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Competitive and Harmonised R&D Policies for International R&D Alliances involving Asymmetric Firms

By

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Abstract

We examine research and development (R&D) policies when a national firm forms an R&D alliance with a foreign competitor. Firms differ in their R&D capabilities, and adopt a profit-sharing rule when R&D decisions are coordinated. National R&D tax/subsidy policies are set independently or harmonised. When firms coodinate their R&D decisions and governments choose R&D policies independently, R&D taxes are chosen. But there is no intervention if policies are harmonised. These policy outcomes affect the types of R&D alliance choosen. Agreements to share R&D information may be preferred to those combining coordination of R&D decisions and information sharing because of the R&D tax that coordination attracts.

JEL Classification: F13, O32, O38, L13, D43

Keywords: R&D efficiency, asymmetric R&D alliance, cost-reducing R&D, R&D policy, cooperative R&D agreement.

Outline

Non-Technical Summary

Cooperation with competitors has become a popular strategy for firms in innovation-led markets. The forms of R&D cooperation that arise are quite heterogeneous and the participarting firms often differ in size, though most alliances are between two partners only. R&D alliances between firms based in different countries are of particular interest because of the implied interactions between national R&D policies. In this paper, we allow firms who are asymmetric in their cost of R&D to choose their cross-border R&D regime from four types according to the way the partner firms make R&D decisions and the degree of information sharing among them. We set up our model by showing that when the home and foreign governments compete in their R&D policy, R&D subsidies are their optimal policies if their firms compete in R&D or form an international Research Joint Venture (RJV). The two traditional motives - rent-shifting and spill-back – drive this intervention, and, regardless of the level of spillovers, the interactions of the two motives always suggest an R&D subsidy.

The innovation in our analysis arises in the cases of a R&D cartel and a RJV cartel which require the asymmetric firms to coordinate their R&D decisions and where we introduce a profit-sharing rule which is implemented through a transfer payment mechanism. Whenever firms coordinate their R&D decisions, this significantly altered the motives underlying government's interventions from what is conventionally considered. Each government realizes that the incidence of any tax/subsidy on its national firm will be internalized by the alliance so that the tax burden (subsidy benefit) is distributed among the alliance members, while the government collects/disburses all the tax/subsidy revenue. We find that in these circumstances a R&D tax is always justified when firms coordinate their decisions. If the firms choose the R&D regime prior to the government interventions, we show that the anticipation of these taxes may mean that a research joint venture cartel, where firms agree to share information completely and coordinate their R&D decisions, may no longer be the most profitable form of R&D cooperation.

We also investigate the optimal form of intervention when the governments harmonize their policies. We confirm that when firms compete in R&D, whether a R&D subsidy or tax is optimal depends on the size of the spillovers between the firms. However, whenever firms coordinate their R&D decisions, harmonised non-intervention is optimal, and if an equal sharing rule is adopted, the firms find an information sharing agreement the most attractive form of cooperation.

1 Introduction

Cooperation with direct competitors has become a common strategy for firms in innovation-led markets. The underlying motives include: sharing the cost and risk of undertaking R&D; gaining access to partner's technology and know-how; enhancing efficiency through economies of scale in production or R&D; and exploiting synergy effects from sharing and monitoring partner's technology (Veugelers, 1999). The forms of R&D cooperation that arise are quite heterogeneous and the participarting firms often differ in size. Veugelers (1993) investigates 668 alliances covering all major economies for the period 1986-1992, and claims that a considerable number of alliances consisted of asymmetrically-sized partners[1]. The sources of asymmetry come not just from home market size differences, but also from differences in partners' technologies, capacities, production and R&D efficiency and absorptive capacity. Veugelers categorizes a company belonging to the "Fortune Global 500 for Industries and Services" as a global company, and reports that 37% of the R&D alliances are between global and non-global players. Interestingly, asymmetric alliances do not necessarily adopt asymmetric profit sharing rules, as Veugelers finds that up to half of all asymmetric alliances (i.e. between global and non global players) adopt an equal sharing rule[2]. Almost all alliances reported are between two partners only.

R&D alliances between firms based in different countries are of particular interest because of the implied interactions between national R&D policies. A number of papers have addressed the issue of R&D policy in a multi-stage international game environment. The Spencer and Brander (1983) model has proved a remarkable workhorse and source of extensions in this area[3]. In Spencer and Brander's three-stage game, the home government commits to a R&D

[1]The data set is built from registration of alliances as they appeared in the financial press. Alliances are codified along relevant organizational dimensions as well as size, sector and nationality of partners. See (Veugelers, 1993).

[2]Of course joint ventures may be impossible under an equal sharing rule if partners are too asymmetric (Veugelers and Kesteloot, 1995).

[3]The literature examining the costs and benefits of R&D cooperation and their policy interactions is by now quite large. We discuss the most relevant work in the text, but other closely related work includes Motta (1996) who shows that R&D alliances between domestic firms can provide a similar advantage to an export subsidy in foreign markets. DeCourcy (2005) extends this work to consider a wider range of alliances. Ghosh and Lim (2011) extend the Brander and Krugman (1983) reciprocal dumping model to consider trade liberalization in a context of R&D spillovers and potential R&D cooperation. Haaland and Kind (2006, 2008) consider R&D subsidy policies in an international duopoly with differentiated products, but ignore R&D spillovers. Petit and Sanna-Randaccio (2000) focus on the choice of market entry (exports or FDI) in the presence of R&D spillovers in a homogeneous product duopoly.

policy in the first stage; a home and a foreign firm engage in R&D rivalry in the second stage before competing in the output market of a third country in the final stage. In the absence of R&D spillovers, they show that a R&D subsidy can be strategically used to perform a rent-shifting role, whereby subsidized domestic R&D reduces foreign R&D, output and profit[4].

Leahy and Neary (1999), Neary and O'Sullivan (1999) and Qui and Tao (1998) incorporate R&D spillovers and R&D cooperation into their studies of R&D policies in a symmetric firms framework[5]. By allowing for domestic and international spillovers, Leahy and Neary (1999) show that a R&D subsidy may be justified not only because each home's firm R&D benefits other home firms, but also because spillovers cause firms' R&D to be strategic complements, so that the increased home firm R&D would induce increased foreign firm R&D which in turn 'spills back' internationally to benefit the home firm. Qui and Tao (1998) consider R&D policy in the case where involuntary spillovers are absent and firms coordinate their R&D decisions. They show that whenever firms coordinate, a R&D subsidy is always justified due to its rent-shifting role and to its ability to raise domestic R&D as the coordinating firms have an incentive to underinvest otherwise.

Several studies have investigated how asymmetries in firms' ability to perform R&D activites and make use of R&D output affect the success of R&D alliances (Veugelers and Kesteloot, 1996; Poyago-Theotoky, 1997; and Chaundhuri, 1995). Barros and Nilssen (1999) incorporate these asymmetries into a model with several domestic and foreign firms in order to consider firm-specific R&D policy[6]. The issues of spillovers and R&D cooperation are omitted from the analysis, however.

In this paper, we allow firms who are asymmetric in their cost of R&D to choose their cross-border R&D regime. We borrow the classification of Kamien, Muller and Zang (1992) where cooperation is classified into four types according to the way the partner firms make R&D

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[4]However, a R&D tax may also be prescribed if an export subsidy is available to play the rent shifting role, allowing the R&D tax to restore production efficiency by reducing the domestic firm's strategic incentive to overinvest compared to the social optimum value. See Neary (1998).

[5]See also Spence (1984), d'Aspremont and Jacquemin (1988), Kamien et al. (1992) and Suzumura (1992) for the effects of R&D spillovers on firms' incentive to invest and how R&D cooperation help internalize this externality.

[6] Neary and O'Sullivan (1999) also take into account these types of asymmetry when comparing the welfare-improving effects of R&D coordination with the provision of an export subsidy. Although the coordinating firms are asymmetric in their model, the issue of a profit-sharing is not taken up. The firm's net profit under R&D coordination is just its sales profit net of R&D cost. Similarly, Hinloopen (2001) assumes firms compete in differentiated products and allows governments to choose whether to subsidize R&D or not before firms decide whether to form cooperation. But again revenue sharing is not considered.

decisions and the degree of information sharing among them. In those R&D regimes which requires the asymmetric firms to coordinate their R&D decisions, we introduce a *profit-sharing rule* which is implemented through a transfer payment mechanism[7]. The presence of the profit-sharing rule directly affects the governments' motives for intervention, as it realizes that the incidence of any tax/subsidy on its national firm will be internalized by the alliance so that the tax/subsidy burden/benefit is distributed among the alliance members, while the home government collects/disburses all the tax/subsidy revenue.We find that in these circumstances a R&D tax is always justified when firms coordinate their decisions. This is contrary to Qui and Tao (1998) who, in a symmetric firms setting, suggest a R&D subsidy is always optimal whenever firms coordinate. If the firms choose the R&D regime prior to the government interventions, we show that the anticipation of these taxes may mean that a research joint venture cartel, where firms agree to share information completely and coordinate their R&D decisions, may no longer be the most profitable form of R&D cooperation. Lastly, we investigate the optimal form of intervention when the governments harmonize their policies. We confirm that when firms compete in R&D, whether a R&D subsidy or tax is optimal depends on the size of the spillovers between the firms. However, whenever firms coordinate their R&D decisions, harmonised non-intervention is optimal, and if an equal sharing rule is adopted, the firms find an information sharing agreement the most attractive form of cooperation.

The paper is organized as follows. Section 2 discusses standard features of the model. In section 3, we assume that governments compete via R&D policies, and conduct detailed analysis of government interventions for each type of R&D regime, and determine the most attractive regime from the firms' perspectives. In section 4, we analyse the case where governments harmonize their interventions, determining the optimal forms of R&D policies and the motives behind them. Section 5 considers the R&D regime firms choose given the cooperation between governments   Concluding remarks are provided in section 6.

[7] While we do conduct some comparative statics analysis on the sharing ratio we do not model its determination here. Veugelers and Kesteloot (1996) consider the impact of asymmetries between alliance partners in terms of their production or R&D efficiency and absorptive capacity on the possibility of a successful joint venture. They compare the effect of using equal sharing rule on the success likelihood of the venture with the use of a bargained rule.

2 The Model

A home (h) and a foreign (f) firm export a homogenous product to a third market with linear inverse demand $P = 1 - \sum_{i=h,f} q_i$, where P and q_i denote price and firm i's product output respectively. In the absence of R&D, both h and f produce with the same marginal cost, $\bar{c}$ (< 1). Each firm can engage in cost-reducing R&D and we let $\beta \in [0,1]$, denote the proportion of involuntary spillovers of R&D output between the firms. If x_i denotes firm i's R&D output, its marginal production cost is $c_i = \max\{0, \bar{c} - X_i\}$, where $X_i \equiv x_i + \beta x_j$ can be interpreted as the effective R&D output available to firm i. The R&D cost function takes a standard form $R_i = \frac{x_i^2}{2\theta_i}$, with the only asymmetry between firms being in their different R&D efficiencies, denoted by $\theta_i \in (0,0.5)$[8]. We assume a unit of R&D output can be delivered at a lower cost by the foreign firm – i.e. $\theta_f > \theta_h$.

Our analysis employs a four-stage game. The first stage involves the firms selecting an R&D regime from the four types available: (1) *R&D Competition* (CP), where firms compete in their R&D; (2) *R&D Cartel* (CT), where firms coordinate their R&D decisions to maximize the alliance's joint profit, but do not share their R&D knowledge; (3) *Research Joint Venture* (RJV), where firms agree to maximize their information flows by fully sharing their R&D knowledge but do not coordinate their R&D decisions; and (4) *Research Joint Venture Cartel* (RCT), which is the most integrated form of cooperation, where firms coordinate their R&D decisions and maximizing the flows of information between them. An important assumption of our analysis is that whenever these asymmetric firms coordinate their R&D decisions, each knows that the profit generated will be *shared* between them in accordance with a predetermined rule. We assume that the R&D alliance is sustainable as long as the profit from cooperation is higher than the profit obtained under R&D competition for each firm.

In the second stage, given the R&D regime chosen by the firms, each government chooses an R&D policy so as to maximize its national benefits. Let s_i denote the R&D subsidy (or tax if negative) government i (G_i) provides to its national firm for each dollar the firm spends on R&D. We consider two alternatives at this stage: (1) *government competition*, where the governments choose their R&D policies simultaneously and independently; and (2)

[8] $\theta_i < 0.5$ is a stability of equilibrium condition that we rely on below.

government coordination, where they harmonize their R&D tax/subsidies.

In the subsequent stages, firms choose their R&D investments, taking as given the governments' interventions, and then compete in the product market. We presume competition policies in the third market preclude cooperation at the production stage. The subgame perfect Nash equilibrium (SPNE) is used as a solution concept in our analysis, hence the game is solved backwards.

3 Government Competition

In order to focus on the game played by governments, we will initially concentrate on the last three stages of the game, taking the R&D configuration as given.

3.1 R&D Competition (CP)

In this case, a firm benefits from the R&D performed by the other firm only through the involuntary spillovers. The post-innovation unit cost of firm i is $c_i = \overline{c} - \left(x_i + \beta x_j\right)$, and the profit maximising output for firm i is then

$$q_i^* = \frac{K+(2-\beta)x_i+(2\beta-1)x_{j\neq i}}{3}; \qquad i = h, f \tag{1}$$

where $K \equiv 1 - \overline{c} > 0$ measures the effective market size. It follows immediately that a firm's R&D reduces its rival's output unless the spillovers are sufficiently large (i.e. unless $\beta > 0.5$).

In the R&D stage, firms independently choose R&D levels to maximizes their fourth-stage profits net of R&D expenditure, i.e. $\pi_i^* = P(q_i^*, q_j^*)q_i^* - c_i(x_i, x_j)q_i^* - \frac{(1-s_i)x_i^2}{2\theta_i}$. The corresponding first order conditions (FOC) gives firm i's reaction function: $x_i = \frac{2(2-\beta)\theta_i[K+(2\beta-1)x_{j\neq i}]}{9(1-s_i)-2\theta_i(2-\beta)^2}$. When spillovers are sufficiently large (i.e. $\beta > 0.5$), the firms' R&D expenditures are strategic complements. But when spillovers are relatively small, firms' R&D expenditures are strategic substitutes. Solving for equilibrium R&Ds, we obtain

$$x_i^* = \frac{6\theta_i(2-\beta)K[3(1-s_j)-2\theta_j(2-\beta)(1-\beta)]}{\Omega_{CP}}; \qquad i \in \{h, f\}, i \neq j^{9} \tag{2}$$

[9] Where $\Omega_{CP} \equiv [9(1-s_i) - 2\theta_i(2-\beta)^2][9(1-s_j) - 2\theta_j(2-\beta)^2] - 4\theta_i\theta_j(2-\beta)^2(2\beta-1)^2 > 0$ from the relevant

Substituting (2) in (1), we have[10]

$$q_i^{**} = \frac{9(1-s_i)K[3(1-s_j)-2\theta_j(2-\beta)(1-\beta)]}{\Omega_{CP}} > 0. \tag{3}$$

One can show that[11] s_i always enhances x_i, and will increase (reduce) firm j's incentive to invest when R&Ds are strategic complements (substitutes). If $\beta = 0.5$, s_i has no impact on x_j.

The analysis of firm's incentives to undertake R&D yields standard results[12]. When spillovers are low $(\beta < 0.5)$, each firm aims to create a gap between its own and its rival's costs (the strategic incentive), and tends to overinvest in R&D compared to the efficient level of R&D which is determined purely by the profit incentive[13]. While if spillovers are high, R&Ds are strategic complements, and each firm underinvests to limit its rival's free-riding.

In the second stage, both governments simultaneously and independently choose R&D subsidies so as to maximize national benefit which comprises the national firm's profit net of subsidy expenditure – i.e.G_i

$$\max_{s_i} W_i = \max_{s_i}[\pi_i^{**} - s_i \frac{(x_i^*)^2}{2\theta_i}] = \max_{s_i}[(q_i^{**})^2 - \frac{(x_i^*)^2}{2\theta_i}]; \;\; i \in \{h, f\} \tag{4}$$

The corresponding FOCs give the governments' reaction functions:

$$s_h(s_f) = \frac{2\theta_f(2\beta-1)^2}{3[3(1-s_f)-2\theta_f(1-\beta^2)]} \text{ and } s_f(s_h) = \frac{2\theta_h(2\beta-1)^2}{3[3(1-s_h)-2\theta_h(1-\beta^2)]}.$$

Solving for equilibrium R&D subsidies, we obtain[14]

$$s_i^{CP} = \begin{cases} \frac{E_i - \sqrt{E_i^2 - Z_i}}{6(3-2\theta_j(1-\beta^2))} > 0 \text{ for } \beta \neq 0.5, i \in \{h, f\}, i \neq j \\ 0 \qquad\qquad\qquad \text{for } \beta = 0.5 \end{cases} \tag{5}$$

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stability condition. The conditions $\theta_h < 0.5$ and $\theta_f < 0.5$ suffice for the second order conditions (SOCs), stability conditions and interior conditions to hold in the R&D and output subgames. Derivations of these and similar conditions assumed in the following subsections are available from the authors upon request.

[10] The stability condition suffices for $q_i^{**} > 0$.

[11] $\frac{dx_i^*}{ds_i} = \frac{18\theta_i(2-\beta)K[9(1-s_j)-2\theta_j(2-\beta)^2][9(1-s_j)-6\theta_j(2-\beta)(1-\beta)]}{\Omega_{CP}^2} > 0$; $\frac{dx_i^*}{ds_j} = \frac{108\theta_i\theta_j(2-\beta)^2(2\beta-1)K[3(1-s_i)-2\theta_i(2-\beta)(1-\beta)]}{\Omega_{CP}^2} \gtreqless 0$ iff $\beta \gtreqless 0.5$.

[12] See also Neary and O' Sullivan (1999), Qui and Tao (1998), Kamien et. al. (1992).

[13] This incentive refers to the attempt to use R&D to reduce its own production cost, thus increases profit.

[14] Where $E_i \equiv 9 - 2\theta_i(2-\beta)^2 - 2\theta_j(2+4\beta-7\beta^2) + 4\theta_i\theta_j(1-\beta^2)^2 > 0$; and $Z_i \equiv 8\theta_j(1-2\beta)^2[3-2\theta_i(1-\beta^2)][3-2\theta_j(1-\beta^2)] > 0$. Since $\frac{ds_f}{ds_h(s_f)} = \frac{(2\beta-1)^2}{9s_h^2} > 0$, $\frac{d^2s_f}{d[s_h(s_f)]^2} = \frac{-2(2\beta-1)^2}{s_h^3} < 0$ and $\frac{ds_f(s_h)}{ds_h} = \frac{2\theta_h(2\beta-1)^2}{[3(1-s_h)-2\theta_h(1-\beta^2)]^2} > 0$, $\frac{d^2s_f(s_h)}{ds_h^2} = \frac{12\theta_h(2\beta-1)^2}{[3(1-s_h)-2\theta_h(1-\beta^2)]^3} > 0$, $s_h(s_f)$ is concave and $s_f(s_h)$ is convex and they intersect twice in the (s_h, s_f) space. However, the unstable equilibrium in the government subgame is ruled out by the s.o.c. and the stability condition derived in the R&D stage (i.e. θ_h and θ_f < 0.5).

Given $\theta_f > \theta_h$, it follows that the superior firm receives a higher subsidy (i.e. $s_f^{CP} > s_h^{CP}$).

As this is our benchmark case, we disentangle the effects of s_i on W_i in more detail. From (4), at the optimum

$$\frac{dW_i(s_i,s_j)}{ds_i} = \frac{d\pi_i^{**}(x_i^*,x_j^*;s_i,s_j)}{ds_i} - \frac{(x_i^*)^2}{2\theta_i} - s_i^{CP}\frac{(x_i^*)^2}{\theta_i}\frac{dx_i^*}{ds_i} = 0. \tag{6}$$

Since
$$\frac{d\pi_i^{**}(x_i^*,x_j^*;s_i,s_j)}{ds_i} = \underbrace{\frac{\partial\pi_i^{**}}{\partial x_i}\frac{dx_i^*}{ds_i}}_{0 \text{ from} 3^{rd} \text{stage FOC}} + \frac{\partial\pi_i^{**}}{\partial x_j}\frac{dx_j^*}{ds_i} + \underbrace{\frac{\partial\pi_i^{**}}{\partial s_i}}_{\frac{(x_i^*)^2}{2\theta_i}}.$$

Equation (6) becomes
$$\frac{dW_i(s_i,s_j)}{ds_i} = \frac{\partial\pi_i^{**}}{\partial x_j}\frac{dx_j^*}{ds_i} - s_i^{CP}\frac{x_i^*}{\theta_i}\frac{dx_i^*}{ds_i} = 0. \tag{7}$$

Now
$$\frac{\partial\pi_i^{**}}{\partial x_j} = \underbrace{\frac{\partial\pi_i^{**}}{\partial q_i}\frac{dq_i^*}{dx_j}}_{0 \text{ from} 4^{th} \text{stageFOC}} + \underbrace{\frac{\partial\pi_i^{**}}{\partial q_j}\frac{dq_j^*}{dx_j}}_{-q_i^{**}\left(\frac{2-\beta}{3}\right)} + \underbrace{\frac{\partial\pi_i^{**}}{\partial x_j}}_{\beta q_i^{**}}.$$

So (7) can be rearranged as

$$s_i^{CP}\frac{x_i^*}{\theta_i}\frac{dx_i^*}{ds_i} = \underbrace{\underbrace{\left(\frac{\partial\pi_i^{**}}{\partial q_j}\frac{dq_j^*}{dx_j}\right)}_{-q_i^{**}\left(\frac{2-\beta}{3}\right)<0} * \underbrace{\frac{dx_j^*}{ds_i}}_{\gtreqless 0 \text{ for } \beta \gtreqless 0.5}}_{\text{rent-shifting motive}} + \underbrace{\underbrace{\left(\frac{\partial\pi_i^{**}}{\partial x_j}\right)}_{\beta q_i^{**}>0} * \underbrace{\frac{dx_j^*}{ds_i}}_{\gtreqless 0 \text{ for} \beta \gtreqless 0.5}}_{\text{spill-back motive}} \tag{8}$$

where we have used $\frac{dx_i^*}{ds_i} > 0$ for all β, and $\frac{dx_j^*}{ds_i} \gtreqless 0$ as $\beta \gtreqless 0.5$ from the R&D subgame. Two motives are involved when a government sets its subsidy. The *rent-shifting motive* (henceforth, RS) reflects G_i's intention to use s_i to influence x_j so as to shift rent to firm i. For $\beta < 0.5$, R&Ds are strategic substitutes and this motive calls for $s_i > 0$ to raise x_i which reduces x_j and raises π_i. When $\beta > 0.5$, R&Ds are strategic complements and this motive is reversed (i.e. $s_i < 0$). The strength of this motive declines as β increases (for all β). As firm i's access to x_j increases, the effectiveness of x_j in raising q_j falls (i.e $\frac{dq_j^*}{dx_j}$ gets smaller), thus the strength of the RS declines. The *spill-back motive* (henceforth, SB) refers to G_i's intention to use s_i to encourage x_j, with the expectation that the home firm free rides on its competitor's innovative output[15] ($\frac{\partial \pi_i^{**}}{\partial x_j} > 0$). When $\beta > (<) 0.5$, R&Ds are strategic complements (substitutes), and an R&D subsidy (tax) on the home firm can encourage x_j. Obviously, the magnitude of SB rises with β.

Ultimately, the sign of s_i^{CP} depends on the interaction of these two motives. When $\beta < 0.5$, RS suggests an R&D subsidy and SB an R&D tax, while the opposite is true for $\beta > 0.5$. But with linear demand and constant marginal costs, we have an unambiguous outcome. When we combine the two motives in (8) we have,

$$s_i^{CP} \frac{x_i^*}{\theta_i} \frac{dx_i^*}{ds_i} = \underbrace{\frac{\partial \pi_i^{**}}{\partial x_j}}_{2(2\beta-1)q_i^{**}} * \underbrace{\frac{dx_j^*}{ds_i}}_{\gtreqless 0 \text{ iff } \beta \gtreqless 0.5} \tag{9}$$

An *R&D subsidy* is always called for, due to the domination of SB when $\beta > 0.5$, and RS when $\beta < 0.5$. Our results so far replicate those found in the case of international R&D collaboration in Qui and Tao (1999). Their degree of collaboration can be interpreted as our level of involuntary R&D spillovers. Using this optimal s^{CP}, we compare the firm's R&D, product quantity, profits, and countries' benefit[16] in the second column of Table 1.

We showed earlier that the superior firm receives a higher R&D subsidy. In the absence of government intervention, this firm also has a higher incentive to invest in R&D due to its higher R&D efficiency. In combination these imply a higher R&D output by the superior firm. When spillovers are not too pervasive, the superior firm receives the higher net profit and the foreign country the higher benefits. But if β is very high, the inferior firm has large gains from free-riding and these could be so significant as to give it the higher profit.

Finally Table 2 (column 2) reports comparative statics on s_i^{CP} for various special cases[17]. If firms are symmetric ($\theta_i = \theta_j = \theta$), the optimal R&D subsidy falls to zero as β increases from 0 to 0.5 and rises again as β increases from 0.5 to 1. The rationale is straightforward; for $0 < \beta < 0.5$, the RS, whose strength is falling in β dominates; while

[15]See Leahy and Neary (1999) for a full analysis of the spill-back effect.

[16]The comparisons for profit and welfare are attained through graphic simulations using Mathematica Software. To facilitate the simulations, we fix θ_f and K at 0.49 and 1 respectively and allow $\theta_h \in (0,0.49)$ and $\beta \in [0,1]$.

[17]Details are available from the authors upon request.

when $0.5 < \beta < 1$ the SB, whose strength rises in β, dominates. Also, as firms become more efficient in R&D, the dominant motive grows stronger, hence justifying a higher R&D subsidy. If there are no involuntary spillovers ($\beta = 0$), SB is absent. A higher θ_i then implies a greater ability of firm i in shifting rent, and a rise in θ_j means that a higher rent shifting subsidy is called for. If involuntary spillovers are complete ($\beta = 1$), SB dominates and is at its maximum. An increase in θ_i enhances the ability of x_i to induce x_j, thus justifying a larger subsidy. In addition, an increase in θ_j results in a higher x_j, and a larger SB, also justifiing a larger subsidy.

3.2 R&D Joint Venture (RJV)

Under this regime, firms avoid inefficient duplication of R&D outcomes, but do not coordinate their R&D decisions. The cost of conducting R&D still differs across firms and this scenerio is equivalent to R&D competition with complete spillovers ($\beta \equiv 1$). We can therefore infer that under a RJV, both firms underinvest in R&D compared to the efficient level due to the large voluntary spillovers. The optimal policy intervention is an R&D subsidy as SB dominates RS at $\beta \equiv 1$. Thus[18],

$$s_i^{RJV} = s_i^{CP}(\beta \equiv 1) = \frac{E_i - \sqrt{E_i^2 - Z_i}}{18} > 0,$$

When $\beta \equiv 1$, the superior firm receives a higher subsidy, invests more and produces more output, but has a lower profit than the inferior firm, and foreign benefits are thus lower than home benefits (Table 1 column 3). In addition, the more efficient a firm or its 'rival' becomes in conducting R&D, the higher the subsidy received, because of the dominance of the spill-back motive[19].

[18] Where $E_i = 9 - 2\theta_i + 2\theta_j$ and $Z_i = 72\theta_j$.

[19] $\frac{ds_i^{RJV}}{d\theta_i} = \frac{E_i - \sqrt{E_i^2 - Z_i}}{9\sqrt{E_i^2 - Z_i}} > 0$, and $\frac{ds_i^{RJV}}{d\theta_j} = \frac{E_i + \sqrt{E_i^2 - Z_i}}{9\sqrt{E_i^2 - Z_i}} > 0$.

3.3 R&D Cartel (CT)

In this scenerio, firms deal with the problem of incomplete appropriability of their R&D output by coordinating their R&D decisions to maximize the cartel joint profits. This requires a profit sharing agreement, and we take the *profit sharing ratio* as exogeneously determined. A transfer payment between firms is required to sustain the agreement, reflecting the R&D cost sharing aspect of the cartel. Since the cooperation does not extend to the output stage, the output subgame is exactly as in the R&D competition case.

In the R&D stage, firms coordinate their R&D decision to maximize the sum of profit net of the R&D cost of each member: $\max_{x_i} \Pi = \max_{x_i} \sum_{i,j} \hat{\pi} = \max_{x_i} \sum_{i,j} ((\hat{q}_i)^2 - \frac{(1-s_i)x_i^2}{2\theta_i})$, where Π denotes the cartel's joint profit, and $\hat{q}_i$ refers to equilibrium quantity derived in the final stage. The corresponding FOCs give the firms' R&D response functions: $x_i = \frac{2\theta_i[(1+\beta)K+2(2\beta-1)(2-\beta)x_j]}{9(1-s_i)-2\theta_i(5\beta^2-8\beta+5)}$. Solving for equilibrium R&D and quantity, x_i and q_i, we obtain[20]

$$\hat{x}_i = \frac{18\theta_i(1+\beta)K[1-s_j-2\theta_j(1-\beta)^2]}{\Omega_{CT}}, \tag{10}$$

$$\hat{\hat{q}}_i = \frac{9k[3(1-s_i)(1-s_j)-2\theta_j(1-s_i)(2-\beta)(1-\beta)-2\theta_i(1-s_j)(1-\beta)(1-2\beta)]}{\Omega_{CT}} \tag{11}$$

One can show that an increase in s_i will always increase x_i, while an increase in s_j will increase (decrease) x_i when R&Ds are strategic complements (substitutes)[21]. Further, $\hat{x}_f > \hat{x}_h$ and $\hat{q}_f > \hat{q}_h$ only when $\frac{(1-s_h)}{\theta_h} > \frac{(1-s_f)}{\theta_f}$ (i.e. the post-subsidy marginal cost of x_h is greater than that of x_j at the same R&D level). In the specific case of no interventions, the more efficient firm invests and produces more than the inferior firm.

In determining its R&D investment, each firm now takes into account (a) that its R&D negatively affects its partner's profit through the output market, and thus tends to reduce its own R&D (a coordination incentive); and (b) that its R&D positively affects its partner's profit via spillovers, and so tends to increase its R&D (a spillover incentive). Since each firm still has the

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[20] $\Omega_{CT} \equiv 9(1-s_i) - 2\theta_i(5\beta^2 - 8\beta + 5)][9(1-s_j) - 2\theta_j(5\beta^2 - 8\beta + 5)] - 16\theta_i\theta_j(2-\beta)^2(2\beta-1)^2 > 0$ from the relevant stability condition.

[21] $\frac{d\hat{x}_i}{ds_i} > 0$ for all β, while $\frac{d\hat{x}_i}{ds_j} \gtreqless 0$ if $\beta \gtreqless 0.5$.

conventional strategic and profit incentives to perform R&D, these additional incentives make the firm's R&D decision more complex. However, it can be shown that the coordination incentive dominates when spillovers are relatively low, thereby causing the partner firms to restrict their R&D; while the spillover incentive dominates, inducing firms to overinvest in R&D, when spillovers are high[22].

In the second stage, governments simultaneously choose policies. Let $\delta \in [0,1]$ denote the proportion of the cartel's profit allocated to h, so that $v_h \equiv \delta\widehat{\Pi}$ and $v_f \equiv (1-\delta)\widehat{\Pi}$ are the profits allocated to the home and foreign firm respectively. Then the countries' welfare functions take the form:

$$W_h(s_h, s_f) = v_h(s_h, s_f) - \frac{s_h\left(\hat{x}_h(s_h,s_f)\right)^2}{2\theta_h}; \tag{12}$$

$$W_f(s_h, s_f) = v_f(s_h, s_f) - \frac{s_f\left(\hat{x}_f(s_h,s_f)\right)^2}{2\theta_f}. \tag{13}$$

The corresponding FOCs yield the governments' reaction functions (not shown) where R&D policies are found to be strategic complements[23]. The equilibrium R&D policies[24] are *R&D taxes (i.e.* $s_h^{CT}, s_f^{CT} < 0$). The comparative statics depend on the value of δ. If we consider the common case where $\delta = 0.5$, it can be easily deduced that the inferior firm is taxed more heavily (i.e. $s_h^{CT} < s_f^{CT}$). Since $\frac{(1-s_h^{CT})}{\theta_h} > \frac{(1-s_f^{CT})}{\theta_f}$ always holds in equilibrium, $x_f^{CT} > x_h^{CT}$ and $q_f^{CT} > q_h^{CT}$ also hold in this case.

One of this paper's intended contributions is disecting the rationale underlying the optimal R&D tax. We adopt common notation for both countries by letting $\hat{\delta}_i$ denote the proportion of $\widehat{\Pi}$ allocated to firm i, i.e $\hat{\delta}_h = \delta$, and $\hat{\delta}_f = (1-\delta)$. From (12) and (13), the welfare maximising FOC for G_i is

$$\frac{dW_i(s_h,s_f)}{ds_i} = \hat{\delta}_i \frac{d\widehat{\Pi}(s_i,s_j)}{ds_i} - \frac{\left(\hat{x}_i(s_i,s_j)\right)^2}{2\theta_i} - s_i \frac{\hat{x}_i}{\theta_i}\frac{d\hat{x}_i}{ds_i} = 0. \tag{14}$$

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22 See Kamien et. al. (1992) for a formal analysis of firm's incentive to invest.

23 $\frac{ds_h(s_f)}{ds_f} = \frac{(1-\delta)16\theta_h\theta_f(2-\beta)^2(1-2\beta)^2}{(1+\delta)[9(1-s_f)-2\theta_f(5-8\beta+5\beta^2)]^2} > 0$, $\frac{ds_f(s_h)}{ds_h} = \frac{16\delta\theta_h\theta_f(2-\beta)^2(1-2\beta)^2}{(2-\delta)[9(1-s_f)-2\theta_f(5-8\beta+5\beta^2)]^2} > 0.$

24 $s_h^{CT} = \frac{9\delta(I+M)+L-\sqrt{9(1+\delta)(1-\delta)H_hH_f(I+M)+\{9\delta(I+M)+L\}^2}}{9(1+\delta)H_f}$; and $s_f^{CT} = \frac{9(1-\delta)I-9\delta M+J-\sqrt{9\delta(2-\delta)H_hH_f(I+M)+\{9(1-\delta)I-9\delta M+J\}^2}}{9(2-\delta)H_h}$,
where $H_h \equiv 9-2\theta_h(5-8\beta+5\beta^2) > 0$, $H_f \equiv 9-2\theta_f(5-8\beta+5\beta^2) > 0$, $I \equiv 9-2\theta_h(5-8\beta+5\beta^2)-2\theta_f(5-8\beta+5\beta^2)$, $M \equiv 4\theta_h\theta_f(1-\beta^2)^2 > 0$, $J \equiv 4\theta_h\theta_f(17-40\beta+48\beta^2-40\beta^3+17\beta^4)$, $L \equiv 8\theta_h\theta_f(2-\beta)^2(1-2\beta)^2$.

The first term on the RHS can be written as:

$$\frac{\hat{\delta}_i d\hat{\Pi}(s_i,s_j)}{ds_i} = \hat{\delta}_i \left(\frac{\partial\hat{\hat{\pi}}_i}{\partial x_i}\frac{d\hat{x}_i}{ds_i} + \frac{\partial\hat{\hat{\pi}}_i}{\partial x_j}\frac{d\hat{x}_j}{ds_i} + \underbrace{\frac{\partial\hat{\hat{\pi}}_i}{\partial s_i}}_{\frac{(\hat{x}_i)^2}{2\theta_i}} + \frac{\partial\hat{\hat{\pi}}_j}{\partial x_i}\frac{d\hat{x}_i}{ds_i} + \frac{\partial\hat{\hat{\pi}}_j}{\partial x_j}\frac{d\hat{x}_j}{ds_i} + \underbrace{\frac{\partial\hat{\hat{\pi}}_j}{\partial s_i}}_{0} \right), \quad (15)$$

Substituting (15) back in (14), we have

$$\frac{dW_i}{ds_i} = \hat{\delta}_i \left[\underbrace{\left(\frac{\partial\hat{\hat{\pi}}_i}{\partial x_i} + \frac{\partial\hat{\hat{\pi}}_j}{\partial x_i}\right)}_{0 \text{ from } 3^{rd} \text{ stage FOC}} \frac{d\hat{x}_i}{ds_i} + \underbrace{\left(\frac{\partial\hat{\hat{\pi}}_i}{\partial x_j} + \frac{\partial\hat{\hat{\pi}}_j}{\partial x_j}\right)}_{0 \text{ from } 3^{rd} \text{ stage FOC}} \frac{d\hat{x}_j}{ds_i} + \underbrace{\frac{\partial\hat{\hat{\pi}}_i}{\partial s_i}}_{\frac{(\hat{x}_i)^2}{2\theta_i}} \right] - \frac{(\hat{x}_i)^2}{2\theta_i} - s_i \frac{\hat{x}_i}{\theta_i}\frac{d\hat{x}_i}{ds_i} = 0$$

Rearranging we obtain

$$s_i^{CT} = -\frac{(1-\hat{\delta}_i)\hat{x}_i}{2} \Big/ \frac{d\hat{x}_i}{ds_i} < 0. \quad (16)$$

Since $\frac{d\hat{x}_i}{ds_i} > 0,$ a *R&D tax* is the optimal policy.

As in the case of R&D competition, the term $\frac{\partial\hat{\hat{\pi}}_i}{\partial x_j}\frac{d\hat{x}_j}{ds_i}$ in (15) represents the combined RS and SB motives. Facing a R&D cartel, G_i considers $\hat{\delta}_i\hat{\Pi}$ when choosing s_i; so the RS and SB motives are internalized. Each government anticipates that any subsidy provided to its firm will be shared among the cartel members, and the direct benefit accrued to its own firm is only $\hat{\delta}_i \frac{\partial\hat{\hat{\pi}}_i}{\partial s_i}$. Therefore, each government has an incentive to tax its national firm, as it knows that the tax cost will be shared within the cartel, while it claims the entire tax revenue. The optimum tax is reached when the negative impact of the R&D tax borne by firm i (i.e. $\hat{\delta}_i \frac{(\hat{x}_i)^2}{2\theta_i}$) is equal to the benefit to country i (i.e. $\frac{(\hat{x}_i)^2}{2\theta_i} + s_i \frac{\hat{x}_i}{\theta_i}\frac{d\hat{x}_i}{ds_i}$). They converge because the higher the tax, the lower the R&D level this firm will be assigned by the cartel and hence the lower the tax revenue. Two points should be noted. First, the governments' incentive to intervene through a R&D tax is unaffected by the level of spillovers as the government takes the cartel's joint profit into account when maximizing benefits. Second, the sharing proportion, $\hat{\delta}_i$, has no effect on the type of intervention, but does affect its magnitude. The optimal home tax is decreasing in the home firms profit share ($\hat{\delta}_i$), *ceteris paribus*. These findings are summarized in the following proposition:

Proposition 1 *When governments compete in their R&D policies, and firms apply a fixed profit-sharing rule to the cartel profit, intervention through a R&D tax is always optimal.*

The comparative statics results on the R&D tax under various specifications are summarized in column 4 of Table 2. If firms are symmetric ($\theta_i = \theta_j$), higher spillovers imply lower taxes for very high β, and the reverse is true for lower β. The intuition is straightforward. With coordinated R&D decisions, the cartel has an incentive to increase x_i as β rises because it knows that both firms gain. G_i can take advantage of this by increasing the tax rate to seek higher tax revenue. However, when β is very high, coordinated actions yield high R&D outputs by both partners implying a tax increase has a strong effect on the firm i's marginal cost of R&D. The cartel therefore switches R&D tasks to the partner, in which case tax revenue may fall.

If $\beta = 0$, we find that any increase in θ_i or θ_j reduces the R&D tax. As θ_i increases, firm i conducts more R&D and incurs a higher unit cost of R&D output. G_i chooses to lower the tax rate to reduce the incentive for the cartel to switch R&D to the partner.[25] If θ_j increases, the cartel responds by reducing x_i, and G_i cuts its tax to moderate the reduction in revenue[26]. In the absence of spillovers, our *R&D cartel* has the characteristics of *R&D coordination* (when firms choose to coordinate decisions but not to share information) in Qui and Tao (1998). In this case joint profit maximisation means each firm *underinvests* in R&D. However, as their firms are symmetric, the need for transfer payments among firms does not arise. Consequently, when G_i chooses its R&D policy, it considers only $\hat{\hat{\pi}}_i$, and hence its motives for intervention are captured by[27] $\frac{\partial \hat{\hat{\pi}}_i}{\partial x_i}\frac{d\hat{x}_i}{ds_i} + \frac{\partial \hat{\hat{\pi}}_i}{\partial x_j}\frac{d\hat{x}_j}{ds_i}$. The first term indicates G_i's intention to boost x_i through s_i, and the second term reflects the traditional rent-shifting motive which implies a R&D subsidy. In

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[25]When domestic firms are competitive, Barros and Nilssen (1999) show that a firm should receive more favourable tax treatment if it becomes more efficient. A more efficient domestic firm is taxed less because it is relatively more successful at shifting rent from foreign firms, thus imposing a smaller negative external effect on the other domestic firms.

[26]When $\beta = 0.5$, $\frac{ds_i^{CT}}{d\theta_j} = 0$, because an increase in x_j does not induce firm i to change its R&D.

[27]There is no spill-back motive in Qui and Tao (1998).

other words, the government uses the R&D subsidy to counter its national firm's commitment to underinvest in R&D under the coordination agreement. But if, as in our case, G_i considers the effect of its policy on joint profits (Π), the only motive for intervention is to maximize tax revenue. In a sense, the tax reinforces the national firm's commitment to reduce R&D output.

If $\beta = 1$, we find that an increase in either firm's efficiency reduces both taxes. The intuition behind the own firm result is similar to that when $\beta = 0$. But that for the non-national firm is slightly different. When θ_j increases, it induces a rise x_j. This in turn increases x_i due to the strategic complementability of firms' R&D. But this gives a higher marginal cost of R&D and a reduction of tax rate can moderate the reallocation of R&D to the partner.

The transfer payment is crucial to making the cartel sustainable. The size and direction of the transfer depends on the sharing rule and the level of spillovers. Consider the simple case where $\hat{\delta}_i = 0.5$ and there are no government interventions. When β is relatively high, we find that[28] $\pi_f^{CT} < \pi_h^{CT}$, even though $x_h^{CT} < x_f^{CT}$ due to h's lower R&D efficiency. Firm h benefits significantly from x_f^{CT} via spillovers, and hence both firms experience similar reductions in marginal costs, while f carries a much larger burden of R&D expenditure. As a result, π_f^{CT} tends to be lower than π_h^{CT}. A payment of $\frac{\pi_h^{CT} - \pi_f^{CT}}{2}$ therefore has to be transfered from h to f to satisfy the equal sharing rule. When spillovers are relatively low, on the other hand, c_f is significant lower than c_h, which causes $q_f^{CT} > q_h^{CT}$ and $\pi_f^{CT} > \pi_h^{CT}$. As a result, a payment of $\frac{\pi_f^{CT} - \pi_h^{CT}}{2}$ has to made from firm f to firm h. Firm f is willing to do so as long as coordination is more beneficial than competition.

To make further analysis tractable, we assume an equal profit sharing rule. Further, due to the complexity of the closed form solutions, we have to resort to numerical simulation when making comparisons across firms and countries. These comparisons are summarized in column 4 of Table 1.The more R&D efficient firm faces a lower tax rate and has the higher incentive to perform R&D. This means f has a greater cost reduction and larger product output, except when $\beta = 1$, and experiences higher profits, except when β is relatively high. Although both firms overinvest compared to their efficient level when they coordinate their decisions in an

[28]Simulations show that $\pi_f^{CT} < \pi_h^{CT}$ when β is relatively high. For example, with θ_f fixed at 0.49, $K = 0.5$ and $\theta_h \in (0,0.49]$, $\pi_f^{CT} < \pi_h^{CT}$ when $\beta = 0.7$.

environment of pervasive spillovers, h is in an advantageous position as it gets free access to x_f. Due to the equal sharing rule, however, a transfer payment will have to be made from h to f. The home country attains lower welfare for all levels of β, mainly due to the lower levels of tax revenue collected.

3.4 RJV Cartel (RCT)

This regime combines the important features of a RJV and a R&D cartel: complete sharing of information and coordinating R&D decisions. It is simply the R&D cartel with $\beta \equiv 1$, and the results and intuition follow accordingly. In this case, firms tends to overinvest compared to its efficient level. The optimal R&D policy is a tax[29]. When $\hat{\delta} = 0.5$, we have $s_f^{RCT} > s_h^{RCT}$, $\frac{ds_h^{RCT}}{d\theta_h} > 0$ and $\frac{ds_h^{RCT}}{d\theta_f} > 0$. Furthermore, from column 4 of Table 2 we see that at $\beta \equiv 1$, $x_f^{RCT} > x_h^{RCT}$; $q_f^{RCT} = q_f^{RCT}$; $\pi_h^{RCT} > \pi_f^{RCT}$, and a transfer payment is to be made from h to f. This payment is equal to half the difference in R&D expenditures $\frac{1}{2}\left(\frac{(x_f^{RCT})^2}{2\theta_f} - \frac{(x_h^{RCT})^2}{2\theta_h}\right)$.

3.5 Choosing a R&D regime when governments compete in R&D policy

We now move to the first stage of the game where firms choose their form of cooperative agreement, taking into account the governments' policy stances for each R&D regime. For tractability, $\hat{\delta} = 0.5$ is assumed for the cases of R&D cartel and RJV cartel. We know from the governments' subgame that both will intervene through R&D subsidies if firms compete in R&D or form a RJV; and through R&D taxes if the firms engage in R&D or RJV cartels. Intervention is a dominant strategy for each government, even though simultaneous interventions may not be beneficial (i.e. welfare in both countries could be reduced)[30].

The profit levels are compared for given θ_i, θ_j and β. To help explain what drives the

[29] $s_h^{RCT} = \frac{9\delta I + L - \sqrt{9(1+\delta)(1-\delta)H_h H_f I + (9\delta I + L)^2}}{9(1+\delta)H_f} < 0$; and $s_f^{RCT} = \frac{9(1-\delta)I + J - \sqrt{9\delta(2-\delta)H_h H_f I + (9(1-\delta)I + J)^2}}{9(2-\delta)H_h} < 0$, where $H_h \equiv 9 - 4\theta_h > 0$, $H_f \equiv 9 - 4\theta_f > 0$, $I \equiv 9 - 4\theta_h - 4\theta_f > 0$ and $J \equiv L \equiv 8\theta_h\theta_f > 0$.

[30] The detailed analysis of the effects of simultaneous interventions on welfare are available from the authors upon request. A unilateral intervention always enhances the country's welfare. See Teerasuwannajak (2004).

omparisons, we compare each firm's R&D level under the different R&D regimes. Due to the complexity of equilibrium profit and R&D expressions, we resort to graphic simulations. Figures 1 and 2 show examples of those simulations. We fix K and θ_f at 1 and 0.49 respectively, and allow θ_h to take three values 0.49; 0.3; and 0.15 so that the role of the firms' relative R&D efficiencies are revealed. The net profit levels of the home and foreign firm are respectively shown in panels 1 to 3 and panels 4 to 6 of Figure 1. Figures 2 and 3 show the firms' autonomous R&D and effective R&D levels respectively.

Claim 2 *Under an equal profit-sharing rule and with government competition in R&D policies, the RJV cartel may not be the most beneficial form of R&D cooperation*[31]*. From the inferior firm's perspective, the RJV agreement always outperforms other regimes. The superior firm may find the RJV cartel most beneficial as long as the R&D efficiency of its potential partner is not too low compared to its own, and may opt for a R&D competition regime otherwise.*

Although in most cases the inferior firm's own R&D and its effective R&D are highest under a RJV cartel, the R&D taxes significantly affect the cartel joint profit. This makes the RJV agreement, which entitles this firm to both the R&D knowledge of the superior firm and a R&D subsidy from its government, the most attractive regime. Interestingly, in the case where firms are symmetric, intervention through taxes also makes the RJV cartel less desirable than the RJV from the home firm's point of view.

For the superior firm, the degree of inferiority of its partner does affect the potential benefit and viability of the RJV cartel. Although the R&D taxes affect the firms' incentives to undertake R&D, f's effective R&D is still highest under the RJV cartel provided that θ_h and β are not too low. Firm f finds that for a given level of θ_h, there exists a level of β, below which R&D competition outperforms a RJV cartel in terms of profits. With relatively low β, coordinating firms underinvest in R&D compared to their efficient levels, and have to bear the imposition of tax under a RJV cartel. This results in low effective R&D compared to that under R&D competition and that is why profit could be higher under the latter. However, as spillovers become more pervasive, the internalization of the free-rider problem that results in relatively

[31] In the symmetric framework with no intervention, Kamien et al. (1992) highlight the RJV cartel as the most promising form of cooperation in terms of investment, profit and welfare.

high effective R&D under a RJV cartel makes this regime more attractive again[32]. The larger the gap between firms' R&D efficiency, the more likely the superior firm is to prefer R&D competition, as its inferior partner cannot contribute much in terms of R&D, and thus profit to the cartel.

In summay, given the prospect of government intervention, a consensus on R&D regime may not be easily reached among asymmetric partners under an equal profit sharing rule. However, by adjusting the ratio of profit sharing to take into account the gap between firms' R&D efficiency, both firms may find that a certain form of cooperation fares better in terms of profits compared to other regimes. A consensus on potential form of R&D configuration could then be reached. Table 3, column 2 summarizes the forms of optimal R&D policy under each R&D regime when governments compete via their R&D policies and the R&D regime prefered by firms.

4 Government Coordination

In this section, we further explore the optimal forms of government intervention under the different R&D regimes, when the governments *harmonize* R&D policies so as to maximize the sum of benefits: $W_h + W_f$. Since the nature of the games played by the firms in the R&D and output stages are unaffected, we can deduce the third-stage equilibria of R&D, quantities and profits under each R&D regime by setting $s_i = s_j = s$. We can then start our analysis at the the government stage. We consider the scenerios in the same order as in Section 3, but due to the complexity of the closed form solutions we focus on the sign of and the rationale behind governments' intervention. The equilibrium value of s will not be shown.

4.1 R&D Competition (CP-C) and Research Joint Venture (RJV-C)

Setting $s_h = s_f = s$ in (2) and (3) gives the expressions for R&D and product outputs, and the cooperative solution chooses s to

[32]In the special case of unilateral government's intervention, the superior firm prefers paying a R&D tax under a RJV cartel to receiving a R&D subsidy under R&D competition.

$$\max\Psi = \max W_h + W_f = \max\left\{\pi_i^{**} + \pi_j^{**} - \frac{s}{2}\left(\frac{(x_i^*)^2}{\theta_i} + \frac{(x_j^*)^2}{\theta_j}\right)\right\}. \quad (17)$$

yielding FOC gives

$$\frac{d\Psi}{ds} = \frac{d\pi_i^{**}}{ds} + \frac{d\pi_j^{**}}{ds} - \frac{1}{2}\left(\frac{(x_i^*)^2}{\theta_i} + \frac{(x_j^*)^2}{\theta_j}\right) - \frac{s^{CP-C}}{2}\left(\frac{2x_i^*}{\theta_i}\frac{dx_i^*}{ds} + \frac{2x_j^*}{\theta_j}\frac{dx_j^*}{ds}\right) \quad (18)$$

$$= \frac{\partial\pi_i^{**}}{\partial x_i^*}\frac{dx_i^*}{ds} + \frac{\partial\pi_i^{**}}{\partial x_j^*}\frac{dx_j^*}{ds} + \frac{\partial\pi_i^{**}}{\partial s} + \frac{\partial\pi_j^{**}}{\partial x_i^*}\frac{dx_i^*}{ds} + \frac{\partial\pi_j^{**}}{\partial x_j^*}\frac{dx_j^*}{ds} + \frac{\partial\pi_j^{**}}{\partial s}$$

$$-\frac{1}{2}\left(\frac{(x_i^*)^2}{\theta_i} + \frac{(x_j^*)^2}{\theta_j}\right) - s^{CP-C}\left(\frac{x_i^*}{\theta_i}\frac{dx_i^*}{ds} + \frac{x_j^*}{\theta_j}\frac{dx_j^*}{ds}\right) = 0$$

Since $\frac{\partial\pi_i^{**}}{\partial x_i^*}$ and $\frac{d\pi_j^{**}}{dx_j^*}$ are both zero from the third stage, $\frac{\partial\pi_i^{**}}{\partial s}$ and $\frac{\partial\pi_j^{**}}{\partial s}$ are equal to $\frac{(x_i^*)^2}{2\theta_i}$ and $\frac{(x_j^*)^2}{2\theta_j}$ respectively, and using

$$\frac{\partial\pi_i^{**}}{\partial x_j^*} = \underbrace{\frac{\partial\pi_i^*}{\partial q_i^*}\frac{dq_i^*}{dx_j}}_{0} + \underbrace{\frac{\partial\pi_i^*}{\partial q_j^*}}_{-q_i^*\frac{(2-\beta)}{3}}\frac{dq_j^*}{dx_j} + \underbrace{\frac{\partial\pi_i^*}{\partial x_j}}_{\beta q_i^*}, \quad \text{and} \quad \frac{\partial\pi_j^{**}}{\partial x_i^*} = \underbrace{\frac{\partial\pi_j^*}{\partial q_i^*}}_{-q_j^*\frac{(2-\beta)}{3}}\frac{dq_i^*}{dx_i} + \underbrace{\frac{\partial\pi_j^*}{\partial q_j^*}\frac{dq_j^*}{dx_i}}_{0} + \underbrace{\frac{\partial\pi_j^*}{\partial x_i}}_{\beta q_j^*}.$$

Equation (18) implies:

$$s^{CP-C}\left(\frac{x_i^*}{\theta_i}\frac{dx_i^*}{ds} + \frac{x_j^*}{\theta_j}\frac{dx_j^*}{ds}\right) = \underbrace{\left(\frac{\partial\pi_i^*}{\partial q_j^*}\frac{dq_j^*}{dx_j}\right)\frac{dx_j^*}{ds}}_{G_i'\text{s rent-shifting motive}} + \underbrace{\frac{\partial\pi_i^*}{\partial x_j}\frac{dx_j^*}{ds}}_{G_i'\text{s spill-back motive}}$$

$$+ \underbrace{\left(\frac{\partial\pi_j^*}{\partial q_i^*}\frac{dq_i^*}{dx_i}\right)\frac{dx_i^*}{ds}}_{G_j'\text{s rent-shifting motive}} + \underbrace{\frac{\partial\pi_j^*}{\partial x_i}\frac{dx_i^*}{ds}}_{G_j'\text{s spill-back motive}} \quad (18')$$

$$= \frac{2}{3}(2\beta - 1)\left(q_i^*\frac{dx_j^*}{ds} + q_j^*\frac{dx_i^*}{ds}\right)$$

It is straightforward to show that $\frac{dx_j^*}{ds} > 0$ and $\frac{dx_i^*}{ds} > 0$ for all spillovers, hence $s^{CP-H} \gtreqless 0$ as $\beta \gtreqless 0.5$. That the optimal policy is a R&D subsidy (tax) when the firms' R&D are strategic complements (substitutes) comes as a result of the internalization of the four motives specified in (18'). The rent-shifting motives of both governments are negative for all levels of spillovers and decrease in magnitude when spillovers rise. However, these negative rent-shifting motives are counteracted by the positive spill-back motives which rise with spillovers. When spillovers are small, the combined rent-shifting motives dominate the combined spill-back motives and s^{CP-C} is a R&D tax. However, when spillovers are relatively pervasive, the spill-back motives which encourage high R&D from both firms become the driving force leading to a harmonised R&D subsidy. The case of *research joint venture* ($\beta \equiv 1$), follows accordingly, the optimal R&D policy is a subsidy $s^{RJV-C} > 0$.

4.2 R&D Cartel (CT-C) and Research Joint Venture Cartel (RCT-C)

Similarly, setting $s_h = s_f = s$ in (10) and (11), gives R&D and product outputs for this case. The harmonisation problem is:

$$\max_s \widehat{\Psi} = \max_s (W_i + W_j) = \max_s \left(\widehat{\Pi} - \frac{s}{2}\left(\frac{(\hat{x}_i)^2}{\theta_i} + \frac{(\hat{x}_j)^2}{\theta_j} \right) \right)$$

with corresponding FOC:

$$\begin{aligned} \frac{d\widehat{\Psi}}{ds} &= \frac{d\widehat{\Pi}}{ds} - \frac{1}{2}\left(\frac{(\hat{x}_i)^2}{\theta_i} + \frac{(\hat{x}_j)^2}{\theta_j} \right) - \frac{s}{2}\left(\frac{2\hat{x}_i}{\theta_i}\frac{d\hat{x}_i}{ds} + \frac{2\hat{x}_j}{\theta_j}\frac{d\hat{x}_j}{ds} \right) \\ &= \frac{d\widehat{\pi}_i}{ds} + \frac{d\widehat{\pi}_j}{ds} - \frac{1}{2}\left(\frac{(\hat{x}_i)^2}{\theta_i} + \frac{(\hat{x}_j)^2}{\theta_j} \right) - s\left(\frac{\hat{x}_i}{\theta_i}\frac{d\hat{x}_i}{ds} + \frac{\hat{x}_j}{\theta_j}\frac{d\hat{x}_j}{ds} \right) \\ &= \frac{\partial\widehat{\pi}_i}{\partial\hat{x}_i}\frac{d\hat{x}_i}{ds} + \frac{\partial\widehat{\pi}_i}{\partial\hat{x}_j}\frac{d\hat{x}_j}{ds} + \frac{\partial\widehat{\pi}_i}{\partial s} + \frac{\partial\widehat{\pi}_j}{\partial\hat{x}_i}\frac{d\hat{x}_i}{ds} + \frac{\partial\widehat{\pi}_j}{\partial\hat{x}_j}\frac{d\hat{x}_j}{ds} + \frac{\partial\widehat{\pi}_j}{\partial s} \\ &\quad - \frac{1}{2}\left(\frac{(\hat{x}_i)^2}{\theta_i} + \frac{(\hat{x}_j)^2}{\theta_j} \right) - s\left(\frac{\hat{x}_i}{\theta_i}\frac{d\hat{x}_i}{ds} + \frac{\hat{x}_j}{\theta_j}\frac{d\hat{x}_j}{ds} \right) = 0 \end{aligned} \tag{19}$$

Since $\frac{\partial\widehat{\pi}_i}{\partial\hat{x}_i}\frac{d\hat{x}_i}{ds} + \frac{\partial\widehat{\pi}_j}{\partial\hat{x}_i}\frac{d\hat{x}_i}{ds} = 0$ and $\frac{\partial\widehat{\pi}_i}{\partial\hat{x}_j}\frac{d\hat{x}_j}{ds} + \frac{\partial\widehat{\pi}_j}{\partial\hat{x}_j}\frac{d\hat{x}_j}{ds} = 0$ from optimization at the R&D stage, (19) can be rewritten as:

$$s\left(\frac{\hat{x}_i}{\theta_i}\frac{d\hat{x}_i}{ds} + \frac{\hat{x}_j}{\theta_j}\frac{d\hat{x}_j}{ds} \right) = \underbrace{\frac{\partial\widehat{\pi}_i}{\partial s}}_{\frac{(\hat{x}_i)^2}{2\theta_i}} + \underbrace{\frac{\partial\widehat{\pi}_j}{\partial s}}_{\frac{(\hat{x}_j)^2}{2\theta_j}} - \frac{1}{2}\left(\frac{(\hat{x}_i)^2}{\theta_i} + \frac{(\hat{x}_j)^2}{\theta_j} \right) = 0.$$

Given that $\frac{\hat{x}_i}{\theta_i}\frac{d\hat{x}_i}{ds} + \frac{\hat{x}_j}{\theta_j}\frac{d\hat{x}_j}{ds} \neq 0$, we conclude that the optimal R&D policy for both governments in this case is *no intervention*, $s^{CT-C} = 0$. This is not unexpected. The welfare gains to the countries come solely from the profits of the firms and the sum of these is being maximised by the cartel. The same argument applies in the case of a RJV cartel (i.e. $s^{RCT-C} = 0$). The results of this and the previous subsection are summarized in:

Proposition 3 *Given a harmonization of R&D policy by governments, the optimal R&D policies for each R&D regime are: (1) a subsidy [tax] when spillovers are large ($\beta > 0.5$)[small ($\beta < 0.5$)], when firms compete in R&D, (2) a subsidy when firms form a research joint venture, (3) no intervention when firms form a R&D cartel or a RJV cartel.*

4.3 Choice of R&D regime when governments harmonise their R&D policy

Following our procedure from subsection 3.5, we assume that $\hat{\delta} = 0.5$ for the cases of R&D cartel and RJV cartel. We know from the governments' subgame that when firms compete in R&D, the coordinating governments will intervene through a R&D tax when spillovers are low and through a subsidy when spillovers are pervasive. If firms form a RJV, the optimal coordinating policy is a R&D subsidy However, in the case where firms form a R&D cartel or a RJV cartel, no intervention gives the highest welfare.

To compare the firms' profit levels across all four regimes we again resort to graphic simulations using the same parameter values as above. The net profit levels of the home and foreign fims are respectively shown in panels 1) to 3) and panels 4) to 6) of Figure 4, while Figures 5 and 6 show the firms' autonomous R&D and effective R&D levels respectively.

Claim 4 *Under an equal profit -sharing rule, with governments harmonising their R&D policies to maximize joint benefits, the RJV is the most beneficial form of R&D cooperation from both firms' perspectives.*

The rationale underlying this claim is straightforward. From Figures 5 and 6, the firms' R&D and effective R&D under RJV and RCT agreements are equal and highest. That means the firms achieve the same cost reduction, and hence supply the same output levels in both R&D regimes. However, the firms' R&D spending is smaller under a RJV as its R&D is subsidized. As a result the firm's profit is highest under the RJV agreement. The explanation for the firms choosing equal R&D levels under the RJV and RCT is as follows. When firms form a RJV sharing full information each has an incentive to underinvest. When the governments coordinate and intervene through a R&D subsidy, it is as if they internalize the positive R&D externality each firm confers on the other and use the subsidy to elevate the firms' R&D levels. In the case of a RJV cartel, the governments need not intervene, as the internalization of the R&D externality occurs at the R&D stage when firms coordinate their R&D decisions. The effects of internalization by governments and by the firms themselves raise firms' R&D (hence, effective R&D) to the same level.

The optimal forms of R&D policy for each R&D regime and the most desirable R&D regime from the firms' perspectives with policy harmonisation are summarized in column 3 of Table 3.

5 Concluding Remarks

Our objective has been to extend the literature on R&D cooperation and R&D policy choice to the case where national firms are asymmetric in their R&D efficiencies. The firms were assumed always to compete at the product level and may also compete in R&D or form an R&D alliance involving either a R&D cartel, a research joint venture (RJV) or a RJV cartel. Firms coordinated their R&D decisions when they formed a R&D cartel; merely shared R&D information in a RJV; and both shared information and coordinated R&D decisions in a RJV cartel. One important feature of the analysis was the adoption of a profit sharing rule whenever firms coordinate their R&D decisions, this significantly altered the motives underlying government's interventions from what is conventionally considered.

We set up our model by showing that when the home and foreign governments compete in their R&D policy, R&D subsidies are their optimal policies if their firms compete in R&D or form an international RJV. The two traditional motives - rent-shifting and spill-back – drive this intervention, and, regardless of the level of spillovers, the interactions of the two motives always suggested an R&D subsidy. These results replicated those in Qui and Tao (1998), where the level of spillovers is interpreted as the degree of R&D collaboration.

The main novelty of analysis arose in the cases of a R&D cartel and a RJV cartel where a profit-sharing rule was employed. This ensured that the national firm's share of the alliance's net profit, and not its profit prior to redistribution, appeared in the government's objective function. It also implied that under these two forms of agreement, the traditional rent-shifting and spill-back motives are internalised, and the optimal policy is a R&D tax. The tax incidence is shared by the cartel members, while the levying government collects all the revenue.

The optimal form of intervention differed when governments harmonized their R&D policies. When firms compete in R&D, a R&D subsidy is the optimal policy when spillovers are pervasive due to the dominating role of the spill-back motive. When spillovers are relatively small, a R&D tax would be chosen as a result of the internalization of the dominating rent-shifting motives of the two governments   If firms form a R&D cartel or a RJV cartel, the governments' interventions are redundant. The cartel arrangement between the firms effectively internalized the governments' rent shifting and spill-back motives.

When we analysed the firms' choice of R&D regime, our results differed somewhat from those in the literature which generally indicates a RJV cartel as the most desirable regime from both firms' and society's perspectives. We compared the firm's equilibrium net profits under the four different R&D regimes, taking into account the endogenous policy stance taken by the governments.. In order to make the analysis tractable, we adopted the empirically common equal-sharing rule whenever firms coordinated their decisions. We showed that when governments compete in R&D policies, a consensus on a R&D regime may not be easy to establish among asymmetric firms. The imposition of R&D taxes when firms coordinate their R&D makes the cartel arrangements less attractive. The inferior firm prefered a RJV to other regimes as it gains access to its partner's R&D while at the same time receiving subsidy support from its government. The superior firm may even find R&D competition preferable especially when its partner's R&D efficiency is significantly lower and spillovers are relatively low. The RJV cartel will be chosen only when involuntary spillovers are so high that the internalization of the free-rider problem under a RJV cartel makes this regime most appealing for the superior firm. Firms' preferences for a particular R&D regime differ again when governments harmonise their decisions. Under the equal profit sharing rule, the RJV agreement seems to outperform the others. Under this regime, the harmonised R&D subsidy not only reduces firms' R&D costs but also leads to higher R&D and effective R&D levels than in the other regimes.

Well-known caveats arise relating to the many simplifying assumptions embodied in the Spencer and Brander model. We wished to present our results in an uncomplicated familiar model, but even then we had to rely on numerical simulations to illustrate some of the later results. We devoted time to identifying and elaborating the relevant ‘effects’ which can be expected to carry through to more general models, even if they are unlikely to combine as conveniently as here. The broad implications of some extensions are readily apparent. Allowing firm’s to have domestic sales, for example, means that national benefits are no longer tied exclusively to national firm’s profits. An equivalent analysis using the Brander and Krugman reciprocal dumping model would be helpful here. At another level, endogenising the profit-sharing rule through bargaining might give a more precise ranking of R&D regimes. The popularity of the equal-sharing rule, even among asymmetric firms in practice, does suggest that a sophisticated bargaining outcome will be challenging for the participants.

Table 1: Comparison of firms' R&D, quantities and profits and countries' benefits under each R&D regime

	R&D competition	RJV	R&D cartel ($\hat{\delta}$=0.5)	RJVcartel ($\hat{\delta}$=0.5)
x_i	$x_h^{cp} < x_f^{cp}$	$x_h^{rjv} < x_f^{rjv}$	$x_h^{ct} < x_f^{ct}$	$x_h^{rct} < x_f^{rct}$
q_i	$q_h^{cp} < q_f^{cp}$	$q_h^{rjv} < q_f^{rjv}$	$q_h^{ct} < q_f^{ct}$	$q_h^{rct} < q_f^{rct}$
π_i	$\pi_h^{cp} < \pi_f^{cp}$ $for\ most\ \beta$ $\pi_h^{cp} > \pi_f^{cp}$ $if\ very\ high\ \beta$	$\pi_h^{rjv} > \pi_f^{rjv}$	$\pi_h^{ct} < \pi_f^{ct}$ $for\ most\ \beta$ $\pi_h^{ct} < \pi_f^{ct}$ $if\ very\ high\ \beta$	$\pi_h^{rct} > \pi_f^{rct}$
υ_i	-	-	$\upsilon_h^{ct} < \upsilon_f^{ct}$	$\upsilon_h^{rct} < \upsilon_f^{rct}$
W_i	$W_h^{cp} < W_f^{cp}$ $for\ most\ \beta$ $W_h^{cp} > W_f^{cp}$ $if\ very\ high\ \beta$	$W_h^{rjv} > W_f^{rjv}$	$W_h^{ct} < W_f^{ct}$	$W_h^{rct} > W_f^{rct}$

Table 2: Comparative statics of optimal R&D policy under each R&D regime

	R&D competition	RJV	R&D cartel	RJV cartel
$s_i\|_{\theta_i=\theta_j}$	$\frac{\mathrm{d}s_i^{cp}}{\mathrm{d}\beta} \gtreqless 0\ for\ \beta \gtreqless 0.5$ $\frac{\mathrm{d}s_i^{cp}}{\mathrm{d}\theta} > 0$	$\frac{\mathrm{d}s_i^{rjv}}{\mathrm{d}\theta} > 0$	$\frac{\mathrm{d}s_i^{ct}}{\mathrm{d}\beta} < 0\ for\ most\ \beta$ $\frac{\mathrm{d}s_i^{ct}}{\mathrm{d}\beta} > 0\ for\ very\ high\ \beta$ $\frac{\mathrm{d}s_i^{ct}}{\mathrm{d}\theta} > 0$	$\frac{\mathrm{d}s_i^{rct}}{\mathrm{d}\theta} > 0$
$s_i\|_{\beta=0}$	$\frac{\mathrm{d}s_i^{cp}}{\mathrm{d}\theta_i} > 0$ $\frac{\mathrm{d}s_i^{cp}}{\mathrm{d}\theta_j} > 0$	-	$\frac{\mathrm{d}s_i^{ct}}{\mathrm{d}\theta_i} > 0$ $\frac{\mathrm{d}s_i^{ct}}{\mathrm{d}\theta_j} > 0$	–
$s_i\|_{\beta=1}$	$\frac{\mathrm{d}s_i^{cp}}{\mathrm{d}\theta_i} > 0$ $\frac{\mathrm{d}s_i^{cp}}{\mathrm{d}\theta_j} > 0$	$\frac{\mathrm{d}s_i^{rjv}}{\mathrm{d}\theta_i} > 0$ $\frac{\mathrm{d}s_i^{rjv}}{\mathrm{d}\theta_j} > 0$	$\frac{\mathrm{d}s_i^{ct}}{\mathrm{d}\theta_i} > 0$ $\frac{\mathrm{d}s_i^{ct}}{\mathrm{d}\theta_j} > 0$	$\frac{\mathrm{d}s_i^{rct}}{\mathrm{d}\theta_i} > 0$ $\frac{\mathrm{d}s_i^{rct}}{\mathrm{d}\theta_j} > 0$

Table 3: Form of optimal R&D policy under each R&D regime and the optimal form of R&D regime

	Governments' Competition	Governments' Coordination
R&D Competition	Subsidy	Tax if low spillovers Subsidy if high spillovers
RJV	Subsidy	Subsidy
R&D Cartel	Tax	No intervention
RJV Cartel	Tax	No intervention
Optimal R&D regime ($\hat{\delta} = 0.5$)	Consensus may not be reached	RJV

Figure 1: Firms' equilibrium profits under different R&D regimes given competition between governments.

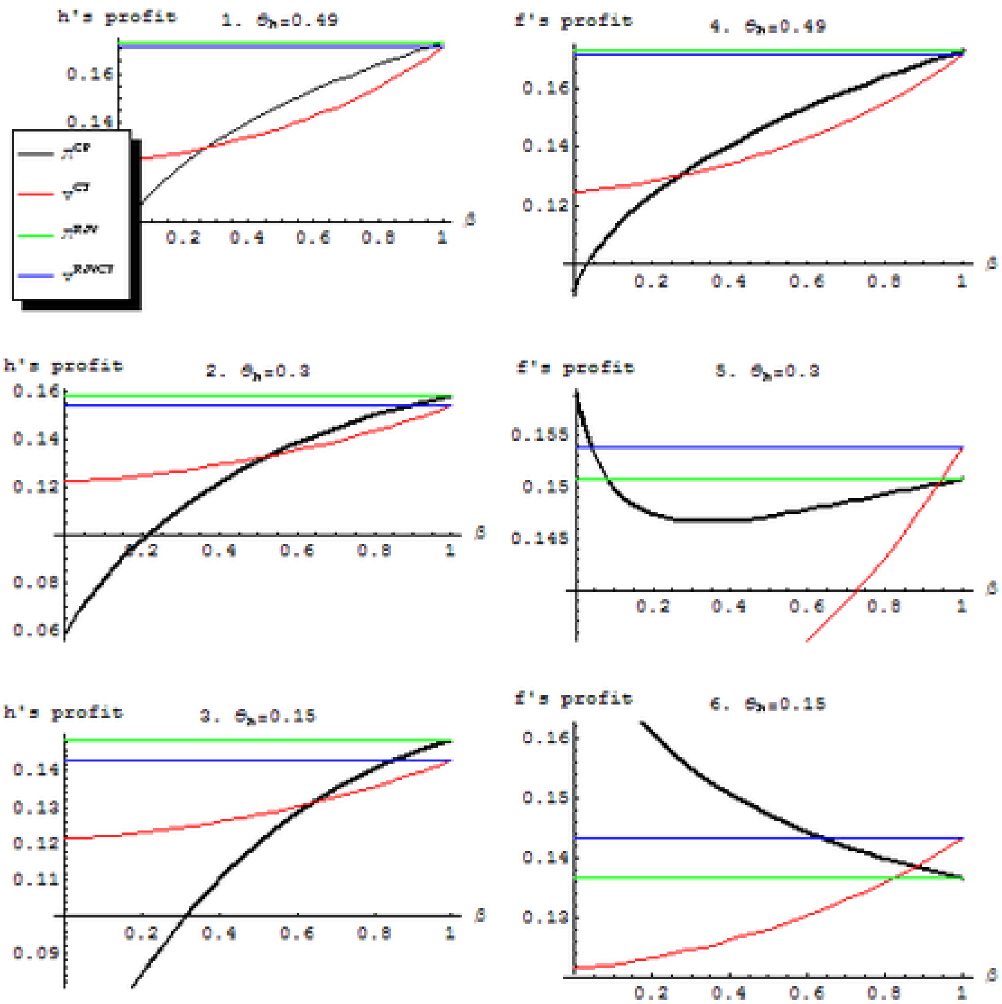


Figure 2: Firms' R&D under different R&D regimes given competition between governments.

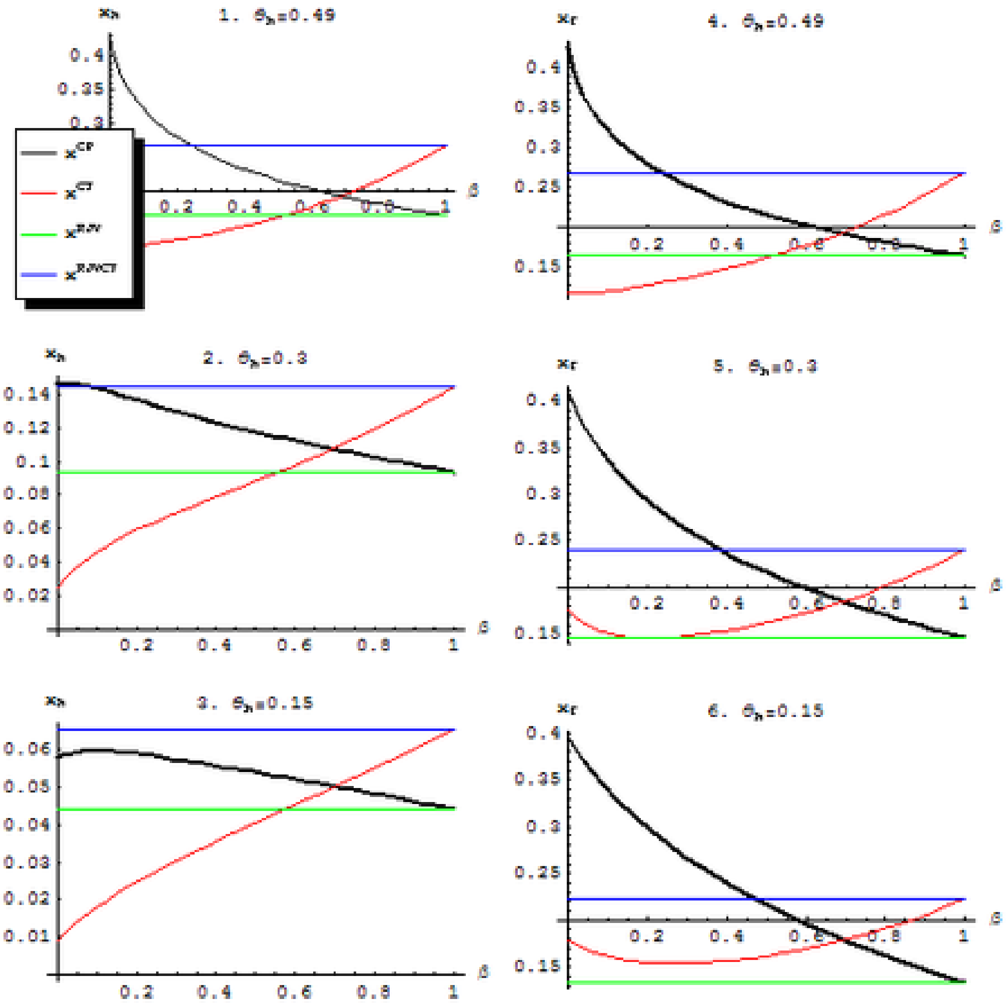


Figure 3: Firms' effective R&D under different R&D regimes given competition between governments

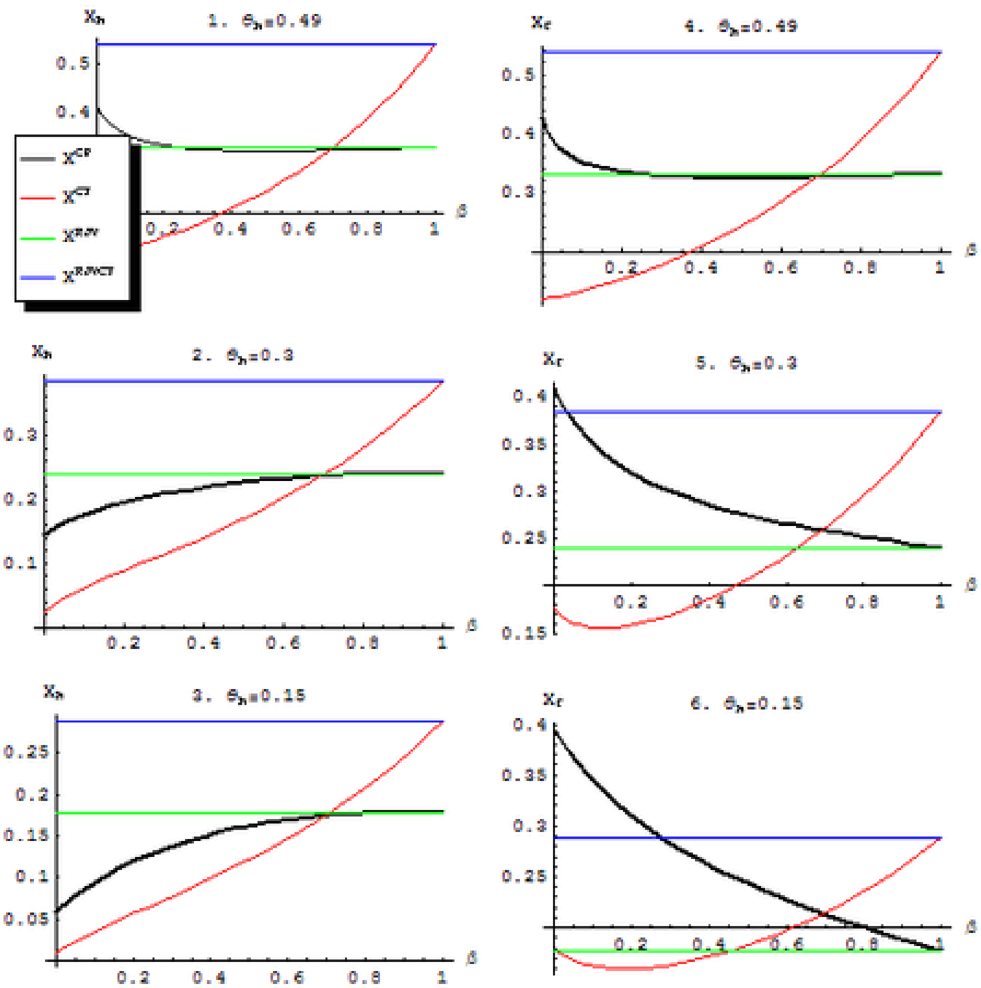


Figure 4: Firms’ equilibrium profits under different R&D regimes given policy harmonisation.

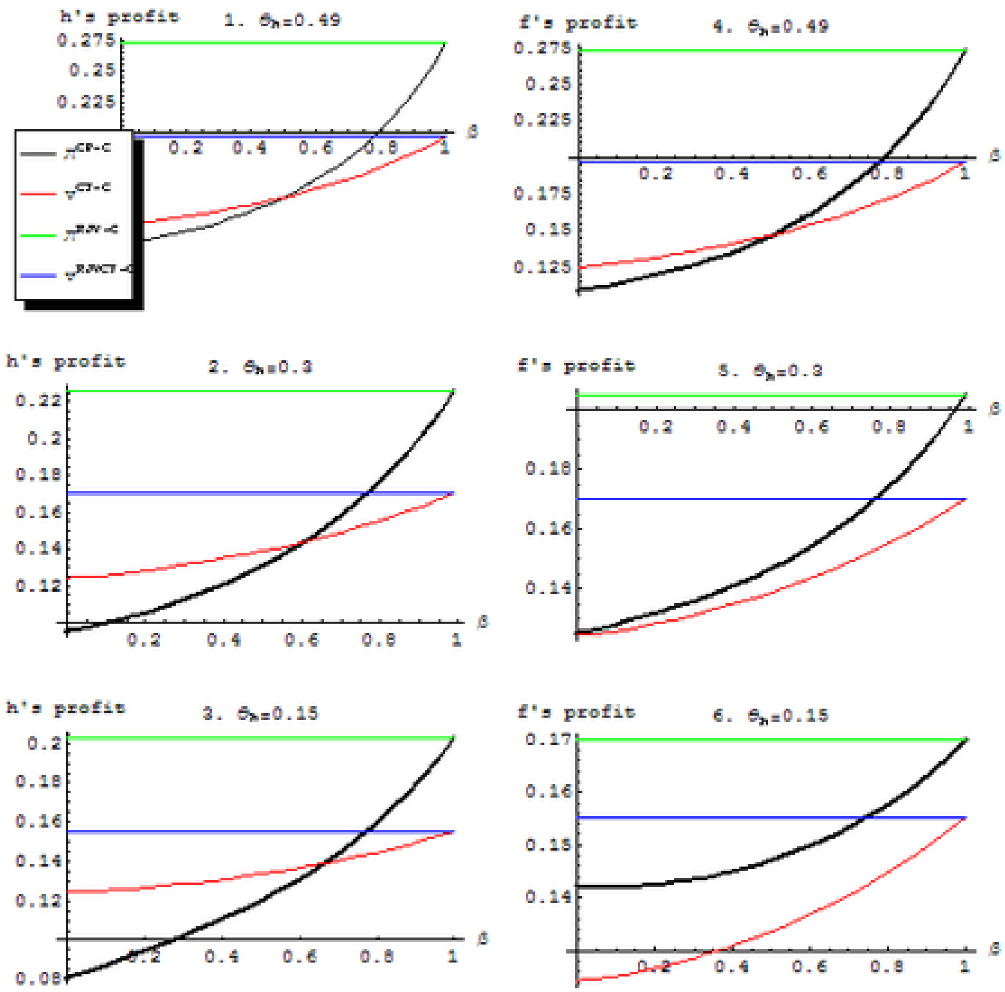


Figure 5: Firms' R&D under different R&D regimes given policy harmonisation.

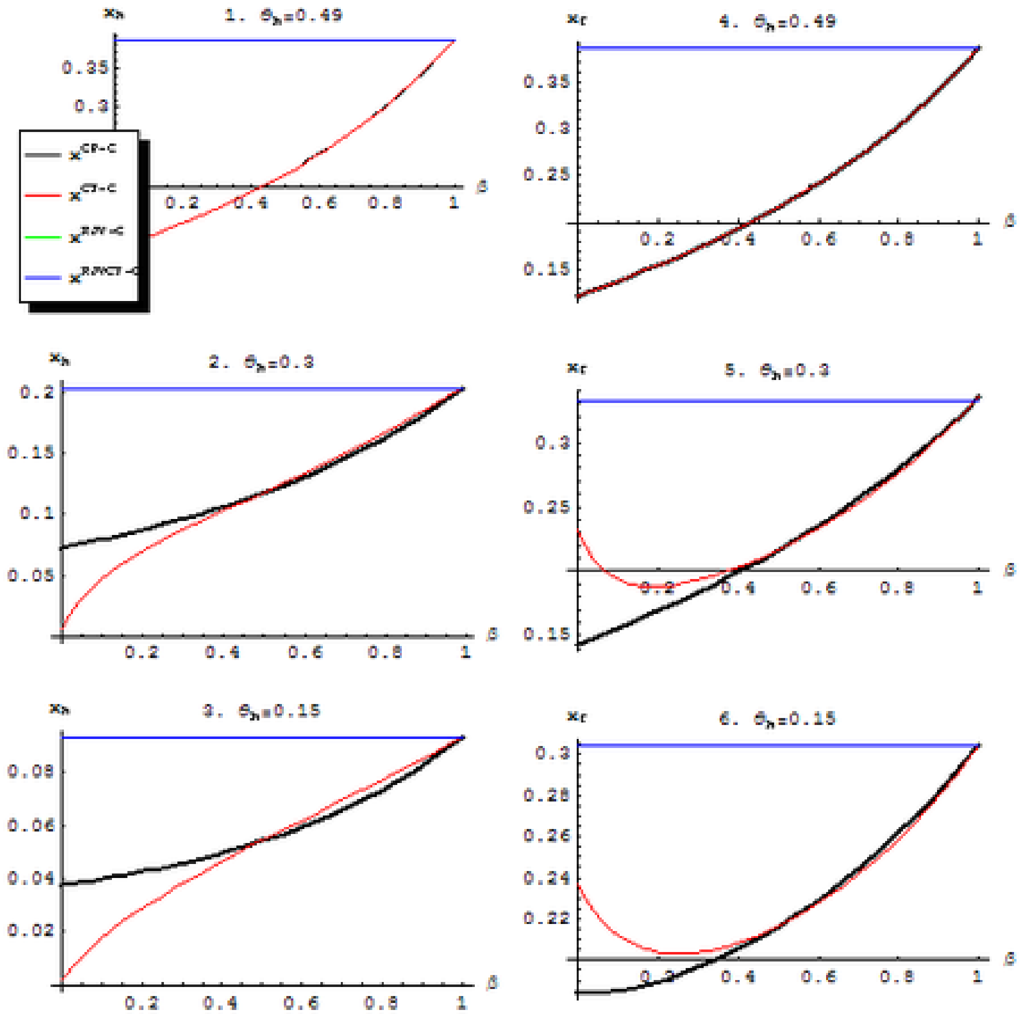
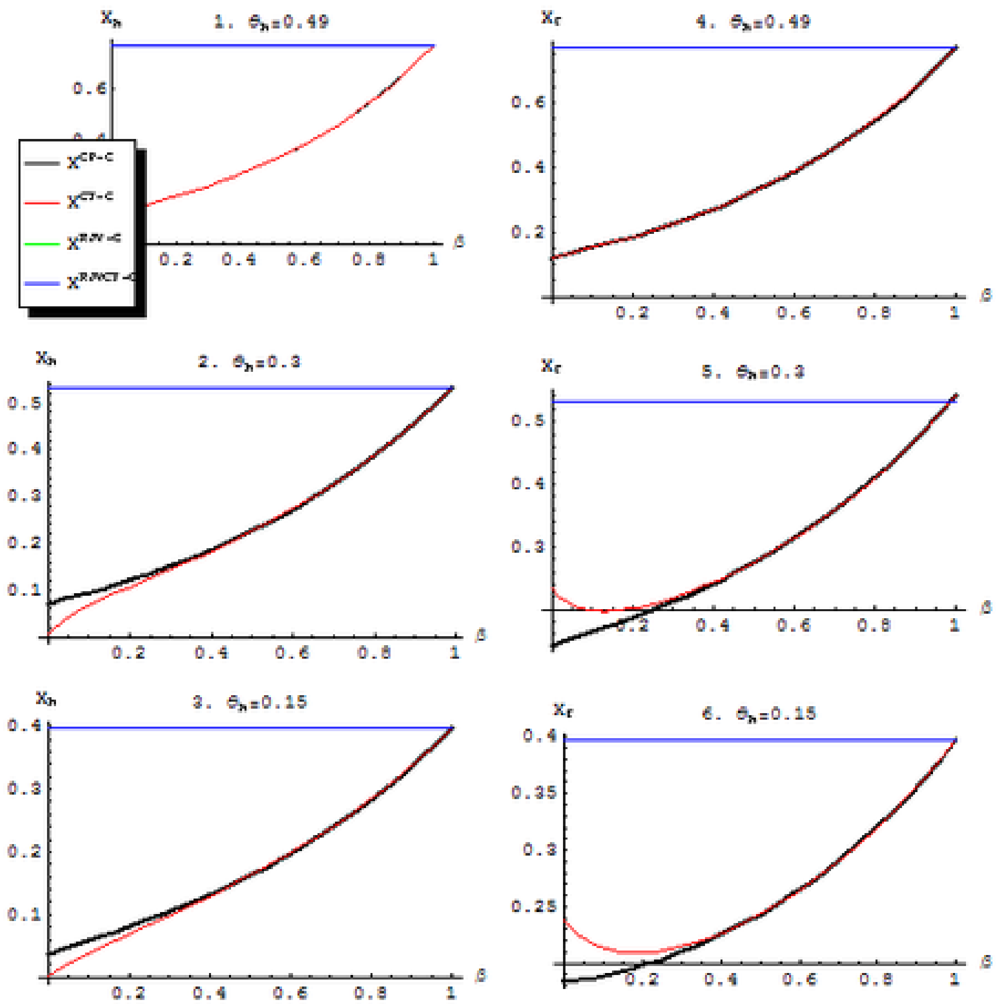


Figure 6: Firm h and firm f 's effective R&D under different R&D regimes given governments' coordination



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