Strategic Trade Policy, the "Committed" versus "Non-Committed" Government, and R&D Spillovers

Krešimir Žigić, CERGE-EI, Politických vězňů 7, 111 21 Prague 1

e–mail: Kresimir.Zigic@cerge-ei.cz

CEPR, London

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Abstract

We compare the social welfare generated by a domestic government in two types of policy setups: a "commitment" regime in which government sets its policy instrument before the strategic choice by the domestic firm and a "non-commitment" regime where the policy variable is set after the strategic choice of the firm. The government implements strategic trade policy in the form of optimal tariffs under which domestic and foreign firms compete in quantities in an imperfectly competitive domestic market where cost reducing R&D spillovers take place from the domestic to the foreign firm. We show that the "non-committed" government generally achieves a higher welfare and levies a lower optimal tariff than the "committed" government. Moreover, when the domestic government is allowed to use an R&D subsidy, which may or may not be accompanied by the optimal tariff, the resulting optimal subsidies are always positive.

JEL: F13; L11; L13; O31

Keywords: government commitment, optimal tariffs and subsides, technological spillovers, first best versus second best strategic policy.

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1. Introduction

It seems that tempting arguments advocating "strategic trade policy" have not convinced the majority of economists that the profession's traditional support for free trade should be abandoned. Until recently, this stance mostly reflected either the *a priori* position of the economists who argued against trade activism, (see, for instance, Baghwati, 1989, Krugman, 1987) or results obtained in "calibration" models, which indicated that gains were at best modest when strategic trade policies are applied as profit shifting or facilitating devices (see, for instance, Venables, 1994 and Krugman and Smith, 1994).

Recently a third serious drawback to the theory of strategic trade policies has surfaced. As Neary and Leahy, (2000) pointed out, "... that governments and firms are likely to differ in their ability to commit to future action". Thus, the government may lack credibility with the firms whose behaviour it tries to influence or there may be a time lag between the announcement and the implementation of strategic trade policies. As a consequence, the government may be forced to select its policy only *after* the strategic choice of domestic firms has taken place.[1] This gives a strategic motive to the domestic firm to influence (or manipulate) the government's policy response. In these circumstances, it has been claimed, implementing the strategic trade policy can cause inefficiencies and consequently can lead to lower social welfare compared to the corresponding social welfare under free trade (see for instance, Goldberg 1995, Karp and Perloff, 1995, Neary and O'Sullivan,1997, Maggi and Grossman, 1998, Leahy and Neary, 2000, Ionaşcu and Žigić, 2001).

Žigić (2000),on the other hand, argued that in the particular case where free trade leads to unilateral violations of intellectual property rights (IPR) via, say, R&D spillovers, efficiency and welfare losses may be large due to the well known appropriability problem[2] as well as to the somewhat less known failure of the domestic firm to fully exploit economies of scale (see Žigić, 2000). This causes the use of strategic trade to be strictly superior to free trade. More

[1] Carmichael (1987) was the first to refer to empirical evidence showing that in practice the government often sets its policy only after it observes firms' action. See also Gruenspecht (1988) and Neary (1991).

[2] See for instance Mansfield, et al. (1981) and Levine, et al. (1987) for a comprehensive empirical analysis of the causes, forms and aspects of attenuated appropriability due to the inability to capture the induced benefits of innovating activity and intellectual property. Vishwasrao (1993), for example, refers to USITC documents (1988) reporting aggregate losses for US firms amounting to 23.8 billion dollars due to inadequate IPR protection.

specifically, Žigić (2000) showed that when domestic and foreign firms compete in quantities on the domestic market and there are IPR violations by the foreign firm, a strategic tariff reduces or completely eliminates illegally appropriated research output and thus thwarts IPR violations and enhances investment in R&D. However, these findings were obtained under the recently challenged assumption that the government can commit to its policy instrument before the domestic firm chooses its strategy.

The primary goal of this paper is to show that when R&D spillovers (or unilateral IPR violations) prevail and the domestic government cannot commit *ex ante*, the benefits of strategic trade policy measured in terms of social welfare are generally larger than social welfare under the corresponding commitment regime. In other words, we claim that the inability of the domestic government to commit to a tariff policy before the domestic firm's strategic decision does not weaken the case for strategic trade policy in the above setup. On contrary, this inability generally reinforces it. Related to this finding is the observation that the optimal tariff in the commitment regime is always larger (and therefore more distortional) than the corresponding optimal tariff in the non-commitment regime[3].

Another contribution of the recent strategic trade literature, primarily due to Neary and Leahy (1996, 1997, 1999, 2000), stresses the distinction between "first–best" and "second–best" policy. The "first–best" versus "second–best" policy issue arises in the context of dynamic games where domestic firms have more than one choice variable (e.g. level of R&D and level of output). In this setup the first best policy in principle includes more than one policy instrument in order to induce socially desirable levels of all choice variable. However, in many circumstances the government may be constrained to a smaller number of instruments or even only one instrument (say an R&D subsidy). Such constrained policies are usually termed "second–best" (or even "third best"). One of the interesting results from this literature is that, in the case of Cournot competition, the R&D subsidy, which is generally positive in the "second–best" policy setup, turned out to be negative (an R&D tax) when the "first–best" policy

[3] It is intriguing that Herguera, et al. (2002) obtained similar results in a rather different context of vertical product differentiation without spillovers but with the three-stage game structure identical to ours. Namely, they found that when government cannot commit to its policy choice, there is a higher social welfare than in the case when the government is able to commit to its policy. Moreover, they also showed that the optimal tariff in the "commitment" case is higher than its corresponding "non-commitment" counterpart. However, the economics and the intuition of their findings are rather different from ours.

was implemented. We show that this is not the case in our model and that the R&D subsidy is always positive in the both “first–best” and “second–best” policy.

2. The model

2.1. Assumptions

The core model is assumed to be a Cournot type duopolistic competition between a "domestic" and a "foreign" firm competing on the domestic market where the domestic firm undertakes the innovation effort in reducing unit costs while the foreign firm benefits from this innovation via spillovers (or IPR violations). Much like in Žigić (2000), the domestic firm is assumed to have constant unit variable costs of production $C = \alpha - f(x)$, where x stands for R&D expenditures and f(x) is an "R&D production function" with properties, $f(x) \leq \alpha$, $f(0) = 0$, $f'(x) > 0$ and $f''(x) < 0$. However, in order to simplify the analysis and also to make it directly comparable with the dominant approach in modelling process innovation (see, for instance, d’Aspermont and Jacquemin, 1988, Leahy and Neary, 1997, Hinloopen, 1997,.etc), we introduce the following transformation: $y \equiv f(x)$ and $x \equiv f^{-1}(y) \equiv h[y]$. Thus, “y” denotes the reduction in the domestic firm’s unit variable costs and represents the first-stage choice variable. Consequently the post-innovative unit[4] cost of the domestic firm now writes as $C = \alpha - y$, whereas h(y) stands for R&D effort or, equivalently, for the expenditures on unit cost reduction.

Parameter α can be thought of as pre-innovative constant unit costs describing an old technology initially accessible to both the domestic and the foreign firms. The foreign firm that exports its production to the domestic country pays a specific tariff *t* per unit of output. Its unit (pre–tariff) cost function is $c = \alpha - \beta y$ where $\beta \in [0,1]$ denotes the level of spillovers (or, equivalently, level of the strength of IPR protection).

The inverse demand function in the domestic market (assumed to be linear with units chosen such that the slope of the inverse demand function is equal to one) is $P = A - Q$ where $Q = q_d + q_f$ and $A > \alpha$. The parameter *A* captures the size of the market, whereas q_d and q_f denote the choice variables, that is, the corresponding quantities, of the domestic and the

[4]In the rest of the article we use the term “unit costs ” instead of the more correct “unit variable costs”.

foreign firms.

Social welfare (W) is defined as the sum of consumer surplus (S), the firm's profit (Π) and the revenue from tariffs (R).

The assumptions concerning the well-defined optimization problems as well as the issue of the existence and viability of duopoly are summarized below:

(i) $h'(0) = h(0) = 0$ and $h'(\alpha) > 8/81\ (2A + \alpha\ (1 - \beta))(3 - \beta)$

(ii) $h''(y^*) \geq 1 - 2/3\ \beta(1 - 2/3\ \beta)$

(iii) a) $h''(y^*) \geq 2/9\ (2 - \beta)\ (4 - 2\beta + (7-\beta(7 -4\beta)\ )^{1/2})$ and b) $W^*_d(t^*(\beta),\beta) \geq W^*_m$

where W^*_d stands for the optimal level of social welfare in duopoly when the domestic government can commit to a tariff and W^*_m stands for social welfare generated when the domestic firm acts as monopolist.

(iv) $h'''(y^*) \geq 0$.

Assumption (i) ensures that the optimal unit cost reduction, y^*, is positive but lower than α. Assumption (ii) ensures that sufficient second order conditions are satisfied for all maximization problems in the analysis[5]. For this to hold the social welfare function, W (.), needs to be strictly concave in y and t which in turn requires the “R&D cost function”, h(y), to be increasing in y and convex enough. We also assume that the corresponding monopoly profit is a strictly concave function for $y \geq 0$.[6] Assumption (iii) guarantees the viability of duopoly. In other words, a strategy that leads to the elimination of the foreign competitor— “strategic predation“— would be too expensive and is never optimal for the domestic firm [7]. Using the language of Dixit (1980), the domestic firm is only able to exhibit “limited leadership”. More specifically, the marginal cost of the unit cost reduction, h’(y), has to be “steep enough” so that its intersection with the accompanied marginal benefit occurs at a level of y^* such that $y^* < y^p \leq \alpha$ where y^p is the level of unit cost reduction that leads to the zero output of the foreign firm in the equilibrium (assumption (iii) a). The sufficient condition that ensures “enough steepness”

[5] Condition (ii) is in fact the value of the Hessian determinant of the function W(y,t) and it verifies the second order conditions for all maximization problems in the analysis.

[6] The monopoly profit as a function of R&D is given by $(A-\alpha+y)^2/\ 4\ -h(y)$. The concavity implies that its derivative and hence the function $½\ (A-\alpha+y)-h'(y)$ decreases in y for $y \geq 0$ (see Kamin et al.)

[7] See Žigić (2000) for a discussion of strategic predation strategy.

of h'(y) is given by (iv).[8] Moreover, it also has to be non-optimal for the welfare maximizing government to set the tariff that would induce the level of y that is equal to or larger than y^p (assumption (iii) b). Finally note that the assumption (iii) imposes even stronger restriction on h''(y) than (ii)[9].

In order to focus on strategic interactions, most authors use a "third market" assumption, whereby domestic and foreign firms compete on a common export market. As a consequence, only the domestic firm's profit (net of subsidy) enters the social welfare function (see for instance, Karp and Perloff, 1995, Neary and O'Sullivan,1997, Leahy and Neary, 2000). Our welfare function is more comprehensive and the task of the domestic government is not constrained to only strategic interactions but also takes into account the impact of the domestic firm's strategic choices on consumer surplus and tariff revenue.

The key assumption, as has been made clear, is that the government imposes the tariff only after it observes the domestic firm's choice of unit cost reduction. We call this government policy the "non-commitment" regime and the associated variables have the attached subscript "nc". On the other hand, the "commitment regime" implies that government is capable of committing inter-temporally to a tariff prior to the domestic firm's choice of unit cost reduction. This policy regime was discussed in Žigić (2000) and the associated variables carry the subscript "c". Note that both "nc" and "c" regimes are in fact "second–best" policies, since there is only one policy instrument and two choice variables (unit cost reduction and quantities).[10]

2.2. The game

We consider a sequential (three–stage) game. In the first stage, the domestic firm strategically chooses its innovation effort and consequent unit cost reduction. In the second

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[8] Note that there is a whole class of exponential and power functions, h(y), that appropriately describe the cost function of innovation and that verify the condition $h'''(y^*) \geq 0$. See, for instance, Ronnen, (1991) or Zhou, et al. (2002) for a similar requirement on the third derivative of the cost function to be nonnegative in order to ensure the sufficiency for the existence of equilibrium in a somewhat different set-up.

[9] In fact, it is not difficult to demonstrate that the viability of duopoly (i.e condition (iii)) automatically implies the satisfaction of the appropriate second order condition described by (ii). Thus in a sense, condition (ii) is redundant, yet we display it due to convenience.

[10] For the whole spectrum of possibilities of commitment patterns between the firms and the government in a dynamic games setting, see Leahy and Neary, 1996.

stage the non-committed government sets the tariff on imports after it observes the firm's choice of y. Finally, in the last stage, the firms select quantities, and consequently, profits and welfare are realised. Alternatively, we can, following Neary and Leahy (2000) adopt a two stage framework in which the government in the second stage of the game is able to commit only intra–temporally, setting its policy instrument, tariff, before the firms choose the quantities. Then, in the first stage the domestic firm selects the unit cost reduction.

We concentrate on the domestic market (alternatively, we may impose a segmented market hypothesis), in which duopoly is assumed to be a viable market form both before and after the tariff is set. In order to ascertain the subgame perfect equilibrium, we proceed by solving the game backwards. In the last (third) stage, the firms choose the equilibrium quantities. The domestic firm maximizes

$$\underset{q_d}{Max}[\Pi_d] = (A-Q)q_d - Cq_d - h(y) \tag{1.a}$$

given q_f .

The first–order condition for an interior maximum is $\partial\Pi_d/\partial q_d = 0$ and yields $A - 2q_d - q_f - C = 0$.

The optimization problem for the foreign firm yields:

$$\underset{q_f}{Max}[\Pi_f] = (A-Q)q_f - cq_f - tq_f \tag{1.b}$$

given q_d and t. The first-order condition is: $A - 2q_f - q_d - c - t = 0$. Solving the reaction functions yields the Cournot outputs as an implicit function of y:

$$q_d(y) = \frac{(A+c-2C+t)}{3} \tag{2.a}$$

$$q_f(y) = \frac{(A-2c+C-2t)}{3}. \tag{2.b}$$

Substituting (2.a) and (2.b) into (1.a) yields the domestic firm's profit function expressed in terms of y, R&D investment costs, h(y), and tariff:

$$\Pi_d^*(y) = \frac{(A+c-2C+t)^2}{9} - h(y). \tag{3}$$

In the second stage of the game, the domestic government selects the optimal tariff given the unit cost reduction of the domestic firm. Its objective function is given by the expression

$$W^*(t) = \Pi^*(t) + S^*(t) + R^*(t) \tag{4}$$

where consumer surplus, S*(t) and tariff revenue, R*(t) are respectively given by

$$S^*(t) = 1/2(q_d^* + q_f^*)^2 = \frac{(2(A-\alpha)-t+(1+\beta)y^2}{18} \tag{5}$$

and

$$R^*(t) = t\ q_f^* = \frac{t\ (A+\alpha-2t-y-2(\alpha-\beta y)}{3}\ . \tag{6}$$

Note that domestic profit monotonically increases in tariff (the higher the tariff the larger the effective unit cost difference and, consequently, the higher the domestic firm's profit) while consumer surplus monotonically declines in tariff. Finally, the function R(t) initially increases in t as t goes above zero, reaches its maximum at t = 1/4 (A - α - y(1-2β)), but eventually falls to zero as t reaches the prohibitive tariff, t_p, a tariff that causes the exit of the foreign firm. Thus, the function W(t) is strictly concave in t with $d^2W(t)/dt^2 = -1 < 0$ while the whole tariff domain on which duopoly is defined is given by the interval $t\varepsilon[0,t_p]$.

Assuming an interior maximum, the optimal tariff, t_{nc}* is obtained by solving dW/dt = 0, yielding[11]:

[11] Note that, t_{nc}*, is, in fact, an optimal time-consistent tariff (see Goldberg,1995).

$$t_{nc}^{*} = \frac{A - \alpha + \beta y}{3} \tag{7}$$

Finally, in the first stage of the game the domestic firm selects the optimal level of marginal costs reduction, y, taking into account its subsequent impact on both its foreign rival's behaviour (strategic effect) and on the government's choice of tariff (manipulation effect). By substituting t_{nc}^* into (3) we obtain

$$\Pi_d^{\circ}(y) = \frac{4(2(A-\alpha)+(3-\beta)y)^2}{81} - h(y). \tag{8}$$

Maximizing (8) with respect to y gives the first order condition[12] and (implicitly) the optimal y_{nc}^*:

$$\frac{8[2(A-\alpha)+(3-\beta)y](3-\beta)}{81} = h'(y) \tag{9}$$

Note that the optimal reduction in unit costs could be obtained more elegantly and more intuitively by comparing the marginal cost and benefits of an increase in y. A small increase of y positively affects the subsequent government tariff by $\partial t/\partial y$. This in turn, increases domestic operational profit, $\pi^* = 1/9\ (A - \alpha + t_{nc}^* + y(2-\beta))^2$, (that is, the profit before the costs of innovation were subtracted) by $\partial \pi^*/\partial t$. In addition, a given increase in y also increases the domestic firm's operational profit directly by $\partial \pi^*/\partial y$. The associated cost of such a marginal increase is h'(y). Thus, the optimal y_{nc}^* is found at the point where the marginal benefit of a decrease in unit costs equals its marginal costs, that is, where $\partial \pi^*/\partial t\ \partial t/\partial y + \partial \pi^*/\partial y = h'(y)$ holds. This expression describes the same first order condition (9).

3. Tariffs, R&D and Welfare in the Two Regimes

3.1. Optimal tariffs are positive

Before comparing relevant variables in the two regimes, we first show that the optimal tariff is indeed positive. This can been checked by evaluating the impact of the tariff on social

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[12] The second order condition requires $h''(y) > (8\ (3- \beta^2)/81$ and is subsumed in (ii).

welfare. We begin with the optimal tariff in the commitment regime where marginal social welfare is given by[13] :

$$\frac{dW_c^*(t)}{dt} = \frac{\partial S^*(t)}{\partial y}\frac{dy_c^*}{dt} + \frac{\partial S^*(t)}{\partial t} + \frac{\partial \Pi^*(t)}{\partial t} + t\,(\frac{\partial q_f^*}{\partial y}\frac{dy_c^*}{dt} + \frac{\partial q_f^*}{\partial t}) + q_f^* \qquad (10)$$

Summing up the direct marginal impact of the tariff on the domestic firm's profit and consumer surplus yields $\partial\Pi^*/\partial t + \partial S^*/\partial t = (y_c^*(1-\beta)+t)/3 > 0$. Since the indirect effect of the tariff (via y) on consumer surplus, $\partial S^*/\partial y\ dy^*_c/dt$, is always nonnegative (see Žigić, 2000 for a proof), this unambiguously implies $dW_c^*(t=0)/dt > 0$. This is in accord with the standard wisdom in strategic trade theory which claims that, given duopoly Cournot competition between foreign and domestic firms, imposing a "low" tariff is beneficial in terms of social welfare under fairly general conditions (see Helpman and Krugman, 1989).[14] Finally, the solution of (10) gives us the optimal tariff, t_c^* in the commitment regime[15]:

$$t_c^* = \frac{(A-\alpha) + \beta y + (2(A-\alpha) + y(3 - (2-\beta)\beta - 3h'(y))y'}{3 - \beta y'} . \qquad (11)$$

The proof that $dW_{nc}^*(t=0)/dt > 0$ is even simpler because in the non-commitment regime the government sets the tariff only after the home firm sets R&D, so the analogue to (10) is given by (12):

$$\frac{dW_{nc}^*(t)}{dt} = \frac{\partial S^*(t)}{\partial t} + \frac{\partial \Pi^*(t)}{\partial t} + t\,\frac{\partial q_f^*}{\partial t} + q_f^* \qquad (12)$$

implying $dW_{nc}^*(t=0)/dt = (y_{nc}^*(1-\beta)+t)/3 > 0$. It is also obvious from expression (7) that the optimal

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[13] Expression (10) is a modified version of the corresponding equation in Žigić, (2000) where the transformation $y \equiv f(x)$ is used.

[14] A sufficient (but not necessary) condition for this result to hold is that there be a "positive terms of trade effect," which, in this context, means that the new equilibrium price rises by less than the increase in tariff. This is surely the case with a linear demand function.

[15] Note that (11) gives only an implicit tariff since $y_c^* = y^*(t)$ is an implicit function of the tariff.

tariff in a non-commitment regime is positive.

The more relevant question than positivity of tariff in this setup would be whether the optimal tariff is in the interior of the set $t\varepsilon[0,t_p]$ since it may easily be the case that the optimal tariff is exactly at t_p or even beyond it (see Žigić, 2000). It is here that assumption (iii) enters into play, ensuring the interior, non-prohibitive duopoly tariff in the optimum. [16]

3.2. Marginal cost reduction in the two regimes

A comparison of the marginal cost reductions and consequently the underlying innovating efforts in the two regimes is not only interesting *per se* but even more importantly, is crucial for the comparison of social welfare in the two regimes as we will see in the next section.

LEMMA 1

The unit cost reduction in the non-commitment regime exceeds the unit cost reduction in the commitment regime as soon as R&D spillovers are above the critical level of β^r. That is, $y^*_{nc} > y^*_c$ when $\beta > \beta^r$. Moreover, $\beta^r < ½$.

Proof: See Appendix 1

In other words, when spillovers are zero or very small, $y_c^* > y_{nc}^*$, but as soon as a certain low level of $\beta = \beta^r < ½$ is reached, the reverse becomes true, implying that y_{nc}^* declines more slowly than y_c^* as the level of spillovers increases.[17]

The relationship between y_c^* and y_{nc}^* is not obvious *a priori.* On the one hand, the government in the commitment regime can affect via tariff the socially insufficient level of unit cost reduction, stimulating the investment in R&D that leads to a higher reduction in unit costs[18].

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[16] More specifically, the only force that preserves duopoly as the optimal market structure in both the commitment and non-commitment regime is tariff revenue.

[17] Both y_c^* and y_{nc}^* decline monotonically in β on the whole range of $\beta \in[0,1]$. This implies the faster decline of y_c^* in β starts already at the level of $\beta = 0$.

[18] Reitzes (1991) was probably the first to demonstrate the positive impact of strategic tariff on R&D.

However, this “technological function” of tariff is of a limited power due to its offsetting, negative side: an increase in tariff leads to a price increase in equilibrium and thus, has an adverse direct effect on the consumer surplus. On the other hand, in the non-commitment regime the technological function of tariff is absent, but the domestic firm has an incentive to invest in unit cost reduction in order to manipulate the government and induce a higher tariff on imports. This additional motive to invest in R&D and in unit cost reduction is not present in the commitment regime so this, so called, “manipulating” incentive leads to the comparably higher investment in R&D and consequently, a higher unit cost reduction as soon as the spillover level exceeds a certain low level, $\beta^r < ½$.

The clue for this result lies in the lower sensitivity of y_{nc}* with respect to the change in spillovers level as compared to corresponding sensitivity of y_c* to spillovers. To understand the intuition behind the lesser sensitivity of unit cost reduction on spillovers in the non-commitment regime, we briefly review the characteristics of the firm’s strategic behaviour in the context under consideration. First, it is well known that in dynamic Cournot duopoly models, where the domestic firm exhibits “limited leadership”, the domestic firm (incumbent) “over-invests” in its strategic variable in order to gain advantage over its competitor. In other words, it pursues a so called “top dog” strategy that makes the domestic firm “tough” (see Fudenberg and Tirole, 1984, Tirole, 1991). The notion of over-investment is defined with respect to the non-strategic benchmark in which the domestic firm selects its strategic variable ignoring its impact on the subsequent stage variable of the competitor. However, this “top dog” strategy becomes more and more “diluted” with an increase in spillovers. In fact, the higher the spillovers, the more the foreign firm appropriates the innovative output of the domestic firm and consequently the higher are the disincentives to invest in R&D. Thus, after a certain threshold level of β a disincentive effect of spillovers starts to dominate so that the “top dog” strategy turns into a “soft”, non aggressive, “puppy dog” strategy leading to under-investment vis-à-vis the non-strategic benchmark (see subsection 3.2.1 for an example and graphic representation). In other words, since this strategic investment is aimed directly at the competitor, it is very sensitive to spillovers.

On the other hand, in the non-commitment regime, there is an additional, “ manipulating” motive that the domestic firm faces on top of the standard strategic investment motive described above. Namely, the domestic firm has an incentive to manipulate the government decision on the tariff because in the non-commitment regime a higher unit cost reduction induces a higher tariff, that in turn benefits the domestic firm's profit. This additional motive for over-investment is not present in the commitment regime and it is targeted at the domestic government and not directly at the foreign firm. Thus the "manipulating" investment is therefore less vulnerable to spillovers. Consequently, the overall R&D investments in the non-commitment regime (that can conceptually be broken up into two parts: strategic and manipulating R&D investment) are less sensitive to spillovers than the corresponding R&D (and unit cost reduction) in the commitment regime.

An example

In order to illustrate the relationship between the unit cost reduction in the two regimes more transparently, we make use of the specific "R&D cost function" which is derived from the following "R&D production function": $y = (g\,x)^{1/2}$ (see Chin and Grossman,1991, and Žigić, 2000, for applications of this R&D production function). The appropriate transformation yields, $h(y) = y^2/g$. The parameter g captures R&D efficiency so that a bigger g implies an easier reduction in unit costs. The assumptions (i), (ii) and especially (iii) impose the upper bound on the parameter g. For duopoly to be an equilibrium market structure, it cannot be optimal for either the domestic firm or the domestic government to pursue strategic predation (see Žigić, 2000). This, in turn, implies that R&D investments are assumed to be not "too efficient" or alternatively, unit cost reduction that induces the exit of the foreign firm should not be a profitable strategy for the domestic actors. The best response of the foreign firm should be such that $q_f^* \geq 0$ holds in equilibrium. (See the Figure 1A in Appendix 2 for the range of permissible values of parameter g as a function of β.)

When $h(y) = y^2/g$, the corresponding optimal unit cost reduction in the two regimes are given by the expressions (13) and (14) below:

$$y_{nc}^* = \frac{8(A-\alpha)(3-\beta)g}{81-4g(3-\beta)^2} \tag{13}$$

$$y_c^* = \frac{(A - \alpha + t_c^*)(2 - \beta)g}{9 - g(2 - \beta)^2} \ . \qquad (14)$$

The expression for the threshold level of spillovers is a bit messy since it depends on g (see Appendix 3). Nevertheless, it suffices for spillovers to be such that $\beta > 0.09$ for $y^*_{nc} > y^*_c$ to hold irrespective of the value of g that is consistent with the duopoly competition (see Appendix 3).

The lower sensitivity of y^*_{nc} to spillovers compared to y^*_c is easy to observe in Figure 1. The benchmark, non-strategic unit cost reduction, labelled y^*_{ns}, is clearly the least sensitive to spillovers due to its non-strategic nature. The threshold level of β after which an over-investment, (the "top dog" strategy) in the commitment regime turns into an under-investment ("puppy dog" behaviour) is labelled β^c and $\beta^c = ½$. Note that due to the lower sensitivity of y^*_{nc}, the analogue critical value of β in the non-commitment regime (labelled β^{nc}) is higher than ½, that is $\beta^{nc} > \beta^c$ =1/2.

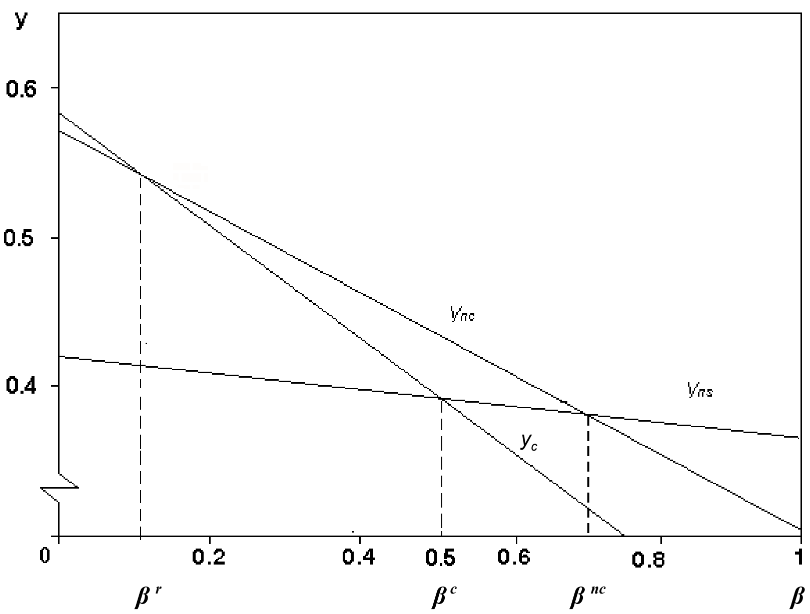

Figure 1

3.3. Welfare in the two regimes

The above discussion of optimal unit cost reduction and of the implied R&D levels in the two regimes serves as a prelude, to the key comparison of relative social welfare. As a corollary of Lemma 1, we put forward the following proposition.

PROPOSITION 1

The sufficient condition for social welfare in the "non-commitment" regime to exceed social welfare in the "commitment" regime is that $y^*_{nc} > y^*_{c}$. Consequently, it suffices for R&D spillovers to be above the critical threshold level, $\beta = \beta^{r} < ½$, in order for $W_{nc}^* > W_c^*$ to hold. Finally, for $\beta > \beta^{r}$, social welfare in the "non-commitment" regime is always higher than social welfare in the corresponding free trade world.

The socially optimal level of unit costs reduction, (labelled y^{**}), does not coincide with the domestic firm's unit cost reduction in either of the two regimes, since the domestic firm does not take into account the beneficial impact of its marginal cost reduction on the consumer surplus and its impact on tariff revenue. More precisely, the socially optimal marginal cost reduction is above both y^*_{nc} and y^*_{c}. To verify the claim that $y^{**} > y^*$ (where "y^*" stands for either y_{nc}^* or y_c^*), it suffices to show that $dW^*(y^*)/dy > 0$ and to recall that the social welfare function is strictly concave in y by assumption (ii). Thus, a "small" increase in y beyond y^* generates more social welfare by increasing consumer surplus than the resulting social welfare loss due to the fall in the firm's profit and a possible decline in tariff revenue.[19] Note that a positive marginal social welfare requires that the marginal impact of y on consumer surplus and tariff revenue at point y^* must be positive. In other words, $dS^*(y^*)/dy + dR^*(y^*)/dy > 0$ must hold in both regimes in order to have $dW^*(y^*)/dy > 0$. (Note that $d\Pi^*(y^*)/dy = 0$ by the first order condition of profit maximizing in each regime.) Thus, in the non-commitment regime we get

[19]It is easy to check that tariff revenue increases in y provided that β is large enough.

$$\frac{dW_{nc}^{*}\ (y_{nc}^{*})}{dy} = \frac{((A-\alpha)(6+25\beta)+(9-6\beta+28\beta^{2})y_{nc}^{*}}{81} > 0 \qquad (15)$$

By the same token, $dW_c^*\ (y_c^*)/dy > 0$ holds as well (see Žigić, 2000).

As can be seen from (15) this result holds even in the absence of spillovers. However, the presence of spillovers aggravates the departure from the social optimum since the domestic firm experiences disincentives to invest in unit cost reduction due to inability to fully appropriate all of the benefits of its innovating activity. In other words, the gap between y** and y* is lower in the absence of spillovers.[20]

The fact that the domestic firm, regardless of the regime, under-invests in R&D from the social point of view and therefore has a lower than socially optimal unit cost reduction, should not be confused with the firm's strategy which we call "over-investment" (which is optimal up to certain level of spillovers). The notion of "over-investment" is defined in relation to the domestic firm's non-strategic behaviour in which it ignores the strategic effect of unit cost reduction on the foreign firm's second stage variable (that is, on its output) and has nothing to do with the socially optimal level of R&D investment, h(y**). However, there is an important case when "top dog" behaviour and "manipulative" over-investment in R&D also imply "over-investment" from the social point of view. This appears in so called "third market" models where the social welfare function coincides with domestic firm profit (net of subsides/taxes) and where the domestic government (assuming the foreign government is passive and also assuming dynamic Cournot duopoly with "small" or zero spillovers) faces potentially three types of strategic considerations: the standard "profit shifting" motive, the government's motive to counteract the domestic firm's strategic over-investment and the government's motive to offset the domestic firm's manipulative investment (see Neary and Leahy, 2000). Transferring it in our framework, if the government cares only about the firm's profit net of taxes and subsidies (which is natural in the third market case), it would seek to provide the profit shifting instrument on its own, as a tariff or export

[20] Technically, the derivative, $dW_{nc}^*\ (y_{nc}^*)/dy$ reaches its lowest value when $\beta = 0$ as seen from (15). The same is valid for $dW_c^*\ (y_c^*)/dy$.

subsidy, and then by means of an R&D tax try to prevent the domestic firm's socially wasteful over-investment associated with both the "top dog" behaviour and (in the case of non-commitment regime) with the manipulative behaviour.

An Example

Once again applying the same functional form for R&D effort, that is, $h(y) = y^2/g$, we calculate the corresponding social welfare levels in the two regimes:

$$W_{nc}^{*} = \frac{(5103-8g(129-6g(1-\beta)^2(3-\beta)-97\beta)(3-\beta))}{2(81-4g(3-\beta)^2)^2}$$

$$W_{c}^{*} = \frac{(63+g(16+g(-2+\beta)(1-\beta)^2-14\beta)(-2+\beta))}{2(-81+g(-2+\beta)(-32+10\beta+g(2-\beta)(3-2\beta)))}$$

and then look for the critical value of spillovers, $\beta^w(g)$, beyond which $W^*_{nc} > W^*_c$. While this critical value as a function of innovation efficiency is a rather messy expression, it is sufficient for spillovers to be such that $\beta > 0.03$, regardless of the value of g for social welfare in the non-commitment regime to dominate the social welfare in the non-commitment regime (see Appendix 4). The summary of the empirical work on spillovers by Griliches (1992) finds that typical values of β range between 0.2 and 0.4, far above any possible value of $\beta^w(g)$. Thus it is possible that $W^*_{nc} > W^*_c$ even when $y^*_{nc} < y^*_c$. The main suspect for this seems to be a higher tariff in the commitment regime that causes a comparatively larger distortion in social welfare at even very low levels of spillovers. These considerations demand that we take a closer look at the tariff comparison in the two regimes, which follows in next section.

3.4. Tariffs in the two regimes

The tariffs are generally different in the two regimes due to the somewhat different functions that they perform. Namely, a tariff in non-commitment regime does not have a "technological function" since R&D investments are already in place when the tariff is set. On the other hand, the committed government that sets the tariff, t_c*, (see expression 11) takes into account the tariff's impact on the subsequent choice of R&D that is below the (first-best) social optimum. Thus, t_c*, besides its profit shifting role, also has the function of stimulating R&D investment. The impact of a tariff on the subsequent unit cost reduction is captured by the term y' (where $y' \equiv dy_c^*/dt$, note that $y' = x' f'(x)$). Thus, in the absence of an R&D subsidy, the tariff, t_c*, assumes part of the R&D subsidy's role and acts not only as a trade policy but also as an industrial or technological policy instrument. As we saw, the tariff, t_{nc}*, does not have this role.

All of the above considerations indicate that $t_{nc}^* < t_c^*$ and, we prove that this is indeed the case.

LEMMA 2

The optimal tariff in the commitment regime always exceeds the optimal tariff in the non-commitment regime.

Proof: See Appendix 5

An Example

When $y = (g\,x)^{1/2}$, yielding $x = h(y) = y^2/g$, the corresponding levels of tariffs in the two regimes are given by the:

$$t_{nc}^* = \frac{(A-\alpha)(27-4g(1-\beta)(3-\beta))}{81-4g(3-\beta)^2} \qquad (15)$$

and

$$t_c^* = \frac{(A-\alpha)(27+g(10+g(-2+\beta)(1-\beta)^2-11\beta)(-2+\beta))}{81-g(32-g(3-2\beta)(2-\beta)-10\beta)(2-\beta)} \;. \qquad (16)$$

The straightforward comparison between (15) and (16) reveals that $t_{nc}^* < t_c^*$ for all permissible values of $g > 0$ and for all $\beta \geq 0$.

Proof: See Appendix 6.

When spillovers are strictly positive, the tariff, t_{nc}*, among other things, serves as an instrument to counteract IPR violation. However, without spillovers (β = 0), (15) collapses to (15.1)

$$t^*_{nc}(\beta=0) = \frac{(A-\alpha)}{3} \tag{15.1}$$

and the optimal tariff becomes a pure, profit shifting tariff (see Bhattacharjea 1995). Thus, the tariff, t_{nc}*, can have two roles at best: profit shifting and countering IPR violation if β >0.

We now turn to the optimal tariff when the government can make commitment, t_c*. Unlike t_{nc}*, this tariff has an additional technological function aimed at boosting R&D investment. This function is clearly seen if we evaluate (16) at β = 0 to get

$$t^*_{c}(\beta=0) = \frac{(A-\alpha)(27-20g+4g^2)}{81-64g+12g^2} \tag{16.1}$$

and observe that dt_c*/dg > 0.[21]

Finally, both (15) and (16) reduce to pure, profit shifting tariffs, when β = g = 0.

4. The "first–best" policy

Since in our "second-best" setup the key strategic variable— R&D investment— is under–supplied, the principle objective of the "first–best" policy is to remove this inefficiency with some other policy instrument. The natural policy tool for this purpose would be an R&D subsidy to the domestic firm.

Before we proceed, it should be made clear at the outset that the term "first–best" is not completely appropriate in this setup (a more correct name would be "constrained first best policy"). The "true" first best policy would involve three policy instruments: import tariff, output subsidy and R&D subsidy or tax. However, the optimal output subsidy would in our setup induce

[21] The fact that dt_{nc}*/dg> 0 for β>0 should not be interpreted as implying the technological function of the tariff, t_{nc}*, since this is only a passive increase of tariff due to the increase in the R&D output, y*, as g gets larger.

the domestic firm to produce at the point where marginal costs equal price, which in turn would imply that the domestic firm serves the whole domestic market. That is, the optimal market structure would be domestic monopoly. Moreover, the optimal tariff would be zero. Since the duopoly interaction between the domestic and foreign firms and strategic tariff are at the core of our analysis, the issue of optimal output subsidy naturally has to be disregarded. More generally, output subsidy is considered to be an unrealistic (Dixit, 1988) and due to its heavy informational content often infeasible and impractical instrument (Bhattacharjea,1995).

Despite the above cautions, we nonetheless stick with the term “first–best” policy to distinguish it from the one-instrument, “second- best” policy (which, by the above logic would be the “third-best policy”) and also to be in line with Neary and Leahy’s (2000) terminology who (although in their setup fully correctly) called the combination of two instruments like output and R&D subsidies the “first–best” policy.

The relevant framework is now a four-stage game that adds one initial stage to the game considered in the previous section: government commitment to a level of R&D subsidy. Again, we can, following Neary and Leahy (2000), consider this game as basically a two stage game where in both stages the government is restrained to committing intra-temporally; thus, in the first stage the government selects the R&D subsidy before the domestic firm chooses R&D, whereas in the second stage the government commits to the tariff before the firms choose their quantities. Since the rest of the game is already solved, we turn immediately to the first stage and the government’s choice of the optimal subsidy.

The objective function of the government that implements the “first–best” policy is now given by the expression (19):

$$W^{*}_{fb}[y^{*}(s),t^{*}(y^{*}(s),s),s] = \Pi^{*}(\cdot) + S^{*}(\cdot) + R^{*}(\cdot) - sh(y^{*}) \tag{19}$$

where "fb"'stands for the “first–best” and "s" denotes the subsidy. The domestic firm’s profit now has an additional term stemming from its subsidy income, $I \equiv s\,h(y)$. The social marginal cost of raising a unit of subsidy is assumed to be one, and so the cost of subsidy payment for the government is $T \equiv s\,h(y)$.

Differentiating (19) with respect to the subsidy and equating it to zero while using the domestic firm's first order condition, (envelope theorem) and noting that ∂Π*/∂s = h(y*) yields (implicitly) the optimal "first-best" subsidy:

$$s^{*} = \frac{1}{h^{/}(y)}\left(\frac{\partial S^{*}}{\partial y} + \frac{\partial R^{*}}{\partial y} + \left(\frac{\partial S^{*}}{\partial t} + \frac{\partial R^{*}}{\partial t}\right)\frac{\partial t}{\partial y}\right) . \tag{20}$$

A positive optimal subsidy requires that the positive impact of unit cost reduction on consumer surplus (the first expression in (20)) dominates the negative impact of the optimal tariff on the consumer surplus and tariff revenue as well as any possible negative impact (which occurs only if $\beta < ½$) of unit cost reduction on the tariff revenue. In other words, the right hand side of (20) has to be positive. Indeed, substituting the relevant values obtained by the

$$s^{*} = \frac{(A-\alpha)(6+25\beta)+(9-6\beta+28\beta^{2})y_{s}^{*}}{81h^{/}(y_{s}^{*})} > 0 . \tag{21}$$

differentiation of the expressions (5) and (6) into (20) gives

Clearly, the optimal "first-best" R&D subsidy is positive, stimulating investments in R&D, removing the distortion between the privately and socially desirable R&D investment levels and ensuring the unit cost reduction to be at the socially optimal level, y_s*.

We will now turn to an "R&D subsidy only" "second-best" policy. Our look at this policy will be brief since this issue is discussed at length elsewhere (see for instance, Spencer and Brander, 1983, Bagwell and Staiger, 1994, Maggi, 1996, and Leahy and Neary, 1997, Hinloopen, 1997). In the absence of tariff, the expression (21) characterizing the optimal subsidy reduces to:

$$s_{sb}^{*} = \frac{\partial S^{*}}{\partial y} = \frac{(1+\beta)(2(A-\alpha)+(1+\beta)y_{sb})}{9h^{/}(y_{sb})} > 0. \tag{22}$$

By comparing (22) with (20), it is easy to show that the sum of remaining effects in (20) is negative yielding the expected relation between the first and second best subsidy, namely

$s^*_{sb} > s^*$. This is in line with findings emphasising the robustness of the R&D subsidy (see for instance, Brander,1995, Bagwell and Staiger,1994, and Leahy and Neary, 1997, Hinloopen,1997, and Neary and Leahy, 2000) since R&D subsidy has to boost inefficient R&D investment and act as a surrogate for the unavailable tariff. Interestingly, the level of spillovers and consequently, "toughness" or "softness" of strategic R&D investment has no impact on the sign of the optimal instrument (R&D subsidy) in either "first" or "second–best" setup. We summarise these observations in the proposition 2.

Proposition 2

Both the "first– best" and "second–best" subsidies are always positive with $s^* < s_{sb}^*$ *irrespective of the level of spillovers and consequently, irrespective of whether R&D investment makes the domestic firm "tough" or "soft".*

The difference from the standard results in Cournot competition where the "first–best" subsidy is negative (i.e., an R&D tax is optimal) stems primarily from the different specification of the welfare function. If we neglect consumer surplus and tariff revenue, then it is clear from (20) that the optimal subsidy will be zero.[22] The reason for this is that in such a situation both the firm and the government have the same ability to commit so the firm can achieve the most advantageous strategic position on its own (see also Neary and Leahy, 2000).

As for the "first–best" tariff, it is given by

$$t_{fb}^* = \frac{A - \alpha + \beta y_s^*}{3}. \tag{22}$$

It obviously has the same functional form as the tariff in the non-commitment regime, since the tariff is no longer an instrument supporting R&D investment. However, note that as long as $\beta > 0$, the optimal "first–best" subsidy exhibits (at least indirectly) a profit shifting role by affecting the optimal tariff through its influence on the optimal level of unit cost reduction. (Note that when $\beta = 0$, R&D has no impact on the optimal tariff and once again the tariff has only a profit shifting

[22] However, this is no longer the case if the foreign firm also invests in R&D.

role). Thus, in the presence of spillovers the division of labour between the two instruments is somewhat blurred. This seems to be a robust finding since a similar phenomenon was also noticed by Leahy and Neary (1999) in a different framework with spillovers and international competition.

An Example

We now turn to the calculation of the optimal, first-best subsidy and tariff when $h(y) = y^2/g$. Substituting it into the expressions (21) and (22) respectively we obtain the expressions for the optimal subsidy and tariff:

$$s^* = \frac{6+\beta(25-4g(1-\beta)(3-\beta))}{9(6+\beta)} \tag{23}$$

$$t_{fb}^* = \frac{(A-\alpha)(6-g(1-\beta)(3-\beta))}{18-g(9-6\beta+4\beta^2)} \tag{24}$$

It is interesting to note that the optimal subsidy increases in the level of spillovers. This may seem counterintuitive at first glance, since as β and y increase, so do the spillover benefits appropriated by the foreign firm. R&D subsidies are, however, an industrial policy instrument with the primary role of enhancing socially insufficient R&D investment while the other instrument (the optimal tariff) has (among other roles), an IPR violation offsetting role (note that $\partial t_{fb}^*/\partial\beta > 0$). Since the optimal R&D subsidy increases with spillovers, it also triggers an increase in the tariff (see expression 22) that thwarts the spillover benefit appropriated by the foreign firm, defined as $F[y_s^*(s),t] \equiv \beta\ y_s^* q_f^*(y_s^*,\ t)$ through the negative impact of the tariff on foreign output. Moreover, as long as spillovers are “not too high,” the investment in R&D makes the domestic firm "tough" and the increase in R&D induced by R&D subsidy also reduces the output of the foreign firm[23] and thus additionally decreases the spillover benefit of the foreign firm. Larger

[23] Recall that when spillovers exceed a certain critical level, the investment in R&D makes the domestic firm “soft” calling for a ”puppy dog” strategy (see Fig 1 and see Fudenberg and Tirole, 1984).

spillovers require larger R&D subsidies, even if the beneficiaries are foreign, not because the home government cares about foreign profits, but because, firstly, it wishes to offset the negative disincentives to investment arising from non-appropriability (see Leahy and Neary, 1999) and, secondly, because it aims to spur better exploitation of scale economies by the domestic firm (see Žigić, 2000).

Calculating the explicit "second–best" subsidy when $y = (g\,x)^{1/2}$ yields

$$s_{sb}^{*} = \frac{(6-g(1-\beta)(2-\beta))(1+\beta)}{18} > s_{fb}^{*}\ .$$

5. Conclusion

We analysed the effect of different degrees of government commitment on social welfare in a duopoly game where domestic and foreign firms compete in quantities on an imperfectly competitive domestic market and where there are R&D spillovers from the domestic to the foreign firm. More specifically, we distinguished between "committed" and "non-committed" policy regimes where a "committed" government selects the policy instrument before the strategic choice of the domestic firm while its "non-committed" counterpart sets the policy instrument only after the strategic variable of the domestic firm is already in place. The latter presumes only intra-temporal commitment on the part of government (and consequently, the absence of inter-temporal commitment).

Concerning government policy, we made a distinction between "first–best" and "second–best" policies. The "first–best" policy in principle includes more than one policy instrument in order to induce a socially desirable level of strategic choice variables whereas strategic choice variable in our set up is unit cost reduction and consequently, investment in R&D. In many circumstances, however, the government may be constrained to a smaller number of policy instruments. In this "second–best" policy environment, there may be only one instrument at the government's disposal. Since, in our context, the domestic firm has two choice variables—the level of R&D investment and the quantities to be produced—the "second–best" policy implies either R&D subsidy or the import tariff (but not both of them).

As for the "second–best" policy when import tariffs are the only instrument, we showed that when R&D spillovers prevail, social welfare in the non-committed regime is higher than social welfare in the commitment regime and, consequently, higher than the corresponding welfare under a free trade regime. The reason for this result is that the optimal tariff in the non-committed regime is lower than the optimal tariff in the committed regime, creating a smaller distortional effect on consumer surplus and tariff revenue. The benefits of the latter exceed the forgone benefits in the domestic firm's profit due to the higher tariff as soon as a small critical level of spillovers is surpassed. A sufficient condition for social welfare in the non–commitment regime to dominate is that the domestic firm's strategic variable— unit cost reduction — be higher than in the commitment regime. In effect, the domestic firm in the non-committed regime has an additional motive to over-invest in order to induce a higher tariff from the government and this additional motive makes it less sensitive to R&D spillovers. Its R&D investment and unit cost reduction, therefore decrease more slowly as spillovers rise, exceeding the R&D investment from the commitment regime as soon as a certain low spillovers threshold level is exceeded.

We demonstrated that the optimal subsidy is always positive in both the "first–best" and "second–best" policy setup irrespective of the level of spillovers and consequently regardless of whether the investment makes the domestic firm soft or tough. The reason for this is the socially inefficient level of private R&D due to the appropriability problem that subsidy aims to correct and due to the scale economies that larger R&D investment brings about. The role of the optimal subsidy in the "first–best" setup is somewhat blurred due to R&D spillovers since, besides its primary role of correcting for socially insufficient R&D, the 'first-best" subsidy also affects the optimal tariff and thus, at least indirectly, has a profit shifting role.

Appendix 1: Comparison of the unit cost reductions in the two regimes for $\beta = 1/2$

The optimal unit cost reductions are determined from the first-order conditions, namely

$$h'(y_c) = 2(2-\beta)(A-\alpha+t_c+(2-\beta)y_c)/9 \qquad \text{(A1a)}$$

in the commitment case and

$$h'(y_{nc}) = 8(3-\beta)(2(A-\alpha)+(3-\beta)y_{nc})/81 \qquad \text{(A1b)}$$

in the non-commitment case. Also recall that the sustainability of duopoly requires that

$$h''(y^*) \geq 2(2-\beta)(4-2\beta+(7-7\beta+4\beta^2)^{1/2})/9 \geq 8/9 \qquad \text{(A2)}$$

under both regimes (see assumption (iii) a in the text).

If the R&D levels are the same ($y_c^* = y_{nc}^*$), then from (A1a) and (A1b) it follows that the commitment tariff should equal

$$t_c^{eq} = ((6+\beta)(A-\alpha)+(12\beta-5\beta^2)y_c)/(9(2-\beta)).$$

If the actual level of t_c^* is less (greater) than t_c^{eq}, then y_c is less (greater) than y_{nc}. This actual level, obtained by setting $dW(y_c(t_c),t_c)/dt_c = 0$, is

$$t_c^* = ((A-\alpha)(27\eta-2(2-\beta)(4-5\beta))+(27\beta\eta+4-2\beta(3-2\beta)^2)y_c)/X, \qquad \text{(A3)}$$

where $\eta = h''(y_c)$ and $X = 81\eta-4(2-\beta)(7-2\beta)$.

For $\beta = 1/2$, $t_c^{eq} = (26(A-\alpha)+19y_c)/54$, whereas (A3) yields:

$$t_c^* = ((A-\alpha)(6\eta-1)+3\eta y_c)/(18\eta-8).$$

The duopoly sustainability (A2) requires now that $\eta \geq 1+(2^{1/2}/2)$. Then

$$t_c^* - t_c^{eq} = ((A-\alpha)(77-72\eta)+(76-90\eta)y_c)/(54(9\eta-4)),$$

which is negative for $\eta \geq 1+(2^{1/2}/2)$. Thus, $t_c^* < t_c^{eq}$ so that $y_c < y_{nc}$ for $\beta = 1/2$.

Appendix 2: Viability of Duopoly– regions of parameters g and β when $h(y) = y^2/g$

We start with the commitment regime. For the duopoly to be a viable market form the best response of the foreign firm should be such that $q_f^* \geq 0$ holds in equilibrium. This requirement is summarised in assumption (iii) a). When $h(y) = y^2/g$ the condition (iii) a) transforms into the following specific expression imposing the upper bound on the innovating efficiency parameter g (see Figure 1A):

$$g_{cr}(\beta) = \frac{9}{(2-\beta)(4-2\beta+\sqrt{(7-(7-4\beta)\beta)}} .$$

Moreover, condition (iii) b) (see page 5 of the text) requires that $W^*_d(t^*(\beta),\beta) \geq W^*_m$, that is, social welfare in duopoly, W^*_d, be higher than the corresponding social welfare, W^*_m, generated when the domestic firm acts as monopolist. For $h(y) = y^2/g$, this yields another upper bound on parameter g described by the function $g_{cc}(\beta)$ in Figure 1A.

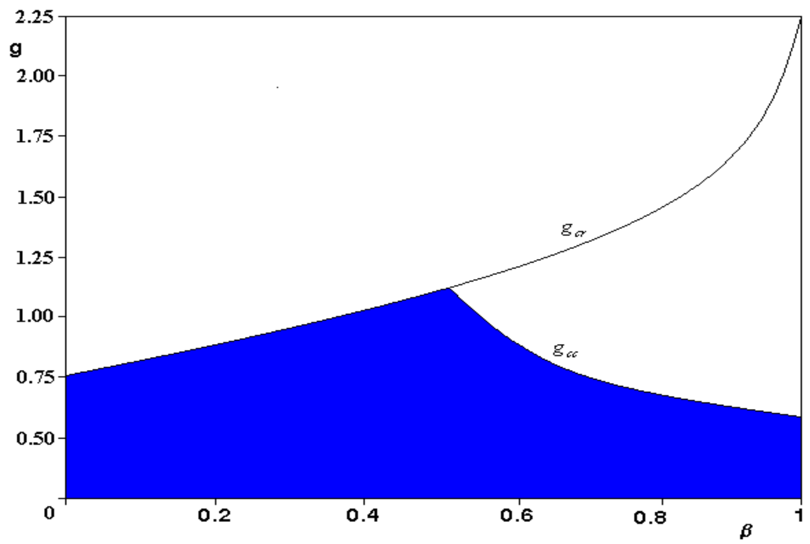

Figure 1A

(The explicit expression for $g_{cc}(\beta)$ is extremely messy and therefore will not be reproduced here). Thus, if $g < g_{cc}(\beta)$, social welfare in duopoly exceeds the welfare from monopoly. The curve g_{cc} is relevant only if $\beta > ½$ since it is easy to demonstrate that welfare in a monopoly is never higher than welfare in a duopoly if $\beta < ½$. A similar procedure was performed for the non-commitment regime, but since it gave the broader regions of the parameters, the intersection of the two feasible regions coincides with the feasibility region of the commitment regime.

Appendix 3: Comparison of the unit cost reduction in the two regimes when h(y) = y^2/g

Solving $y_{nc}^* - y_c^* = 0$ for the critical value of $g_r(\beta)$ yields:

$$g_r(\beta) = \frac{648\beta}{24+\beta(220-\beta(214-49\beta))+\sqrt{(2-\beta)^2(144+\beta(2784-\beta(3272-(9368-2783\beta)\beta))}},$$

where $g_r(\beta)$ represents an upper border below which $y_{nc}^* > y_c^*$. Adding the upper contour of the duopoly feasibility region, $g_{cr}(\beta)$, shows that there is a non-empty intersection for which (shaded area in Figure 2A) $y_c^* > y_{nc}^*$. The critical value of $\beta_r(g)$ is obtained by inverting the function $g_r(\beta)$. Note that irrespective of the value of g, $y_{nc}^* > y_c^*$ for any β such that $\beta > \beta_1^r$ where the value of $\beta_1^r = 0.0909$.

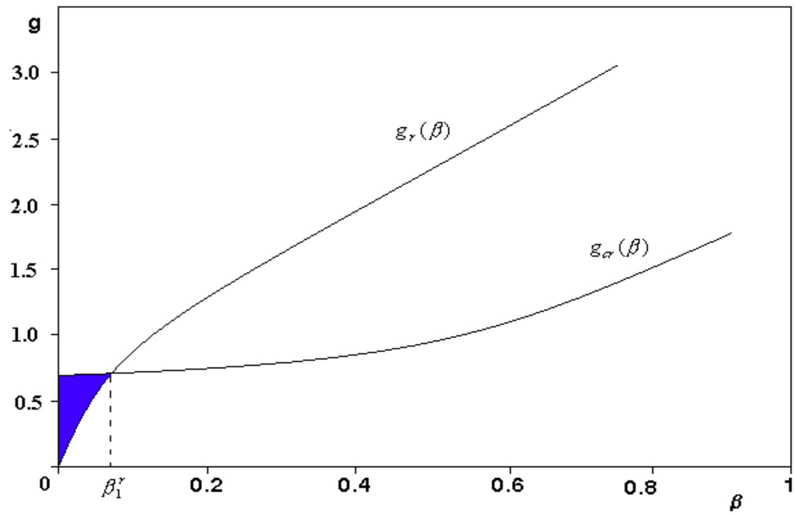

Figure 2A

Appendix 4: Comparison of the social welfare in the two regimes when $h(y) = y^2/g$

Solving $W_{nc}^* - W_c^* = 0$ for the critical value of $g_w(\beta)$ implies

$$W_{nc}^* - W_c^* = \frac{(5103 - 8g(129 - 6g(1-\beta)^2(3-\beta) - 97\beta)(3-\beta))}{2(81 - 4g(3-\beta)^2)^2} + \frac{(63 + g(16 + g(-2+\beta)(1-\beta)^2 - 14\beta)(-2+\beta))}{2(-81 + g(-2+\beta)(-32 + 10\beta + g(2-\beta)(3-2\beta)))} = 0.$$

To get the critical value $g_w(\beta)$ that depicts the upper border below which $W_{nc}^* > W_c^*$, it is necessary to solve the following equation for g:

$$16g^3(1-\beta)^2(2-\beta)^2(3-\beta)^2\beta^2 - 648\beta(6+29\beta) - 8g^2(1-\beta)(2-\beta)(3-\beta)\beta(12-\beta(-116+49\beta)) + g(144 + \beta(2784 + \beta(16168 + \beta(-19144 + 4993\beta)))) = 0.$$

Since the solution is extremely messy, it will not be reproduced in the text. The intersection of the areas of $g(\beta) \geq g_w(\beta)$ and $g(\beta) \leq g_{cr}(\beta)$ yields a small shaded area for which $W_c^* > W_{nc}^*$ (see Figure 3A). The critical value of $\beta^w(g)$ is obtained by inverting $g_w(\beta)$. Note that irrespective of the value of g, $W_{nc}^* > W_c^*$ for any β such that $\beta > \beta_1^w$ where $\beta_1^w = 0.03909$. The graphical representation of W_{nc}^*, W_c^* and W_{ft}^* (social welfare in a free trade regime) is given in Figure 4A below.

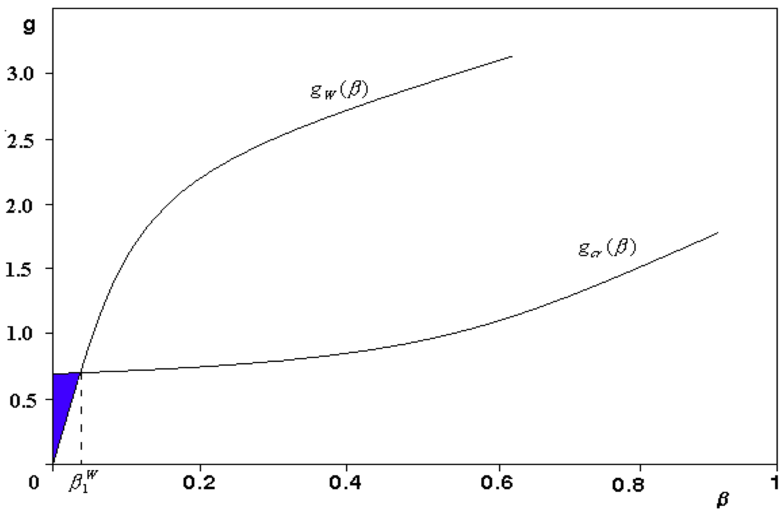

Figure 3A

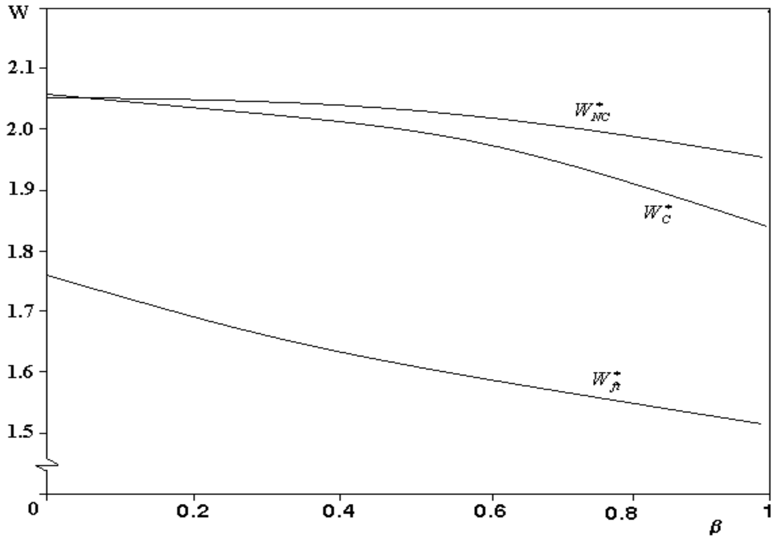

Figure 4A

Appendix 5: Comparison of the tariffs in the two regimes

In order to prove that $t_c^* - t_{nc}^* > 0$ for all $\beta \in [0,1]$ and for duopoly being a viable market form, it is sufficient to show that $t_c^* - t_{nc}^{up} > 0$ where t_{nc}^{up} is an appropriately defined upper bound of t_{nc}^*. To obtain t_{nc}^{up} we first derive the upper bound of y_{nc} (labeled as y_{nc}^{up}) as a function of y_c. The most challenging and the relevant case is when $y_{nc} > y_c$. (If on the other hand, $y_c > y_{nc}$, the proof is straightforward by direct comparison of the t_c^* and t_{nc}^* evaluated at the same level of y.)

Thus $y_{nc} > y_c \Rightarrow h'(y_{nc}) > h'(y_c)$ or

$$h'(y_{nc}) - h'(y_c) > 0. \tag{4A}$$

By the mean-value theorem (4A) can be expressed as

$$h'(y_{nc}) - h'(y_c) = h''(z)(y_{nc} - y_c). \tag{5}$$

Since we assume that $h'''(y) \geq 0 \Rightarrow h''(z) \geq h''(y_c) \Rightarrow$

$$h'(y_{nc}) - h'(y_c) \geq h''(y_c)(y_{nc} - y_c). \tag{6}$$

To get y_{nc} explicitly we substitute the domestic firm's first order conditions from both commitment and non-commitment regimes, (1a) and (1b), into (6). To simplify the notation we rearrange the above first order conditions in the following form: $h'(y_c) = B_c + D_c y_c$ and $h'(y_{nc}) = B_{nc} + D_{nc} y_{nc}$, where

$$B_c = 4(A - \alpha)(2 - \beta)(6\eta - (2 - \beta)^2)/X,$$

$$D_c = 4(2 - \beta)(3(3 - \beta)\eta - 2\beta^2 + 7\beta - 6)/X,$$

$$B_{nc} = 16(A - \alpha)(3 - \beta)/81,$$

$$D_{nc} = 8(3 - \beta)^2/81,$$

and η and X are defined above. Note that in constructing B_c and D_c, a tariff under commitment, t_c, from expression (1a) is replaced by the optimal tariff (3).

Combining these two equations the upper bound of y_{nc} write now as

$$y_{nc}^{up} = (B_{nc} - B_c) / (\eta - D_{nc}) + ((\eta - D_c)\, y_c) / (\eta - D_{nc}) \geq y_{nc}.$$

Then $t_{nc}^* = (A - \alpha + \beta\, y_{nc}) / 3 \leq (A - \alpha + \beta\, y_{nc}^{up}) / 3 = t_{nc}^{up}$, the upper bound on t_{nc}.

Thus, the difference between the tariffs is bounded from below by $t_c^* - t_{nc}^{up}$, which can be represented as a function of β, $\eta = h''(y_c)$, and y_c, i.e., $t_c^* - t_{nc}^{up} = \Phi(\beta, \eta, y_c)$. It is possible to show that $\Phi(.)$ increases in y_c. To evaluate the sign of the function $\Phi(.)$ we now introduce the lower bound of y_c that we label y_c^{low} to get $\Phi(\beta, \eta, y_c^{low}) = \Psi(\beta, \eta)$, a lower bound on $\Phi(\beta, \eta, y_c)$.

The lower bound of y_c is obtained again by relying on the mean-value theorem. Namely,

$$h'(y_c) - h'(0) = h''(z)\,(y_c - 0) => h'(y_c) = h''(z)\, y_c$$

since $h'(0) = 0$ by assumption and finally, since $h''' \geq 0$,

$$h'(y_c) = B_c + D_c\, y_c \leq h''(y_c)\, y_c,$$

whence

$$y_c \leq y_c^{low} = B_c / (\eta - D_c).$$

Thus, to complete the proof it suffices to demonstrate that $\Psi(\beta, \eta) \geq 0$ for all $\beta \in [0,1]$ and for all η such that duopoly is sustainable. After some arithmetical transformations, it is possible to show that $\Psi(\beta, \eta)$ has the same sign as $\Theta(\beta, \eta)$, namely

$$\Psi(\beta, \eta) = 2\,(A - \alpha) \times \Theta(\beta, \eta) / (81\eta^2 + 4\,(2 - \beta)^2\,(3 - 2\beta) - 4\eta\,(2 - \beta)\,(16 - 5\beta)),$$ where

$$\Theta(\beta, \eta) = 27\eta^2(4 + 20\beta - 15\beta^2) - 2\eta(2 - \beta)^2(12 + 116\beta - 85\beta^2) + 16\beta(1 - \beta)(2 - \beta)^3(3 - \beta).$$

It is easy to show that $\Theta(\beta, \eta)$ increases in η when $\eta \geq 8 / 9$ (see (2)) regardless of β. Thus,

$$\Theta(\beta, \eta) \geq \Theta(\beta, 8 / 9) = 16 \beta (40 + 210 \beta^2 - 266 \beta^3 + 90 \beta^4 - 9 \beta^5) / 9,$$

and the graph of $9 \Theta(\beta, 8 / 9) / (16 \beta)$ is displayed in Figure 5A below.

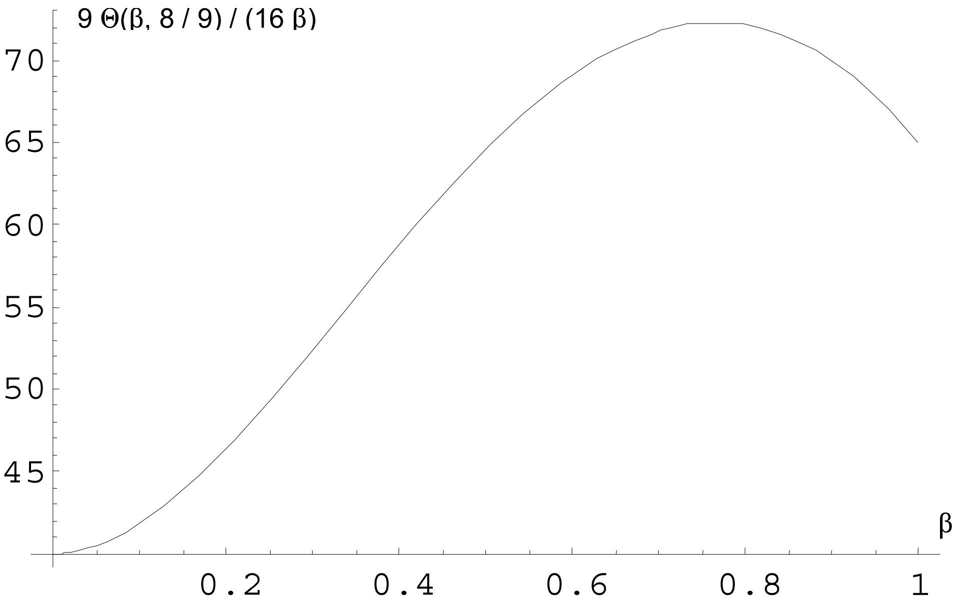

Figure 5A

Thus, $t_c^* - t_{nc}^* \geq t_c^* - t_{nc}^{up} = \Phi(\beta, \eta, y_c) \geq \Psi(\beta, \eta)$, and $\Psi(\beta, \eta)$ is positive as $\Theta(\beta, 8 / 9)$ is positive.

Appendix 6: Comparison of the tariffs in the two regimes when $h(y) = y^2/g$

Solving $t_c^* - t_{nc}^* = 0$ for the critical value of $g_t(\beta)$ yields

$$g_t(\beta) = \frac{24+\beta(220+\beta(-286+85\beta))}{8(1-\beta)(2-\beta)^2(3-\beta)\beta}$$

$$-\frac{\sqrt{(2-\beta)}\sqrt{(288-\beta(-240+\beta(-1040+\beta(-1416+5\beta(78+149\beta)))}}{8(1-\beta)(2-\beta)^2(3-\beta)\beta},$$

where $g_t(\beta)$ represents an upper border below which $t_{nc}^* < t_c^*$. However, as seen from Figure 6A, $g_t(\beta) > g_{cr}(\beta)$ for all $\beta \in [0,1]$ where

$$g_{cr}(\beta) = \frac{9}{[(2-\beta)(-2(-2+\beta)+(7-7\beta+4\beta^2)^{1/2})]}$$

delineates the upper border of the duopoly's feasibility region when β < ½ and it is obtained by solving the equation $q_f^*(.) = 0$. Consequently, the whole feasibility region for the duopoly market structure is a proper subset of the region $g(\beta) \le g_t(\beta)$, implying $t_c^* - t_{nc} > 0$ will hold in the whole duopoly region.

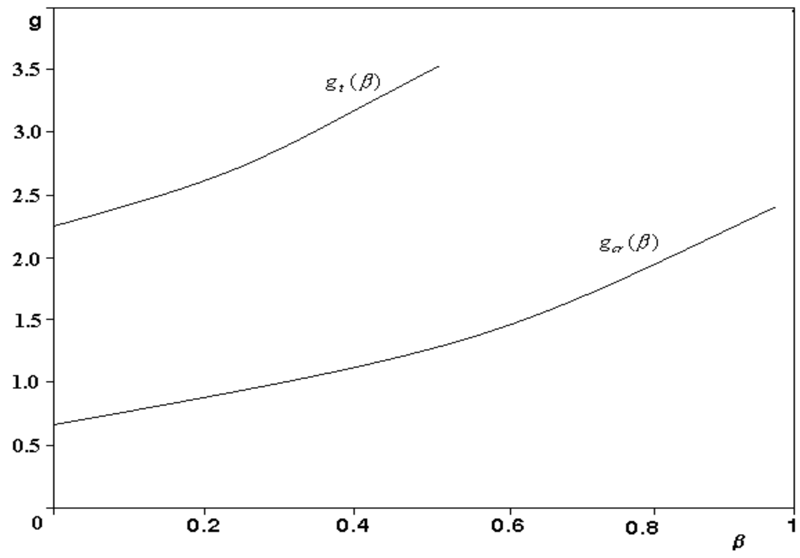

Figure 6A

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