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by

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INTERNATIONAL R&D RIVALRY AND INDUSTRIAL STRATEGY WITHOUT GOVERNMENT COMMITMENT*

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Abstract

We examine optimal industrial and trade policies in a series of dynamic oligopoly games in which a home and a foreign firm compete in R&D and output. Alternative assumptions about the timing of moves and the ability of agents to commit intertemporally are considered. We show that the home export subsidy, R&D subsidy and welfare are higher when government commitment is credible than in the dynamically consistent equilibrium without commitment. Commitment thus yields welfare gains (though they are small) but so does unanticipated reneging, whereas reneging which is anticipated by firms yields the lowest welfare of all.

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INTERNATIONAL R&D RIVALRY AND INDUSTRIAL STRATEGY

WITHOUT GOVERNMENT COMMITMENT

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INTERNATIONAL R&D RIVALRY AND INDUSTRIAL STRATEGY WITHOUT GOVERNMENT COMMITMENT

1. Introduction

In open-economy oligopolistic industries, governments typically have an incentive to employ a strategic trade policy. This involves commitment to subsidies or tariffs that are designed to shift rents from foreign firms to home firms or to the home government itself. If the firms are also engaged in international R&D competition then the government's optimal industrial policy will interact with its optimal trade policy.

R&D is like any form of investment in that it is chosen before production takes place. Given this temporal sequence, R&D is likely to be chosen before policies such as export subsidies which are intended to affect output. In such circumstances the choice of R&D level will influence the government's optimal export subsidy. Hence issues of time consistency and strategic commitment inevitably arise in considering the choice of optimal R&D policy. However, they have been little studied.[1] In this paper we examine the implications for strategic trade and industrial policy of different assumptions about the timing of moves and the ability of agents to commit in a series of dynamic oligopoly games with process R&D.

The model we use is similar to that of Spencer and Brander (1983). Like them, we address the issue of the jointly optimal strategic export subsidy and R&D subsidy. However, in their model the government can always credibly commit to its policies before firms move. This assumes away the problem of time consistency and precludes any possibility of the firms playing strategically against the government.

Maskin and Newbery (1990) are an exception to the general neglect of dynamic consistency and commitment issues in international trade policy. They examine the choice of optimal tariff in a two-period model where dynamic linkages between periods arise from the exploitation of an exhaustible resource. However, in their model the private sector is atomistic. Hence, while government policy announcements may lack credibility, individual firms do not possess sufficient market power that their first-period

[1] A number of papers have examined the implications of reversing the move order of firms and government for the Eaton and Grossman (1986) analysis of export taxes in price competition. See Carmichael (1987), Gruenspecht (1988) and Neary (1991 and 1994).

choice can affect the government's second-period decision. By contrast, in our model, firms compete in an oligopolistic setting and have an incentive to try and influence future government decisions directly.

In this paper we examine a series of two-period models in which a home and a foreign firm compete on a third market. The firms choose how much process R&D to carry out in the first period and how much output to produce in the second period. The higher the level of R&D chosen the lower are marginal production costs. The home government can intervene to subsidise or tax R&D and output.

Our focus is on the timing of moves and the ability of agents to commit to future actions. Similar issues of timing, commitment and time consistency have been much discussed in the macroeconomics literature but, with Maskin and Newbery (1990), Leahy and Neary (1994) and Karp and Paul (1995), this paper is among the first to discuss such issues in the context of microeconomic policy in an open economy. The novelty of our approach hopefully compensates for the fact that, in order to obtain definite results, we have been forced to use simple functional forms. Thus we adopt a simple linear specification of demand and assume that R&D affects marginal production costs in a linear fashion and is itself subject to quadratic costs.

Section 2 sets up the model. In Section 3 we look at equilibria in which commitment to a future export subsidy is credible and compare the outcome when the firms can commit to future output with the outcome when they cannot commit intertemporally. In Section 4 we explore the implications of the government's inability to commit to future trade policies. This gives it an incentive to renege on its announced subsidy and we consider the cases where this time-inconsistent behaviour is or is not anticipated by firms. In Section 5 we turn to the fully time-consistent case in which no agent can commit to future actions but where this inability to commit is fully anticipated. Section 6 concludes.

2. The Model

We examine a model in which a home and a foreign firm export a homogeneous commodity to a third market.[2] The inverse demand function is given by:

[2] The third market framework has been used by Spencer and Brander (1983), Brander and Spencer (1985) and Eaton and Grossman (1986) among others. It has the advantage

$$p = a - b(q + q*), \tag{1}$$

where a and b are positive constants, q represents home exports and q* represents foreign exports. (An asterisk will often be used to represent a foreign variable.) We distinguish two time periods: the pre-market R&D phase, period 1, and the output phase, period 2. The home and foreign firms choose R&D levels x and x* respectively for period 1 and outputs for period 2. This accords with a natural temporal sequence in which R&D is carried out before production takes place. A higher R&D level implies lower marginal cost. This effect of R&D is captured by the following specification of marginal production costs:

$$\begin{aligned} c &= c_o - \theta x, \\ c* &= c_o - \theta x^*, \end{aligned} \tag{2}$$

where θ is a positive constant[3]. In period 1 the home and foreign firms must incur R&D costs: $\gamma x^2/2$ and $\gamma x^{*2}/2$ respectively.

Given demands and costs the home firm maximises the following profit function:

$$\pi = (p-c+s)q - \gamma x^2/2 + \sigma x, \tag{3}$$

where s is the per unit export subsidy and σ is the per unit R&D subsidy. The foreign firm maximises: $(p-c^*)q^*-\gamma x^{*2}/2$ since it does not receive subsidies. The home government maximises welfare which equals profits net of subsidy payments:

$$W(q,q^*,x) = \pi - sq - \sigma x = (p-c)q - \gamma x^2/2. \tag{4}$$

Welfare does not depend directly on x*, since changes in foreign R&D only affect domestic welfare through their effect on output levels and home R&D. However, welfare depends directly on q, q* and x. Hence the home government has three targets but at most only two instruments, the R&D subsidy and the export subsidy.

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of allowing one to abstract from home market welfare issues and to concentrate on the implications of strategic effects. Extending the model to imperfect substitutes is straightforward but does not yield any additional interesting insights.

[3] Under our assumptions, R&D is indistinguishable from other types of investment, since each firm's R&D affects its own costs only. R&D spillovers between firms are considered in Leahy and Neary (1995).

For later use we need an expression for changes in welfare. Totally differentiating (4) yields:

$$dW = (p-c)dq - bq(dq+dq*) + (\theta q - \gamma x)dx. \tag{5}$$

When the coefficient of dx is zero, the marginal return to R&D, θq, equals its marginal cost, γx, so R&D is at the efficient or social-cost-minimising level.

In specifying firm and government behaviour we need to consider the order in which agents move. We assume that within periods firms choose their actions simultaneously. Thus neither firm has Stackelberg leader type first-mover advantages in output or in R&D. We also assume *intratemporal* commitment by the government, in the sense that within each time period the government moves before firms. The government commits to its R&D subsidy before R&D is chosen and to its export subsidy before exports are chosen. However, there still remains a number of different possible assumptions about the degree of *intertemporal* commitment. As in Leahy and Neary (1994) there are three different subgame perfect equilibria corresponding to three different move orders:

1. *Full Commitment Equilibrium (FCE):* In this case all agents take their decisions for both periods at the start of period 1. That is, they commit intertemporally. In this case the game has two stages and firms cannot play strategically.
2. *Government-Only Commitment Equilibrium (GCE):* This is a three-stage game in which, as under FCE, the government can commit to its export subsidy at the start of the first period. In the second stage firms choose R&D and in the third stage firms choose outputs. Given subgame perfection, firms behave strategically in stage 2, choosing their R&D levels with a view to improving their position in the third-stage output game.
3. *Sequence Equilibrium (SE):* In this four-stage game no agent can commit intertemporally. In stage 1 the government sets its R&D subsidy. In the second stage R&D levels are chosen. Then in stage 3 the export subsidy is chosen and in stage 4 firms choose outputs.

In addition to these three cases we consider two interesting equilibria that involve a departure from subgame perfection. In these cases the government announces that it is committing to an export subsidy but it subsequently reneges on this announcement. There are two cases, depending on whether or not the government's announcement is believed by firms:

4. *Unanticipated Government-Reneging Equilibrium (URE)*: In this case the government sets the GCE R&D subsidy and announces the GCE export subsidy; the firms do not expect the government to renege and so they choose the GCE R&D levels; however, the government reoptimises (reneges) in period 2, choosing a different value of s. In the final stage the firms choose quantities given the subsidies and R&D levels.
5. *Anticipated Government-Reneging Equilibrium (ARE)*: In this case the government sets the GCE R&D subsidy and announces the GCE export subsidy. The firms correctly anticipate that the government will renege on its announced export subsidy when choosing their R&D. The government then chooses a new export subsidy. In the final stage the firms choose quantities given the subsidies and R&D levels.

In the remainder of the paper, we solve the model for each of these five equilibria and compare the levels of home output, R&D, subsidies and welfare in each. The comparison is greatly facilitated by the fact that, when appropriately normalised, the values of all these variables can be expressed as functions of a single parameter, which we denote by η. This is defined as $\theta^2/b\gamma$ and can be interpreted as the *relative return to R&D*. Figures 1 to 5 illustrate how the variables of interest behave as functions of η in each of the five equilibria, and they will be referred to repeatedly in subsequent sections[4].

3. Equilibria with Credible Government Commitment

3.1 Output Behaviour

We now begin our discussion of optimal trade and R&D policy. In this section we examine equilibria in which the home government's commitment to its future policy choice is fully credible. The two equilibria considered here, FCE and GCE, have in common that the home government chooses its R&D and export subsidy at the beginning of period 1.

In all cases firms choose their outputs given the export subsidy and the R&D and output levels of their rival. The home and foreign first-order conditions for output satisfy:

$$\frac{\partial \pi}{\partial q} = p - bq - c + s = 0, \tag{6}$$

$$\frac{\partial \pi*}{\partial q*} = p - bq* - c* = 0. \tag{7}$$

Substituting from (1) for p and from (2) for c and c*, these two first-order conditions give the firms' output reaction functions conditional on their levels of R&D.

3.2 Optimal Policy under FCE

We will first consider optimal policy under FCE. In this case each firm chooses its R&D taking both the output and R&D levels of its rival as given. The home and foreign first-order conditions for R&D are respectively:

$$\begin{aligned} \frac{\partial \pi}{\partial x} &= \theta q - \gamma x + \sigma = 0, \\ \frac{\partial \pi^*}{\partial x^*} &= \theta q^* - \gamma x^* = 0. \end{aligned} \tag{8}$$

[4] These variables are illustrated only for values of η consistent with interior equilibria. The binding constraint is that foreign output cannot be negative. From the foreign firm's first-order conditions (equation (6) for output and whichever of (8), (12), or (22) is appropriate for R&D), q* is always proportional to $a-c_o-bq$. Hence the maximum admissible value for η in each of the five equilibria is found by equating the value for q in each case to $(a-c_o)/b$. This implies maximum values (to two decimal places) of: 0.38 (FCE), 0.35 (GCE), 0.38 (URE), 0.29 (ARE) and 0.40 (SE). Since $(a-c_o)/b$ is normalised at unity in Figure 1, each locus hits its upper bound of unity when η reaches the corresponding maximum value.

R&D is chosen so as to minimise total costs given output and the R&D subsidy.[5]

Using (6) and (8) in (5), the expression for welfare change becomes:

$$dW = -sdq - bqdq^* - \sigma dx. \tag{9}$$

This shows that the optimal policy implies a clear division of labour between the two subsidies. On the one hand, the export subsidy is targeted exclusively towards rent-shifting. From (6) and (8) (eliminating x^*) the foreign firm's output depends directly on the home firm's; in terms of changes: $dq^* = -dq/(1-\eta)$. Hence the first two terms on the right-hand side of (6) can be combined to solve for the optimal export subsidy. This plays the same rent-shifting role as in the one-period model of Brander and Spencer (1985). On the other hand, the R&D subsidy is targeted exclusively towards influencing the home firm's choice of R&D. The final term in (9) shows that at the optimum, the R&D subsidy must be zero:

$$\sigma^F = 0, \qquad s^F = -bq^F\frac{dq^*}{dq} = \frac{b}{2-\eta}q^F, \tag{10}$$

where the superscript F denotes FCE. The R&D subsidy is zero, unlike in Spencer and Brander (1983), because firms commit to outputs and hence do not strategically overinvest in R&D. Since the home firm chooses the efficient level of R&D in the absence of a subsidy, there is no need for intervention. As for the export subsidy, if there were no incentive to invest in R&D ($\eta=0$), the second equation in (10) would reduce to the standard Brander and Spencer (1985) formula for the optimal export subsidy. It is increasing in η because the export subsidy is being used not just to reduce foreign output as in Brander and Spencer (1985) but also to reduce foreign R&D.

Combining (10) with (6) and (8) yields expressions for home R&D, home output and the export subsidy in terms of parameters alone:

$$x^F = \eta\frac{1-\eta}{2-4\eta+\eta^2}\frac{A}{\theta}, \qquad q^F = \frac{1-\eta}{2-4\eta+\eta^2}\frac{A}{b}, \qquad s^F = \frac{1-\eta}{2-\eta}\frac{A}{2-4\eta+\eta^2}. \tag{11}$$

where $A \equiv a-c_o>0$. As shown in Figures 1, 2 and 4 these are all increasing in η.

3.3 Optimal Policy under GCE

We turn next to GCE, the case examined in Spencer and Brander (1983). Each firm now takes account of the effect of its R&D on its rival's output. Hence the appropriate first-order conditions for the home and foreign firm respectively become:

$$\frac{d\pi}{dx} = \frac{\partial\pi}{\partial x} + \frac{\partial\pi}{\partial q^*}\frac{dq^*}{dx} = \frac{4}{3}\theta q - \gamma x + \sigma = 0,$$
$$\frac{d\pi^*}{dx^*} = \frac{\partial\pi^*}{\partial x^*} + \frac{\partial\pi^*}{\partial q}\frac{dq}{dx^*} = \frac{4}{3}\theta q^* - \gamma x^* = 0, \tag{12}$$

where we use $\partial\pi/\partial q^*=-bq$ and $\partial\pi^*/\partial q=-bq^*$ from (3) and $\partial q^*/\partial x=\partial q/\partial x^*=-1/3b$ from (6) and (7). It is clear from (12) that, without intervention, the GCE R&D levels exceed the private-cost-minimising levels. This is because firms are using R&D strategically to reduce their rivals' outputs, reflecting the strategic overinvestment

[5] The market or no-intervention outcome under FCE is found by combining (6), (7) and (8) at $s=\sigma=0$ to obtain the symmetric output levels:

$$q_M^F = q_M^{*F} = \frac{1}{3-\eta}\frac{A}{b}.$$

The subscript "M" indicates that this is a market outcome and the superscript "F" indicates FCE. The market R&D level under FCE is also obtained by combining (6), (7) and (8) at $s=\sigma=0$ to get:

$$x_M^F = x_M^{*F} = \frac{\eta}{3-\eta}\frac{A}{\theta}.$$

An explicit expression for home welfare (which is equal to the profit of the home firm in this no-intervention case) can be obtained by substituting the appropriate values of x and q into the welfare function in (4) to obtain:

$$W_M^F = \pi_M^F = \frac{(2-\eta)}{2(3-\eta)^2}\frac{A^2}{b},$$

which is increasing in η.

phenomenon of Spence (1977), Dixit (1980) and Brander and Spencer (1983).[6]

The expression for welfare change now becomes:

$$dW = -sdq - bqdq^* - \left(\sigma + \frac{\theta}{3}q\right)dx. \tag{13}$$

As in the FCE case, (7) and (12) imply that q* depends only on q (and not directly on x): $dq^* = -dq/(2-4\eta/3)$. Hence once again the export subsidy can be targeted towards rent-shifting and the R&D subsidy towards ensuring that R&D is at its efficient level:

$$\sigma^G = -\frac{\theta}{3}q^G, \qquad s^G = -bq^G\frac{dq^*}{dq} = \frac{b}{2-\frac{4}{3}\eta}q^G, \tag{14}$$

where the superscripts denote GCE. Now, as shown by Spencer and Brander (1983), the optimal policy is to tax R&D. When the optimal R&D tax is in place the level of home R&D is chosen so as to minimise total costs for given output. To see this, substitute σ^G into (12), which gives: $\theta q^G = \gamma x^G$. As in FCE, there is a well-defined division of labour between R&D policy and export policy. The role of the R&D tax is to counteract strategic behaviour by the home firm and so keep home R&D at the efficient level. By contrast, the export subsidy is used to shift profits to the home firm by inducing a fall in foreign R&D and output. Equilibrium outputs and R&D levels differ under FCE and GCE because the behaviour of the foreign firm, which is outside the control of the home government, differs in the two cases.

The expressions for home R&D and output and the two subsidies in terms of parameters alone are:

$$x^G = \eta\frac{3-4\eta}{(1-2\eta)(3-\eta)}\frac{A}{2\theta}, \qquad q^G = \frac{3-4\eta}{(1-2\eta)(3-\eta)}\frac{A}{2b},$$
$$\sigma^G = -\frac{\eta(3-4\eta)}{(1-2\eta)(3-\eta)}\frac{\gamma}{\theta}\frac{A}{6}, \qquad s^G = \frac{3}{3-2\eta}\frac{3-4\eta}{(1-2\eta)(3-\eta)}\frac{A}{4}. \tag{15}$$

R&D, output and the export subsidy are all increasing in η while the R&D subsidy is declining in η. Simulation results are illustrated in Figures 1 to 4. Output and R&D levels are higher under GCE than FCE, yet R&D is taxed under GCE but not under FCE. The reason for this apparent paradox is that the R&D tax simply restores the efficient condition for R&D; the incentive to engage in R&D is greater because q is higher.

3.4 Welfare when Government Commitment is Credible

To obtain explicit expressions for welfare under FCE and GCE first eliminate $(p-c)$ from the right-hand side of (4) using (6) and then eliminate q, x and s using (11) in the FCE case, and (15) in the GCE case. This yields:

$$W^F = \frac{(1-\eta)^2}{(2-\eta)(2-4\eta+\eta^2)}\frac{A^2}{2b}, \tag{16}$$

for welfare under FCE and:

$$W^G = \frac{(3-4\eta)^2}{4(1-2\eta)(3-2\eta)(3-\eta)}\frac{A^2}{2b}, \tag{17}$$

under GCE. The results of this section are summarised by the following Proposition:

Proposition 1: *Home output, home R&D and the export subsidy increase faster in the relative return to R&D under GCE than FCE. The R&D subsidy is zero under FCE but falls in η under GCE. Welfare, which increases in the relative return to R&D under both FCE and GCE, is higher under FCE than GCE at all η.*

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[6] To obtain explicit expressions for outputs and R&D under no-intervention GCE combine (12) with (6) and (7) and set s and σ equal to zero. The R&D and output levels are:

$$q_M^G = q_M^{*G} = \frac{3}{9-4\eta}\frac{A}{b},$$

$$x_M^G = x_M^{*G} = \frac{4\eta}{9-4\eta}\frac{A}{\theta},$$

where the "G" superscript indicates GCE. Comparing these with the no-intervention FCE case, set out in footnote 5, it is clear that R&D and output are higher under GCE than under FCE. This reflects the strategic overinvestment phenomenon. Home country welfare under GCE is obtained by using the above outputs and R&D levels in (4). It is:

$$W_M^G = \pi_M^G = \frac{(9-8\eta)}{(9-4\eta)^2}\frac{A^2}{b}.$$

This is falling in η which seems paradoxical: when firms play strategically more effective R&D reduces welfare. To explain this result recall that the firms are selling to a third market. Hence strategic overproduction implies a deterioration of the terms of trade, benefiting the consumers in the importing country at the expense of the exporters.

These results are illustrated in Figures 1 to 5.

4. Equilibria with Reneging

4.1 The Incentive to Renege

So far we have assumed that the government can commit to its second-period export subsidy at the start of the first period. However, this may not be possible. In this section we look at what happens when the government cannot commit to a future export subsidy but acts in the first period as if it could. It thus offers the GCE R&D subsidy in the first period and announces that it will offer the GCE export subsidy in period 2. However, this announced export subsidy is time-inconsistent because the government has an incentive to reoptimise in period 2 by choosing the export subsidy to maximise welfare given the R&D levels that have already been sunk. At the beginning of period 2 the government faces the following optimisation problem:

$$\underset{s}{Max}\ W_2(s) = (p-c)q, \tag{18}$$

where $W_2(s)$ represents the second-period welfare function (welfare given the R&D levels already in place). This is the standard Brander and Spencer (1985) one-period export subsidy problem. The optimal subsidy is simply:

$$s^R = \frac{b}{2}q, \tag{19}$$

where the superscript R indicates that this is the formula for the reoptimised export subsidy. The reoptimised export subsidy is lower *per unit output* than the precommited FCE and GCE export subsidies. This is because, with R&D sunk, the export subsidy cannot affect it and the only role left for the subsidy is static Brander and Spencer (1985) rent-shifting.

It is possible to combine (19) with (6) and (7) to give expressions for the export subsidy and home and foreign output in terms of R&D levels:

$$s^R = \frac{A+\theta(2x-x*)}{4},$$
$$q^R = \frac{1}{2b}[A+\theta(2x-x*)], \quad q^{*R} = \frac{1}{2b}\left[\frac{A}{2}+\theta\left(\frac{3}{2}x*-x\right)\right]. \tag{20}$$

These will prove useful later.

We now consider the choice of first-period variables. The R&D levels chosen by the firms depend on whether or not the firms believe the government is committed to its future export subsidy.

4.2 Unanticipated Reneging

We first consider the case in which firms believe that the government *can* commit to its export subsidy at the beginning of period 1. Since the firms do not expect the government to renege on the GCE export subsidy they choose the GCE R&D levels given in (15). In other words, stages 1 and 2 of the game are identical to those under GCE. The equilibrium outputs and export subsidy for the Unanticipated Government-Reneging Equilibrium (URE) are then found by using (15) and the corresponding expression for x* in equation (20).[7] The resulting reduced form equations for q and s are:

$$q^U = \frac{3(1-\eta)(3-4\eta)}{(1-2\eta)(3-\eta)(3-2\eta)}\frac{A}{2b},$$
$$s^U = \frac{3(1-\eta)(3-4\eta)}{(1-2\eta)(3-\eta)(3-2\eta)}\frac{A}{4}, \tag{21}$$

where the superscripts denote URE.

The URE export subsidy and home output level are strictly lower than their corresponding values under GCE (this is shown in Figures 1 and 2). Since the government could offer the GCE subsidy if it wished, it must attain at least as high a level of welfare under URE as under GCE. Indeed, as Figure 5 shows, URE yields the

[7] Foreign R&D under GCE can be shown using (7), (12), and (15) to be:

$$x*^G = \eta\frac{3-10\eta+4\eta^2}{(1-2\eta)(3-\eta)(3-2\eta)}\frac{A}{\theta}$$

highest welfare of all the equilibria in which R&D is chosen before output.[8]

4.3 Anticipated Reneging

Now consider the Anticipated Government-Reneging Equilibrium (ARE). Here the firms anticipate that the government will deviate from the GCE export subsidy but the government acts as if it can commit intertemporally. Stages 3 and 4 of this game are just as in the URE case and the export subsidy and outputs as a function of R&D are given in (20) above. The difference is stage 2 where the firms anticipate the dependence of the export subsidy on the levels of R&D, and play strategically against the government. Both firms tend to overinvest in R&D, the home firm in order to secure a higher subsidy and the foreign firm to reduce the export subsidy. The two firms' first-order condition are:

$$\frac{d\pi}{dx} = \frac{\partial\pi}{\partial x} + \frac{\partial\pi}{\partial q^*}\frac{dq^*}{dx} + \frac{\partial\pi}{\partial s}\frac{ds}{dx} = 2\theta q - \gamma x + \sigma = 0,$$
$$\frac{d\pi^*}{dx^*} = \frac{\partial\pi^*}{\partial x^*} + \frac{\partial\pi^*}{\partial q}\frac{dq}{dx^*} = \frac{3}{2}\theta q^* - \gamma x^* = 0, \qquad (22)$$

where use has been made of $\partial\pi/\partial s = q$ and the derivatives of output and the subsidy with respect to x and x* are taken from (20). Compared to GCE (equation (12)) there is an additional term in the home firm's first-order condition which captures the effect of R&D on the export subsidy. The R&D chosen under ARE is above the efficient level.[9]

Proceed by using (20) to eliminate outputs in (22). This yields expressions for R&D

[8] URE can be interpreted as an equilibrium in which the government has *three* instruments, the R&D subsidy, the announced export subsidy (which affects the level of R&D chosen) and the actual export subsidy. In fact, since the announced export subsidy is costless the government can in principle do even better than URE. The first-best for the government is to set the R&D subsidy at zero, announce an export subsidy sufficiently high to drive the foreign firm out of business and then renege by giving a zero export subsidy in period 2. However, it does not seem plausible that the announcement of such an export subsidy would be credible. If the announcement is not believed and firms use their R&D levels to strategically manipulate the export subsidy, the equilibrium level of home R&D will be very high and welfare will be even lower than in ARE.

[9] Eliminate σ from the right-hand side of (22) using (14) to get: $\gamma x^A = \theta(2q^A - q^G/3) > \theta q^A$, which implies that R&D is above the cost-minimising level.

and output levels as functions of the R&D subsidy and parameters:

$$x = \frac{\eta}{\theta(8-25\eta+12\eta^2)}\left\{4(2-3\eta)A + (8-9\eta)\frac{b}{\theta}\sigma\right\},$$
$$q = \frac{2}{8-25\eta+12\eta^2}\left\{(2-3\eta)\frac{A}{b} + (4-3\eta)\frac{\eta}{\theta}\sigma\right\}. \qquad (23)$$

Now make use of the GCE R&D subsidy given in (15) in (23) to obtain the reduced form expressions for R&D and output under ARE:

$$x^A = \frac{\eta(120-493\eta+564\eta^2-144\eta^3)}{3(1-2\eta)(3-\eta)(8-25\eta+12\eta^2)}\frac{A}{2\theta},$$
$$q^A = \frac{2(36-150\eta+175\eta^2-48\eta^3)}{3(1-2\eta)(3-\eta)(8-25\eta+12\eta^2)}\frac{A}{2b}. \qquad (24)$$

Welfare under ARE can be found by using (24) in (4). As shown in Figure 5 this is falling in the relative return to R&D. ARE yields the lowest welfare of all the equilibria considered, lower even that the case of no intervention given in footnote 6. Moreover, as shown in Figure 5, $W^G - W^A$ is much larger than $W^U - W^G$ so that unless the probability that reneging will be unanticipated is very high the expected value of reneging is negative.

5. The Sequence Equilibrium

If the home government does not have the ability to commit to its export subsidy then optimally it should take this into account when choosing its R&D subsidy. This corresponds to what we call the Sequence Equilibrium (SE), a fully time-consistent four-stage game in which no agent can commit intertemporally.

The final three stages of the game take the same form as the Anticipated Government-Reneging Equilibrium and the R&D and output levels as a function of the R&D subsidy are given in (23) above. The difference now is that the R&D subsidy is chosen optimally in the first stage of the game. The home government chooses σ to maximise the welfare function in (4). To examine optimal policy we proceed as in FCE and GCE, combining the home firm's first-order conditions for output and R&D from (6) and (22) with the total derivative of welfare (5). This yields the following:

$$dW = -sdq - bqdq^* - (\sigma + \theta q)dx. \tag{25}$$

The crucial difference from the FCE and GCE cases is that the export subsidy is determined in stage 3 (after foreign R&D has been chosen) and so it has a reduced ability to influence the foreign firm's output. Hence the R&D subsidy or tax must take on part of the rent-shifting role. To simplify (25) we use (19) to substitute for s and (7) to eliminate dq*. The resulting expression for the optimal subsidy is:

$$\sigma^S = -\left(1 + \frac{1}{2}\frac{dx^*}{dx}\right)\theta q, \tag{26}$$

where the superscript "s" denotes sequence equilibrium and where dx*/dx is the slope of the foreign firm's R&D reaction function.[10] To interpret (26), note that the right-hand side consists of two terms. The first, $-\theta$q, serves to counteract strategic overinvestment in R&D by the home firm, and is negative; the second, $-\theta$q(dx*/dx)/2, serves to shift rents and is positive. The R&D subsidy under SE is more negative *per unit output* than the GCE subsidy but less negative than $-\theta$q so that R&D remains above the efficient level.[11] We have already seen that in the GCE case the sole role of the (negative) R&D subsidy is to counteract strategic overinvestment by the home firm and thus to keep home R&D at the efficient level. By contrast, in the sequence equilibrium, since the export subsidy is chosen after the first period, it is unable to affect the level of foreign R&D and so the export subsidy cannot do all the rent shifting on its own. There is a rent-shifting role for the R&D subsidy under SE.

Reduced form expressions for R&D and output under SE are obtained by using (26) in (23) to get:

[10] An explicit formula for the slope of the foreign reaction function can be obtained by combining the third equation in (20) with the second equation in (22). It can be shown to be: dx*/dx = $-6\eta/(8-9\eta)<0$. Substituting this into (26) yields:

$$\sigma^S = -4\frac{2-3\eta}{8-9\eta}\theta q^S < 0.$$

[11] When the first equation in (22) is combined with (26) it is clear that: $\gamma x^S > \theta q^S$.

$$x^S = \frac{8\eta(2-3\eta)(4-3\eta)}{\Delta}\frac{A}{2\theta}, \qquad q^S = \frac{4(2-3\eta)(8-9\eta)}{\Delta}\frac{A}{2b}, \tag{27}$$

where $\Delta \equiv 64-208\eta+177\eta^2-36\eta^3>0$. The following closed-form expressions for subsidies can be obtained by using (27) in (20) and (26):

$$\sigma^S = -8\frac{\eta(2-3\eta)^2}{\Delta}\frac{\gamma}{\theta}A, \qquad s^S = \frac{(2-3\eta)(8-9\eta)}{\Delta}A. \tag{28}$$

From (11), (15), (27) and (28) we obtain the following result:

Proposition 2: *For all stable interior equilibria at given values of the relative return to R&D: $q^G>q^F>q^S$, $s^G>s^F>s^S$, $0=\sigma^F>\sigma^G>\sigma^S$ and $x^G>x^S>x^F$.*

To compare outputs, R&D levels, and subsidies under SE with those under ARE it is sufficient to compare the R&D subsidy levels. The GCE R&D subsidy, which is also the ARE subsidy, is larger than the SE R&D subsidy. Thus using (23) we obtain the result:

Proposition 3: *For all admissible values of the relative return to R&D, the R&D subsidy under SE is lower than the R&D subsidy under ARE and consequently home R&D, home output and the export subsidy are all lower under SE than under ARE. Welfare is higher under SE than under ARE.*

These results are illustrated in Figures 1 to 5.

Welfare under SE must be higher than that under ARE as the government is optimising in stage 1 rather than choosing the suboptimal GCE R&D subsidy. Welfare as a function of parameters alone can be shown to be:

$$W^S = \frac{4(2-3\eta)^2}{\Delta}\frac{A^2}{2b}. \tag{29}$$

A comparison of (17) and (29) shows that welfare under SE is below that under GCE (and hence lower than welfare under FCE). There are two differences between GCE and SE that together account for this. Firstly, under SE the foreign firm is choosing R&D more aggressively than under GCE because it is attempting to reduce home output by depressing the home export subsidy. Secondly, as explained earlier, because the export subsidy is chosen after R&D under SE the R&D subsidy has a rent-shifting role and home R&D is not chosen at the efficient level.

We are now able to rank welfare levels under SE, GCE and the equilibria with reneging:

Proposition 4: *The following welfare ranking holds for all stable interior equilibria at given values of the relative return to R&D:*

$$W^U > W^G > W^S > W^A.$$

Domestic welfare is highest in those equilibria in which firms do not expect the government to renege.

6. Summary and Conclusions

In this paper we have examined optimal R&D and trade policy under different assumptions about firms' and the government's ability to commit intertemporally. We have been able to rank outputs, R&D levels and welfare levels in the different equilibria.

We have seen that welfare is higher in the equilibrium we refer to as the *Government-only Commitment Equilibrium* (GCE), an equilibrium in which government commitment to its future actions is credible, than in the case we call *Sequence Equilibrium* (SE) in which no agent can commit to future actions. There are welfare gains from credible government commitment. When the government cannot credibly commit as under SE, the foreign firm chooses R&D more aggressively than under GCE, in an attempt to reduce home output by reducing the home export subsidy. This more aggressive foreign behaviour tends to reduce domestic welfare. When the government can commit to its export subsidy level, there is a clear division of labour between the roles of the two policy instruments. The export subsidy is targeted in standard fashion towards rent-shifting, inducing the foreign firm to reduce both its R&D and its output. As for the R&D tax, this is targeted towards ensuring that home R&D is chosen at the efficient level. This matching of targets and instruments is no longer possible in the absence of commitment. The export subsidy is chosen after R&D under SE and hence the R&D subsidy must carry some of the burden of rent shifting. A consequence of this is that home R&D is not chosen at the efficient level under SE. However, the Sequence Equilibrium is credible, fully time-consistent and leads to welfare levels only slightly less than those with government commitment. In this respect, our results are similar to those obtained in a very different model by Karp and Paul (1995): commitment matters, but not

too much.

We have also considered the incentive for the government to renege on its announced GCE export subsidy. Welfare is higher in the case we call the *Unanticipated Government-Reneging Equilibrium* (URE), where the government's decision to renege is not anticipated by the private sector, than under GCE. In URE firms choose the GCE R&D levels and the government achieves the benefits of credible commitment while retaining the option to reoptimise in its choice of export subsidy. However, the level of welfare under the *Anticipated Government-Reneging Equilibrium* (ARE), where government reneging is fully anticipated, is lower than under SE. Hence from a domestic welfare perspective ARE yields the worst outcome of all. In ARE and SE firms invest in high levels of R&D in an attempt to manipulate the home export subsidy. The difference between the two is that the R&D subsidy is chosen optimally under SE while it is at the excessively high GCE level under ARE.

We conclude that welfare is highest in the equilibria in which firms do not expect the government to renege. Credible commitment yields welfare gains in this model but so too does unanticipated reneging. Reneging that is anticipated by firms yields the lowest welfare of all. Our simulations also show that the loss in welfare when reneging is anticipated greatly exceeds the gain in welfare when reneging is unanticipated. Hence, unless the probability that reneging is unanticipated is very high the expected value of reneging is negative.

Of course the results in this paper have been obtained with rather special functional forms and questions of robustness naturally arise. These important issues are left to future research.

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Figure 1: Home Output as a Function of the Relative Return to R&D
(Normalisation: A=b)

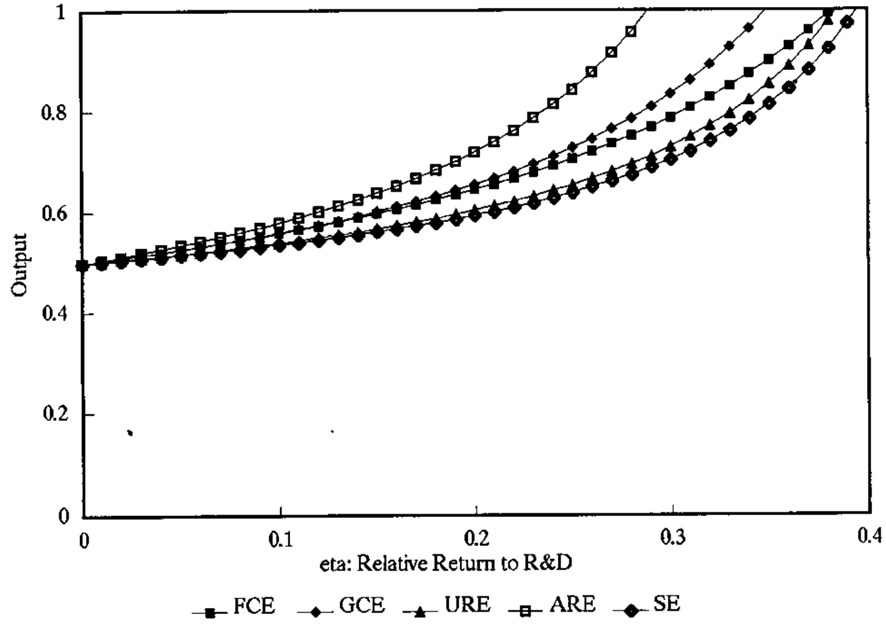

Figure 2: Output Subsidies as a Function of the Relative Return to R&D
(Normalisation: A=4)

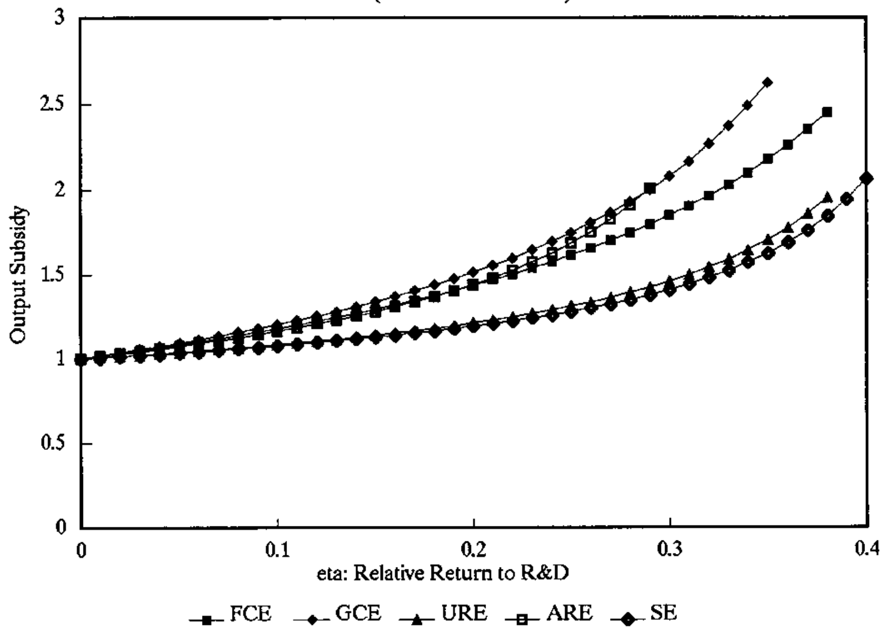

Figure 3: Optimal R&D Subsidies as a Function of the Relative Return to R&D
(Normalisation: gamma.A=theta)

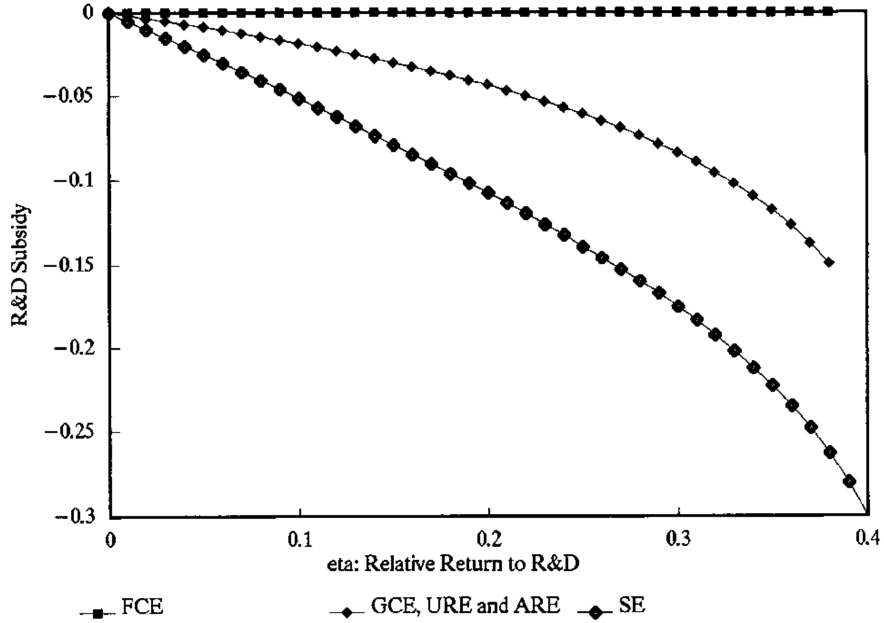

Figure 4: Home R&D as a Function of the Relative Return to R&D
(Normalisation: A=theta)

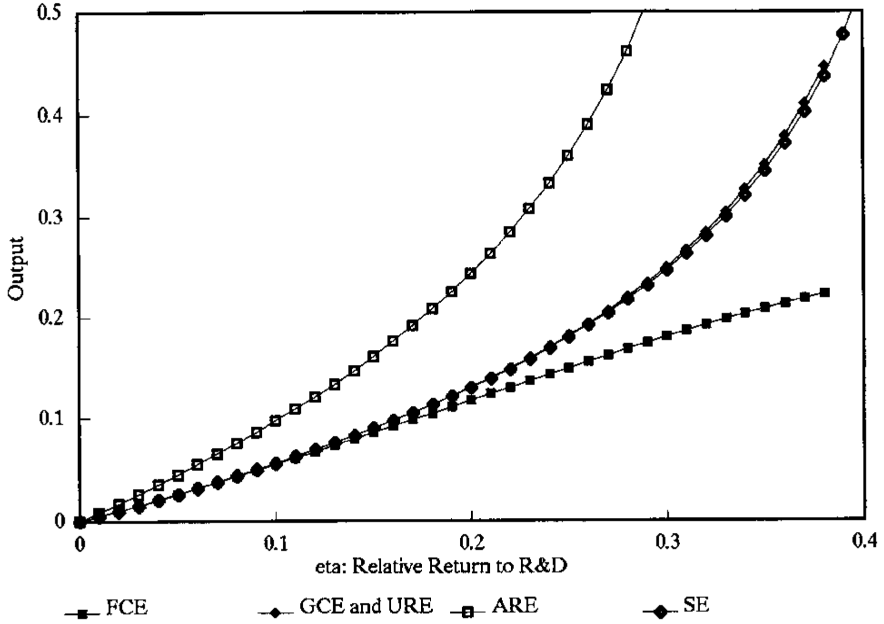

Figure 5: Welfare as a Function of the Relative Return to R&D
(Normalisation: A^2=b)