

# Cost-Reducing R&D with Spillovers and Trade

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## ABSTRACT

This research incorporates research spillovers and examines behavior of firms in a two-stage, international trade game with process innovation. Governments choose optimal research subsidies in stage one, while firms take account of subsidies in choosing research and production in stage two. Results show that optimal research subsidies differ under spillovers and no spillovers. Strategic responses to foreign research subsidies uniquely occur in cases with spillovers. At certain spillover levels, the optimal R&D policy is a negative subsidy (tax). Findings regarding the effects of trade liberalization support earlier results with perfect appropriability, although responses to trade liberalization are different with spillovers.

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## INTRODUCTION

Firms trading across national borders face numerous (exogenous) bottlenecks that affect the costs of doing business. These bottlenecks might stem from differing regulations or dissimilar business practices. Examples include foreign car makers having to comply with stricter emissions requirements in some countries and different standardization systems used across nations (i.e., not all nations uniformly using the metric system). Trade agreements or other initiatives might over time lower or eliminate these bottlenecks. The present research examines the effect of such trade liberalization on government subsidies and on firm behavior.

This paper incorporates research spillovers in the presence of process innovation into an international trade game. Firms operating in a country benefit from the research of foreign firms, while governments try to bolster research by granting subsidies. For instance, domestic car makers might learn from foreign cars to produce cheaper cars. Research spillovers are generally imperfect because outside firms are unable to unravel all of a firm's research secrets. However, sometimes research knowledge can flow seamlessly across firms when they form a research joint venture (RJV). Some governments, including the U.S. government, have in recent years relaxed antitrust laws to promote RJs.

Whereas the economics literature in recent years has recognized and examined the causes and effects of research spillovers (see, for example, d'ASPREMONT AND JACQUEMIN [1988] and KAMIEN ET AL. [1992]), inclusion of research spillovers in international trade studies is rather limited (see HARUNA [2003], LEAHY AND NEARY [1999]; and GRILICHES [1992], GROSSMAN AND HELPMAN [1993, 1995], and LEVIN ET AL. [1987] for relevant surveys).<sup>1</sup> Consideration of research spillovers is a more realistic depiction of an increasingly globalized world economy (see BLOMSTRÖM AND KOKKO [1998]). Advances in transportation and telecommunications have enabled faster and cheaper transfer of research, both intentional and unintentional, across jurisdictions. Consequently firms and policymakers take account of these research spillovers in their decision-making.

The game studied can be seen as involving two stages. Policymakers choose optimal research subsidies in the first stage, while firms take account of the subsidy levels in choosing research and production in the second stage. Although there are two types of innovation - such as process innovation and product innovation - we assume that firms make an investment in process research to reduce production costs. It has been assumed elsewhere that when firms make an investment in R&D as a method for business stealing, they determine the levels of R&D investment (research) and output

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<sup>1</sup> Significant earlier contributions to international trade models include BRANDER AND SPENCER [1985] and EATON AND GROSSMAN [1986]; more broadly see BRANDER [1995].

(or price) at different stages (see, e.g. d'ASPREMONT AND JACQUEMIN [1988], KAMIEN ET AL. [1992], and GOEL AND HARUNA [2007]).<sup>2</sup> Production activities and process innovation, however, cannot be always separated. When the levels of cost-reducing R&D and output are chosen at the same stage, the R&D for firms is chosen at the efficient level and no strategic role for R&D is taken into account. HAALAND AND KIND [2008] employ the assumption that research and production are simultaneously chosen.

Our results show that optimal research subsidies with spillovers differ from the no spillover case (see HAALAND AND KIND [2008]). Although HAALAND AND KIND implicitly assume that the optimal R&D policy is to grant research subsidies, we are able to demonstrate that their assumption leads to a potential contradiction when there are research spillovers. Specifically, when spillovers are substantial, the optimal research policy involves negative subsidies or taxes. Further, the magnitudes of responses to trade policy changes are dissimilar under no research spillovers versus spillovers. Strategic output and R&D responses to foreign subsidies are shown to uniquely occur in the presence of spillovers even if output markets are separated or each output market is monopolized by one firm. Other results regarding the effects of trade

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<sup>2</sup> Further, since the seminal paper of BRANDER AND SPENCER [1985], numerous researchers studying trade and strategic R&D have employed the assumption that R&D investment and exports are chosen at different stages (see, for example, SPENCER AND BRANDER [1983], BRANDER AND SPENCER [1985], EATON AND GROSSMAN [1986], LEAHY AND NEARY [1999], DECOURCY [2005], and COLLIE [2005]). This assumption appears to be less relevant in the case of cost-reducing investment (research) considered here.

liberalization on R&D and output generally reinforce earlier conclusions with perfect appropriability. The formal model follows.

## THE MODEL

To address the issue of cross-country trade with research spillovers, our underlying framework draws on a recent article by HAALAND AND KIND [2008], hereafter H-K, which examines the effects of policy changes on research subsidies and firm behavior in the context of international trade when there are deterministic process innovations.<sup>3</sup> The authors find that optimal research subsidies, R&D and output increase in the face of trade liberalization. This research extends previous analysis by incorporating research spillovers, namely allowing for imperfect appropriability of research returns. Further, H-K [p. 186] note that the inclusion of research spillovers would be an “interesting extension” to their work (also see LEAHY AND NEARY [2009]).

We sketch the underlying model and introduce the degree of research spillovers ( $\beta$ ), such that  $0 \leq \beta \leq 1$ , with  $\beta = 0$  denoting no spillovers;  $0 < \beta < 1$  signifying imperfect spillovers; and  $\beta = 1$  denoting perfect spillovers or an RJV. These spillovers might emerge from industrial spying, reverse engineering, or labor movements (see LEVIN ET AL. [1987]). One could argue that recent (exogenous) advances in transportation and

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<sup>3</sup> COLLIE [2005] evaluates the relative welfare effects of research subsidies and investment subsidies in the presence of research subsidies.

telecommunications have increased the speed and perhaps even the magnitude of research spillovers.

The basic trade model employed has two symmetric countries and two symmetric firms, with each country hosting and owning one firm. The population of each country is assumed to be unity. Using a dual subscript notation, where the first subscript denotes the country of the good's production and the second subscript signifies the country of consumption, the respective inverse demand curves are given by

$$\begin{aligned}
 p_{ii} &= \alpha - (q_{ii} + bq_{ji}) \\
 p_{ij} &= \alpha - (q_{ij} + bq_{jj}), \quad \alpha > 0, \quad 0 \leq b \leq 1.
 \end{aligned}
 \tag{1}^4$$

The parameter  $b$  in the demand functions is the cross-price effect and can be seen as capturing the degree of substitution between domestic and foreign goods, with  $b = 1$  denoting perfect substitutes, and  $b = 0$  signifying complete independence.

The constant marginal production costs of the firms are denoted by  $c$ . Country  $i$  incurs exogenous (per unit) trade costs of  $\tau$  to export to country  $j$ . These costs may be seen to proxy for transportation, regulatory or standardization bottlenecks.<sup>5</sup> Trade liberalization would involve a lowering of trade costs,  $\tau$ . An example of lowering of trade costs is the decrease in customs duties when nations form trading blocks such as

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<sup>4</sup> These demand curves follow from utility maximization by consumers  $i$  and  $j$  with the utility function denoted by  $U_i = \alpha q_{ii} + \alpha q_{ji} - (q_{ii}^2/2 + q_{ji}^2/2 + bq_{ii}q_{ji})$  and  $U_j = \alpha q_{jj} + \alpha q_{ij} - (q_{jj}^2/2 + q_{ij}^2/2 + bq_{jj}q_{ij})$ , respectively.

<sup>5</sup> One could alternately consider, in a more involved framework, the case where trade costs are somewhat endogenous.

NAFTA and the EU.

Although the marginal production costs of firm  $i$  are constant in the units of production, these costs can be lowered by investing in R&D ( $x_i$ ). Total research costs,  $C(x_i)$ , of firm  $i$  are the sum of fixed outlays ( $f$ ) and variable outlays ( $x_i^2$ ); formally  $C(x_i) = x_i^2 + f$ . However, due to research spillovers each firm is also able to benefit in the form of cost reduction from the research of others ( $x_j$ ). In other words, spillovers from R&D flow in both directions. Such spillovers are increasingly common in a global economy. Thus, taking account of cost-reduction by R&D process innovation and R&D spillovers, firm  $i$ 's production cost is finally reduced to  $(c - x_i - \beta x_j)$ . Again, previous research has considered the case with  $\beta = 0$ .

Domestic governments subsidize R&D to the tune of  $s_i$  per-unit. This subsidy is optimally chosen by governments seeking to maximize welfare (denoted as the sum of consumer surplus and producer surplus, i.e., the firm's profits net of research subsidy).<sup>6</sup> Given all this, the  $i$ th firm's overall profit function can be written as

$$\begin{aligned}\pi_i &= [p_{ii} - (c - x_i - \beta x_j)]q_{ii} + [p_{ij} - (c - x_i - \beta x_j) - \tau]q_{ij} - x_i^2 - f + s_i x_i \\ &= [\alpha - q_{ii} - bq_{ji} - c + x_i + \beta x_j]q_{ii} + [\alpha - q_{ij} - bq_{ij} - c + x_i + \beta x_j - \tau]q_{ij} \\ &\quad - x_i^2 - f + s_i x_i.\end{aligned}\tag{2}$$

In other words, the  $i$ th firm's profits are revenues net of production costs from domestic and foreign sales minus research costs and trade costs plus research subsidies and

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<sup>6</sup> An alternative subsidy approach might be to let firms bid for research subsidies in an auction (GIEBE ET AL. [2006]).

benefits from own and foreign cost-reduction. These profits are maximized by simultaneously choosing research and output.

This trade game is comprised of two steps. Governments choose the optimal research subsidy in Stage 1; and the firms simultaneously choose the levels of R&D and production in Stage 2. We are interested in the effects of policy changes (trade liberalization) in both stages in the presence of spillovers: (i) examining the level of optimal subsidies with spillovers and the effects of trade policy changes (Stage 1); and (ii) the effects on R&D and production in the presence of spillovers (Stage 2). Are research and production responses to trade liberalization similar with and without research spillovers?

## ANALYSIS AND RESULTS

### **Benchmark case: Optimal R&D subsidies to a monopoly with spillovers**

In the benchmark case firms produce non-competing goods and have monopoly power in both markets. This is akin to assuming  $b = 0$  in demand relations denoted in (1) above. Monopolies would generally have little incentives to form research joint ventures.

Holding R&D investments constant, the  $i$ th firm's profit-maximizing monopoly outputs, using  $(\partial\pi_i/\partial q_{ii}) = (\partial\pi_i/\partial q_{ij}) = 0$  from (2), are given by

$$q_{ii} = [\alpha - (c - x_i - \beta x_j)]/2$$



$$q_{ij} = [\alpha - \tau - (c - x_i - \beta x_j)]/2. \quad (3)^7$$

Equating the MC ( $= 2x_i - s_i$ ) and MB ( $= q_{ii} + q_{ij}$ ) of R&D, we get

$$x_i = (q_{ii} + q_{ij} + s_i)/2. \quad (4)$$

Using (3) and (4), we get the monopoly R&D

$$x_i = (\alpha - c - \tau/2)/(1 - \beta) + (s_i + \beta s_j)/(1 - \beta^2). \quad (5)^{8, 9}$$

Then, substituting (4) and (5) into (3), the respective outputs (domestic and foreign) are obtained as

$$\begin{aligned} q_{ii} &= (1/2)[2(\alpha - c)/(1 - \beta) - (1 + \beta)\tau/2(1 - \beta) + (1/(1 - \beta^2))[(1 + \beta^2)s_i + 2\beta s_j]] \\ q_{ij} &= (1/2)[2(\alpha - c)/(1 - \beta) - (3 - \beta)\tau/2(1 - \beta) + (1/(1 - \beta^2))[(1 + \beta^2)s_i + 2\beta s_j]]. \end{aligned} \quad (6)$$

Equations (5) and (6) denote R&D and output in the second stage of the game described above. It is clear from (5) and (6) that, holding subsidies fixed, R&D declines when trade costs ( $\tau$ ) increase, and increases in trade costs have a similar (negative) effect on

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<sup>7</sup> Alternately,  $q_{ij} = q_{ii} - \tau/2$ .

<sup>8</sup> Recall that in the monopoly case  $b = 0$ , yielding  $p_{ii} = \alpha - q_{ii}$ ; and  $p_{ij} = \alpha - q_{ij}$ .

<sup>9</sup> Equation (5) implies that with complete spillovers ( $\beta = 1$ ), optimal R&D in the monopoly is undefined. This is due to the fact that the relative return to R&D is high relative to its cost, resulting in no interior equilibrium. In such a situation one firm ends up capturing the market.

As suggested by the insightful referee, an interior solution can emerge when one considers an alternate specification of R&D costs such that  $C(x_i) = \gamma x_i^2/2 + f$ , with  $\gamma > 0$ ; and the corresponding cost-reduction denoted by  $(c - \theta(x_i + \beta x_j))$ , with  $\theta > 0$ . Note that the case considered in the paper (i.e., with  $C(x_i) = x_i^2 + f$ ) involves  $\gamma = 2$  and  $\theta = 1$ . Solving the benchmark case for monopoly R&D in this instance yields

$$x_i = [(\theta - \gamma - \theta\beta)(\alpha - c - \tau/2) + (\theta - \gamma)s_i - \theta\beta s_j]/[(\theta\beta)^2 - (\theta - \gamma)^2]. \quad (5)'$$

Thus,  $x_i > 0$ , even with  $\beta = 1$ , so long as  $(\theta/\gamma) < 1/2$ .

domestic and foreign sales.

The strategic effects of a change in foreign research subsidy (from (5) and (6)) can be summarized in the following. An increase in foreign subsidy increases domestic R&D as well as domestic output:  $(\partial x_i / \partial s_j) = \beta / (1 - \beta^2) > 0$  and  $(\partial q_{ii} / \partial s_j) = \beta / (1 - \beta^2) > 0$ . Increased foreign subsidy lowers R&D costs for the foreign firm, and therefore, the domestic firm feels compelled to increase its own research. With the resulting cost-reduction, the domestic firm raises the amount of output when foreign subsidies increase. These strategic responses uniquely arise with research spillovers as the presence of research spillovers induces the domestic firm to take account of foreign research subsidies, even in the monopoly case when firms do not compete in the product market. Presence of research spillovers is what is driving this strategic consideration. In the absence of R&D spillovers, the domestic firm's R&D and output are independent of the subsidy decision of the foreign government (H-K [2008]). However, in the presence of spillovers they are influenced by the foreign government's subsidy.

In the first stage, the government in each country chooses the optimal (welfare-maximizing) R&D subsidy, where welfare is the sum of consumer surplus ( $CS$ ) and producer surplus ( $PS$ ), i.e., profits net of subsidy. Formally, welfare is given as

$$W_i \equiv CS_i + PS_i (\equiv \pi_i - s_i x_i). \quad (7)$$

The first-order condition for maximizing (7) yields <sup>10</sup>

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<sup>10</sup> Recall that the profit is given in (2) above, and  $CS_i = U_i - p_{ii}q_{ii} - p_{ji}q_{ji}$ , where  $U_i = \alpha q_{ii} +$

$$\begin{aligned}
\partial W_i / \partial s_i &= [(1 + \beta^2)q_{ii} + 2\beta q_{ji} - 2s_i] / 2(1 - \beta^2) \\
&= \{4(1 + \beta)^2(\alpha - c) - [(1 + \beta)^3 + 4\beta(1 - \beta)]\tau + 2[(1 + \beta)(1 + \beta)^2 - \\
&\quad 4(1 - \beta)]s_i + 4\beta(1 + \beta)s_j\} / 8(1 - \beta^2)(1 - \beta) = 0, \tag{8}
\end{aligned}$$

where  $(\partial CS_i / \partial s_i) = [(1 + \beta^2)q_{ii} + 2\beta q_{ji}] / 2(1 - \beta^2)$ , and  $(\partial PS_i / \partial s_i) = -s_i / (1 - \beta^2)$ . Using the symmetry assumption and  $q_{ij} = q_{ii} - \tau/2$  (fn. 7), and solving (8) for  $s_i$ , we obtain

$$s_i = \{4(1 + \beta)^2(\alpha - c) - [(1 + \beta)^3 + 4\beta(1 - \beta)]\tau\} / 2(3 - 7\beta - 3\beta^2 - \beta^3). \tag{9}$$

The optimal R&D policy of the domestic government is sensitive to the degree of research spillovers ( $\beta$ ). Now, when an interior equilibrium in the first stage is assumed, the numerator of (9) is positive, but the sign of the denominator depends on the degree of spillovers. For example, if  $s_i$  is positive or negative, then this implies that the optimal policy is either to subsidize or tax R&D. The denominator becomes positive or negative according to whether  $0 \leq \beta < \beta^*$  or  $\beta^* < \beta < 1$ , respectively, where

$$\beta^* = -1 - 2[2/3(9 + \sqrt{93})]^{1/3} + (2/3)^{2/3}(9 + \sqrt{93})^{1/3} \approx 0.36, \text{ which satisfies } (3 - 7\beta - 3\beta^2 - \beta^3) = 0.$$

Incidentally, the subsidy function  $s_i$  does not exist at the point where

spillovers  $\beta = \beta^*$ . Thus it follows that when research spillovers are incorporated into the model, the result of H-K regarding R&D policy does not always hold. This result is summarized as follows:

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$$\alpha q_{ji} - (q_{ii}^2 / 2 + q_{ji}^2 / 2 + b q_{ii} q_{ji}).$$

**Proposition 1.**

Suppose that the firms are monopolists in their own market segments. The domestic government will subsidize domestic R&D when research spillovers are small, i.e.,  $0 \leq \beta < \beta^*$ , but tax it when spillovers are large, i.e.,  $\beta^* < \beta < 1$ , where

$$\beta^* = -1 - 2[2/3(9 + \sqrt{93})]^{1/3} + (2/3)^{2/3}(9 + \sqrt{93})^{1/3}.$$

This result is unambiguously different from the finding that in the absence of spillovers the optimal trade policy of the domestic government is to subsidize domestic R&D (HAALAND AND KIND [2008, eq. 13]). Although H-K implicitly assume that  $s_i$  is an R&D subsidy, we show that their assumption is not always valid in the presence of research spillovers. According to the extent (degree) of spillovers, the optimal policy is reduced either to subsidizing or to taxing domestic R&D. Our result shows that research spillovers have a great influence on R&D policy of the domestic government. Interestingly, when the spillovers are introduced, the optimal subsidy or tax policy will not exist at some spillover level even if the markets are separated into domestic and foreign. Intuitively, with substantial spillovers the foreign benefit (in terms of cost-reduction and subsequent output increase) is greater. Thus, the domestic government taxes rather than subsidizes domestic R&D. However, when spillovers are modest, the domestic benefit is greater than foreign gain, justifying subsidizing R&D.<sup>11</sup>

To determine the effects of trade liberalization, we differentiate (9) with respect

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<sup>11</sup> Subsidies might be justified at high spillover levels from a global welfare perspective (LEAHY AND NEARY [2009]).

to trade costs ( $\tau$ ):

$$\partial s_i / \partial \tau = - [(1 + \beta)^3 + 4\beta(1 - \beta)] / 2(3 - 7\beta - 3\beta^2 - \beta^3). \quad (10)$$

It follows that  $(\partial s_i / \partial \tau)$  is negative or positive according to whether  $0 \leq \beta < \beta^*$  or  $\beta^* < \beta < 1$ , respectively. Namely, trade liberalization increases R&D subsidies of the domestic government in the presence of small spillovers and decreases R&D taxes in the presence of substantial research leakages.

In Figure 1 the relationship between the effects on R&D subsidies or taxes and research spillovers is shown. The figure demonstrates that the effect not only decreases with increased spillovers in the region of  $0 \leq \beta < \beta^*$ , but also decreases in the region of  $\beta^* < \beta < 1$ , and, moreover, the derivative function of  $s_i$  does not exist at the point  $\beta = \beta^*$ , just like the function  $s_i$ . In the neighborhood of the point  $\beta^*$  the effect of trade liberalization on subsidy rapidly goes up or down. Taking account of the fact that  $s_i$  is a decreasing function of  $\beta$  for  $\beta^* < \beta \leq 1$  and  $(\partial s_i / \partial \tau) = 1/2$  at  $\beta = 1$ , we note that  $(\partial s_i / \partial \tau) = |(\partial s_i / \partial \tau)| > 1/2$  for  $\beta^* < \beta < 1$ .

\*\*\*\* *Insert Figure 1 here* \*\*\*\*

The possibility of research subsidies turning to taxes is quite instructive. Whether or not policymakers raise subsidies or taxes to boost research when trade bottlenecks are lifted or relaxed depends on the degree of research spillovers. The existing finding regarding (positive) research subsidies are supported only when research spillovers are small, i.e.,  $0 \leq \beta < \beta^*$ . However, with large spillovers, the

spillover externalities are partially internalized as information flows largely between the firms, so changes in research subsidies are different in the case above.

Next we compare the magnitudes of the effects of trade policy changes on optimal research subsidies with and without research spillovers. Are subsidy responses to liberalization similar with and without spillovers?

**Proposition 1a**

The effect of trade liberalization on optimal subsidy is negative in small spillovers, i.e.,  $0 \leq \beta < \beta^*$ , but is positive in large spillovers, i.e.,  $\beta^* < \beta < 1$ . Furthermore, the absolute value of the effect of trade liberalization on optimal subsidy or tax is larger (more pronounced) in the presence of research spillovers, compared to the case when no spillovers are present:

$$(\partial s_i / \partial \tau)|_{\beta \neq 0} < (\partial s_i / \partial \tau)|_{\beta=0} \quad \text{or} \quad |(\partial s_i / \partial \tau)|_{\beta \neq 0} > |(\partial s_i / \partial \tau)|_{\beta=0} \quad \text{for} \quad 0 \leq \beta < \beta^*.$$

$$(\partial s_i / \partial \tau)|_{\beta \neq 0} < (\partial s_i / \partial \tau)|_{\beta \neq 0} \quad \text{or} \quad |(\partial s_i / \partial \tau)|_{\beta \neq 0} > |(\partial s_i / \partial \tau)|_{\beta \neq 0} \quad \text{for} \quad \beta^* < \beta < 1$$

Proof: From (10) we have  $(\partial s_i / \partial \tau)|_{\beta \neq 0} - (\partial s_i / \partial \tau)|_{\beta=0} = -2\beta(7 + \beta^2)/3(3 - 7\beta - 3\beta^2 - \beta^3) < 0$  for  $0 \leq \beta < \beta^*$ , so  $|(\partial s_i / \partial \tau)|_{\beta \neq 0} > |(\partial s_i / \partial \tau)|_{\beta=0}$  ( $= 1/6$ ) holds because both  $(\partial s_i / \partial \tau)|_{\beta \neq 0}$  and  $(\partial s_i / \partial \tau)|_{\beta=0}$  are negative. In the region of  $\beta^* < \beta < 1$  the same result is obtained from (10) because  $(\partial s_i / \partial \tau)$  is a decreasing function of  $s_i$  and  $(\partial s_i / \partial \tau)|_{\beta \neq 0} > 1/2$ .

Q.E.D.

R&D policy responses are greater in the presence of research spillovers. Thus, incorporation of research spillovers plays a crucial role in the choice of trade policy of

the domestic government.

This is a key result from this exercise: The level of optimal subsidy is different under research spillovers, compared to the no spillovers case. Incorporation of research spillovers generally supports the findings regarding the effect of trade liberalization on optimal research subsidy; however, the magnitude of the change in subsidy can vary substantially between the spillover and no spillover cases. Furthermore, the optimal research policy does not always involve subsidizing research and, depending upon the extent of spillovers, might in fact involve a tax.

### **Market equilibrium with competition between firms**

Moving away from the monopoly case, we allow for direct competition between firms by considering the case of  $0 < b \leq 1$ . In this case, firms simultaneously choose output and R&D in the second-stage, when the government has determined the optimal research subsidy in the first stage. In other words, we move from a monopoly situation to a duopolistic one. Solving the first-order conditions, i.e.,  $(\partial\pi_i/\partial q_{ii}) = (\partial\pi_i/\partial q_{ij}) = (\partial\pi_i/\partial x_i) = 0$ , for the profit function given in (2), using symmetry and simplifying gives

$$q_{ii} = (\alpha - c)/(2 + b) + b\tau/(4 - b^2) + [(2 - b\beta)x_i + (2\beta - b)x_j]/(4 - b^2) \quad (11)$$

$$q_{ji} = (\alpha - c)/(2 + b) - 2\tau/(4 - b^2) + [(2 - b\beta)x_i + (2\beta - b)x_j]/(4 - b^2).$$

Taking account of  $(\partial\pi_i/\partial x_i) = q_{ii} + q_{ij} - 2x_i + s_i = 0$ , it follows from (11) and symmetry that

$$x_i = (\alpha - c)/(1 + b - \beta) - \tau/2(1 + b - \beta) + [(2 - b(b - \beta))s_i + (2\beta - b)s_j]/2(1 + b - \beta)(1 - b + \beta) \quad (12)$$

The relation (12) denotes the  $i$ th firm's profit-maximizing R&D in the presence of spillovers. In the absence of spillovers ( $\beta = 0$ ), the firms' profit-maximizing R&D boils down to the expression derived by H-K [2008, eq. 19].

Similarly, the foreign firm's R&D is given by

$$x_j = (\alpha - c)/(1 + b - \beta) - \tau/2(1 + b - \beta) + [(2 - b(b - \beta))s_j + (2\beta - b)s_i]/2(1 + b - \beta)(1 - b + \beta) \quad (13)$$

Substituting (12) and (13) into (11), the quantities become a function of  $(s_i, s_j)$ . The profit-maximizing quantities are dependent on the degree of spillovers. In the absence of spillovers, these quantities reduce to those obtained earlier (H-K [2008, eq.18]). The following proposition reports the effects of trade liberalization (i.e., a decrease in  $\tau$ ) on Stage 2.

### **Proposition 2**

Holding subsidies fixed, trade liberalization in the presence of research spillovers involves an increase in equilibrium export and R&D, i.e.,  $(\partial x_i/\partial\tau) < 0$  and  $(\partial q_{ij}/\partial\tau) < 0$  for any  $b \in (0, 1]$  and  $\beta \in [0, 1]$ , and also increase in domestic output  $(\partial q_{ii}/\partial\tau) < 0$  for  $b < (1 + \beta)/2$ .



Proof: From (12) we have  $(\partial x_i/\partial \tau) = -1/2(1 + b - \beta) < 0$ . It follows from this and (11) that  $(\partial q_{ij}/\partial \tau) = (2b - 1 - \beta)/2(2 - b)(1 + b - \beta)$  and  $(\partial q_{ij}/\partial \tau) = -(3 - \beta)/2(2 - b)(1 + b - \beta) < 0$ . Q.E.D.

Removal of trade bottlenecks enables firms to better exploit scale economies and they respond by increasing research and production. We can also compare the relative magnitudes of responses to liberalization under trade. This result is given in Proposition 2a.

### Proposition 2a

With international trade and given subsidies, the absolute value of magnitude of responses to liberalization in terms of their effects on R&D and output are larger in the presence of spillovers than in their absence, i.e.,

$$|(\partial x_i/\partial \tau)|_{\beta \neq 0} > |(\partial x_i/\partial \tau)|_{\beta=0} \text{ for any } b \in (0, 1] \text{ and } \beta \in [0, 1], |(\partial q_{ij}/\partial \tau)|_{\beta \neq 0} > |(\partial q_{ij}/\partial \tau)|_{\beta=0} \text{ for any } b \in (0, 1] \text{ and } \beta \in [0, 1], \text{ and } |(\partial q_{ii}/\partial \tau)|_{\beta \neq 0} > |(\partial q_{ii}/\partial \tau)|_{\beta=0} \text{ for } b < (1 + \beta)/2.$$

Proof: Let us take the results of Proposition 2 into consideration. Then from (12)

$$(\partial x_i/\partial \tau)|_{\beta \neq 0} - (\partial x_i/\partial \tau)|_{\beta=0} = -\beta/2(1 + b)(1 + b - \beta) < 0. \quad (14)$$

Then it follows from the result of Proposition 2 that  $|(\partial x_i/\partial \tau)|_{\beta \neq 0} > |(\partial x_i/\partial \tau)|_{\beta=0}$ .

From (11)

$$(\partial q_{ij}/\partial \tau)|_{\beta \neq 0} - (\partial q_{ij}/\partial \tau)|_{\beta=0} = -\beta/2(1 + b)(1 + b - \beta) < 0. \quad (15)$$

Then it follows the result that  $|(\partial q_{ij}/\partial \tau)|_{\beta \neq 0} > |(\partial q_{ij}/\partial \tau)|_{\beta=0}$ , and, similarly, from (11)

$$(\partial q_{ii}/\partial \tau)|_{\beta \neq 0} - (\partial q_{ii}/\partial \tau)|_{\beta=0} = -\beta/2(1+b)(1+b-\beta) < 0. \quad (16)$$

Given  $b < (1+\beta)/2$ , both  $(\partial q_{ii}/\partial \tau)|_{\beta \neq 0}$  and  $(\partial q_{ii}/\partial \tau)|_{\beta=0}$  are negative, so that  $|(\partial q_{ii}/\partial \tau)|_{\beta \neq 0} > |(\partial q_{ii}/\partial \tau)|_{\beta=0}$  holds. Otherwise, it may or may not hold. Q.E.D.

The presence of spillovers allows the domestic firm to take better account of foreign research (and its benefits via spillovers) and its own research leakages to the foreign firm. Therefore, its output and research responses to liberalization are more pronounced.

Further insight can be obtained regarding the output response from (11). Using (11) and (12), the relation denoting the output response to trade liberalization is given by  $(\partial q_{ii}/\partial \tau)|_{\beta \neq 0} = (2b - 1 - \beta)/2(2 - b)(1 + b - \beta)$ , so that  $(\partial q_{ii}/\partial \tau)|_{\beta \neq 0} < 0$  iff  $b < (1 + \beta)/2$ . In other words, with spillovers, the region of  $b$  (the degree of product substitutability) where  $(\partial q_{ii}/\partial \tau) < 0$  holds is extended, and, particularly for  $\beta = 1$  we have  $(\partial q_{ii}/\partial \tau)|_{\beta=1} = (b - 1)/b(2 - b)$ . This is illustrated in Figure 2. It demonstrates that the degree of output response to trade liberalization increases as the degree of product substitutability ascends and as research spillovers decline.

*\*\*\*Insert Figure 2 here\*\*\**

To sum up, we see that incorporation of research spillovers in a two-stage trade game has important effects in Stage 1 involving the choice of optimal research subsidy. In Stage 2 findings regarding the effects of trade liberalization generally support the earlier results with complete research appropriability, albeit the magnitudes of responses

to liberalization in the presence of spillovers are different. The presence of spillovers also enables firms to take account of changes in foreign research subsidies by strategically altering own research and production. Interestingly, the optimal research policy does not always involve subsidizing research and, at high spillovers, might in fact involve a tax.

### **CONCLUDING REMARKS**

The present research adds to the literature by incorporating research spillovers and allowing for imperfect appropriability of research returns. Introduction of research spillovers in the trade game model of HAALAND AND KIND [2008] makes the framework more realistic and yields a number of interesting results. The underlying framework examines the effects of policy changes on research subsidies and firm behavior in the context of international trade when there are cost-reducing innovations and no uncertainty. In the two-stage game under consideration policymakers choose optimal research subsidies in the first stage, while firms take account of the subsidy levels in choosing research and production in the second stage.

Our results show that incorporation of research spillovers in a two-stage game has important effects. Specifically, optimal research subsidies under spillovers are different from those when spillovers are not considered. In Stage 2 findings regarding the effects of trade liberalization generally support the earlier results with perfect

research appropriability. The magnitudes of responses to trade liberalization, however, are different – with spillovers the (absolute values of) effects are larger in magnitude. Research spillovers also induce the domestic firm to take strategic account of foreign subsidy changes. Interestingly, the optimal research policy does not always involve subsidizing research and, depending upon the extent of spillovers, might in fact involve a tax. This happens because with substantial research leakages foreign benefit outweighs domestic research gains. Hence, governments maximize domestic welfare by taxing R&D.

From a policy angle, research subsidies that maximize welfare are different in the presence of spillovers than in their absence. Policy makers might need to revise technology policies as there are changes in degrees of technological leakages. Policy changes lowering international trade costs also trigger more pronounced responses under spillovers. Research subsidies might give way to taxes at high spillover levels. Domestic subsidies to boost research might also prove unnecessary when increases in foreign subsidies in the presence of spillovers are enough to raise domestic R&D. Thus, policymakers might have to periodically reconsider subsidies as the structure of research markets changes, there are changes in foreign subsidies or there is a change in firms' abilities to guard proprietary information. Ignoring spillovers would imply a lack of consideration of important strategic connections and is likely to leave existing subsidies unchanged.

Future research could extend the analysis by examining indirect R&D spillovers (see LUMENGA-NESO ET AL. [2005]), alternate aspects of policy competition (see HAALAND AND KIND [2006, 2008], LEAHY AND NEARY [2009]; also CARLSON [2008], DECOURCY [2005]) and/or by allowing for innovation/spillover uncertainty (BAGWELL AND STAIGER [1994], GOEL [1999], and MIYAGIWA AND OHNO [1997]). These extensions seem beyond the scope of present research.

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