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R&D SPILLOVERS AND THE CASE FOR INDUSTRIAL POLICY IN AN OPEN ECONOMY

D. Leahy and J. P. Neary

ABSTRACT

In this paper we consider the case for subsidies towards firms which generate R&D spillovers in open economies. We show that many expected results are overturned in the presence of strategic behaviour by firms. Local R&D spillovers to other domestic firms may justify an R&D tax rather than a subsidy; R&D cooperation by local firms over-internalises the externality and also justifies an R&D tax; and international spillovers which benefit foreign firms may justify a subsidy, even though the government cares only about the profits of home firms.

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1. INTRODUCTION

The now conventional view of R&D spillovers in the 1990s is that they are pervasive, quantitatively important and a justification for industrial policy. But these views were also held by Marshall in the 1890s and they were made explicit by Pigou in his 1912 *Economics of Welfare*. In this paper we ask: what have we learned in the intervening hundred years? More specifically, what additional arguments for industrial policy are provided by R&D spillovers in the light of recent work in the theory of international trade policy?

Most recent discussions of R&D spillovers in open economies, such as the work on endogenous growth by Grossman and Helpman (1991), have assumed they occur in industries characterised by monopolistic competition. The combination of free entry (so long-run profits are competed away) and no strategic interdependence between firms leads to models which, while complicated in other respects, have very simple implications for policy. R&D spillovers towards other domestic firms generate an externality which should be subsidised. In this paper we explore a different approach to R&D subsidies, which combines them with the other half of the 'new' trade theory, the theory of strategic trade policy. We show that even simple oligopoly models, where profits persist and firms behave strategically, have surprising implications for optimal policy in the presence of R&D spillovers.

Most previous work on R&D spillovers and strategic behaviour has focused on intra-industry spillovers in a closed economy.[1] This issue was addressed by Spence (1984) who showed that spillovers tend to weaken the strategic incentive to invest in R&D. d'Aspremont and Jacquemin (1988) demonstrated in a linear duopoly model that R&D cooperation can internalise this externality. Their work was extended and generalised by Suzumura (1992) who considered many firms and general demands, and by Kamien, Muller and Zang (1992) and Ziss

(1994) who also considered price competition. Leahy and Neary (1997b) synthesise this literature, disentangling the effects of cooperation from those of strategic behaviour, and apply the model to examine optimal industrial policy in a closed economy.

R&D spillovers in an open economy raise additional issues which are inherently more complex. This is because the assumption of symmetry between firms which is normally made in closed economy models cannot be maintained. In the first place, a nationalistic government cares only about the profits of home firms. In the second place, the nature of spillovers is more complicated. They may be either local or international[2], and either inter- or intra-industry. Intuitively we might expect that local spillovers justify subsidising R&D, and international spillovers justify taxing them. For example, Spencer (1986) argues that a domestic industry will be a better candidate for R&D subsidies the lower the spillovers are of new technology to foreign firms. However, we shall see that strategic behaviour by firms may reverse these expected results.

The other issue raised by R&D spillovers is whether they can be internalised by cooperation between firms, thus rendering industrial policy redundant. Once again, it turns out that this presumption is overturned if firms behave strategically.

The plan of the paper is as follows. Section 2 sets up the model, which builds on Spencer and Brander (1983) and Leahy and Neary (1996). Like these papers we examine trade and industrial policy in a two-period duopoly model in which firms choose R&D and output. However, these earlier papers did not discuss R&D spillovers. In Section 3 we explore how strategic behaviour and R&D cooperation affect optimal industrial policy in a model when spillovers are local and inter-industry. In Section 4 we explore strategic effects in the presence of international spillovers. In Section 5 we examine the linear case in order to obtain more definite results. Finally, Section 6 concludes with a summary of results.

2. THE MODEL

Consider a model in which there are two oligopolistic industries.[3] In each industry a different domestic firm and a foreign firm export a homogeneous commodity to a third market. The third-country demand function facing industry i is:

$$p_i = p_i(q_i + q_i^*), \quad -b_i = p_i'(q_i + q_i^*) < 0 \quad i = 1,2, \tag{1}$$

where q_i represents home exports and q_i^* represents foreign exports in sector i. (An asterisk will often be used to represent a foreign variable.) We also define $r_i=(q_i+q_i^*)b_i'/b_i$, the elasticity of the slope of the industry i demand function. This will prove useful later. In this model we distinguish two time periods. Period 1 is the pre-market R&D phase and period 2 is the output phase.

The home and foreign firms in each industry choose R&D levels x_i and x_i^* 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. Marginal production costs are constant in output but are declining in the firms' own R&D expenditure and (through spillover effects) in the R&D expenditures of home firms in other industries and the R&D expenditure of foreign firms in their own sector. Thus, in the general case there are both international intra-industry R&D spillovers and local inter-industry spillovers. The marginal costs of a typical home firm can thus be written as:

$$c_i = c_i(x_i, x_j, x_i^*), \quad j \neq i, \quad \frac{\partial c_i}{\partial x_i} = -\theta_i < 0. \tag{2}$$

A typical foreign firm faces marginal production costs:

$$c_i^* = c_i^*(x_i^*, x_i), \quad \frac{\partial c_i^*}{\partial x_i^*} = -\theta_i^* < 0, \tag{3}$$

where we ignore the possibility of inter-industry spillovers between foreign firms[4]. Local inter-industry spillovers are captured by:

$$\beta_i \equiv -\frac{\partial c_i/\partial x_j}{\gamma_i} \geq 0, \tag{4}$$

and international intra-industry spillovers are represented by:

$$\epsilon_i \equiv -\frac{\partial c_i/\partial x_i^*}{\gamma_i} \geq 0, \qquad \epsilon_i^* \equiv -\frac{\partial c_i^*/\partial x_i}{\gamma_i^*} \geq 0. \tag{5}$$

In practice, we only consider the cases where spillovers are *either* intra- or inter-industry. Finally, in period 1 the home and foreign firms must incur R&D costs of $\Gamma_i(x_i)$ and $\Gamma_i^*(x_i^*)$ respectively.

The typical home firm chooses its levels of R&D and output to maximise profits:

$$\pi^i = R^i - (c_i - s_i)q_i - \Gamma_i(x_i) + \sigma_i x_i, \tag{6}$$

where $R^i = p_i q_i$ is total revenue, s_i is the per unit export subsidy and σ_i is the per unit R&D subsidy. The first-order condition for R&D depends on assumptions about move order and inter-firm cooperation, to be considered below. However, in *all* the equilibria considered the firms choose their outputs simultaneously given the export subsidy and R&D levels. The home first-order condition for output is therefore:

$$\frac{\partial \pi_i}{\partial q_i} = R_q^i - c_i + s_i = 0, \tag{7}$$

This first-order condition defines the home firm's reaction function conditional on the export subsidy and the R&D levels. The typical foreign firm faces a similar problem. Its profits equal $R^{*i} - c_i^* q_i^* - \Gamma_i^*(x_i^*)$ and its first-order condition for output is:

$$\frac{\partial \pi_i^*}{\partial q_i^*} = R^{*i}_{q^*} - c_i^* = 0. \tag{8}$$

which depends only on R&D levels since it does not receive subsidies.

Next, consider government behaviour. We assume that only the home government is policy active and it maximises welfare which equals the sum of profits net of subsidy payments in the two sectors:

$$W = \sum_i^2 \{\pi_i - s_i q_i - \sigma_i x_i\} = \sum_i^2 \{R^i - c_i q_i - \Gamma_i(x_i)\} \tag{9}$$

Totally differentiating (9) and using the first-order condition (7) to simplify yields an expression for welfare change which will prove useful later:

$$dW = \sum_i^2 \left\{ - s_i dq_i + R^i_{q^*} dq_i^* - q_i dc_i - \Gamma_i' dx_i \right\}. \tag{10}$$

This shows the proximate determinants of welfare in the model. A rise in home exports raises the deadweight loss of subsidies and so lowers welfare; a rise in foreign exports lowers home profits ($R^i_{q*}<0$) and so lowers welfare; finally, welfare rises with any fall in unit production costs but falls with extra R&D as additional direct costs are incurred.

The primary focus of the paper is on the implications for optimal industrial policy of strategic behaviour by firms. To investigate this, we contrast two equilibria, which differ in their assumptions about the ability of firms to commit. First, the case in which firms can commit in period 1 to future outputs will be referred to as a *Full Commitment Equilibrium (FCE)*. Second, the case in which firms cannot commit to future output will be called a *Government-Only Commitment Equilibrium (GCE)*. In FCE, firms simultaneously choose their R&D and output levels at the start of period 1 and cannot use R&D strategically to affect rival output. By contrast, in GCE firms choose their R&D *before* output and therefore have a strategic incentive to vary their R&D in order to manipulate the output of their rival. In both FCE and GCE we assume that the government can choose both its R&D subsidy and its export subsidy before firms choose their actions.[5]

A second issue with which the paper is concerned is the effect of inter-industry R&D cooperation on optimal policy. To examine this we compare the case in which home firms cooperate on their R&D levels with the case in which they choose their R&D non-cooperatively.[6] With local spillovers there are therefore four different combinations of assumptions (FCE or GCE, with or without R&D cooperation) and in each case we assume that the equilibrium is subgame perfect.

3. LOCAL INTER-INDUSTRY SPILLOVERS

3.1 The Non-strategic and Non-cooperative Benchmark

In this section we consider the case in which there are positive spillovers between domestic firms but no international spillovers. We will first consider the benchmark case in which firms do not cooperate on their R&D levels and do not choose their R&D strategically. This is the non-cooperative FCE case in which the government chooses its subsidies in stage 1 and the firms choose R&D levels and output levels simultaneously in stage 2. The typical home firm's first-order condition for R&D is thus:

$$\frac{\partial \pi_i}{\partial x_i} = \theta_i q_i - \Gamma_i' + \sigma_i = 0, \tag{11}$$

and each foreign firm's first-order condition for R&D is:

$$\frac{\partial \pi_i^*}{\partial x_i^*} = \gamma_i^* q_i^* - \Gamma_i^{*\prime} = 0. \tag{12}$$

In the first stage of the game the government sets its two policy variables, the export subsidy and the R&D subsidy, in each of the two markets. In effect the government uses these four policy instruments to choose the home firms' R&D and output levels before the foreign firms choose their actions. The foreign R&D and outputs then respond to the home actions according to generalised reaction functions which are derived by combining the two foreign first-order conditions (8) and (12). These generalised reaction functions can be written as:

$$q_i^* = Q_i^{FL}(q_i), \qquad x_i^* = X_i^{FL}(q_i), \tag{13}$$

where the superscript FL denotes FCE with local spillovers. As shown in the Appendix these are independent of home R&D in either industry.

Proceed by using the home firms' first-order condition for R&D, (11), and the total derivatives of (13) in (10) to obtain:[7]

$$dW = \sum_i^2 \left\{ \left(-s_i + R^i_{q^*} \frac{dQ_i^{FL}}{dq_i} \right) dq_i - (\sigma_i - \beta_j \gamma_j q_j) dx_i \right\}. \tag{14}$$

The optimal export subsidies are obtained from (14) by setting the coefficients of dq_i equal to zero for each i. The optimal export subsidy to industry i is:

$$s_i^{FL} = R^i_{q^*} \frac{dQ_i^{FL}}{dq_i}, \tag{15}$$

where $R^i_{q*} = !b_i q_i < 0$. The right-hand side of (15) captures the standard Brander-Spencer (1985) rent-shifting effect. This export subsidy must be positive when foreign output is a *strategic substitute* for home output.[8] In that case the subsidy, by committing the home firm to larger output, reduces the output of the foreign firm in that industry which in turn raises home profits and welfare. Unlike in the standard Brander and Spencer (1985) case, the export subsidy is being used not just to reduce foreign output directly, but also to reduce foreign R&D which has an additional indirect effect tending to reduce foreign output. The derivative dQ^{FL}_i/dq_i captures both the direct effect of home output and the indirect effect that works through changes in foreign R&D.

The optimal R&D subsidies are obtained from (14) by setting the coefficients of dx_i equal to zero for each i. These are:

$$s^{FL}_i \; ' \; ß_j ?_j q_j \, . \qquad (16)$$

These subsidies are positive since they correct for the positive R&D externalities within the economy. This confirms the presumption that R&D spillovers justify a subsidy.

There is a clear division of labour between the export subsidy and the R&D subsidy in this case. The export subsidy plays a purely rent-shifting role while the R&D subsidy is targeted towards ensuring that R&D is chosen at the socially cost-minimising level; i.e. the level at which the marginal social benefit of R&D, $?_i q_i + ß_j ?_j q_j$, equals its marginal cost GN_i. This may be confirmed by substituting from (16) into (11).

3.2 The Effect of Strategic Behaviour without R&D Cooperation

We will now begin our analysis of the effect of strategic behaviour on optimal policy. We first consider this government-only commitment equilibrium in the absence of R&D cooperation. In the GCE case firms play strategically, taking account of the effect of their R&D on the output of the rival firm. The appropriate first-order conditions for home and foreign output are, as in all cases, given by (7) and (8) above. The first-order condition for R&D for a typical home firm is:

$$\frac{d\pi_i}{dx_i} = \frac{\partial \pi_i}{\partial x_i} + \frac{\partial \pi_i}{\partial q_i^*}\frac{dq_i^*}{dx_i} = 0, \tag{17}$$

where:

$$\frac{\partial \pi_i}{\partial q_i^*} = R^i_{q^*}, \qquad \frac{dq_i^*}{dx_i} = -\frac{\lambda_i E_i}{b_i}, \qquad E_i \equiv \frac{1+\alpha_i^* r_i}{3+r_i}.$$

Here $\alpha_i = q_i/(q_i+q_i^*)$ is the market share of the home firm in industry i and $\alpha_i^* = 1-\alpha_i$ is that of the foreign firm in industry i. E_i is positive when foreign output is a strategic substitute for home output.[9] This simplifies to:

$$(1+E_i)\lambda_i q_i - \Gamma_i' + \sigma_i = 0. \tag{18}$$

Assuming outputs are strategic substitutes, the home firms strategically overinvest in R&D in the manner of Spence (1977), Dixit (1980) and Brander and Spencer (1983). The same is true of the foreign firms, whose first-order condition can similarly be written as:

$$\frac{d\pi_i^*}{dx_i^*} = \frac{\partial \pi_i^*}{\partial x_i^*} + \frac{\partial \pi_i^*}{\partial q_i}\frac{dq_i}{dx_i^*} = 0. \tag{19}$$

In stage 1 the government sets its policy variables anticipating that foreign R&D and output will respond according to generalised reaction functions. In the GCE case these reaction functions are derived by combining the foreign firms' first-order conditions, (8) and (19), and can be written as:

$$q_i^{*} = Q_i^{GL}(q_i), \quad x_i^{*} = X_i^{GL}(q_i). \tag{20}$$

where the superscript G refers to GCE. As in the FCE case these reaction functions are independent of home R&D. Proceed by substituting the home firm's first-order condition for R&D, (11), and the derivatives of (20) in the expression for welfare change, (10). The resulting optimal export subsidies have the same form as those represented in (15) for the FCE case. In the GCE case the optimal export subsidy to sector i can be written as:

$$s_i^{GL} = R^i_{q^*} \frac{dQ_i^{GL}}{dq_i}. \tag{21}$$

As in the FCE case the export subsidy is used to shift rent from foreigners to the home country. As shown in the Appendix, strategic substitutability still works towards a positive optimal subsidy though it is no longer sufficient to ensure it.

The optimal R&D subsidy is:

$$\mathrm{s}_i^{GL} = ß_j ?_j q_j - E_i ?_i q_i. \tag{22}$$

The first term on the right hand side of (22) can be interpreted in the same manner as the corresponding term in (16). The government encourages investment in R&D because there is a positive externality. The second term corrects for strategic overinvestment in R&D by the home firm. As in FCE the R&D subsidy ensures that home R&D is at the socially cost minimising level. This can be seen by using (22) to eliminate the R&D subsidy in (18).

Export subsidies and R&D subsidies under GCE cannot be directly compared with those under FCE as they are evaluated at different levels of output and R&D. However, the additional term in the GCE R&D subsidy makes it presumptively smaller than its counterpart under FCE when foreign output is a strategic substitute for home output. The optimal policy towards R&D may even be a *tax* if the strategic effect outweighs the externality effect. In the special case of no externalities ($ß_j=0$) considered by Spencer and Brander (1983), R&D should definitely be taxed.

3.3 The Effect of R&D Cooperation without Strategic Behaviour

We will begin our analysis of the effect of R&D cooperation on the optimal industrial policy by considering the benchmark FCE case in which the firms do not choose R&D strategically. Given R&D levels the industries are unlinked, so cooperation between home firms at the output stage is not an issue. At the output stage firms behave as before and their first-order conditions are given in (7) and (8) above. Since there are no inter-industry spillovers among foreign firms, they have nothing to gain by cooperating with each other and foreign R&D first-order conditions are the same as those in (12) above. Hence only the R&D behaviour of home firms is affected by cooperation. We will assume that levels of home R&D are chosen to maximise the home firms' joint profits but the decision to cooperate does not itself affect the levels of spillovers. The ß's only depend on R&D levels and are independent of the decision to cooperate[10]. In the case of cooperative FCE each home firm takes output levels as given and chooses its R&D to maximise the following joint profit function:

$$\Pi = \sum_{i}^{2} \left\{ R^{i} - (c_i - s_i) q_i - \Gamma_i + \sigma_i x_i \right\}. \tag{23}$$

This implies the first-order condition:

$$\frac{\partial \Pi}{\partial x_i} = \theta_i q_i + \beta_j \theta_j q_j - \Gamma_i' + \sigma_i = 0, \tag{24}$$

Compared to (11) this has an additional term in the spillover parameter $ß_j$. The cooperative internalises the national R&D externality and sets the marginal social benefit of R&D equal to its marginal cost inclusive of subsidies. As in the non-cooperative case, the home government effectively chooses the two R&D levels and the two output levels to maximise welfare with foreign R&D and output reacting according to (13). Since the behaviour of the foreign firms is unchanged by the decision of the home firms to cooperate, the foreign generalised reaction functions are also unchanged. The optimal subsidies are obtained by substituting (24) and the total derivatives of (13) in the expression for welfare change, (10). The optimal export subsidy is identical both in form and *magnitude* to that under non-cooperative FCE and given in equation (15).[11] The optimal R&D subsidy is:

$$s_i^{FLC} = 0. \tag{25}$$

The superscript C indicates R&D cooperation. Compared to the R&D subsidy under non-cooperative FCE, the term in $ß_j$ disappears because the firms now internalise the externality so there is no need for government intervention.

Proposition 1: The optimal R&D subsidy is zero under FCE with cooperation on R&D, and hence is lower than the optimal R&D subsidy under FCE with no cooperation on R&D for any positive spillover parameter $ß_j$.

Another way of expressing this result is that the Coase Theorem applies in this case: R&D cooperation is a perfect substitute for industrial policy.

3.4 The Effect of Strategic Behaviour with R&D Cooperation

We now consider how strategic behaviour interacts with R&D cooperation and how this affects optimal policy. In the GCE case the home cooperative takes account of how its R&D affects the output of the foreign firm. The first-order condition for home R&D is:

$$\frac{d?}{dx_i} = \frac{\partial ?}{\partial x_i} + \frac{\partial p_i}{\partial q_i^*}\frac{dq_i^*}{dx_i} + \frac{\partial p_j}{\partial q_j^*}\frac{dq_j^*}{dx_i}, \qquad \text{where:} \qquad \frac{dq_j^*}{dx_i} = -\frac{ß_j ?_j E_j}{b_j}. \tag{26}$$

As before E_j is positive if outputs are strategic substitutes in industry j. This first-order condition can be rewritten as:

$$(1+E_i)?_i q_i + (1+E_j)\beta_j ?_j q_j - G_i' + s_i = 0. \qquad (27)$$

In stage 1 the government chooses its subsidies and the foreign firms react according to the GCE reaction functions in (20). The resulting optimal export subsidies are identical to those under non-cooperative GCE and are given in (21). The optimal R&D subsidy is:

$$s_i^{GLC} = -(E_i ?_i q_i + \beta_j E_j ?_j q_j). \qquad (28)$$

While in the non-cooperation case higher spillovers contribute to a higher R&D subsidy, in this case they work in the opposite direction. To find the effect on optimal policy of R&D cooperation when firms are playing strategically we can subtract the cooperative R&D subsidy from the non-cooperative R&D subsidy to get:

$$s_i^{GL} - s_i^{GLC} = \beta_j ?_j q_j (1 + E_j) \geq 0. \qquad (29)$$

Unlike in the non-strategic FCE case, R&D cooperation under GCE does not render industrial intervention redundant.

Proposition 2: For any positive spillover parameter β_j the optimal R&D subsidy to the ith firm is larger under GCE with no cooperation on R&D than under GCE with cooperation on R&D.

The Coase Theorem does not apply in this case because the cooperative 'over-internalises' the externality. It overinvests in R&D in industry *i* to obtain a strategic advantage over the foreign firms in *both* industries and a subsidy is required to restrain it from this socially wasteful activity.

4. INTERNATIONAL SPILLOVERS

4.1 The Non-strategic Benchmark

In this section we turn to examine the case in which there are international spillovers between firms. To keep the analysis from becoming excessively complicated we will assume no inter-industry spillovers between firms: ß=0. In all cases the firms’ first-order conditions for output are given in (7) and (8) above, and under FCE the firms’ first-order conditions for R&D are given in (11) and (12). The only difference is that now the marginal costs and the ?’s depend on the R&D levels of foreign rivals as well as those of the firms themselves. This is due to the presence of international R&D spillovers. As demonstrated in the Appendix, this difference implies that the foreign generalised reaction functions for R&D and output depend not just on home output as in the case without international spillovers, but on the levels of home R&D. Intuitively this is because home R&D now directly affects the foreign first-order condition through the spillover effects. The resulting reaction functions under FCE with international spillovers can be written as:

$$q^{*} = Q^{FI}(q,x), \qquad x^{*} = X^{FI}(q,x). \tag{30}$$

where the superscript I indicates international spillovers. We can drop industry subscripts in this section because there are no links between industries in the absence of local spillovers and hence each industry can be treated separately.

Proceed by using the home firms’ first-order condition for R&D, (11), and the total derivatives of (30) in the expression for welfare change, (10), to obtain:

$$dW = \left(-s + R_{q^*}\frac{\partial Q^{FI}}{\partial q} + \gamma' q \frac{\partial X^{FI}}{\partial q} \right) dq \;+\; \left(-\sigma + R_{q^*}\frac{\partial Q^{FI}}{\partial x} + \gamma' q \frac{\partial X^{FI}}{\partial x} \right) dx. \tag{31}$$

The optimal export subsidy is obtained from (31) by setting the coefficient of *dq* equal to zero:

$$s^{FI} = R_{q^*}\frac{\partial Q^{FI}}{\partial q} + \gamma' q \frac{\partial X^{FI}}{\partial q} . \tag{32}$$

The first term on the right-hand side is the usual rent-shifting effect and it is shown in the Appendix that this must be positive if foreign output is a strategic substitute for home output. We also show in the Appendix that if foreign output is a strategic substitute for home output then the second term on the right-hand side is negative. In that case the subsidy, by raising home output, reduces foreign R&D and thus the beneficial spillover enjoyed by the home firm. Hence with strategic substitutes this effect works against a positive optimal export subsidy.

The optimal R&D subsidy is also obtained from (31) by setting the coefficient of *dx* equal to zero:

$$\sigma^{FI} = R_{q^*}\frac{\partial Q^{FI}}{\partial x} + \gamma' q \frac{\partial X^{FI}}{\partial x}. \tag{33}$$

Unlike in the purely local spillover case, there is now a rent-shifting role for the R&D subsidy. The government can reduce foreign output, thus shifting rent to the home country by taxing R&D and thus reducing the beneficial spillovers to foreigners. The first term on the right hand side captures this rent-shifting effect of R&D. This term is negative because q^* is directly increasing in x.

The second term on the right-hand side captures the welfare effect of more home R&D *via* its effect on the level of foreign R&D. As shown in the Appendix, an increase in home R&D leads to more foreign R&D and thus increases beneficial spillovers to home firms. Hence this term, which we can call a *spillback* effect, works towards a positive R&D subsidy.

Proposition 3: The optimal R&D subsidy under FCE with international spillovers is negative if, and only if, the negative rent-shifting effect outweighs the positive spillback effect.

Note the apparent paradox: even without strategic behaviour, the fact that R&D spillovers benefit the foreign firm provides a motive for subsidisation.

4.2 The Effect of Strategic Behaviour

We consider next the GCE case with international spillovers in which the firms choose their R&D strategically. The first-order condition for home R&D is:

$$\frac{d\pi}{dx} = \frac{\partial\pi}{\partial x} + \frac{\partial\pi}{\partial q^*}\frac{dq^*}{dx} = [1 + A(\bar{e}^* - e^*)]\gamma q - \Gamma' + s = 0, \tag{34}$$

where:

$$A \equiv \left(\frac{2+\alpha r}{3+r}\right)\frac{\gamma^*}{\gamma} > 0 \quad \text{and} \quad \bar{e}^* \equiv \left(\frac{1+\alpha^* r}{2+\alpha r}\right)\frac{\gamma}{\gamma^*}. \tag{35}$$

The home firm strategically overinvests in R&D when the spillover to the foreign firm is below the threshold level $\bar{e}^*$. As in d'Aspremont and Jacquemin (1988), the threshold equals 0.5 when demands are linear ($r=0$) and R&D is equally efficient in both firms ($\gamma=\gamma^*$). The foreign first-order condition can similarly be written as:

$$\frac{dp^*}{dx^*} = [1 + A^*(\bar{e} - e)]?^*q^* - G^{*\prime} = 0, \qquad (36)$$

where:

$$A^* \equiv \left(\frac{2+a^*r}{3+r}\right)\frac{?}{?^*} > 0 \quad \text{and} \quad \bar{e} \equiv \left(\frac{1+ar}{2+a^*r}\right)\frac{?^*}{?}. \qquad (37)$$

In stage 1 the government sets both the R&D subsidy and export subsidy anticipating that the foreign firm responds according to the generalised reaction functions which are derived by combining (8) and (36). These generalised reaction functions can be written as:

$$q^* = Q^{GI}(q,x), \quad x^* = X^{GI}(q,x). \qquad (38)$$

The optimal export subsidy has the same form as (32) in the FCE case:

$$s^{GI} = R_{q^*}\frac{\partial Q^{GI}}{\partial q} + e?q\frac{\partial X^{GI}}{\partial q}. \qquad (39)$$

These terms have the same interpretation as in the FCE case but, as is shown in the Appendix, it is somewhat more difficult to sign them. Finally, the optimal R&D subsidy is:

$$s^{GI} = R_{q^*}\frac{\partial Q^{GI}}{\partial x} + e?q\frac{\partial X^{GI}}{\partial x} - A(\bar{e}^* - e^*)?q. \qquad (40)$$

The first two terms on the right hand side of (40) can be interpreted in the same manner as the corresponding terms in (33). The final term corrects for strategic overinvestment or underinvestment in R&D by the home firm: it is negative for low spillovers but *positive* for high spillovers ($\overline{e}^*>e^*$).

Proposition 4: In GCE with international spillovers the optimal R&D subsidy has the same form as in FCE, except for an extra term which offsets the strategic behaviour of the home firm.

Since the sign of the optimal R&D subsidy in this case is inherently ambiguous, it is desirable to examine its magnitude under special functional forms and we turn to this in the next section.

5. THE LINEAR CASE

We can illustrate more forcefully some of the general results of previous sections if we specialise to specific functional forms. In this section we adopt a simple linear specification of demand and assume that R&D affects marginal costs in a linear fashion and is itself subject to quadratic costs. The linear inverse demand function is given by:

$$p_i = a_i - b_i(q_i + q_i^*), \tag{41}$$

where a_i and b_i are constants. Marginal costs for the home and foreign firm are given by:

$$c_i = \overline{c_i} - ?_i(x_i + ß_i x_j + e_i x_i^*) \quad \text{and} \quad c_i^* = \overline{c_i^*} - ?_i^*(x_i^* + e_i^* x_i), \tag{42}$$

where the **&**'s, ?'s, ß's and e's are all constant. It will also prove useful to define the parameters: $?_i = ?_i^2/b_i ?_i$ and $?_i^* = ?_i^{*2}/b_i ?_i^*$. These represent the *relative return* to R&D for a typical home and foreign firm respectively.

In all cases, the optimal export subsidies are positive: the ambiguities noted in some cases under general demands vanish. We therefore concentrate on the R&D subsidies, which are shown in Table 1. In the absence of strategic behaviour (i.e., in FCE), the signs of the optimal R&D subsidies accord with simple intuition. R&D should be subsidised when spillovers are local, though not when firms cooperate on R&D (when no intervention is warranted); and it should be taxed when spillovers are international. (The latter result shows that the ambiguity found in (33) for the general case is resolved: the rent-shifting effect dominates the spillback effect.)

However, when firms behave strategically the results are much less clearcut. With local spillovers, the GCE results confirm equations (22) and (28). In particular, the optimal subsidy without R&D cooperation is increasing in the spillover parameter $ß_j$ whereas with cooperation it is *decreasing* in $ß_j$. This shows clearly that the cooperative over-internalises the externality when it plays strategically. Finally, the case of international spillovers (corresponding to equation (40)) is the most complex of all and this subsidy may even be positive.

Figure 1 shows the results of simulating the optimal GCE subsidy with international spillovers when firms are symmetric (so ?=?*, e=e* and ?=?*). As can be seen from the diagram the R&D subsidy is falling in ?, the relative effectiveness of R&D, at e=0. With zero spillovers the government's only motive for intervention is to correct for strategic overproduction on the part of the home firm. As e becomes positive the other two motives for intervention, the rent-shifting effect which works towards a tax and the spillback effect which works towards a subsidy, come into play. In addition as e gets larger the need to correct for the home firm's strategic overproduction is reduced. For most values of ? and e the per-unit R&D subsidy is increasing in the spillover parameter and at high values of both ? and e it turns positive.

6. SUMMARY AND CONCLUSION

In this paper we have explored the implications for trade and industrial policy in open economies of R&D spillovers between oligopolistic firms. Specifically, we have investigated a strategic trade model which allows for local R&D spillovers between firms in different industries and international R&D spillovers between firms in different countries.

Our analysis has identified three distinct motives for R&D policy, whose qualitative implications are summarised in Table 2. First, there is the standard Pigovian motive: R&D should be encouraged because it yields externalities which cannot be captured by home firms acting alone. This naturally mandates a subsidy when the spillovers are local. More surprisingly, and contrary to the suggestion of Spencer (1986), it also justifies a subsidy when the spillovers are international. This is because of what we call the 'spillback' effect which arises from the reciprocal nature of the R&D spillovers. The home firm benefits from the additional R&D undertaken by the foreign firm as a result of an increase in its own R&D.

The second motive for R&D policy is to shift rents or, more accurately, to exercise the government's superior commitment power in order to move the home firm to the position it would adopt on its own if it were a Stackelberg leader. In the presence of international spillovers, changes in home R&D affect foreign output directly and thus affect the level of home profits. This mandates an R&D tax to reduce foreign output and so shift rents to the home country.

Finally, when firms behave strategically there is a third motive for intervention. Such strategic behaviour involves over- or under-investment in R&D which is socially wasteful, and so intervention to offset it is justified. This motive for intervention has highly counter-intuitive implications. In the absence of intra-industry spillovers (and irrespective of whether or not there are local inter-industry spillovers), a home firm tends to overinvest strategically in R&D and so an R&D tax is justified. However, the greater the degree of intra-industry spillovers, the more the home firm tends to underinvest in R&D (since it anticipates that some of the benefits will accrue to its foreign rival). Hence the more an R&D *subsidy* is justified, even though the spillovers accrue to a foreign firm whose profits are of no concern to the home government.

The other issue considered in the paper is whether R&D cooperation by firms can internalise inter-industry R&D spillovers, thus rendering industrial policy redundant. We have shown that this does indeed happen when strategic behaviour is absent. However, when firms cooperate *and* behave strategically they will typically *over-internalise* the externality and engage in too much R&D, thus mandating an offsetting R&D tax.

Our model has naturally simplified in many respects. We have assumed that there is only one firm in each domestic industry. Relaxing this would provide a strategic motive for R&D subsidies; but it would also dilute the rent-shifting motive for subsidising exports and the net effect is uncertain. We have considered only the first-best case, where the R&D subsidy is supplemented by an optimal export subsidy. In the alternative case where an export subsidy is not available, there is an additional second-best motive for subsidising R&D, as in Spencer and Brander (1983). Finally, we have concentrated on the Cournot case of output competition in the second stage. As is well known, many of the conclusions are likely to be reversed if instead firms compete on price in a Bertrand manner.

It would be desirable in future work to relax these assumptions. However, doing so is unlikely to overturn our basic point, which has been obscured by the concentration on studying R&D spillovers in models of monopolistic competition. When strategic behaviour is taken into account, the case for subsidising local R&D spillovers and taxing international spillovers is much less clearcut.

ENDNOTES

1. International R&D spillovers between firms in the same industry have been examined in Cheng (1987), Motta (1994) and Neary and O'Sullivan (1997). Inter-industry spillovers have recently been examined in a closed economy by Katsoulacos and Ulph (1995).

2. The distinction between local and international spillovers is studied in a different context by Rivera-Batiz and Oliva (1996).

3. Extension to *n* industries is straightforward and adds nothing important to the analysis.

4. It is possible that the foreign firms have different nationalities.

5. For models in which governments cannot commit to their future second-period intervention, see Leahy and Neary (1996, 1997a and 1997b) and Neary and Leahy (1996).

6. International cooperation with spillovers is discussed in Neary and O'Sullivan (1997).

7. The derivatives of (13) are examined in the Appendix.

8. The relationship between strategic substitutability and the sign of dQ_i^{FL}/dq_i is discussed in the Appendix. Foreign output is a strategic substitute for home output if the marginal profitability of foreign output falls in home output; i.e. if $R^{*i}_{qq^*}$ is negative. This may be considered the 'norma' case under Cournot competition.

9. To see this note that the numerator $1+a^*_i r_i$ equals $!R^{*i}_{q^*q}/b_i$; and as shown in the Appendix the denominator $3+r_i$ must be positive to ensure stability.

10. For an alternative account in which the decision to cooperate itself affects spillovers at given R&D levels see Katz (1986), Kamien *et al* (1992), Katsoulacos and Ulph (1994) and Motta (1994).

11. The optimal subsidies can be directly compared because the real equilibria with optimal policy are the same whether firms cooperate or not.

APPENDIX

1. Strategic Effects in GCE

To calculate the strategic effects in GCE, we totally differentiate the home and foreign firms' first-order conditions for output (7) and (8) to get:

$$R^i_{qq} dq_i + R^i_{qq^*} dq_i^* + \gamma_i\left(dx_i + \varepsilon_i dx_i^* + \beta_i dx_j\right) + ds_i = 0. \tag{43}$$

$$R^{*i}_{q^*q^*} dq_i^* + R^{*i}_{q^*q} dq_i + \gamma_i^*\left(dx_i^* + \varepsilon_i^* dx_i\right) = 0 \tag{44}$$

These can be solved for dq_i and dq_i^* to get:

$$D^i dq_i = -(R^{*i}_{q^*q^*}\gamma_i - \varepsilon_i^*\gamma_i^* R^i_{qq^*})dx_i - (R^{*i}_{q^*q^*}\varepsilon_i\gamma_i - \gamma_i^* R^i_{qq^*})dx_i^* - R^{*i}_{q^*q^*}(ds_i + \gamma_i\beta_i dx_j) \tag{45}$$

$$D^i dq_i^* = -(R^i_{qq}\gamma_i^* - \varepsilon_i\gamma_i R^{*i}_{q^*q})dx_i^* - (R^i_{qq}\varepsilon_i^*\gamma_i^* - \gamma_i R^{*i}_{q^*q})dx_i + R^{*i}_{q^*q}(ds_i + \gamma_i\beta_i dx_j), \tag{46}$$

where:

$$D^i = R^i_{qq}R^{*i}_{q^*q^*} - R^i_{qq^*}R^{*i}_{q^*q} = b_i^2(3+r_i) > 0. \tag{47}$$

We assume D^i is positive to ensure stability of the output game. In the text we make frequent use of the following:

$$\begin{aligned} R^i_{qq} &= -b_i(2+\alpha_i r_i), \quad R^{*i}_{q^*q^*} = -b_i(2+\alpha_i^* r_i), \\ R^i_{qq^*} &= -b_i(1+\alpha_i r_i), \quad R^{*i}_{q^*q} = -b_i(1+\alpha_i^* r_i). \end{aligned} \tag{48}$$

R^{i}_{qq} and $R^{*i}_{q^*q^*}$ are negative from the firms' second-order conditions and the other two terms are negative provided home and foreign output are strategic substitutes.

2. Generalised Reaction Functions When Spillovers Are Local

2.1 FCE

To calculate the slopes of the generalised reaction functions under FCE, totally differentiate the two first-order conditions for a typical foreign firm (8) and (12). The total derivative of (8), the first-order condition for output, is given in (44) above and the total derivative of (12), the first-order condition for R&D, is:

$$\pi^{*i}_{x^*x^*}\, dx_i^* + \pi^{*i}_{x^*q^*}\, dq_i^* = 0, \tag{49}$$

where $p^{*i}_{x^*x^*} = ?^*_i N q^*_i \,!\, G^*0 < 0$ and $p^{*i}_{x^*q^*} = ?^*_i > 0$. Solving equations (44) and (49) for dx_i^* and dq_i^* and setting $e^*=0$ yields:

$$\Delta^{i} dx_i^* = \pi^{*i}_{x^*q^*} R^{i*}_{q^*q}\, dq_i, \tag{50}$$

$$\Delta^{i} dq_i^* = -\pi^{*i}_{x^*x^*} R^{i*}_{q^*q}\, dq_i, \tag{51}$$

where:

$$\Delta^{i} = \pi^{*i}_{x^*x^*} R^{i*}_{q^*q^*} - \pi^{*i}_{x^*q^*} \Delta^{*}_{i} > 0. \tag{52}$$

Note that $p^{*i}_{x^*x^*}$ and $R^{*i}_{q^*q^*}$ are negative and Δ^{i} is positive from the typical foreign firm's second-order conditions. As mentioned in the text $R^{*i}_{q^*q}$ is negative if foreign output is a strategic substitute for home output.

From (50) and (51) we can now see that: (i) x^*_i and q^*_i depend only on q_i; and (ii) the sign of the derivatives of the generalised reaction functions depend only on the sign of R^{*i}_{q*q}.

2.2 GCE

To determine the slopes of the generalised reaction functions under GCE we first need the total derivative of (19), the typical foreign firm's first-order condition for R&D under GCE:

$$\mathrm{p}^{(i}_{x(x(}dx_i^{(} \ \% \ \mathrm{p}^{(i}_{x(q(}dq_i^{(} \ \% \ \mathrm{p}^{(i}_{x(q}dq_i \ ' \ 0, \tag{53}$$

Compared to (49) there is now an additional term in dq_i. Let $E^{*i}=(1+a_ir_i)/(3+r_i)$. Then under GCE: $p^{*i}_{x^*x^*}=?^*_i N(1+E^{*i})q^*_i \,!\, G^*_i 0$, $p^{*i}_{x^*q^*}=?^*_i(1+E^{*i})+?^*_i q^* E^{*i}_q$ and $p^{*i}_{x^*q}=?^*_i q^* E^{*i}_q$. Stability considerations mean that we continue to assume that $p^{*i}_{x^*x^*}$ is negative and that $?^{\,i}$ is positive. However, $p^{*i}_{x^*q^*}$ and $p^{*i}_{x^*q}$ cannot be unambiguously signed. Nevertheless, $p^{*i}_{x^*q^*}$ will be positive provided the term in $E^{*i}_{q^*}$ is not too negative.

To obtain expressions for dx^*_i and dq^*_i, set e*=0 and combine (44) with (53) to get:

$$?^{\,i}dx_i^{(} \ ' \ \left\{\mathrm{p}^{(i}_{x(q(}R^{(i}_{q(q} \,\&\, \mathrm{p}^{(i}_{x(q}R^{(i}_{q(q(}\right\}dq_i, \tag{54}$$

$$?^{\,i}dq_i^{(} \ ' \ \&\left\{\mathrm{p}^{(i}_{x(x(}R^{(i}_{q(q} \,\&\, \mathrm{p}^{(i}_{x(q}?^{(}_i\right\}dq_i. \tag{55}$$

From these equations we can see that x^*_i and q^*_i depend only on q_i and that strategic substitutes contribute to x^*_i and q^*_i falling in q_i.

3. Generalised Reaction Functions: International Spillovers

3.1 FCE

To compute the slopes of the generalised reaction functions in this case totally differentiate (12) to get:

$$\mathrm{p}^{(}_{x(x(}\,dx^{(}\ \%\ \mathrm{p}^{(}_{x(q(}\,dq^{(}\ \%\ \mathrm{p}^{(}_{x(x}\,dx\ \ '\ \ 0, \tag{56}$$

(Note we have dropped the industry superscripts and subscripts as there are no inter-industry spillovers). Compared to (49), the presence of international spillovers implies that there is an additional term in dx. This is because in the international spillover case $?^*$ depends not just on x^* but also on x via the spillover effect.

The derivatives of the foreign marginal profit functions can be written more explicitly as: $p^*_{x^*x^*}=?^*_{x^*}q^*\,!\,\mathrm{G}^*0<0$, $p^*_{x^*q^*}=?^*>0$ and $p^*_{x^*x}=?^*_x q^*$ which cannot be signed. To obtain expressions for dx^* and dq^* combine (44) with (56) to get:

$$?\,dx^{(}\ \ '\ \ \mathrm{p}^{(}_{x(q(}\,R^{(}_{q(q}\,dq\ \%\left\{\mathrm{p}^{(}_{x(q(}\mathrm{e}^{(}?^{(}\ \&\ \mathrm{p}^{(}_{x(x}R^{(}_{q(q(}\right\}dx \tag{57}$$

$$?\,dq^{(}\ \ '\ \ \&\ \mathrm{p}^{(}_{x(x(}\,R^{(}_{q(q}\,dq\ \&\left\{\mathrm{p}^{(}_{x(x(}\mathrm{e}^{(}\ \&\ \mathrm{p}^{(}_{x(x}\right\}?^{(}dx \tag{58}$$

From these we can see that: (i) x^* and q^* depend on q and x; (ii) the sign of the derivatives with respect to q of the generalised reaction functions depend only on the sign of $R^*_{q^*q}$; and (iii) the derivatives with respect to x will be positive provided $p^*_{x^*x}$ is not too negative. (This includes the linear case when $p^*_{x^*x}$ is zero.)

3.2 GCE

To obtain slopes of the generalised reaction function totally differentiate (36) to get:

$$\pi^{*}_{x^{*}x^{*}} dx^{*} + \pi^{*}_{x^{*}q^{*}} dq^{*} + \pi^{*}_{x^{*}x} dx + \pi^{*}_{x^{*}q} dq = 0, \tag{59}$$

Compared to (56) there is an additional term in dq. This arises because the term in brackets in (36) depends on q.

The derivatives in (59) are somewhat harder to sign than in the FCE case. It will help in determining the signs of these derivatives to define: $T(x,x^{*},q,q^{*})=1+A^{*}(\&-e)>0$. ($T$ is greater or less than unity as & is greater or less than e.) Then: $p^{*}_{x^{*}x^{*}}=T?^{*}_{x^{*}}q^{*}+?^{*}q^{*}T_{x^{*}} ! G^{*}0 < 0$, $p^{*}_{x^{*}q^{*}}=?^{*}(T+q^{*}T_{q^{*}})$, $p^{*}_{x^{*}x}=T?^{*}_{x}q^{*}+?^{*}q^{*}T_{x}$ and $p^{*}_{x^{*}q}=?^{*}q^{*}T_{q}$. To obtain expressions for dx^{*} and dq^{*}, combine (44) and (59) to get:

$$? dx^{*} = (\pi^{*}_{x^{*}q^{*}} R^{*}_{q^{*}q} - \pi^{*}_{x^{*}q} R^{*}_{q^{*}q^{*}}) dq + (\pi^{*}_{x^{*}q^{*}} \epsilon^{*} ?^{*} - \pi^{*}_{x^{*}x} R^{*}_{q^{*}q^{*}}) dx, \tag{60}$$

$$? dq^{*} = -(\pi^{*}_{x^{*}x^{*}} R^{*}_{q^{*}q} - \pi^{*}_{x^{*}q} R^{*}_{q^{*}q^{*}}) dq - (\pi^{*}_{x^{*}x^{*}} \epsilon^{*} - \pi^{*}_{x^{*}x}) ?^{*} dx. \tag{61}$$

As in the FCE case, strategic substitutes contribute to foreign R&D and foreign output falling in q. However, as in the GCE case with local spillovers, they are not sufficient now due to the term in $p^{*}_{x^{*}q}$. The derivatives with respect to home R&D take the same form as those under FCE and can be interpreted in the same way.