advantage of simplicity. Some possible implications of non-linear policies are discussed in the concluding remarks.

In the second stage, referred to as the market stage, the two firms compete in quantities on the basis of their respective information sets. Between the two stages there is a transition period in which firm 2 observes the policy choice made in the first stage and then updates its belief concerning firms 1's true marginal cost. This belief is correctly inferred by firm 1 and government 1. In particular, if government 1 designs a menu of policies inducing firm 1 to reveal its true type, then firm 2 observes this and the outputs of both firms are determined as if there were full information. Otherwise both firm 2 and

[5]The government's ability to commit is commonly assumed in the literature. If this is not assumed, precommitment effects should be carefully investigated, as in Caillaud et al. (1990).

[6]Policy menus have been explored extensively in the regulation literature. The studies of incentive-compatible policies can also be found in the literature on trade policy. See, for example, Feenstra (1987) and Prusa (1990).

[7]In a real-world context, one could perhaps view the lump-sum tax as a tax on profit. However, it is hard to find a case in which an industry-specific profit tax is tied to an export subsidy. As suggested by a referee, another possibility is that the fixed cost represents a cost of lobbying. To be viewed as a low-cost firm, the firm must incur a lobbying cost that exceeds some threshold set by the government.

government 1 believe the marginal cost of firm 1 is given by its prior distribution.

3. Analysis

We analyze the model by solving the game backwards. Since we consider pure strategies only, the policy selection is either pooling or separating. The analysis proceeds as follows. We first determine the optimal policy among the class of policies that lead to separating equilibria (in subsections 3.1 and 3.2). We then consider pooling equilibria (in subsection 3.3). Finally, we derive the optimal policy (in subsection 3.4) by comparing the maximum social welfare achieved under these two types of policies. In considering pooling equilibria, we assume, without loss of generality, that the government sets a uniform policy. A uniform policy causes pooling (involuntarily).

For the purpose of comparison, we briefly illustrate the optimal policy in the case of full information. Obviously, neither a policy menu nor a lump-sum tax is necessary. We denote variables in the full information case with a superscript f. Then, given any export subsidy rate, s, the second stage game yields

$$q_1^{\mathrm{f}}=\frac{a-2c+2s}{3b} \quad \text{and} \quad q_2^{\mathrm{f}}=\frac{a+c-s}{3b}.$$

Government 1 chooses s^{f} to maximize its objective function, denoted $W^{\mathrm{f}}(s)$, which is simply the profit the home firm earns from exports less any subsidy payments. With linear demand, this can be expressed as

$$W^{\mathrm{f}}(s)=[a-b(q_1^{\mathrm{f}}(s)+q_2^{\mathrm{f}}(s))-c]q_1^{\mathrm{f}}(s).$$

Thus to obtain

$$s^{\mathrm{f}}=\frac{a-2c}{4}. \tag{1}$$

3.1. Separation-inducing menus

We now consider separating equilibria. Let $t=(t_{\mathrm{L}};t_{\mathrm{H}})$ denote a policy menu, where t_{L} is a policy intended for the low-cost firm and t_{H} is a policy intended for the high-cost firm. Each policy $t_i=(s_i,\tau_i)$ for $i=\mathrm{L},\mathrm{H}$ consists of two elements, a specific export subsidy rate, s_i, and a lump-sum tax, τ_i.

Let $\pi^i(t_j)$ denote firm 1's profit when it is of type i and chooses policy t_j for $i,j=\mathrm{L},\mathrm{H}$. A menu t is called a *separation-inducing menu* if for $i\neq j$

(i) $\pi^i(t_i)\geqq\pi^i(t_j)$, and

(ii) $\pi^i(t_i) \geqq 0$, $i, j = \mathrm{L}, \mathrm{H}$.

Condition (i) is the self-selection constraint while condition (ii) is the participation constraint. As mentioned above, if a separation-inducing menu is used by government 1, firm 2 will be able to discern firm 1's type and it then follows that all parties act as if they have complete information in the second-stage Cournot game.

Given a separation-inducing menu t, the market-stage game can be described by the following maximization problems, $i = \mathrm{L}, \mathrm{H}$:

$$\max_{q_{si}} \{[a - b(q_{si} + q_{2i}) - c_i + s_i] q_{si} - \tau_i\}, \tag{2}$$

$$\max_{q_{2i}} [a - b(q_{si} + q_{2i})] q_{2i}, \tag{3}$$

where q_{si} is firm 1's output and q_{2i} firm 2's output under the policy menu regime and when firm 1 is type i. If t_{L} (t_{H}) is adopted, then $i = \mathrm{L}$ (H) in both (2) and (3), which constitute a Cournot game between firm 2 and a low (high) cost firm 1 with firm 2 knowing firm 1's true type. Thus, the respective reaction functions are

$$\begin{aligned} q_{si} &= \frac{a - c_i + s_i - bq_{2i}}{2b}, \quad i = \mathrm{L}, \mathrm{H}, \\ q_{2i} &= \frac{a - bq_{si}}{2b}, \qquad\qquad i = \mathrm{L}, \mathrm{H}. \end{aligned} \tag{4}$$

Given s, the market-stage equilibrium outputs are

$$q_{si} = \frac{a - 2c_i + 2s_i}{3b} \quad \text{and} \quad q_{2i} = \frac{a + c_i - s_i}{3b}, \quad i = \mathrm{L}, \mathrm{H}. \tag{5}$$

As mentioned in the introduction, the model incorporates both screening and signalling. Use of a menu of policies allows the government to screen for the type of firm so as to better design its export policy, but at the same time, firm 1's policy selection signals the same information to firm 2. To understand the implications of this, it is helpful to first consider a pure screening version of the model in which firm 2 knows firm 1's marginal cost. In this case, firm 2's output level will be affected by the policy imposed by the government, but the means by which the policy is chosen conveys no information. In particular, if firm 1 chooses a policy t_j that is not consistent with its type i, then firm 2 will produce $q_{2i} = (a + c_i - s_j)/3b$, the Cournot output based on firm 1's true marginal cost, c_i, and subsidy, s_j. Therefore, we have

$$\pi^i(t_j)=\frac{1}{9b}(a-2c_i+2s_j)^2-\tau_j, \quad i, j=\mathrm{L}, \mathrm{H}. \tag{6}$$

If the firm selects policy t_i corresponding to its type i, its profit, $\pi^i(t_i)$, is given by setting $j=i$ in (6).

If menu t is separation-inducing, condition (i) must be satisfied. Comparing $\pi^i(t_i)$ with $\pi^i(t_j)$ $(j\neq i)$, we obtain Lemma 1.

Lemma 1. In the pure screening model, if t is a separation-inducing menu, then $s_\mathrm{L}\geqq s_\mathrm{H}$ and $\tau_\mathrm{L}\geqq\tau_\mathrm{H}$. Conversely, if $s_\mathrm{L}\geqq s_\mathrm{H}$, there exists $\tau_\mathrm{L}\geqq\tau_\mathrm{H}$ such that $(t_\mathrm{L}, t_\mathrm{H})$ is a separation-inducing menu, where $t_i=(s_i, \tau_i)$ for $i=\mathrm{L}, \mathrm{H}$.

Proof. See the appendix.

Next, we provide some intuitions for Lemma 1. First and foremost, the two instruments in a separation-inducing menu have to go hand in hand, with a high subsidy associated with a high tax and vice versa. Otherwise both types would pick the policy with higher subsidy and lower tax. Second, a separation-inducing menu must have $s_\mathrm{L}\geqq s_\mathrm{H}$. To see this, note that $\partial\pi^i/\partial s_j$ is the marginal rate of substitution of taxes for subsidies, by (6). Moreover, the isoprofit curves of the types satisfy the single crossing property, since $\partial^2\pi^i/\partial s_j\,\partial c_i=-8/9b$, also by (6). The single crossing property implies monotonicity of the subsidies, by a standard argument from the incentive literature. By both (5) and Lemma 1, it is necessary that $q_{s\mathrm{L}}>q_{s\mathrm{H}}$. Thus, an alternative intuition is that the low-cost firm benefits more than the high-cost firm from an increase in the subsidy rate. For the converse, moving along the high type's isoprofit curve, in the direction of increasing subsidy and tax, raises the profit of the low type. Thus, pairs of policies that are equally profitable for the higher type satisfy self-selection for the low type.

We now return to our original model incorporating both signalling and screening. Since firm 2 does not know firm 1's marginal cost, its output level will depend on its updated belief which is influenced by firm 1's policy selection. Suppose that the government offers a separation-inducing menu and firm 2 believes firm 1's type is signalled by the adopted policy. More precisely, if firm 1 chooses t_j, then firm 2 believes that firm 1 is of type j and correspondingly sets $q_{2j}=(a+c_j-s_j)/3b$. Taking this into account, firm 1 with type i will optimally set $q_{si}=(2a-3c_i-c_j+4s_j)/6b$. Consequently,

$$\pi^i(t_j)=\frac{1}{36b}(2a-3c_i-c_j+4s_j)^2-\tau_j \quad \text{and} \quad \pi^i(t_i)=\frac{1}{9b}(a-2c_i+2s_i)^2-\tau_i. \tag{7}$$

Lemma 2 gives a necessary condition for the separation of types (the proof is similar to that of Lemma 1).

Lemma 2. In the model with screening and signalling, if t is a separation-inducing menu, then $s_L - s_H \geqq -(c_H - c_L)/4$. *Conversely, if* $s_L - s_H \geqq -(c_H - c_L)/4$ *there exists* $\tau_L \geqq \tau_H$ *such that* (t_L, t_H) *is a separation-inducing menu.*

The inclusion of signalling weakens the constraint required for the separation of types. When signalling is taken into account, the separation does not rule out the possibility that $s_L < s_H$. This follows because it is still necessary that $q_{SL} \geqq q_{SH}$, by (5) and Lemma 2. Thus, as in the case of the pure screening model, the low-cost firm benefits more than the high-cost firm from an increase in the export subsidy rate, holding the beliefs of firm 2 fixed. In addition, the low-cost firm loses more than the high-cost firm when firm 2's belief about firm 1's type changes from low to high, because firm 2 will increase its output in response to this change in its beliefs. This second effect is absent in the case of the pure screening model. With the second effect, the subsidy need not do as much work to induce separation.

3.2. Optimal separation-inducing menu

In designing its optimal profit-shifting policy in stage 1, the objective of the government is to maximize the expected social welfare in country 1. This is simply the profit of each type of firm 1 less any net subsidy, since the subsidy is already counted in the profit, weighted by the probability of that type. When menus induce separation, the expected social welfare is given by

$$W(t) \equiv \mu(\pi^L(t_L) - s_L q_{SL} + \tau_L) + (1-\mu)(\pi^H(t_H) - s_H q_{SH} + \tau_H),$$

where outputs q_{SL} and q_{SH} are given by (5) and $\pi^L(t_L)$ and $\pi^H(t_H)$ are given by (7).

To derive the optimal menu, we first maximize $W(t)$ by ignoring the separation constraints. The first-order condition yields the optimal subsidy rates, s_L^* and s_H^*:

$$s_L^* = \tfrac{1}{4}(a - 2c_L) \quad \text{and} \quad s_H^* = \tfrac{1}{4}(a - 2c_H), \tag{8}$$

from which, and (5), we obtain the equilibrium outputs of each type of firm 1 and firm 2:

$$q_{si} = \frac{a - 2c_i}{2b} \quad \text{and} \quad q_{2i} = \frac{a + 2c_i}{4b}, \quad i = \mathrm{L}, \mathrm{H}. \tag{9}$$

As expected, the optimal subsidy rates (8) are just the full information subsidy rates corresponding to the firm's particular type. Since the optimal menu imposes no restrictions on the lump-sum tax instrument, we are free to use lump-sum taxes to ensure separation. For convenience, we first normalize the lump-sum tax by setting $\tau_H^*=0$. When s_L^* and s_H^* are set at their optimal levels as in (8), we demonstrate in the appendix that the menu t^* induces separation [i.e. $\pi^L(t_L^*)\geqq\pi^L(t_H^*)$ and $\pi^H(t_H^*)\geqq\pi^H(t_L^*)$] if

$$\tau_L^*=\frac{1}{2b}(c_H-c_L)(a-c_H-c_L). \tag{10}$$

These results are summarized in Proposition 1.

Proposition 1. *t^*, as defined in* (8) *and* (10), *is an optimal separation-inducing menu.*

The intuition behind Proposition 1 is clear. It is well known in the literature of strategic trade policy that when demand is linear, the optimal profit-shifting policy requires that a higher export subsidy rate s_L^* (relative to s_H^*) be granted to the low-cost firm.[8] Thus, these subsidies satisfy Lemma 2. A lump-sum tax, τ_L^*, is levied on the low-cost firm in order to prevent the high-cost firm from pooling so as to obtain the higher subsidy rate. The tax τ_L^* is chosen so that the low-cost firm still selects t_L^* but the high-cost firm chooses t_H^*.

3.3. Optimal uniform policy

We now consider uniform policies. Whenever a uniform policy is adopted by the government, firm 2 receives no information from the policy stage, so it remains uninformed. It follows that the market-stage game is a quantity competition with asymmetric information (firm 2 has incomplete information about firm 1's cost). Let s denote the common subsidy rates, q_{pi} denote firm 1's output under the uniform policy regime when it is type i ($i=\mathrm{L,H}$), and $\bar{q}_2$ denote firm 2's output. Then the market-stage game is characterized by the following maximization problems:

$$\max_{q_{pi}}\,[a-b(q_{pi}+\bar{q}_2)-c_i+s]q_{pi}, \quad i=\mathrm{L,H},$$

$$\max_{\bar{q}_2}\,[a-b(\bar{q}_1+\bar{q}_2)]\bar{q}_2,$$

where $\bar{q}_1\equiv\mu q_{PL}+(1-\mu)q_{PH}$. Let $\bar{\pi}^i(s)$ denote firm 1's equilibrium profit when it is of type i and under subsidy rate s. Firm 1's reaction function is the same as (4) except $q_{2i}\equiv\bar{q}_2$, but firm 2 now reacts to firm 1's expected output $\bar{q}_1$, giving rise to the reaction function

[8]This can be seen from the formula for the optimal subsidy in Brander and Spencer (1985) or eq. (1).

$$\bar{q}_2 = \frac{a - b\bar{q}_1}{2b}. \tag{11}$$

Hence, given s, the market-stage equilibrium outputs are

$$q_{pi} = \frac{1}{6b}(2a - 3c_i - \bar{c} + 4s) \quad \text{and} \quad \bar{q}_2 = \frac{1}{3b}(a + \bar{c} - s), \quad i = \text{L, H}, \tag{12}$$

where $\bar{c}$ stands for the expected value of firm 1's marginal cost, i.e. $\bar{c} = \mu c_L + (1-\mu)c_H$. Thus, the resulting firm 1's profit given s is [using (12)]

$$\tilde{\pi}^i(s) = \frac{1}{36b}(2a - 3c_i + 4s - \bar{c})^2, \quad i = \text{L, H}.$$

Under the uniform policy regime, the expected social welfare in country 1 is the weighted sum of each type's profit net of subsidy, which is given by

$$\tilde{W}(s) \equiv \mu(\tilde{\pi}^L(s) - sq_{PL}) + (1-\mu)(\tilde{\pi}^H(s) - sq_{PH}).$$

From the first-order condition for the maximization of $\tilde{W}(s)$, we can easily derive the optimal subsidy rate, s_p^*, and the equilibrium outputs:

$$s_p^* = \frac{a - 2\bar{c}}{4}, \qquad q_{pi} = \frac{a - c_i - \bar{c}}{2b} \quad \text{and} \quad \bar{q}_2 = \frac{a + 2\bar{c}}{4b}, \quad i = \text{L, H}. \tag{13}$$

Relative to the complete information case, asymmetric information creates some distortions when the optimal uniform policy, s_p^*, is adopted and the prior is non-degenerate. Then, by comparing s_p^* in (13) with s^f in (1), we realize that s_p^* does not shift profit from firm 2 optimally since $c_L < \bar{c} < c_H$. It oversubsidizes (undersubsidizes) firm 1 and causes overproduction (underproduction) when firm 1 is a high (low) cost firm.

3.4. Optimal policy and equilibrium

In this subsection we derive the overall optimal policy by comparing the social welfare under the optimal separation-inducing menu with the welfare under the optimal uniform policy.

We first illustrate the equilibria under the two different optimal policies using fig. 1. Note that the level of per unit subsidy rate affects the position of firm 1's reaction curve. Since $s_L^* > s_p^*$, the low-cost firm's reaction curve in the separating case, R_{SL}, is to the right of R_{PL}, its reaction curve in the pooling case. Similarly, the high-cost firm's reaction curve in the separating case, R_{SH}, is to the left of R_{PH}, its reaction curve in the pooling case because $s_H^* < s_p^*$. However, firm 2's reaction curve in the separating case, as shown by R_2, is

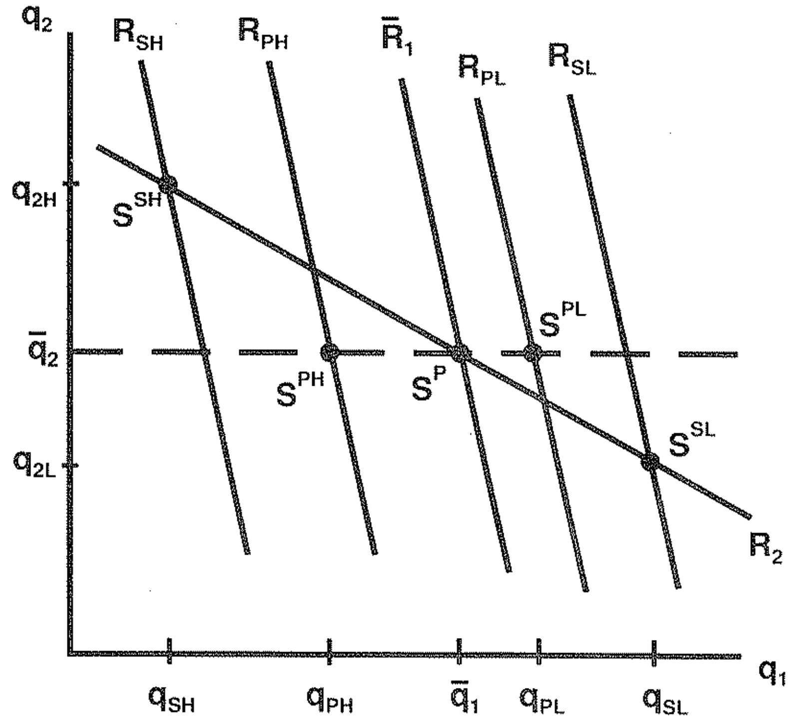

Fig. 1

unaffected by the subsidy level in country 1. Thus, in fig. 1, S^{SL} and S^{SH} are the equilibria in the separating case.

In the pooling case, firm 2's output, $\bar{q}_2$, is a function of firm 1's expected output, $\bar{q}_1$ [see (11)]. If firm 1 is actually a low-cost firm, then the equilibrium is at S^{PL}, where the horizontal line at $\bar{q}_2$ intersects firm 1's reaction function, R_{PL}. Similarly, the equilibrium is at S^{PH} if firm 1 is a high-cost firm. The expected value of these two equilibria is shown by S^{P}, the intersection of $\bar{q}_2$ and firm 1's expected reaction curve, $\bar{R}_1$ (which is derived as if firm 1 had marginal cost $\bar{c}$).

It is well known in the strategic trade literature that the optimal subsidies place the home firm (firm 1) in a Stackelberg leader position vis-à-vis the foreign firm (firm 2). Thus, S^{SL} and S^{SH} are the respective Stackelberg quantity equilibria in the separating case when firm 1 is respectively the low-cost firm and the high-cost firm. In the pooling case, S^{P} could be viewed as a modified Stackelberg equilibrium in which a Stackelberg leader reveals only its average output $\bar{q}_1$ (and firm 2 responds by committing to $\bar{q}_2$) but the leader's actual output subsequently varies with its type. Due to the linear reaction function (R_2), it is not difficult to see that firm 1's average outputs are the same under both cases and that firm 2's output in the pooling case is equal to its average output in the separating case. Our previous results in subsections 3.2 and 3.3 also prove this. By (9) and (13),

$$\bar{q}_1 \equiv \mu q_{PL} + (1-\mu) q_{PH} = \frac{a - 2\bar{c}}{2b} = \mu q_{SL} + (1-\mu) q_{SH},$$
$$\bar{q}_2 = \frac{a - 2\bar{c}}{4b} = \mu q_{2L} + (1-\mu) q_{2H}. \tag{14}$$

Moreover, the total outputs in the market are unchanged in the two cases since using (9) and (13):

$$q_{si} + q_{2i} = \frac{3b - 2c_i}{4b} = q_{pi} + \bar{q}_2, \quad i = \mathrm{L}, \mathrm{H}.$$

Thus, the optimal separation-inducing menu and the optimal uniform policy give rise to the same equilibrium price for the product, i.e.

$$p_{SL} = p_{PL} \quad \text{and} \quad p_{SH} = p_{PH}. \tag{15}$$

Although the expected outputs and the equilibrium price of firms 1 and 2 do not vary in the separating and pooling cases, Lemma 3 below shows that the optimal separation-inducing menu dominates the optimal uniform policy. If we denote the expected social welfare under these two optimal policies as W^* and $\tilde{W}^*$, respectively, where

$$W^* = \mu(p_{SL} - c_L) q_{SL} + (1-\mu)(p_{SH} - c_H) q_{SH}, \tag{16}$$

$$\tilde{W}^* = \mu(p_{PL} - c_L) q_{PL} + (1-\mu)(p_{PH} - c_H) q_{PH}, \tag{17}$$

then we have Lemma 3.

Lemma 3. The optimal separation-inducing menu gives country 1 higher welfare than the optimal uniform policy: $W^* > \tilde{W}^*$.

Proof. Using (14) and (15) in (16) and (17), the welfare difference can be expressed by

$$W^* - \tilde{W}^* = \mu(p_{SL} - c_L)(q_{SL} - q_{PL}) + (1-\mu)(p_{SH} - c_H)(q_{SH} - q_{PH}). \tag{18}$$

$$= \mu(q_{SL} - q_{PL})[(p_{SL} - c_L) - (p_{SH} - c_H)]. \tag{19}$$

Because the low-cost firm produces more in the separating case than in the pooling case, i.e. $q_{SL} > q_{PL}$, and the low-cost firm's price–cost margin is higher than the high-cost firm's since

$$p_{SL} - c_L = \frac{a - 2c_L}{4} > \frac{a - 2c_H}{4} = p_{SH} - c_H, \tag{20}$$

(19) shows $W^* - \tilde{W}^* > 0$. Q.E.D.

Note that the first term in (18) is positive (since $q_{SL} > q_{PL}$) but the second term is negative (since $p_{SH} < p_{PH}$). This implies that use of the optimal separation-inducing menu instead of the optimal uniform policy results in a welfare gain if firm 1 turns out to be a low-cost firm but a welfare loss if it is in fact a high-cost firm. Thus, there is an ex ante tradeoff using the optimal separation-inducing menu.

To understand how the tradeoff is resolved, let us make use of fig. 1. Since points S^{SH} and S^{PH} entail the same total output and the same price, all points on the segment (which is not depicted in the figure) between these two points also entail the same total output and the same price. Similarly, all points on the segment between points S^{SL} and S^{PL} (including these two points) entail the same total output and the same price. It follows that firm 1 has equal price–cost margin $(p_{SH} - c_H)$ at all points on the segment between S^{SH} and S^{PH} and equal price–cost margin $(p_{SL} - c_L)$ at all points on the segment between S^{SL} and S^{PL}. Note that at both the pooling equilibrium [shown by (S^{PH}, S^{PL})] and the separating equilibrium [shown by (S^{SH}, S^{SL})], firm 1 has the same expected output $(\bar{q}_1)$ but a higher variance in its output at the separating equilibrium. Thus, the issue is whether country 1's welfare is increasing or decreasing in the variance of firm 1's output. To answer this, let us consider a continuum of 'outcomes' between the pooling and separating equilibria. An 'outcome' here is represented by a pair of points with one on the segment between S^{PL} and S^{SL}, the other on the segment between S^{PH} and S^{SH}, and the expectation at S^P. Then an increase in the variance in firm 1's output is achieved by an increase in the low-cost firm's output (a point on the segment between S^{PL} and S^{SL}) and a decrease in the high-cost firm's output (a point on the segment between S^{PH} and S^{SH}) keeping expected output unchanged at $\bar{q}_1$. Since the low-cost firm's price–cost margin is higher than the high-cost firm's [see (20)], welfare in country 1 must rise as the variance in firm 1's output increases. Hence, the optimal separation-inducing menu is preferred to the optimal uniform policy.

With Lemma 3 we are now ready to analyze the entire game described in section 2. To do this, we must consider all policy options, both menu and uniform, at the same time.

Since government 1 is a Stackelberg leader vis-à-vis the firms, it will choose a policy that results in the highest social welfare in country 1. This, together with Lemma 3, rules out the uniform policies. Moreover, Lemma 3 and Proposition 1 indicate that t^* is the optimal one among all policies. Once the government adopts t^*, we have all results obtained in subsection 3.2. We now conclude the above analysis in Proposition 2.

Proposition 2. In the two-stage sequential game with asymmetric information and Cournot competition, there exists a separating equilibrium with t^* as the separation-inducing menu. The full information equilibrium allocation is achieved. Pooling is never an equilibrium.

The result that the full information allocation is attained is not surprising. On the one hand, the export subsidy rate that firm 1 receives in an optimal separation-inducing menu is identical to that in the full information case corresponding to the firm's type.[9] On the other hand, the additional policy instrument used in our model has no impact on the export market, i.e. the introduction of a lump-sum tax per se does not cause the firms' outputs and price to differ from those in the full information model.[10]

Lemma 3 and Proposition 2 seem to suggest that it is always preferable for the government to set a policy so as to induce firm 1 to reveal its information. This result, however, is sensitive to the nature of market competition. We will see this in the next section.

4. Bertrand competition

The government always wants to learn firm 1's true cost in order to design a precise policy. However, if firm 1 tries to inform the government or if the government uses some rules to induce firm 1 to reveal its cost, in our setting, the information is also released to firm 1's rival (firm 2), which may not be desirable. Earlier results indicate that information revelation is desirable in a Cournot game. The question is whether revelation is always optimal. To answer this, we now consider another model which differs from the earlier one in two respects: the firms produce imperfect substitutes and compete in prices.

Suppose the demand system is given by

$$q_i = \alpha - \beta p_i + \gamma p_j, \quad \text{where } i, j = 1, 2, i \neq j, \alpha > 0, \text{and } \beta > \gamma > 0. \tag{21}$$

[9]Because of this, the government's commitment is not a problem in the Cournot model. Although the government knows the firm's type after the firm has chosen a policy from this optimal menu, there is no need to revise the level of that policy because it is already equal to the optimal level in the full information case.

[10]This result of course depends upon a common assumption that monetary transfer either from the government to firm 1 (i.e. subsidy) or from firm 1 to the government (i.e. tax) is costless. The government is never reluctant to introduce an additional instrument when it is necessary, for example a lump-sum tax in this model, as it can be implemented at no expense. For the possible effects of relaxing this assumption, see Caillaud et al (1988) and Brainard and Martimort (1992).

We adopt the same notations defined before but interpret them in the context of a Bertrand game. For brevity, we only present results related to Lemma 3 and Proposition 2. In doing so, we first derive the optimal uniform policy. We then characterize the optimal separation-inducing menu. Finally, we compare the social welfare under these two optimal policies. Results are summarized in Proposition 3.

Given s under the uniform policy regime, the market-stage game is characterized by the following two maximization problems:

$$\max_{p_{pi}} (p_{pi}-c_i+s)(\alpha-\beta p_{pi}+\gamma\bar{p}_2), \quad i=\mathrm{L,H},$$
$$\max_{\bar{p}_2} \bar{p}_2(\alpha-\beta\bar{p}_2+\gamma\bar{p}_1), \tag{22}$$

where p_{pi} is firm 1's price when it is type i in the pooling case, $\bar{p}_1 \equiv \mu p_{\mathrm{PL}} + (1-\mu)p_{\mathrm{PH}}$ is the expected price charged by firm 1, and $\bar{p}_2$ is firm 2's price in the pooling case. By solving these problems simultaneously, we obtain the market-stage equilibrium prices ($i=\mathrm{L,H}$):

$$\bar{p}_2=\frac{1}{4\beta^2-\gamma^2}[\alpha(2\beta+\gamma)+\beta\gamma(\bar{c}-s)],$$

$$p_{pi}=\frac{1}{2(4\beta^2-\gamma^2)}[2\alpha(2\beta+\gamma)+\gamma^2(\bar{c}-c_i)+4\beta^2(c_i-s)].$$

Maximizing the expected social welfare, which is

$$\tilde{W}(s)\equiv\mu(p_{\mathrm{PL}}-c_{\mathrm{L}})(\alpha-\beta p_{\mathrm{PL}}+\gamma\bar{p}_2)$$
$$+(1-\mu)(p_{\mathrm{PH}}-c_{\mathrm{H}})(\alpha-\beta p_{\mathrm{PH}}+\gamma\bar{p}_2),$$

gives the optimal uniform policy s_{p}^*:

$$s_{\mathrm{p}}^*=-\frac{\gamma^2}{4\beta^2(2\beta^2-\gamma^2)}[\alpha(2\beta+\gamma)-(2\beta^2-\gamma^2)\bar{c}].$$

Therefore, the equilibrium prices are

$$p_{pi}=\tfrac{1}{2}\left[c_i+\frac{\alpha(2\beta+\gamma)}{2\beta^2-\gamma^2}\right], \quad i=\mathrm{L,H} \quad \text{and} \quad \bar{p}_2=\frac{1}{4\beta}\left[\alpha+\gamma\bar{c}+\frac{2\alpha\beta(\beta+\gamma)}{2\beta^2-\gamma^2}\right], \tag{23}$$

and analogously to (17), country 1's expected welfare at the pooling equilibrium is

$$\tilde{W}^*=\mu(p_{\mathrm{PL}}-c_{\mathrm{L}})p_{\mathrm{PL}}+(1-\mu)(p_{\mathrm{PH}}-c_{\mathrm{H}})q_{\mathrm{PH}}, \tag{24}$$

where

$$q_{\mathrm{PL}}=\alpha-\beta p_{\mathrm{PL}}+\gamma\bar{p}_2 \quad \text{and} \quad q_{\mathrm{PH}}=\alpha-\beta p_{\mathrm{PH}}+\gamma\bar{p}_2.$$

To avoid repetition, we omit the derivation of the optimal separation-inducing menu and the resulting market equilibrium. The optimal separation-inducing menu has the per unit subsidy rates[11]

$$s_i^*=-\frac{\gamma^2}{4\beta^2(2\beta^2-\gamma^2)}[\alpha(2\beta+\gamma)-(2\beta^2-\gamma^2)c_i], \quad i=\mathrm{L,H},$$

and the market equilibrium prices are

$$p_{si}=\frac{1}{2}\left[c_i+\frac{\alpha(2\beta+\gamma)}{2\beta^2-\gamma^2}\right] \quad \text{and} \quad p_{2i}=\frac{1}{4b}\left[\alpha+\gamma c_i+\frac{2\alpha\beta(\beta+\gamma)}{2\beta^2-\gamma^2}\right], \quad i=\mathrm{L,H}. \tag{25}$$

Moreover, analogously to (16), the separating equilibrium welfare of country 1 is

$$W^*=\mu(p_{\mathrm{SL}}-c_{\mathrm{L}})q_{\mathrm{SL}}+(1-\mu)(p_{\mathrm{SH}}-c_{\mathrm{H}})q_{\mathrm{SH}}, \tag{26}$$

where

$$q_{\mathrm{SL}}=\alpha-\beta p_{\mathrm{SL}}+\gamma p_{2\mathrm{L}} \quad \text{and} \quad q_{\mathrm{SH}}=\alpha-\beta p_{\mathrm{SH}}+\gamma p_{2\mathrm{H}}.$$

We illustrate the above equilibria in fig. 2. Note that the position of firm 1's reaction curve (shown as R_{SL}, R_{SH}, R_{PL}, and R_{PH} in fig. 2) depends on its type and the tax rate. When changing from the optimal uniform policy to the menu, the low-cost firm's reaction curve is shifted downward (because $s_{\mathrm{L}}^*<s_{\mathrm{p}}^*$, i.e. the firm faces a higher tax); and the high-cost firm's reaction curve is shifted upward (since $s_{\mathrm{H}}^*>s_{\mathrm{p}}^*$, i.e. the firm faces a lower tax). Also in fig. 2, S^{SL} and S^{SH} represent the Stackelberg price equilibria in the separating case. S^{P} would be the Stackelberg price equilibrium if the firm had marginal cost $\bar{c}$. S^{PL} and S^{PH} are the actual equilibria in the pooling case.

Similar to the Cournot case, linearity of the reaction function implies that the price $\bar{p}_2$ charged by firm 2 in the pooling case is equal to the average price in the separating case: i.e. by (23) and (25)

$$\mu p_{2\mathrm{L}}+(1-\mu)p_{2\mathrm{H}}=\frac{1}{4b}\left[\alpha+\gamma\bar{c}+\frac{2\alpha\beta(\beta+\gamma)}{2\beta^2-\gamma^2}\right]=\bar{p}_2. \tag{27}$$

Also by (23) and (25), we have

$$p_{\mathrm{SL}}=p_{\mathrm{PL}} \quad \text{and} \quad p_{\mathrm{SH}}=p_{\mathrm{PH}}, \tag{28}$$

[11]The levels of lump-sum tax are chosen to make the policy satisfy the separation constraints.

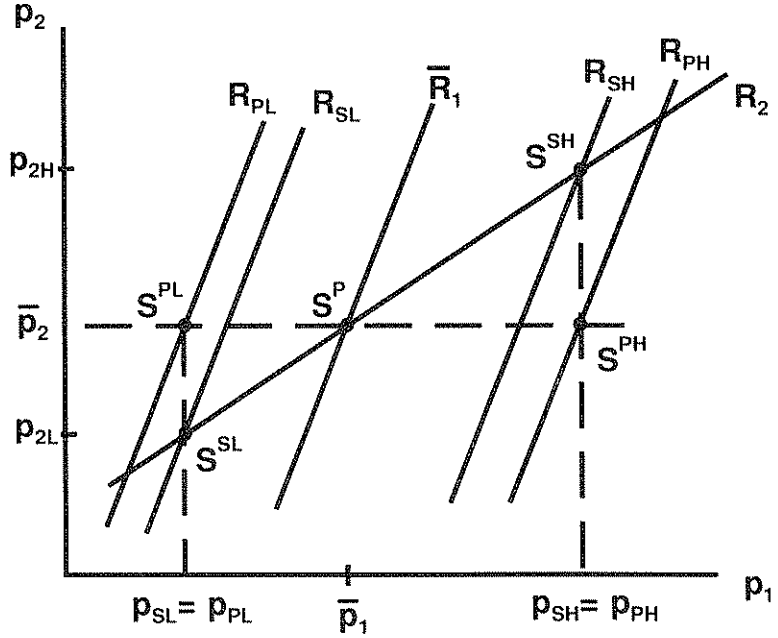

Fig. 2

meaning that each type of firm 1 sets the same price under these two cases, but

$$p_{2L} < \bar{p}_2 \quad \text{and} \quad p_{2H} > \bar{p}_2. \tag{29}$$

Due to the strategic complementarity of Bertrand competition, firm 2 sets a lower price if it knows that its rival is a low-cost firm than if it does not know. Similarly, firm 2 sets a higher price when it knows that it is competing with a high-cost firm.

We now make welfare comparison between the pooling and separating equilibria. From (24) and (26), the welfare difference can be expressed in the same form as (18) for the Cournot case:

$$W^* - \tilde{W}^* = \mu(p_{SL} - c_L)(q_{SL} - q_{PL}) + (1-\mu)(p_{SH} - c_H)(q_{SH} - q_{PH}). \tag{30}$$

Note from the demand system (21) and (29),

$$q_{SL} - q_{PL} = \gamma(p_{2L} - \bar{p}_2) < 0 \quad \text{and} \quad q_{SH} - q_{PH} = \gamma(p_{2H} - \bar{p}_2) > 0. \tag{31}$$

Thus, the first term of (30) is negative, implying a loss from using the separation-inducing menu when firm 1 is a low-cost firm. However, the second term is positive, which captures the gain from adopting the menu when firm 1 is a high-cost firm. Moreover, the gain and loss are proportional to firm 1's price–cost margin. To show that welfare is lower at the separating equilibrium than at the pooling equilibrium, we need only to show that firm 1 earns a higher price–cost margin when it is low cost than it is high cost. To do this, we use (27) and (31) to rewrite the welfare difference (30) as

$$W^* - \tilde{W}^* = \frac{1}{\gamma}\mu(q_{\mathrm{SL}} - q_{\mathrm{PL}})[(p_{\mathrm{SL}} - c_{\mathrm{L}}) - (p_{\mathrm{SH}} - c_{\mathrm{H}})]. \tag{32}$$

By (25),

$$p_{\mathrm{SL}} - c_{\mathrm{L}} = \frac{1}{2}\left[\frac{\alpha(2\beta+\gamma)}{2\beta^2-\gamma^2} - c_L\right] > \frac{1}{2}\left[\frac{\alpha(2\beta+\gamma)}{2\beta^2-\gamma^2} - c_{\mathrm{H}}\right] = p_{\mathrm{SH}} - c_{\mathrm{H}}. \tag{33}$$

Using (31) and (33) in (32), we immediately obtain $W^* < \tilde{W}^*$. This establishes Proposition 3.

Proposition 3. In the two-stage sequential game with asymmetric information and Bertrand competition, $\tilde{W}^* > W^*$, i.e. the optimal uniform policy achieves higher social welfare than a separation-inducing menu. The equilibrium is pooling.

The welfare difference (30) for the Bertrand case is identical in form to (18) for the Cournot case. Moreover, since firm 1 has the same expected output ($\bar{q}_1$) at the separating and pooling equilibria,[12] it is again true that the difference between the separating and pooling equilibria could be explained on the basis of the difference in the variance of output. However, in the Bertrand case it is more convenient to use fig. 2 to express the explanation in terms of the difference in the variance of firm 2's price. As can be seen from (31), when firm 2's price is high, then firm 1's output is high (and vice versa) and an increase in the variance of firm 2's price causes a proportional increase in the variance of firm 1's output.

In fig. 2 and from (28), firm 1 has the same price and price–cost margin at all points on the segment between S^{PL} and S^{SL} and likewise on the segment between S^{PH} and S^{SH}. However, firm 2's price varies as an 'outcome' moves from the separating equilibrium [shown by $(S^{\mathrm{SL}}, S^{\mathrm{SH}})$] to the pooling equilibrium [shown by $(S^{\mathrm{PL}}, S^{PH})$]. The variance in firm 2's price is higher at the separating equilibrium than at the pooling equilibrium. In fact, a reduction in firm 2's price variance is achieved by a rise in firm 2's price when firm 1 is a low-cost firm (a point moving upwards from S^{SL} towards S^{PL}) and a drop in firm 2's price when firm 1 is a high-cost firm (a point moving downwards from S^{SH} towards S^{PH}) keeping the expected price

[12] Following (27) and (28), one can easily check this by calculating the two expected outputs.

unchanged at $\bar{p}_2$. Thus, to select between these two equilibria, we must know whether country 1's welfare is increasing or decreasing in firm 2's price variance.

Since the welfare difference (30) for the Bertrand case is identical in form to (18) for the Cournot case and that the low-cost firm has a higher price–cost margin than the high-cost firm in both cases [see (20) and (30)], as discussed before (for Lemma 3), we prefer a higher output from the low-cost firm. Note that a higher output for the low-cost firm is achieved by a lower variance in firm 2's price (and thus a low variance in firm 1's output). Consequently, the optimal uniform policy that results in a smaller variance in firm 2's price is preferred to the menu in Bertrand competition.

The sharp difference between Lemma 3 and Proposition 3 arises because the pooling and separating equilibria have significantly different consequences for outputs in the Bertrand case than in the Cournot case. It is known from (31) that, in the Bertrand case, the low-cost firm produces less while the high-cost firm produces more in the separating equilibrium than in the pooling equilibrium. However, in the Cournot case, the low-cost firm produces more but the high-cost firm produces less in the separating equilibrium than in the pooling equilibrium, i.e. the expreessions in (31) have opposite signs in the Cournot case.[13]

When government 1 adopts an optimal uniform policy, the equilibrium necessarily differs from the full information equilibrium. Interestingly enough, Proposition 3 indicates that country 1 achieves higher social welfare in a world with incomplete information than in a world with full information. This is because firm 1's cost information has positive net effects on the social welfare if it is kept private. One important implication of this finding is that in a 'rivalrous agency' model,[14] it is better not to induce the agent to reveal its information, in some cases, because the revelation has a signalling effect.

5. Conclusion

When information asymmetry problems are present in the Brander–Spencer model, the home government can design a menu of policies, by introducing an additional policy instrument, to induce information revelation and achieve the full information social welfare. But the rival firm is also uninformed. Hence, the model is characterized by a mix of screening and signalling. In models of this kind it is not always optimal for the uninformed government to design a mechanism that induces the informed home firm to reveal its information, because this also informs the foreign firm. The nature

[13]It can be easily verified that this is also true if we had differentiated products instead of homogeneous products in the Cournot case.

[14]Our model differs from Fershtman and Judd's (1987) owner-manager model. In a 'rivalrous agency' environment we consider a hidden information problem while they deal with issues of hidden action.

of the optimal policy is sensitive to the type of competition between home and foreign firms. Under Cournot competition, the government offers a menu of policies that induces the home firm to reveal its type. Under Bertrand competition, however, the government chooses a uniform policy, allowing the home firm to conceal its information.

As suggested by a referee, it would be of interest to investigate non-linear policies that do not reveal the home firm's cost information to the foreign firm and compare them with linear polices.[15] Under the non-linear policy regime, the government first offers a subsidy scheme in which subsidy rates are contingent on output level, then firms produce, and finally the home firm receives subsidy payments at the rate corresponding to its output. This has the advantage that different types of the home firm receive different marginal subsidy rates. Also the types are separated only *after* the foreign firm has produced and so the home firm's cost information does not influence the foreign firm's output decision. Such non-linear policies might dominate linear policies, especially when information-concealing is desirable, for the reason that the non-linear policies share the advantages that are respectively attained by separation-inducing menus and uniform policies.

Appendix

Proof of Lemma 1. By (6), $\pi^{L}(t_{H})-\pi^{H}(t_{H})=4(c_{H}-c_{L})(a-c_{L}-c_{H}+2s_{H})/9b$. Since $\pi^{L}(t_{L})\geqq\pi^{L}(t_{H})$ from the separation constraint, we obtain

$$\pi^{L}(t_{L})-\pi^{H}(t_{H})\geqq\frac{4}{9b}(c_{H}-c_{L})(a-c_{L}-c_{H}+2s_{H}). \tag{A.1}$$

Similarly,

$$\pi^{H}(r_{H})-\pi^{L}(t_{L})\geqq-\frac{4}{9b}(c_{H}-c_{L})(a-c_{L}-c_{H}+2s_{L}). \tag{A.2}$$

Combining (A.1) and (A.2) yields

$$\frac{4}{9b}(c_{H}-c_{L})(a-c_{L}-c_{H}+2s_{H})\leqq\frac{4}{9b}(c_{H}-c_{L})(a-c_{L}-c_{H}+2s_{L}).$$

So $s_{L}\geqq s_{H}$. Using $\pi^{H}(t_{H})\geqq\pi^{H}(t_{L})$ once again, we have

$$\frac{(a-2c_{H}+2s_{H})^{2}}{9b}-\tau_{H}\geqq\frac{(a-2c_{H}+2s_{L})^{2}}{9b}-\tau_{L},$$

[15] In a model in which the foreign firm knows the home firm's marginal cost (no signalling), Maggi (1992) shows that non-linear policies enhance the government's degree of freedom to implement the Stackelberg outcome.

which confirms $\tau_H \leqq \tau_L$.

For the converse, set

$$\tau_L = \frac{(a-2c_H+2s_L)^2}{9b} \quad \text{and} \quad \tau_H = \frac{(a-2c_H+2s_H)^2}{9b}.$$

Proof of Proposition 1. We shall show that t^* induces separation. By using optimal subsidy levels (8) and the normalization $\tau_H^* = 0$, we obtain

$$\pi^L(t_L^*) = \frac{(a-2c_L)^2}{4b} - \tau_L^*, \qquad \pi^H(t_H^*) = \frac{(a-2c_H)^2}{4b},$$

$$\pi^L(t_H^*) = \frac{(a-c_L-c_H)^2}{4b}, \qquad \pi^H(t_L^*) = \frac{(a-c_L-c_H)^2}{4b} - \tau_L^*.$$

Therefore, $\pi^L(s_L^*) \geqq \pi^L(s_H^*)$ iff

$$\tau_L^* \leqq \frac{1}{4b}[(a-2c_L)^2 - (a-c_L-c_H)^2] = \frac{1}{4b}(c_H-c_L)^2$$

$$+\frac{1}{2b}(c_H-c_L)(a-c_L-c_H),$$

and $\pi^H(t_H^*) \geqq \pi^H(t_L^*)$ iff

$$\tau_L^* \geqq \frac{1}{4b}[(a-c_L-c_H)^2 - (a-2c_H)^2] = \frac{1}{2b}(c_H-c_L)(a-c_L-c_H)$$

$$-\frac{1}{4b}(c_H-c_L)^2.$$

Hence the separation constraints are satisfied iff

$$-\frac{1}{4b}(c_H-c_L)^2 \leqq \tau_L^* - \frac{1}{2b}(c_H-c_L)(a-c_L-c_H) \leqq \frac{1}{4b}(c_H-c_L)^2.$$

Obviously, τ_L^* defined as in (10) satisfies the above condition. Thus t^* induces separation.

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