Sensitivity of Tariffs and Quotas: A Signaling Game*

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Abstract

Abstract: In a model with cost-based informational asymmetry and trade policy determined endogenously, we show that tariffs and import-quotas have different *sensitivities* to the signal sent by the private agents to the home government. Specifically, the optimal quota is shown to be more sensitive than the optimal tariff as measured in terms of the reduction in equilibrium import-volume caused by the change in the government's perception about the true cost of the domestic firm. Consequently, signaling distortion is larger in the quota regime than in the tariff regime. Non-equivalence between the two policy tools follows from this difference in their sensitivities. The model is benchmarked so that under complete information tariffs and quotas are equivalent.

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Introduction

A wide body of literature has developed in trade policy comparing tariffs and import-quotas. A prominent theme in this area is that the two policy instruments may not be equivalent under a variety of situations. When tariffs and quotas are exogenously fixed then replacing the tariff with its equivalent quota, in the sense that the two yield the same import-volume, may generate different equilibrium prices and output levels. The intuition for this can be outlined in a simple "home duopoly model" where there are two countries, home and foreign, and one firm in each country selling a homogenous good in home's domestic market. In the quota regime, the home-firm believes, and rationally so, that the output of the foreign-firm is fixed at the quota limit so that its "conjecture" about the rival firm's response to a change in its own output is simply zero.[1] That is, the home-firm behaves like a "follower". In the tariff regime, however, output of the foreign-firm is flexible so that the home-firm's conjecture now depends on the underlying market structure (Hwang and Mai, 1988; Itoh and Ono, 1984). Specifically, in the simple Cournot model, the home firm behaves like a follower in that it treats the output of the rival firm as fixed when choosing its best-response output. Since the conjecture of the home-firm is identical in the two regimes, tariffs and quotas are equivalent here.[2] It is simple to see from this that the equivalence result will hold in general provided that the conjecture of the home-firm is that of a follower.

From the point of view of this paper, we can summarize the arguments above by noting that, as perceived by the home-firm, the differential "sensitivity" (response) of equilibrium

[1] Formally, this argument requires that the quota limit is always fully utilized in equilibrium. This holds throughout in our model.

[2] Brander and Spencer (1986) extend this result to Cournot oligopoly case.

import-volume to the action chosen by the home-firm is the key factor that determines the equivalence, or the lack of it, between the two policy tools.

In contrast to the literature discussed above, we consider the case where the tariff/quota level is endogenously determined.[3] Specifically, we consider a two period (stage) game where the home country operates under autarky in the first period followed by (optimal) trade liberalization in the second period. The critical feature of the model is that the home-firm has private information about its true cost. A simple signaling game arises where the home-firm can signal its true cost in the first period (the signaling stage) before trade liberalization is to occur. Having observed the signal, the government updates its belief about the cost of the firm in a Bayesian manner and accordingly implements the optimal trade policy for the second period. The two firms then compete in quantities under Cournot conjectures in home's domestic market. This set up broadly captures a host of real-world situations. One example of this is that the home country initially operates under high trade barriers to develop an "infant industry" and wants to liberalize once the industry has reached a mature phase. The government's lack of complete information reflects that it is not sure how much the home-firm improved during the infant-industry-protection phase.

In this scenario, we first show that tariffs and quotas are equivalent under complete information. As discussed above, this follows directly from the fact that the firms hold Cournot conjectures. Allowing for asymmetric information, we show that the government always targets the same import-volume (and all other endogenous variables) under the two regimes for any given belief held by it about the true cost of the home-firm. In fact a stronger

[3] As common in the literature dealing with tariffs versus quotas issue, we assume that the choice of the policy regime (tariff or quota) is exogenously given. Also, we restrict policies to be either a tariff or quota but not both.

result is derived in that in the unique signaling equilibrium of the game in the tariff and quota regime, the two Types separate out so that the identity of the home-firm is fully revealed *before* policy is implemented. Consequently, endogenously determined tariffs and quotas are equivalent in that they lead to identical outcome in the second stage of the game. Despite this tariff-quota equivalence in period-2 outcome, we show that the "signaling distortion" in the first period is higher in the quota regime than in the tariff regime. The non-equivalence in period-1 outcome is entirely driven by a *sensitivity effect* which can be easily motivated from the following example. Suppose that the high-cost firm is successfully able to alter the government's belief through a credible signal that its true cost is lower than the initial belief held by the government. As we show in the sections, this implies that the government would like implement higher protection in order to maximize its politically motivated objective function. In the quota regime this requires squeezing the quota limit by, say, 2 units of imports. However if tariffs are used then, with the tariff held fixed momentarily, the change in the government's belief implies that the government rationally believes that the import-volume is already lower by, say, 1 unit. As perceived by the government, and rationally so, this is simply the "direct effect" of cost movement on equilibrium import-volume. Thus, the *revision* in the optimal tariff is targeted to lower the import-volume by the remaining 1 unit only. In our simple linear model, the change in equilibrium import-volume through the revision in the tariff is independent of the underlying cost structure so that the equilibrium import-volume changes by 1 units in the tariff regime and by 2 units in the quota regime. Thus, equilibrium import-volume is much more sensitive to a credible signal sent by the private agent in the quota regime than in the tariff regime. It is direct to see from this that this *sensitivity effect* makes it more difficult for the two Types to separate out. Consequently, signaling distortion is higher in the quota regime leading to a non-equivalence result.

It is important to note here that our *sensitivity effect* is completely the opposite of the key reason put forward in the literature to explain non-equivalence between tariffs and quotas. That is, as discussed above, when policy levels are exogenously given then non-equivalence arises because the home-firm perceives that import-volume is rigid with quotas in place and sensitive to its own action with the tariff in place when its conjecture is different from that of a follower. The *sensitivity effect* contrasts sharply from this in that it establishes that, when policy levels are endogenously determined, then import-volume is *more* sensitive in the quota regime. Thus, the paper contributes in making a more general point that the basic intuition and results with exogenously fixed policy levels cannot be extended to the case with endogenously determined policy levels.

The structure of the remaining paper is as follows. In section 1 we set up the basic model and derive our results under complete information. The *sensitivity effect* is formally stated here. In section 2 we introduce asymmetric information and define the equilibrium concept used to derived the signaling equilibria. In section 3 we derive the signaling equilibrium and formally prove the non-equivalence result. In section 4 we discuss the generality of the *sensitivity effect* in an alternative market structure. In the conclusion we summarize our findings and suggest possible extensions of the model.

Section 1

1.1 *Basic structure of the game*

We consider a partial equilibrium model with two countries called home and foreign, and two time periods indexed by 1 and 2. There are two goods, X and Y, with good Y being the numeraire good. Throughout the paper we will focus on the home country. Home's per-period (inverse) demand function for good X is given by $P = \alpha - X^d$ where P is the relative price of the good in home's local market, X^d is the amount of good X demanded by all of home's consumers and, α is a strictly positive parameter given exogenously to the model. Home imports good X and exports Y in return to balance trade. For completeness, assume that the foreign-agents do not consume good X. At the beginning of each period, each country is endowed with a given amount of good Y which can be either consumed or used to produce good X. Specifically, we will use c to denote home-firm's marginal and average cost of producing 1 unit of good X as measured in terms of the numeraire. The same for the foreign-firm is assumed to be zero.[4] The different stages of the game and structure of the informational asymmetry are as follows.[5]

At the beginning of the first period, "nature" assigns a non-negative value to c, drawn from an underlying distribution function. This remains unchanged for the rest of the game. To keep the model simple, we assume that c can take two possible values denoted by c_H and c_L, where $c_H > c_L$. The properties of the distribution function are common knowledge to all the players. Let θ_o denote the "prior" probability that $c = c_L$. At this stage of the game, c is

[4] Our results are not affected in any way by assuming that foreign's cost is equal to zero.

[5] The structure of demand and production outlined above for the home country can be formally derived by assuming a quasi-linear utility function for a representative home agent as given by $C_y + \alpha C_x - LC_x^2/2$, where L is the total number of agents in the home country. Similarly, the production structure can be obtained from a Ricardian technology where 1 unit of labor is required to produce 1 unit of Y and c units of labor to make 1 unit of good X.

observed by the home-firm and the foreign-firm but not by the home-government.[6] There is no trade in period 1 so that the home-firm enjoys monopoly in the domestic market. Thus, as discussed in the introduction, this period serves as the signaling stage of the game. Having observed the value of c, the home-firm chooses its output level for this period. Consumption takes place and utilities are realized. The government observes the choice made by its firm and updates its belief about the value of c. It implements the optimal tariff/quota for the second period of the game. If the optimal policy is non-prohibitive, then the two firms choose their output levels simultaneously as in a standard Cournot duopoly game with quantity competition. The game ends with markets being cleared and utilities realized for all agents for the second period (stage) of the game.

Since the home country operates under autarky in the first period, the issue of tariffs versus quotas in irrelevant here. Consequently, our focus will be on the choice of policy levels for the second period of the game. As common in the literature, we assume that the choice of policy regime (tariffs or quotas) is exogenous to the model. The aim of the paper is to analyze whether tariffs and quotas lead to the same outcome in the two periods or not. To this end, let t denote home's specific tariff on its imports in the second period and measured in terms of the numeraire good. Similarly, let q denote the import-quota limit in this period. The values of t, q will be endogenously determined. Throughout the paper we will assume that t, q are non-prohibitive and imply equilibrium import-volumes strictly less than the free trade level as this property will be satisfied in the equilibria that we derive.

We assume that the objective of the government in the second period is politically

[6] The motivation for this form of informational asymmetry is that the firms are likely to have better information about the industry structure than the government. For a similar approach see, for example, Brainard and Martimort, 1997.

motivated. That is, the government maximizes the sum of pure national welfare and β times the (producer) surplus of the home-firm, where β is a non-negative parameter and given exogenously. A higher value of β implies that the government is more concerned about the welfare of its firm (the lobby) relative to national welfare. Our main results hold when the government maximizes pure national welfare which can be seen by setting β equal to zero. We assume that tariff revenue/quota rent is distributed back to home's consumers in a lump-sum fashion. Further, the ownership of the home-firm is assumed to be extremely concentrated so that its objective is to maximize its profit in the conventional sense.[7]

1.2.1 *Complete information solution*

With complete information there is no dynamic link between the two periods. Thus, period 1 outcome is given by the home-firm choosing its monopoly output level and the second period solution is the standard Cournot duopoly-outcome with optimal tariff/quota in place. Let $X_h(X_f)$ denote the output of the home-firm (foreign-firm) in the second period. We have that, for any given t, $X_h = (\alpha - 2c + t)/3$ and $X_f = (\alpha - 2t + c)/3$. The overall welfare of the government is equal to

$$G^t(t,c) \equiv \frac{(2\alpha - c - t)^2}{18} + t\frac{\alpha - 2t + c}{3} + (1+\beta)\frac{(\alpha - 2c + t)^2}{9}$$

The first term on right-hand side (RHS) of the previous identity is the consumer surplus from the consumption of good X, the second one is the tariff revenue and the third term is the weighted producer surplus in sector X.

In order to derive the corresponding expression for the quota regime we first need to

[7] This assumption is common in the literature and implies that the home-firm's output decision is independent of tariff revenue/quota rent considerations and the prices that owners of the firm may themselves face as consumers. For more details on this point, see, for example, Grossman and Helpman, 1994, pp. 846-847.

state how the quota rent is distributed between the home-government and the foreign-firm. As is well-known in the literature, this can be quite arbitrary ranging from the government appropriating all of it to nothing. To ensure that non-equivalence between tariffs and quotas does not arise due to this arbitrariness, we benchmark the quota-rent rule such that if a tariff is replaced by a quota such that the two generate the same import-volume then the quota rent accruing to the government must equal the tariff revenue. Thus, with $QR(q)$ denoting the quota-rent accruing to the government when the quota limit is set at q, the above rule implies that: $QR(q) = (q/2)(\alpha - 3q + c)$. The market outcome for any given q is given by $X_f = q$, $X_h = (\alpha - c - q)/2$. We note here that the solution implies that the quota limit is always fully utilized by the foreign firm. A formal proof of this is stated in Appendix A1. Home government's overall welfare in the quota regime is equal to

$$G^q(q, c) \equiv \frac{(\alpha - c + q)^2}{8} + q\frac{\alpha + c - 3q}{2} + (1 + \beta)\frac{(\alpha - q - c)^2}{4}$$

The first term on RHS of the previous identity is the consumer surplus from good X, the second is the quota rent accruing to the government and the third term is the weighted producer surplus in sector X.

Using the $G^t(.), G^q(.)$ functions, we can derive the optimal tariff and quota levels. Let these be denoted by $t(c)$, $q(c)$ respectively. We have that:

$$t(c) = \frac{(3 + 2\beta)\alpha - 4\beta c}{9 - 2\beta} \quad .....(1)$$

$$q(c) = \frac{\alpha(1 - 2\beta) + (3 + 2\beta)c}{9 - 2\beta} \quad ......(2)$$

Assumption A1

(i) $\beta < (\alpha + 3c_L)/(2\alpha - 2c_L)$

(ii) $\alpha > 2c_H$

The assumption is necessary and sufficient to ensure that the optimal tariff/quota levels stated above are strictly interior[8] and that all equilibrium prices, output level of each firm, are strictly positive.[9] It can be checked that under the assumption, the second order maximization condition for optimal tariff and quota is globally satisfied. We also note that the assumption implies that $9 - 2\beta > 0$.

With the above solution in place, we state our first result as follows.

Lemma 1

Tariffs and quotas are equivalent under complete information. Equilibrium prices, output levels, welfare of all agents and the government's overall welfare is the same in the two policy regimes in each period.

Intuition for Lemma 1 has already been discussed in the introduction and it confirms the findings in the literature that in the simple Cournot model, tariffs and quotas are equivalent. Thus, any non-equivalence between tariffs and quotas must be due to informational asymmetry discussed later in the paper.

1.2.2 *Solution for arbitrarily given belief*

We now consider the solution for any arbitrary given belief of the government about the true cost of the home-firm. That is, let θ denote the probability that the government

[8] Interior solution for the optimal tariff/quota here means that these are non-prohibitive and generate an import-volume strictly below the free trade level.

[9] When Assumption A1 is violated then we get a corner solution for either $c = c_L$ or $c = c_H$ or for both. Our results are unaffected when the corner solution applies at either c_L or c_H but not both. With a corner solution at c_L and c_H, optimal policy is either free trade or autarky. In both these cases, optimal protection is invariant to the government's belief about the true cost of the home-firm so that signaling issue is then irrelevant.

attaches to $c = c_L$ and $1-\theta$ to $c = c_H$. We treat θ as exogenously fixed in this sub-section. The government maximizes its expected welfare which is equal to $\theta G^t(t, c_L) + (1-\theta)G^t(t, c_H)$ in the tariff regime and equal to $\theta G^q(q, c_L) + (1-\theta)G^q(q, c_H)$ in the quota regime. Solving for the optimal tariff we get that this is equal to $t(\tilde{c})$ and the optimal quota is equal to $q(\tilde{c})$, where $\tilde{c} \equiv \theta c_L + (1-\theta)c_H$ and $t(.), q(.)$ functions are as derived above.

We are now in a position to state our next Lemma which will prepare the ground to show that the *sensitivity effect* defined later in the only reason for the non-equivalence result that we will finally establish.

Lemma 2

For any $\theta \in [0, 1]$, the government targets the same value of equilibrium import-volume and all other endogenous variables under $t(\tilde{c})$ and $q(\tilde{c})$.

Proof: See Appendix A2.

Lemma 2 prepares the ground to better understand the importance of the *sensitivity effect* defined below. It strengthens the findings in *Lemma* 1 in that it shows that tariffs and quotas are equivalent in the expected value sense. Our final solution features a unique equilibrium in each policy regime which is a separating equilibrium. This implies that the government knows the true cost of the firm before trade policy is implemented so that the findings in *Lemma* 2 are not directly applicable to our results. However, it will be useful in interpreting the "out of equilibrium" beliefs which are critical in sustaining the separating equilibrium.

1.3 *Sensitivity effect*

Consider a hypothetical situation where the government's belief (about the true cost of the home-firm) changes from c_H to c_L. That is, the government initially believed that its firm was a high-cost Type but revises it to being a low-cost Type. From equation (2) we note that this change in the belief implies that the optimal quota limit, and thus the equilibrium import-volume, will be lower by amount

$$\lambda_q \equiv |q(c_L) - q(c_H)| = (3 + 2\beta)(c_H - c_L)/(9 - 2\beta)$$

Next we note that the if tariffs are used instead, then the change in the optimal tariff implies that equilibrium import-volume will fall by amount

$$\lambda_t \equiv |(-2/3)[t(c_L) - t(c_H)]| = (8/3)\beta(c_H - c_L)/(9 - 2\beta)$$

The *sensitivity effect* can now be formally stated as follows.

Definition: Sensitivity effect

$\lambda_q > \lambda_t$.[10]

The interpretation of the *sensitivity effect* is as follows. Following the stated change in the government's belief, it is direct to check from $q(c)$ and $t(c)$ functions that the government would now like to impose a lower quota limit and a higher tariff. From *Lemma* 2 it follows that the government intends to achieve the same change in import-volume in the quota and tariff regimes. In the quota regime, the change in equilibrium import-volume is always equal to the change in the quota limit since this is always binding. Thus, the intended change in import-volume is equal to λ_q in absolute value which is achieved in the quota regime. Now consider the tariff regime. With the tariff held fixed momentarily, the change in the

[10] The inequality is evident from the fact that $9 - 2\beta > 0$ as discussed above. We restate here that when this inequality does not hold then signaling motives are completely irrelevant and the optimal tariff/quota features either autarky or free trade.

government's belief implies that it rationally believes that import-volume will be lower by amount $(c_H - c_L)/3$ which can be seen from the expression for X_f (for the tariff regime) stated above. This is simply the "direct effect" of the change in c on equilibrium import-volume as perceived by the government. Naturally, this direct effect is completely absent in the quota regime. The revision in the tariff is thus intended to lower import-volume by the remaining amount equal to $\lambda_q - (c_H - c_L)/3 = \lambda_t$. It is important to note that the actual (realized) change in import-volume due to the *revision* in the optimal tariff and quota is as anticipated by the government. That is, equal to λ_q in the quota regime and λ_t in the tariff regime. This result follows directly from the linear structure of the model where the actual changes in import-volume due to a change in the value of t, q, are independent of the true cost of the home-firm. Clearly, what is not realized is the direct effect referred to above so that the actual change in import-volume is larger (in absolute value) in the quota regime than in the tariff regime. Thus, we summarize our findings here by noting that import-volume is more sensitive in the quota regime than in the tariff regime to a given change in the government's belief about the true cost of the home-firm. The result suggests that the high-cost firm will have greater incentive to mimic the low-cost firm in the quota regime because by doing so it can get a larger reduction in import-volume resulting in higher profit for it. We confirm this intuition in the next section and establish our non-equivalence result on this feature.

It is direct to verify that the *sensitivity effect* as defined above holds for marginal changes in the value of θ too. We chose to describe it for a discrete change above because this will be relevant for our results in the next section.

Section 2

With the solution for arbitrarily given beliefs determined above, the remaining task is to derive the structure of equilibrium beliefs and the outcome in the first period of the game. To this end, we define the following functions:

$S : \{L, H\} \rightarrow R_+$ where $R_+ = [0, \infty)$

$B : R_+ \rightarrow [0, 1]$

$T : [0, 1] \rightarrow R_+$ and $Q : [0, 1] \rightarrow R_+$.

The interpretation of these functions is as follows. L denotes the case when $c = c_L$ and H is equivalent to $c = c_H$. S defines the strategy of the home-firm in period 1 as a function of its Type. We will use this notation for the tariff and quota regimes as the distinction between the two cases will be evident. The same remark applies to the function B which gives the probability that the government assigns to $c = c_L$ as a function of the output chosen by the home-firm in the first period. The function T describes the tariff chosen by the government in the second period as a function of the government's belief (value of $B(.)$) while Q is the quota limit chosen by the government in the second period as function of its belief.

We next define the total profit of the home-firm which in the sum of its profits in the two time periods. For any $\{S, B, T, i\}$, $i \in \{L, H\}$, we denote the total payoff of the (home) firm by $V(S(i), T(B), i)$, where

$V(S(i), T(B), i) \equiv (\alpha - S(i) - c_i)S(i) + (\alpha - c_i + 2T(B))^2/9$. The same in the quota regime is given by $W(S(i), Q(B), i) \equiv (\alpha - S(i) - c_i)S(i) + ((\alpha - Q(B) - c_i)^2/4$.

To solve for the equilibrium values of S, B, T, Q, we impose the following restrictions on the solution.

(E1) Sub game perfection: Given T, Q, the outcome in the second period is the Cournot outcome as stated in the previous section with $t = T(B)$, $q = Q(B)$, $\theta = B(.)$.

(E2) Sequential rationality: This restriction requires that equilibrium strategies are *sequentially rational*, in that each player's strategy maximizes his expected payoff, given his beliefs and the strategy of his opponents. That is, the following condition holds:

$T(B(.) = \theta) = t(\tilde{c})$, $S(i) \in \arg\max_{S(i)} V(S(i), T(B), i)$ in the tariff regime. For the quota regime we require $Q(B(.) = \theta) = q(\tilde{c})$ and, $S(i) \in \arg\max_{S(i)} W(S(i), Q(B), i)$. Note that $t(\tilde{c})$, $q(\tilde{c})$ functions are as derived above.

(E3) Bayes consistency: The belief function must be Baye's consistent with respect to the strategy, S. That is:

(i) $S(L) = S(H) = X_p \Longrightarrow B(X_p) = \theta_o$ where $X_p \in [0, \infty)$, and

(ii)$S(L) = X_L \neq S(H) = X_H \Longrightarrow B(X_H) = 0$ and $B(X_L) = 1$.

In case (i) *pooling* occurs in that the output chosen by the firm provides no information about the true cost of the home-firm. Bayesian updating then requires the posterior belief (B) to equal the prior belief (θ_o). In contrast to this, in cases (ii) output choices *separate* the firm Types. Consequently, Bayesian updating requires the government to correctly guess the firm's Type. As common in the literature, the Bayesian rule above does not specify the "out of equilibrium beliefs". That is, case (i) does not impose any restrictions on the value of $B(X \neq X_p)$. Similarly, case (ii) does not impose any restriction on the value of $B(X) \notin \{S(L), S(H)\}$. This problem with Bayes rule is well known in the literature. It arises because out of equilibrium events are zero probability events and Bayes rule cannot be applied to such events.

(E4) Intuitive beliefs: We assume that the belief function, B, satisfies the Cho-Kreps (1987)

Intuitive Criterion. That is, if a deviant output level $X \notin \{S(L), S(H)\}$ is observed that could possibly improve upon the equilibrium profit only for a low-cost (high-cost) firm, then the government should believe that the home firm has low (high) cost. Specifically, in the tariff regime, for any given $\{S, T\}$, beliefs are intuitive under the following condition:

$\forall X \notin \{S(L), S(H)\}, B(X) = I(J)$, where $I(J)$ is such that $I(L) = 1$, $I(H) = 0$, if for $J \neq J'$ $\in \{L, H\}$:

$V(X, T(1), J) \geq V(S(J), T(B(S(J))), J)$ and,

$V(X, T(1), J') < V(S(J'), T(B(S(J'))), J')$

For the quota regime the restriction is the same with $V(.)$ replaced by $W(.)$ and $T(.)$ replaced by $Q(.)$.

(E5) Pessimistic beliefs: Lastly, following the signaling literature, if a deviant output is observed (i.e. $X \notin \{S(L), S(H)\}$) and the intuitive criterion does not apply then this is followed by the most pessimistic belief (i.e. $B(X) = 0$).[11]

We define a triplet $\{S, B, T\}$ to be an *intuitive equilibrium* in the tariff regime if it satisfies E1-E5. Similarly for $\{S, B, Q\}$ in the quota regime. An *intuitive equilibrium* with $S(L) \neq S(H)$ constitutes a *separating intuitive equilibrium* and an *intuitive pooling equilibrium* otherwise.

Section 3

The derivation of the intuitive equilibria in the two regimes is relatively simple since the appropriate version of the single crossing property is satisfied. That is, if the high-cost

[11] This assumption is common in the literature. Also, it is standard in the literature to impose further restrictions on out of equilibrium beliefs to narrow the set of possible equilibria. This is not relevant for our model since the equilibrium concept defined above ensures that there is a unique equilibrium in both the policy regimes.

firm is indifferent between any two output-tariff (output-quota limit) pair, then the low-cost firm strictly prefers the one with a higher output level and no lower (higher) tariff (quota limit). Further, the optimal protection is higher (higher tariff and lower quota limit) for the low-cost firm than for the high-cost firm. These features imply that there is a unique equilibrium in the two regimes which is a *separating intuitive equilibrium* with the property that the period-1 output of the low-cost firm is the conventional least costly way of signaling its true cost. This is stated formally in the following Proposition.

Proposition 1

(a) Period 2 outcome: Equilibrium prices, output of both the firms and welfare of all the agents including the home-government is exactly the same in period-2 in the tariff and quota regimes. Equilibrium tariff is equal to $t(c)$ and quota limit is equal to $q(c)$ for $c \in \{c_L, c_H\}$. $B(S(H)) = 0$ and $B(S(L)) = 1$. Thus, in period 2 we observe that the complete information solution is realized with tariffs and quotas being equivalent here.

(b) Period 1 outcome: $S(H) = (\alpha - c_H)/2 \equiv X_H^m$ in the tariff and quota regime where X_H^m is the monopoly output of the high-cost firm. For convenience in stating the value of $S(L)$ we introduce the following notations. Let $X_L^m \equiv (\alpha - c_L)/2$ which is the monopoly output of the low-cost firm; $\Delta c \equiv c_H - c_L$ and, $\pi_H \equiv (4\alpha - 6c_H)/(9 - 2\beta) > 0$ which is the profit of the high-cost firm in the second period under complete information when the optimal tariff/quota is in place. The solution value of $S(L)$ in the two regimes is as follows.

In the tariff regime we have:

$$S(L) = max \left\{ X_L^m,\ X_L^m - \Delta c/2 + \sqrt{\pi_H \lambda_t + \lambda_t^2/4} \right\} \quad ...... (3)$$

In the quota regime we have:

$$S(L) = max\left\{X_L^m,\ X_L^m - \Delta c/2 + \sqrt{\pi_H \lambda_q + \lambda_q^2/4}\right\} \quad ......\ (4)$$

Proof: For the proof and explicit expressions for the solution in (3), (4), see Appendix B.

Interpretation of the solution

The solution stated in *Proposition* 1 shows that there is a unique equilibrium in each regime where the two types separate out. This result follows from the underlying structure of the model which ensures that the appropriate version of the single crossing property is satisfied as discussed above. As noted in the signaling literature, this implies that the unique equilibrium is the standard least costly "no-mimicking" equilibrium.

Since the two types separate out, the government knows the true cost of the home-firm at the end of the first period and before policy is implemented. Thus, the period 2 solution is simply the complete information solution which, given Counrot-conjectures, is exactly the same in the tariff and the quota regime. This is confirmed in part (a) of the Proposition.

For period 2 outcome, we first note that the high-cost firm always chooses its monopoly output level (X_H^m). This result is well-known in the literature and arises because in the separating equilibrium the identity of the high-cost is fully revealed so that it has no incentive to deviate from its profit maximizing output level. Thus, the non-equivalence between tariffs and quotas in our model relates to the value of $S(L)$ as stated in equations (3) and (4) above. From these equations it is evident that any non-equivalence must arise due to the difference in the values of λ_t and λ_q which, by definition, is due to the *sensitivity effect* defined earlier. To see this, we first note that substituting the values of $\lambda_t, \lambda_q, \pi_H$ in (3) and (4) we get a critical value of Δc, Δc_q, such that for $\forall \Delta c < \Delta c_q$, $S(L) > X_L^m$ in the quota regime.

Similarly, $\forall\beta > 0$, $\exists\Delta c = \Delta c_t$ such that $\forall\Delta c < \Delta c_t$, $S(L) > X_L^m$ in the tariff regime.[12] This result is standard in the signaling literature in that the signaling distortion (as reflected in the previous inequality) arises when the two types are not too different. From (3) and (4) it is evident that $\Delta c_q > \Delta c_t$ since $\lambda_q > \lambda_t$. Thus, we get the first form of non-equivalence between tariffs and quotas when $\Delta c_q > \Delta c > \Delta c_t$ so that in the unique separating equilibrium the low-cost firm chooses its monopoly output in the tariff regime but a strictly higher output in the quota regime. The intuition for this is that the incentive to mimic is much higher in the quota regime than in the tariff regime due to the *sensitivity effect* so that while the high-cost Type would mimic the low-cost type in the quota regime but not in the tariff regime. A special case of this arises when the home government maximizes its pure national welfare so that $\beta = 0$. It is direct to verify that in this case $\lambda_t = 0$ since the optimal tariff is invariant to the true cost of the home firm, however, $\lambda_q > 0$. Thus, we get that in this case $S(L) = X_L^m$ in the tariff regime $\forall\Delta c$, while in the quota regime $S(L) > X_L^m$ for all $\Delta c < \Delta c_q$.

Now consider the remaining possibility when Δc is strictly less than Δc_q and Δc_t so that the output of the low-cost Type is distorted beyond X_L^m in both the policy regimes. From (3) and (4) it evident that in this case too the signaling distortion is greater in the quota regime than in the tariff regime since $\lambda_q > \lambda_t$. The reason for this is exactly the same as noted above; that is, since equilibrium import-volume in the quota regime is more sensitive to the signal sent by the home-firm than in the tariff regime, the incentive to mimic is much higher in the former regime. Thus, the low-cost Type has to distort its output more in order to credibly signal its Type.

[12] For explicit expressions of Δc_t and Δc_q, see Appendix B3 and B4.

Welfare implications of the stated non-equivalence can be obtained from the results above. Since the home-firm enjoys a monopoly in the first period, a larger output level under the quota regime implies higher national welfare for the home country through greater consumer surplus net of lower producer surplus of the firm. However, if the government attaches a sufficiently higher weight to the welfare of the firm (β is sufficiently high) then the tariff regime will be superior from the government's point of view since the output of the home-firm is closer to its monopoly output level in this case.[13]

We now proceed to the next section where we put forward an alternative environment and show that the *sensitivity effect* as defined above is still preserved.

Section 4

In this section we provide an example to show that the *sensitivity effect* is likely to be replicated in alternative environments also. Specifically, we consider the situation similar to the one above with the foreign-firm being the leader and the home-firm being the follower in the second period. The rest of the model is kept intact.

We first note that in this foreign-leadership model, tariffs and quotas are equivalent under complete information. This holds whether policy levels are exogenously set or endogenously determined. The simple intuition for this follows the one in Hwang and Mai. Briefly, in the tariff regime, the home-firm being the follower takes the output of the foreign-firm as given and chooses its best response output level. Now replace the tariff with a quota at the original

[13] We have not stated formally why home operates under autarky in the first period. Our motivation, as stated in the introduction, was that it could either due to an "infant industry" phase or due to political reasons. Without specifying the exact nature of the government's objective here, it is not possible to say which is the more preferred policy tool. However, our non-equivalence will hold in general for any given objective of the government in the first period.

import-volume level. With the quota limit in place, the home-firm again takes treats the output of the foreign-firm as fixed. Thus, its conjecture is exactly the same in the two cases, implying that its best response output is unchanged. With this in place, equilibrium prices and welfare of all agents is left unchanged.[14] Thus, any non-equivalence between the two policy tools must be due to the informational asymmetry.

The *sensitivity effect* can be easily demonstrated in this modified game as follows. Assume interior solutions throughout as this will hold in the final equilibrium. For any given output of the foreign firm denoted by X_f, home-firm's best response output level is equal to $(\alpha - X_f - c)/2$. Solving the equilibrium of the game for any given tariff t, we get that equilibrium import-volume is equal to $\hat{X}_f = (\alpha + c - 2t)/2$ which is the usual Stackelberg-solution for the leader. From this we can compute home government's overall welfare which is equal to

$$(1.5\alpha - 0.5c - t)^2/8 + \frac{\alpha t + ct - 2t^2}{2} + (1+\beta)(0.5\alpha - 1.5c + t)^2/4$$

The first term in the previous expression is the consumer surplus from good X, the second is the tariff revenue and the third is the weighted producer surplus of the home-firm. Differentiating the welfare function and solving we get home's optimal tariff is equal to: $\hat{t}(c) = [(1.5 + \beta)\alpha - (3\beta + 0.5)c]/(5 - 2\beta)$. For any arbitrary belief of the government denoted by θ, we get that the optimal tariff equals $\hat{t}(\tilde{c})$ where $\tilde{c}$ is as defined above. To compute the optimal quota limit, we benchmark the quota-rent rule as in the previous section such that if a tariff and quota generate the same import-volume then the quota-rent accruing to the

[14] To be more precise, the argument requires that the quota limit is always fully utilized. This is normally assumed in the literature and holds in our model. The proof of this can be constructed along the lines provided in Appendix A1 for the Cournot model.

government must equal the tariff revenue. This gives us the quota rent accruing to the home government as equal to $(q\alpha + qc - 2q^2)/2$. Computing the government's welfare and then the optimal quota limit we get the latter is equal to: $\hat{q}(c) = [(1-2\beta)\alpha + (2\beta+3)c]/(5-2\beta)$. For any given θ, the optimal quota is given by $\hat{q}(\tilde{c})$. It can be checked that under complete information, equilibrium values of all endogenous variables are exactly the same in the two policy regimes.

We now note the *sensitivity effect*. That is, $d\hat{q}(\tilde{c})/d\theta = [(2\beta+3)/(5-2\beta)]d\tilde{c}/d\theta$ and $d\hat{X}_f/d\theta = [(3\beta+0.5)/(5-2\beta)]d\tilde{c}/d\theta$. It is direct to verify that $|d\hat{q}(\tilde{c})/d\theta| > \left|d\hat{X}_f/d\theta\right|$ under the interior solution condition that $5-2\beta > 0$. This result confirms that the *sensitivity effect* holds here. The rest of the solution can be derived as in the previous section. Since the reduction in import volume is larger in the quota regime, it follows that the low-cost firm must distort its output in period 1 above its monopoly output level to a greater extent in this regime as compared to in the tariff regime.[15]

Conclusion

The paper aims to contribute to the literature on tariffs versus quotas at a general level and highlight the role of asymmetric information in this area in particular. Under complete information and when tariffs and quotas are exogenously fixed at equivalent levels, non-equivalence between the two policy tools has been shown to arise because import-volume in the quota regime is fixed but is sensitive to the action of the private agents when tariffs are used. However, in this paper we have shown that under asymmetric information and when policy levels are endogenously set then equilibrium import-volume is much *more* sensitive to

[15] It can be checked that the appropriate version of the single crossing property holds here so that there will be a unique signaling equilibrium in the two regimes where the two Types will separate out.

the signal sent by the private agent when quotas are used as compared to when tariffs are used. The non-equivalence derived above is based on this differential sensitivity of the two policy tools.

Appendix A

Appendix A1

Claim: The quota limit is always fully utilized by the foreign-firm.

Proof: For any given output of the home-firm denoted by X_h, foreign firm's total profit by selling amount X_f is equal to $(\alpha - X_f - X_h)X_f - QR(X_f)$. Differentiating foreign firm's profit function with respect to X_f we get that this is equal to $\pi'_f \equiv (\alpha - c - X_h)/2 + X_f$. In equilibrium, home firm must be on its reaction function implying that: $X_h = (\alpha - c - X_f)/2$. Substituting this value of X_h in π'_f expression, it is direct to verify that $\pi'_f > 0$. Thus, the foreign-firm will always find it profitable to utilize the quota limit fully.

Q.E.D.

Appendix A2

Proof of *Lemma* 2

When $q(\tilde{c})$ is implemented then the actual (ex-post) import-volume is equal to $q(\tilde{c})$ irrespective of the actual value of c. Thus, the expected import-volume here is simply equal to $q(\tilde{c})$. When $t(\tilde{c})$ is implemented then the actual import-volume when $c = c_i$ is equal to $(\alpha - 2t(\tilde{c}) + c_i)/3$, $i = L, H$. The expected value of this is equal to $(\alpha - 2t(\tilde{c}) + \tilde{c})/3$. Substituting for $t(\tilde{c})$ from section 1, it is direct to verify that the expected import-volume under $t(\tilde{c})$ is equal to $q(\tilde{c})$.

Q.E.D.

Appendix A3

Claim: $|q'(\tilde{c})d\tilde{c}/d\theta| > |(-2/3)t'(\tilde{c})d\tilde{c}/d\theta|$ as stated in section 1.3.

Proof: $d\tilde{c}/d\theta = c_L - c_H < 0$. $t'(\tilde{c}) = -4\beta/(9-2\beta) < 0$ and, $q'(\tilde{c}) = (3+2\beta)/(9-2\beta) > 0$. Substituting we get that $|q'(\tilde{c})d\tilde{c}/d\theta| = \dfrac{(3+2\beta)(c_H - c_L)}{9-2\beta} > \dfrac{8\beta(c_H - c_L)}{3(9-2\beta)} = |(-2/3)t'(\tilde{c})d\tilde{c}/d\theta|$. Note that the previous inequality holds if and only if $9 - 2\beta > 0$ which is guaranteed under Assumption A1. It can be easily checked that Assumption A1 is sufficient but not necessary for this inequality to hold. Specifically, in the context of our linear model, the result will hold when the optimal tariff under complete information is strictly interior.

Q.E.D.

Appendix B

Appendix B1: Proof of *Proposition* 1

Claim: There is no intuitive pooling equilibrium in the tariff regime.

Proof: Consider a possible pooling equilibrium with $S(L) = S(H) = X_p$, $B(X_p) = \theta_o$ and $T(B(X_p)) = t(\tilde{c}_o)$, where $\tilde{c}_o \equiv \theta_o c_L + (1-\theta_o)c_H$, the function $t(.)$ is as defined in equation (1). A necessary condition for this to be an equilibrium is that no Type should do better by unilaterally deviating to its monopoly output followed by the worst possible beliefs. That is, $V(X_p, t(\tilde{c}_o), L) \geq V(X_L^m, t(c_H), L)$ and $V(X_p, t(\tilde{c}_o), H) \geq V(X_H^m, t(c_H), H)$. It is trivial to note that $V(0, t(c_L), H) < V(X_H^m, t(c_H), H)$ since the RHS of the inequality is strictly higher than π_H while its LHS is strictly than π_H where π_H is the period 1 monopoly profit of the high-cost firm. From the previous two inequalities it follows that $V(0, t(c_L), H) < V(X_p, t(\tilde{c}_o), H)$. Next note that $V(X_H^m, t(c_L), H) > V(X_p, t(\tilde{c}_o), H)$ since $t(c_L) > t(\tilde{c}_o)$. From the continuity of the all our functions, the previous two inequalities imply that $\exists Y_1 \in (0, X_H^m)$ such that $V(Y_1, t(c_L), H) = V(X_p, t(\tilde{c}_o), H)$. Next note that the function $V(Y_1, t(c_L), H)$ is symmetric in Y_1 around X_H^m, is strictly concave in Y_1 and achieves its maximum value at Y_1 equal to X_H^m. These properties together with the previous equality imply that $\exists Y_2 =$

$X_H^m + X_H^m - Y_1$ such that $V(Y_2, t(c_L), H) = V(X_p, t(\tilde{c}_o), H)$ with $Y_2 > X_p$ and that:

$$V(Y_2 + \epsilon, t(c_L), H) < V(X_p, t(\tilde{c}_o), H) \text{ for } \forall \epsilon > 0 \quad \text{.........} \quad \text{(B1.1)}$$

The remaining proof is straightforward. Note that $V(X_p, t(\tilde{c}_o), L) > V(X_p, t(\tilde{c}_o), H)$ since Type L has lower cost. Similarly, $V(Y_2, t(c_L), L) > V(Y_2, t(c_L), H)$. The important property to note next is that $V(Y_2, t(c_L), L) - V(Y_2, t(c_L), H) > V(X_p, t(\tilde{c}_o), L) - V(X_p, t(\tilde{c}_o), H)$. This can be seen by noting that LHS of this inequality is equal to $Y_2 \Delta c + (4\Delta c/9)(\alpha + t(c_L) - (c_L + c_H))$, and its RHS is equal to $X_p \Delta c + (4\Delta c/9)(\alpha + t(\tilde{c}_o) - (c_L + c_H))$. Noting that $Y_2 > X_p$ and $t(c_L) > t(\tilde{c}_o)$, the previous inequality is established. Noting the previous inequality and the result above that $V(Y_2, t(c_L), H) = V(X_p, t(\tilde{c}_o), H)$, we get that $V(Y_2, t(c_L), L) > V(X_p, t(\tilde{c}_o), L)$. Since $V(X, .)$ in continuous in X, previous inequality then implies that:

$$V(Y_2 + \epsilon, t(c_L), L) > V(X_p, t(\tilde{c}_o), L) \text{ for } \epsilon \approx 0 \quad \text{.........} \text{ (B1.2)}$$

From the inequalities in (B1.1) and (B1.2) it follows that there exists $\epsilon \approx 0$ such that under the Cho-Kreps intuitive criterion, $B(Y_2 + \epsilon) = 1$ for any possible X_p value. It is direct to note from this result and (B1.2) that the low-cost firm will deviate from X_p to $Y + \epsilon$. Thus, our initial supposition that X_p is a possible intuitive pooling equilibrium is contradicted.

Q.E.D.

Appendix B2

Claim: There is no intuitive pooling equilibrium in the quota regime.

Proof: The proof is exactly the same as in Appendix B1 in the following way. Replace $V(.)$ by $W(.)$ function, $T(.)$ by $Q(.)$, $t(.)$ by $q(.)$. Replace the inequality $t(c_L) > t(\tilde{c}_o)$ above by $q(c_L) < q(\tilde{c}_o)$. With this follow exactly the same steps as in the previous Appendix till the end of the condition in (B1.1). Now note that $W(Y_2, q(c_L), L) - W(Y_2, q(c_L), H) > W(X_p, q(\tilde{c}_o), L) - W(X_p, q(\tilde{c}_o), H)$. This inequality holds because its LHS is equal to $Y_2 \Delta c + (\Delta c/4)(2\alpha - 2q(c_L) - (c_L + c_H))$ and its RHS is equal to $X_p \Delta c + (\Delta c/4)(2\alpha - 2q(\tilde{c}_o) - (c_L + c_H))$. The inequality is evident since $Y_2 > X_p$ and $q(c_L) < q(\tilde{c}_o)$. With this result in place, the rest of the proof can be completed by following the remaining steps in Appendix B1.

Q.E.D.

Appendix B3: Separating equilibrium in the tariff regime:

Set $S(H) = X_H^m$, $B(X_H^m) = 0$, $T(X_H^m) = t(c_H)$. Let the Cournot-Nash equilibrium in period 2 when Nature chooses c_H be as stated in section 1 with $t = t(c_H)$ and $c = c_H$. Next define Y_3 as the largest possible number such that $V(X_H^m, t(c_H), H) = V(Y_3, t(c_L), H)$. Computing we get that $Y_3 = X_H^m + \sqrt{\dfrac{4\beta(\Delta c)(6\alpha - 9c_H + \beta(\Delta c))}{(9-2\beta)^2 9/4}} > X_H^m$. The inequality follows from Assumption A1. Next note that since $V(X,.)$ is concave in X, $V(X_H^m, t(c_H), H) > V(Y_3 + \varepsilon, t(c_L), H)$ for all $\varepsilon > 0$. Now set $S(L) = max\{X_L^m, Y_3\}$, $B(S(L)) = 1$, and $T(B(S(L))) = t(c_L)$. Let the Cournot-Nash equilibrium in period 2 when Nature chooses c_L be as stated in section 1 with $t = t(c_L)$ and $c = c_L$. Note that so far our proposed solution is sub-game perfect, satisfies Baye's rule and is sequentially rational for the government given its belief function. We now need to show that it is sequentially rational for each firm-Type. To see this, first note that when $S(L) = X_L^m \geq Y_3$ then the low-cost firm enjoys the best possible beliefs and also obtains its monopoly-profit in period 1. Thus, it has no incentive to deviate irrespective of the structure of out of equilibrium beliefs. For the high cost firm we assume that when $X_L^m = Y_3$ so that it is indifferent between deviating from X_H^m to X_L^m, then it will not deviate. This is a standard tie-breaking assumption. When $X_L^m > Y_3$ then by construction of Y_3 and the concavity of $V(X,.)$ in X it follows that $V(X_H^m, t(c_H), H) > V(X_L^m, t(c_L), H)$ so that the high-cost will not deviate even if the deviation were followed by the most favorable belief. Thus, we have shown that when $X_L^m \geq Y_3$ then our stated solution is sequentially rational. We note here that the previous inequality holds if and only if $\Delta c \geq \dfrac{(384\alpha - 576c_L)\beta}{729 + 252\beta - 28\beta^2} \equiv \Delta c_t$ where Δc_t is as discussed in section 3. We note that this is the only possible separating equilibrium when $X_L^m \geq Y_3$. Simple way to see this is that suppose $S(L) = X_1 \neq X_L^m$. We know from above that $V(X_H^m, t(c_H), H) > V(Y_3 + \varepsilon, t(c_L), H)$ $\forall \epsilon > 0$. Set $\varepsilon = (1/2)(|X_1 - X_L^m| \equiv \epsilon_1$. It is direct to note that $V(X_H^m, t(c_H), H) > V(X_L^m + \varepsilon_1, t(c_L), H)$ and $V(X_L^m + \epsilon_1, t(c_L), L) > V(X_1, t(c_L), L)$ where the previous inequality follows from the fact that $X_L^m + \epsilon_1$ is closer (in absolute value) to X_L^m than X_1. The previous two inequalities imply that $B(X_L^m + \epsilon_1) = 1$ by the Intuitive Cho-Kreps criterion. Thus, the low-cost firm will always find it optimal to from X_1 to $X_L^m + \epsilon_1$ since this increases its period 1 payoff and leaves the government's belief unchanged.

Now consider the remaining possibility when $Y_3 > X_L^m$ or, equivalently, that $\Delta c < \Delta c_t$. Our claim is that $S(L) = Y_3$ is the unique intuitive separating equilibrium strategy for the low-cost firm. The proof is as follows. Since $Y_3 > X_L^m$, concavity of $V(.)$ in period 1 output implies that $V(Y_3 + \varepsilon, t(c_L), L) < V(Y_3, t(c_L), L)$ $\forall \varepsilon > 0$ so that the low-cost firm has no incentive to deviate from Y_3 to a higher output level. Next note that under the Intuitive criterion, out of equilibrium beliefs are either 0 or 1. Further, when this criterion does not bind then we assume the most pessimistic belief ($B(.) = 0$) for an out of equilibrium event which is a common practice in the literature. Thus, when the low-cost firm deviates then the deviation will be followed by either the most optimistic or the most pessimistic belief. In the latter case, the highest possible payoff to the low-cost firm occurs when it deviates to its monopoly output level. It can be checked with some algebra that $V(X_L^m, t(c_H), L) < V(Y_3, t(c_L), L)$ so that such a deviation will not occur. Now consider a deviation by the low-cost Type to output level $Y_4 < Y_3$ which is followed by the most optimistic belief. Since occurrence of Y_4 is an out of equilibrium event we have that $B(Y_4) = 1$ implies that the Cho-Kreps intuitive criterion must apply at Y_4. This requires that $V(X_H^m, t(c_H), H) < V(Y_4, t(c_L), H)$. This previous two inequalities implies that $Y_3 > Y_4 > X_H^m - \sqrt{\dfrac{4\beta(\Delta c)(6\alpha - 9c_H + \beta(\Delta c))}{(9-2\beta)^2 9/4}} \equiv Y_3^-$. It is direct to verify that $X_L^m - Y_3^- > Y_3 - X_L^m$. Since $V(X, .)$ is symmetric in X around X_L^m, the previous inequality implies that $V(Y_3, t(c_L), L) > V(Y_3^-, t(c_L), L)$. Concavity of $V(X.,)$ in X and $Y_4 < Y_3^-$ together with the previous inequality then imply that $V(Y_3, t(c_L), L) > V(Y_4, t(c_L), L)$. Thus, the low-cost firm has no incentive to deviate to from Y_3 to Y_4. By definition of Y_3, we have already stated that our tie-breaking assumption implies that the high-cost firm will not want to deviate from X_H^m even if the deviation is followed by the best possible belief. Lastly, we need to establish that the separating equilibrium derived above is the unique equilibrium. To this end, consider any possible separating equilibrium with $S(L) = X_2 \neq Y_3$. We maintain that $Y_3 > X_L^m$. If $X_2 > Y_3$, then from the concavity of $V(.)$ in period 1 output, we have that $V(X_2, t(c_L), L) < V(Y_3 + \epsilon, t(c_L), L)$ with $0 < \epsilon < X_2 - Y_3$. By definition of Y_3, $V(X_H^m, t(c_H), H) > V(Y_3 + \epsilon, t(c_L), H)$ $\forall \epsilon > 0$. These results imply that under the Cho-Kreps intuitive criterion, $B(Y_3 + \epsilon) = 1$, $0 < \epsilon < X_2 - Y_3$. It is trivial to note then that the low-cost firm will do better by deviating from X_2 to $a\mu_y^{*f}$ point in the interval (Y_3, X_2). Thus, $S(L) = X_2$ cannot be part of a separating equilibrium strategy. Next consider the case when $X_2 < Y_3$. As noted above, for this to be a possible separating equilibrium strategy, we must have $X_2 \leq Y_3^-$ for otherwise the high-cost firm will deviate from X_H^m and mimic the low-cost firm. Since $Y_3^- < X_L^m$, the best possible scenario for the low-cost firm occurs when $X_2 = Y_3^-$ and $B(Y_3^-) = 1$. Assume that this holds. We have already noted above that $X_L^m - Y_3^- > Y_3 - X_L^m > 0$. Since, $V(X.,)$ is symmetric in X around X_L^m, it follows that $V(Y_3^-, t(c_L), L) < V(Y_3, t(c_L), L)$. Continuity of all our functions then implies that $V(Y_3^-, t(c_L), L) < V(Y_3 + \varepsilon, t(c_L), L)$ for $\epsilon \approx 0$ and strictly positive. Since the high-cost firm is worse off in deviating to an output level higher than Y_3 even when the deviation is followed by the most optimistic belief, the Cho-Kreps intuitive criterion then implies that $B(Y_3 + \varepsilon) = 1$ for such an ϵ value. This together with the previous inequality implies directly that the low-cost firm will deviate from X_2 to $Y_3 + \varepsilon$. Thus, we have proved that the separating intuitive equilibrium above is the unique equilibrium of the game.

Q.E.D.

Appendix B4: Separating equilibrium in the quota regime

The basic structure of the arguments is exactly the same as in the previous Appendix. To derive this first make the same substitutions as outlined in Appendix B2. Then follows the same steps as in Appendix B3. Solving we get that the unique separating intuitive equilibrium here is: $S(H) = X_H^m$ and $S(L) = max\{X_L^m, y\}$, where y is obtained in the same way as Y_3 above and its value is given by:

$y = X_H^m + \sqrt{\dfrac{(3+2\beta)\Delta c[16\alpha - 24c_H + (3+2\beta)\Delta c]}{4(9-2\beta)^2}}$. With some algebra, it can checked that $max\{X_L^m, y\} = X_L^m$ if and only if $\Delta c \geq (3+2\beta)[\dfrac{A}{9} - \dfrac{c_L}{6}] \equiv \Delta c_q$ which is as discussed in section 3.

(The full proof is available on request.)

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