JOURNAL OF PUBLIC ECONOMIC THEORY
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Submission Number: PED11-11-00005

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We highlight a government''s role in promoting societal welfare through R&D policy when its national .firm may have engaged in R&D cooperation which involves coordination of R&D decisions or information sharing or both with its foreign rival who is more superior in terms of R&D efficiency. The policy games between governments are analyzed. We find that the optimal forms of intervention and the motives behind when governments cooperate are very different from those attained when governments compete in their R&D policy. Under R&D regimes where firms coordinate their decisions, we adopt an exogenously-determined profit-sharing rule and find that contrasting to what suggested in the existing literature R&D cooperation which heavily focuses on the case of symmetric .firms, R&D tax is always justified whenever .firms coordinate and governments compete in the R&D policy. In a special case where a 50% profit sharing rule is adopted, agreements to share R&D information can easily outperform those that combine both coordination of R&D decisions and information sharing due to the adverse effect that R&D tax has on firms'' R&D incentives. On the contrary, when governments agree to harmonize their R&D policy, the R&D policy stance suitable for coordinating firms is no interventions from the governments.

Submitted: Feb 27 2011. **Resubmitted:** February 28, 2011.

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We highlight a government's role in promoting societal welfare through R&D policy when its national firm may have engaged in R&D cooperation which involves coordination of R&D decisions or information sharing or both with its foreign rival who is more superior in terms of R&D efficiency. The policy games between governments are analyzed. We find that the optimal forms of intervention and the motives behind when governments cooperate are very different from those attained when governments compete in their R&D policy. Under R&D regimes where firms coordinate their decisions, we adopt an exogenously-determined profit-sharing rule and find that contrasting to what suggested in the existing literature of R&D cooperation which heavily focuses on the case of symmetric firms, R&D tax is always justified whenever firms coordinate and governments compete in the R&D policy. In a special case where a 50% profit sharing rule is adopted, agreements to share R&D information can easily outperform those that combine both coordination of R&D decisions and information sharing due to the adverse effect that R&D tax has on the firms' R&D incentives. On the contrary, when governments agree to harmonize their R&D policy, the R&D policy stance suitable for coordinating firms is no interventions from the governments.

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

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

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1 Introduction

Cooperation with direct competitors have become one of the directions frequently chosen by firms competing in an innovation-led market. Their motives for allying ranges from sharing cost and risk that usually arises from undertaking R&D, gaining access to technology and know-how of the partners, enhancing efficiency through economies of scale in production or R&D, exploiting synergy effects from sharing to monitoring partner's technology (see Veugelers, 1999). These various motives give rise to heterogeneous forms of R&D cooperation.

Interestingly, the empirical relevance of asymmetries among partners of joint venture is also massive. Veugelers (1993) investigates a data set of 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 only from geographical or home market differences, but also from differences in partners' technological origins, capacities, production and R&D efficiency and R&D absorptive capacity. Even the organizational format of cooperation can influence the alliance asymmetries[2]. By categorizing a company belonging to the "Fortune Global 500 for industries and services" as *a global company*, he reports that already 37% of the R&D alliances[3] are between the global and non global players. However, the asymmetric alliances do not necessarily require asymmetric profit sharing rules. Veugelers finds that as high as 50% of all asymmetric alliances (i.e. an alliance between global and non global players) adopt an equal sharing rule[4]. However, theoretical studies on R&D cooperation has mostly concentrated on cases of symmetric firms (Mukherjee and Ramani, 2009).

What interests us is how asymmetries between partner firms change the organization of R&D production, would an inferior firm relies on a superior firm to undertake more R&D as it expects the partner to share R&D information and how would this change the direction of governments' R&D policies. A number of scholarly papers have addressed the issue of R&D policy in multistage game environment. The work of Spencer and Brander (1983) has been a remarkable source of various extensions, e.g. Leahy and Neary (1997,1999), Neary (1994,1998), Neary and O'Sullivan (1999), Qui and Tao (1999), Barros and Nilssen (1999) and DeCourcy (2005). Using a two-country model, Spencer and Brander present the theory of strategic industrial policy in the market of imperfect competition. In their three-stage game, a home government commits

[1] The data set builds on registration of alliances as they appeared in the financial press and codification along relevant dimensions as organizational structure and activities organized within the venture, as well as size, sector and nationality of partners, using various data sources (Veugelers, 1993).

[2] Sakakibara (1997)'s empirical study considers firms' motives in joining R&D consortia in which participants are heterogeneous in terms of R&D capability, and suggests that the skill-sharing motive is relatively more important for participants with heterogenous capability, while the cost-sharing motive becomes more dominant when the participants capabilities are relatively homogenous.

[3] Almost all alliances reported are between two partners only.

[4] Nonetheless, joint ventures may be impossible to form under equal sharing rule given partners from are too asymmetric (Veugelers and Kesteloot, 1995)

to its R&D policy in the first stage; home and a foreign firm engage in R&D rivalry in the second stage before competing in the output market. In the absence of R&D spillovers, they show that R&D subsidy is strategically used to perform the rent-shifting role whereby the subsidized domestic R&D would in effect reduce foreign R&D, output and profit. However, R&D tax may also be prescribed if the government export subsidy to play the rent shifting role, while leaving R&D tax to restores production efficiency by reducing firm's strategic incentive to overinvest compared to the social optimum value [5],[6].

Leahy and Neary (1999), Neary and O'Sullivan (1999) and Qui and Tao (1998) incorporate the issue of R&D spillovers and R&D cooperation in their studies of R&D policies in their symmetric firms framework[7]. By allowing for local spillovers between domestic firms and international spillovers, Leahy and Neary (1999) show that R&D subsidy is justified not only because other domestic firms would benefit from positive externality of R&D, but also from the fact that foreign R&D would spill back to benefit the home firm via international spillovers which cause firms' R&D to be strategic complements in nature. Qui and Tao (1998) consider R&D policies in cases where firms either choose to coordinate their decisions or collaborate through sharing of R&D information. Given involuntary spillovers are absent, they show that whenever firms coordinate, R&D subsidy is always justified due to first; its rent- shifting role and second; its ability to raise domestic R&D as the coordinating firms have incentive to underinvest. However, R&D tax may be possible if the degree of collaboration is high enough owing to the dominating role of the rent-shifting motive.

As far as firms' asymmetry is concerned, Barros and Nilssen (1999) incorporate asymmetries between firms R&D efficiency and productivity of R&D output into their model of several domestic and foreign firms in order to consider firm-specific R&D policy[8] However, the issue of spillovers and R&D cooperation are left out of the analysis. Several other studies have attempted to elaborate how asymmetries in firms' ability to perform R&D activites and make use of R&D output affect the success of R&D alliance formation (Veugelers and Kesteloot (1996), Poyago-Theotoky (1997), Chaundhuri (1995)), however, the study on how cooperations/coordination between asymmetric firms affect forms of governmental interventions is still lacking.

In this paper, we allow firms who are asymmetric in their cost of R&D effort to engage in some particular type of cross-border R&D regime. In classifying

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[5] With no spillovers, the firm has strategic incentive to overinvest (compared to their cost-minimizing levels of R&D) so as to reduce its rivals' investments.

[6] These results are reaffirmed in Neary (1998)

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

[8] Neary and O'Sullivan (1999) also take into account these types of asymmetry when attempting to compare the welfare-improving effect of R&D coordination with the provision of export subsidy. Although the coordinating firms are asymmetric in their model, the issue of a transfer payment between firms is not taken up. The firm's net profit under R&D coordination is just its sales profit net R&D cost.

form of R&D regimes, we borrow the terminologies invented by Kamien, Muller and Zang (1992); that means four types of R&D regimes are identified: 1) **R&D competition**, where firms compete in R&D; 2) **R&D cartel,** where firms coordinate R&D decisions; 3) **Research Joint Venture (RJV),** where firms maximize the sharing of R&D information; and 4) **RJV cartel,** where firms agree to both coordination and information sharing. To facilitate R&D coordination, we assume that firms adopt an exogeneously determined *profit-sharing rule* where firms agree a priori on the sharing ratio before any joint R&D effort is underway. It is implemented through transfer payment mechanism. The effects of such adoption on the forms of optimal R&D policies remains theoretically unexplored[9].

We find that by introducing such kind of sharing rule into the analysis of R&D coordination provides us with interesting results. Unlike Qui and Tao (1998), we find that R&D tax is always justified whenever firms coordinate. The profit- sharing rule directly affect government's motives for intervention. Although the conventional rent shifting motive which used to be the main driving force behind the R&D policy disappears when the sharing rule is adopted, the prescribed R&D tax here still helps draw revenue from the firm's partner resided across border. In our framework, the government realizes that any incidence of tax on its national firm would be internalized by the alliance's profit maximizing procedure. It is as if the tax burden is distributed among the alliance members, while only the home government collects tax revenue. In addition, the optimal tax level is reached when any further increase in tax would cause excessive reduction in the home firm's R&D, causing a fall in the tax revenue collected. In the case where the firms can choose type of R&D regime at the stage prior to the interventions, and a specific 50% profit-sharing rule is adopted, graphic simulations show that RJV cartel may no longer be the most profitable form of R&D cooperation as established in Kamien et al (1992) due to these impositions of taxes. Lastly, we explore the rationale behind governments' interventions when the governments cooperate by harmonizing their form of intervention.

The paper is organized as follows. The standard features of the model used is discussed in the section 2. Section 3 provides detailed analysis of government interventions through R&D policies for each type of R&D regimes assuming competition between governments. The end of this section focuses on the very first stage of the game where we find out what is the most promising R&D regime from firms' point of view given competition between governments In section 4, we extend our analysis to the case where governments are allowed to cooperate by harmonizing their forms of intervention, the optimal forms of R&D policies and motives behind the interventions are searched for. Finally, concluding remarks are provided in section 5.

[9] 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 50% sharing rule on the success likelihood of the venture with the use of bargained rule. However, they do not address the issue of industrial policies.

2 The Model

A home (h) and a foreign (f) firm engage in cost-reducing R&D and export all their homogenous product to a third market with linear inverse demand $P(q_i) = A - \sum_{i=h,f} q_i$, where P, A and q_i denote price, market size and firm i 's output respectively. For simplicity, we normalize the size of the market to 1.

In the absence of R&D, both h and f produce with the same marginal cost, $\bar{c}$ (< 1). Each firm's post-innovation cost is denoted by c_i, $i \in \{h, f\}$. The two-way R&D spillovers, denoted by β captures the involuntary flow of R&D output between the firms and $\beta \in [0, 1]$. Let x_i denote firm i 's R&D output. Hence, under R&D competition regime, firm i's unit cost of production is $c_i = \max\{0, \bar{c} - (x_i + \beta x_j)\}$. The term $x_i + \beta x_j$ can be interpreted as effective R&D, the total R&D output available to firm i, let it be denoted by X_i. The R&D cost function takes the form $R_i = \frac{x_i^2}{2\theta_i}$, where R_i denotes R&D cost. Asymmetry between firms lies in different R&D efficiency which is denoted by θ_i, where[10]. $\theta_i \in (0, 1]$, and we assume a unit of R&D output can be delivered at a lower cost in foreign firm's R&D lab than in the home firm's, thus $\theta_f > \theta_h$.

Our analysis employs a framework of four-stage game. Firms are allowed to form international R&D agreements in the first stage. There are four types of R&D configuration in which firms may find themselve engage in: 1) *R&D Competition* (CP), where firms compete both in their R&D and production; 2) *R&D Cartel* (CT), where firms coordinate their R&D decisions to maximize the alliance's joint profit but do not intentionally 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 decisions on R&D level; 4) *Research Joint Venture Cartel* ($RJVCT$), where firms form the most integrated form of cooperation by coordinating their R&D decisions and maximizing the flows of information between them.

The important assumption in our analysis is that whenever these asymmetric firms coordinate their R&D decisions, each knows that the profit made on using new R&D process discovered by the R&D alliance is to be *shared* between partners in the manner governed by the adopted profit sharing rule[11]. It is assumed that the formation of alliance between asymmetric partners is sustainable as long as both firms find the profit each entails from cooperation is higher than the profit obtained under R&D competition. We will be using the case of R&D competition as a benchmark case, when making profit comparison across regime.

For any given R&D configuration decided upon by firms, a government aims

[10] This R&D cost function takes a slightly different form from what shown in other well-known papers e.g. d'Aspremont and Jacquemin (1988), Kamien Muller and Zang (1992). However, the same interpretation can be drawn from both functional forms. We choose $\frac{x^2}{2\theta}$ instead of $\frac{\gamma x^2}{2}$ where γ denotes R&D efficiency, for convenience.

[11] Veugelers and Kesteloot (1996) define the coordinating firm's profit as its agreed share times the successful R&D alliance's joint profit and assume that the cooperation extends to the production stage.

to use R&D policy so as to maximize its societal welfare in the second stage of the game. For each country, let s_i denote R&D subsidy government i provides to its national firm i for each dollar the firm spends on R&D. We assume that the total amount of subsidy will not be greater than the firm's R&D expense, thus $\frac{(1-s_i)x_i^2}{2\theta_i} > 0$ We consider two different types of game in the government stage: 1) *government competition*, both the home (G_h) and foreign (G_f) governments compete in their R&D policies; 2) *government coordination,* both governments coordinate to harmonize it R&D policy (s).

In the subsequent stage of the game, firms choose R&D investment in the manner governed by the R&D configuration they engage in, taking as given the governments' forms of interventions. The firms then compete in a product market in the final stage. Cooperation in the production stage is curtailed by antitrust policy. 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. That means we take type of R&D configuration as given, when solving for equibrium solutions in the governments subgame.

3.1 R&D Competition (CP)

In this case, a firm benefits from the R&D performed by the other firm as much as the level of involuntary spillovers would allow. The post-innovation unit cost of firm i is $c_i = \overline{c} - (x_i + \beta x_j)$.

In the final (output) stage, taking s_i, s_j, x_i and x_j determined in prior stages as given, each firm chooses it output to maximize profit, yeilding $q_i^* = \frac{1-2c_i+c_{j\neq i}}{3}$. Substitute for c_i and c_j, we have

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

where $K \equiv 1 - \overline{c} > 0$ measures the effective market size, and $\frac{dq_i^*}{dx_j} = \frac{2\beta-1}{3} \gtreqless 0$ if and only if $\beta \gtreqless \frac{1}{2}$; that means a firm's R&D reduces its rival's output unless the spillovers are greater than a half.

In the R&D stage of the game, the competing firms independently choose R&D levels to maximizes their fourth-stage profit net 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 the firms' reaction functions: $x_i = \frac{2(2-\beta)\theta_i[K+(2\beta-1)x_{j\neq i}]}{9(1-s_i)-2\theta_i(2-\beta)^2}$. The firms' R&D are strategic complements (substitutes) when[12] $\beta > \frac{1}{2}$ ($\beta < \frac{1}{2}$). Only when spillovers are sufficiently large, firm i's R&D helps reduce firm j's

[12] $\frac{dx_i}{dx_j} = \frac{2(2-\beta)(2\beta-1)\theta_i}{9(1-s_i)-2\theta_i(2-\beta)^2} \gtreqless 0$ iff $\beta \gtreqless \frac{1}{2}$.

unit cost, enhances marginal profitability of firm j's R&D. Solving for equilibrium R&D (x_i^*), we obtain

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

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 stability condition). Note that $\theta_h < \frac{1}{2}$ and $\theta_f < \frac{1}{2}$ suffice for the second order conditions (SOCs), stability conditions and interior conditions to hold in the R&D and output subgames[13], and are assumed throughout. Substituting for x_i in (1), we have[14]

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

Comparative statics show that[15] $\frac{dx_i^*}{ds_i} > 0$, and $\frac{dx_j^*}{ds_i} \gtreqless 0$ iff $\beta \gtreqless \frac{1}{2}$; that means government i's R&D subsidy always enhances firm i's R&D, but will increase firm j's incentive to invest only when the firms' R&D are strategic complements; however, when firms' R&D are strategic substitutes, s_i raises x_i which in turn induces a reduction in x_j. When $\beta = \frac{1}{2}$, $\frac{dx_j^*}{ds_i} = 0$, a rise of x_i has no impact on level of x_j, so s_i has no impact on x_j.

An analysis of firm's incentive to invest gives us standard results; when spillovers are not too pervasive $\beta < \frac{1}{2}$, each firm aims to strategically create cost gap between its own and its rival's (so-called strategic incentive), and tends to overinvest in R&D compared to the efficient level of R&D which is determined purely by profit incentive[16] While in the case of high spillovers, firms' R&D are strategic complements, each does not want the rival to free-ride on its R&D R&D, thus tends to underinvest.

In the second stage, both governments simultaneously and independently choose R&D policies so as to maximize the country's welfare which comprises the national firm's profit net subsidy expenditure;

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

where x_i^* denote the third-stage R&D and $\pi_i^{**} = f(x_i^*, x_j^*; s_i, s_j)$. The corresponding FOCs give governments' reaction functions[17]: $s_h(s_f) = \frac{2\theta_f(2\beta-1)^2}{3[3(1-s_f)-2\theta_f(1-\beta^2)]}$ and $s_f(s_h) = \frac{2\theta_h(2\beta-1)^2}{3[3(1-s_h)-2\theta_h(1-\beta^2)]}$. These reaction functions are not constant in

[13] Derivations of these conditions, including similar conditions assumed in the following subsections are available from the authors upon request.

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

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

[16] That is to use R&D to reduce its own production cost, thus increases profit.

[17] With the corresponding s.o.c. satisfied, i.e. $\frac{dW_i^2}{ds_i^2} < 0$.

slope[18] and they intersect twice in the (s_h, s_f) space. However, the unstable equilibrium in the government subgame is discarded as a result of the s.o.c. and stability condition derived in the R&D stage[19] i.e. $\theta_h < \frac{1}{2}$ and $\theta_f < \frac{1}{2}$. Solving for equilibrium R&D subsidies, we attain

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

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 $G_i \equiv 8\theta_j(1-2\beta)^2[3-2\theta_i(1-\beta^2)][3-2\theta_j(1-\beta^2)] > 0$. Given $\theta_f > \theta_h$, It follows that $s_f^{CP} > s_h^{CP}$.

To understand the government i's motive behind this R&D subsidies, we disentangle the effects of s_i on W_i. The analysis in this part is quite elaborative as we aim to use it as the benchmark when comparing with the government's motives for intervention in other cases.

From (4),

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

The first component on the RHS can be written as

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

Hence, (6) becomes

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

Observe that the term $\frac{\partial \pi_i^{**}}{\partial x_j}$ in the above equation can be written as

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

Thus, together with $\frac{dx_i^*}{ds_i} > 0$ for all β, and $\frac{dx_j^*}{ds_i} \gtrless 0$ for $\beta \gtrless \frac{1}{2}$ from the R&D subgame, (7) can be rearranged as

[18] Since $\frac{ds_f}{ds_h(s_f)} = \frac{(2\beta-1)^2}{9s_h^2} > 0$, $\frac{d^2 s_f}{d[s_h(s_f)]^2} = \frac{-2(2\beta-1)^2}{s_h^3} < 0$ and $\frac{ds_f(s_h)}{ds_h} = \frac{2\theta_h(2\beta-1)^2}{[3(1-s_h)-2\theta_h(1-\beta^2)]^2} > 0$, $\frac{d^2 s_f(s_h)}{ds_h^2} = \frac{12\theta_h(2\beta-1)^2}{[3(1-s_h)-2\theta_h(1-\beta^2)]^3} > 0$, therefore $s_h(s_f)$ is concave and $s_f(s_h)$ is convex in the (s_h, s_f) space.

[19] Detailed analysis is available from the authors upon request.

$$s_i^{CP}\frac{x_i^*}{\theta_i}\frac{dx_i^*}{ds_i}=\underbrace{\underbrace{\left(\frac{\partial\pi_i^{**}}{\partial q_j}\frac{dq_j^*}{dx_j}\right)}_{-q_i^{**}\left(\frac{2-\beta}{3}\right)<0} * \underbrace{\frac{dx_j^*}{ds_i}}_{\gtrless 0 \text{ for } \beta\gtrless\frac{1}{2}}}_{\text{rent-shifting motive}}+\underbrace{\underbrace{\left(\frac{\partial\pi_i^{**}}{\partial x_j}\right)}_{\beta q_i^{**}>0} * \underbrace{\frac{dx_j^*}{ds_i}}_{\gtrless 0 \text{ for } \beta\gtrless\frac{1}{2}}}_{\text{spill-back motive}} \tag{8}$$

There are two motives involved when a government makes decision on s_i: "*rent-shifting motive*" and "*spill-back motive* ". The rent-shifting motive (henceforth, RS) reflects government i's intention to use s_i to influence x_j so as to shift rent to country i. For $\beta < \frac{1}{2}$, the firms' R&D are strategic substitutes, $s_i > 0$ will promote x_i, which in turn reduce x_j, so π_i increases, thus this motive is positive. However, its magnitude decreases with β. When $\beta > \frac{1}{2}$, this motive turns negative; as firms' R&D are strategic complements, $s_i < 0$ which restraints x_i also indirectly limits x_j. As a result, π_i increases. The magnitude of this motive declines as β gets higher; firm j knows that x_j positively affects q_i which in turn reduces $\frac{dq_j^*}{dx_j}$, and causes a fall in this motive.

The spill-back motive (henceforth, SB) refers to government i's intention to use s_i to encourage x_j,with the hope to free ride on firm j's innovative output $(\frac{\partial\pi_i^{**}}{\partial x_j} > 0)$. When $\beta > \frac{1}{2}$, firms' R&D are strategic complements, $s_i > 0$ can encourage x_j, so SB is positive. On the contrary, when $\beta < \frac{1}{2}$, firms' R&D are strategic substitutes, SB turns negative. $s_i < 0$ imposed on firm i induces larger x_j, which means more R&D knowledge will spill back from firm j to firm i. Obviously, the magnitude of this SB rises with β.

Ultimately, the sign of s_i^{CP} depends on the interaction of these two motives. When $\beta < \frac{1}{2}$, RS suggests an R&D subsidy while the SB recommends an R&D tax. Whereas RS suggests an R&D tax, while SB supports R&D subsidy when $\beta > \frac{1}{2}$ Due to the nature of linear demand and constant marginal cost, the net results of these interactions can be unambiguously determined. From (8), we combine the two motives,

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

Thus, *R&D subsidy* is always called for due to the dominations of the SB when $\beta > \frac{1}{2}$, and the RS when $\beta \leq \frac{1}{2}$. With optimal s^{CP}, the equilibrium values of firms' R&D, output, profit, country's welfare and comparison results[20] are summarized in table 1.

[20] The comparison results of profit and welfare are attained through graphic simulations (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 $\beta \in [0, 1]$.

	equibrium values	*comparison results*
x_i^{CP}	$\frac{6\theta_i(2-\beta)K[3(1-s_j^{CP})-2\theta_j(2-\beta)(1-\beta)]}{\Omega_{CP}}$	$x_h^{CP} < x_f^{CP}$
q_i^{CP}	$\frac{K+(2-\beta)x_i^{CP}+(2\beta-1)x_j^{CP}}{3}$	$q_h^{CP} < q_f^{CP}$
π_i^{CP}	$(q_i^{CP})^2 - \frac{(1-s_i^{CP})x_i^2}{2\theta_i}$	$\pi_h^{CP} < \pi_f^{CP}$ for most β, $\pi_h^{CP} > \pi_f^{CP}$ for very high β
W_i^{CP}	$(q_i^{CP})^2 - \frac{(x_i^{CP})^2}{2\theta_i}$	$W_h^{CP} < W_f^{CP}$ for most β, $W_h^{CP} > W_f^{CP}$ for very high β

The more efficient firm f has incentive to invest more than h, this incentive is fuelled by higher R&D subsidy from G_f. This results in higher quantity supplied by f. In the situation where spillovers are not too pervasive, f is in an advantageous position, and receives higher net profit compared to its inferior counterpart, h. In such case, country f also fares better in terms of welfare. On the contrary, when β is very high, h benefits largely from free-riding on x_f. This could be significant as to make h profit more than f.

In the last part of this section, we perform comparative statics of s_i^{CP} under various specifications[21], the results are summarized in table 2.

Specification	*Comparative statics*
1. $s_i^{CP} \mid_{\theta_i=\theta_j}$	$\frac{ds_i^{CP}}{d\beta} \gtreqless 0$ for $\beta \gtreqless \frac{1}{2}$, $\frac{ds_i^{CP}}{d\theta} > 0$
2. $s_i^{CP} \mid_{\beta=0}$	$\frac{ds_i^{CP}}{d\theta_i} > 0, \frac{ds_i^{CP}}{d\theta_j} > 0$
3. $s_i^{CP} \mid_{\beta=1}$	$\frac{ds_i^{CP}}{d\theta_i} > 0, \frac{ds_i^{CP}}{d\theta_j} > 0$

Specification 1 portrays the case of symmetric firms ($\theta_i = \theta_j = \theta$),the comparative statics show that the optimal R&D subsidy falls to zero as β increases from 0 to $\frac{1}{2}$ and rises again as β increases from $\frac{1}{2}$ to 1. The rationale is straightforward; for $0 < \beta < \frac{1}{2}$, the RS which is falling with β dominates, while the SB whose magnitude rises with β dominates only when $\frac{1}{2} < \beta < 1$. Also, as firms become more efficient in R&D, the dominating motive grows stronger, hence

[21] Detailed investigations are available from the authors upon request.

justifying higher R&D subsidy.

In the case where involuntary spillovers do not exist, thus no presence of SB. An increase in θ_i implies higher ability of firm i in shifting rent. However, a rise in θ_j also means that more subsidy is needed to help firm i shift rent.

In the last specification, involuntary spillovers are at the maximum, the SB dominates and at its height. An increase in θ_i enhances ability of x_i in inducing x_j, thus justifying larger subsidy. In addition, an increase in θ_j results in higher x_j, and larger magnitude of SB, this justifies higher subsidy.

3.2 R&D Joint Venture (RJV)

Under this agreement, firms avoid inefficient duplication by sharing fully their complementary R&D knowledge, but do not coordinate their R&D decisions. This arrangement does not alter the firms' *marginal costs of R&D*, an asymmetry between θ_h and θ_f is not affected by the cooperative agreement. The cost of conducting R&D still differs from one firm to another, as it depends not only on the technology know-how each firm possess, but also on the cost of R&D inputs (e.g. laboratory's equipments and computer systems) and the firm's organizational structure.

This scenerio possess the same characteristics as those in the case of R&D competition with complete spillovers, $\beta \equiv 1$. Thus, we can simply deduce from the previous case that under RJV, both firms underinvest in R&D compared to the efficient level due to large voluntary spillovers. The optimal policy intervention is R&D subsidy due to the domination of the SB over the RS at $\beta \equiv 1$ (refer to (5). Thus,

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

where $E_i = 9 - 2\theta_i + 2\theta_j$ and $G_i = 72\theta_j$. The comparison results of the partner firms' equilibrium R&D, output, profit and country welfare are shown in table 1. That means the more superior foreign firm's although receives higher subsidy, invest more and produce more output, but experiences less profit compared to the home firm. This has direct implication on welfare, the foreign country' welfare is thus lower than the home country's. In addition, we can also deduce that[22] $\frac{ds_i^{RJV}}{d\theta_i} > 0$ and $\frac{ds_i^{RJV}}{d\theta_j} > 0$; the rationale behind is exactly the same of that provided for specification 3 in table 2.

3.3 R&D Cartel (CT)

In this scenerio, firms deal with the problem of inappropriability of their R&D by coordinating their R&D decisions to maximize the cartel joint profits. Adopting **a profit- sharing rule** which is exogeneously determined, the coordinating firms must agree on an amount of transfer payment to be made between them

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

to sustain the agreement. Such transfer reflects the R&D cost sharing aspect of the cartel. We also assume that the more R&D efficient firm cannot pay the less efficient one not to produce; that means the foreign firm cannot use side payment scheme to establish itself as a monopolist.

Since the cooperation does not extend to the output stage, the characteristics of the output subgame is exactly the same as that in the R&D competition case. The equilibrium quantity is represented by (1).

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; $\max_{x_i} \Pi = \max_{x_i} \sum_{i,j} \widehat{\pi} = \max_{x_i} \sum_{i,j} ((\widehat{q}_i)^2 - \frac{(1-s_i)x_i^2}{2\theta_i})$, where Π denotes the cartel's joint profit, and $\widehat{q}_i$ refers to equilibrium quantity derived from the last stage (1). 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

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

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

where $\Omega_{CT} \equiv [9(1-s_i)-2\theta_i(5\beta^2-8\beta+5)][9(1-s_j)-2\theta_j(5\beta^2-8\beta+5)] - 16\theta_i\theta_j(2-\beta)^2(2\beta-1)^2 > 0$ (from relevant stability condition). It is straightforward to show that $\frac{d\widehat{x}_i}{ds_i} > 0$, and $\frac{d\widehat{x}_i}{ds_j} \gtreqless 0$ if $\beta \gtreqless \frac{1}{2}$. A subsidy to firm i will always increase x_i, while subsidy to firm j will only increase x_i when the firms' R&D are strategic complements. The assumption: $\theta_i < \frac{1}{2}$ suffices for the SOCs, stability condition and interior solution to hold in this R&D subgame. It is straightforward to show that $\widehat{x}_f > \widehat{x}_h$ and $\widehat{q}_f > \widehat{q}_h$ only when $\frac{(1-s_h)}{\theta_h} > \frac{(1-s_f)}{\theta_f}$. In the specific case of no interventions, the more efficient foreign firm invests and produces more than the inferior home firm.

As far as firm's incentive to invest is concerned, as firms coordinate, each takes into account how its R&D adversely affects its partner's R&D (coordination incentive) and how its R&D raises its partner's profit via spillovers (spillovers incentive). Although each firm still has the original strategic incentive and profit incentive in performing R&D, the additional two incentives make the firm's R&D decision more complex. Standard analysis can show that the coordination incentive has dominating effect when spillovers are relatively low, thus causes partner firms to restrict their R&D. However, with high spillovers, the spillovers incentive dominates others and induce firms to overinvest in their R&D[23].

In the second stage of the game, each government simultaneously chooses s_i, to maximize the country's welfare. Let δ- *sharing rule* simply mean a δ proportion of the cartel's profit made from using new R&D process discovered by the alliance is to be allocated to h, while the rest is for f and $\delta \in [0,1]$. For

[23] See Kamien etal (1992) for formal analysis of firm's incentive to invest.

example, when $\delta = \frac{1}{2}$, the firms adopt a 50% profit sharing rule, so each member receives $\frac{\widehat{\Pi}}{2}$ from the cartel agreement. In the following analysis, we denote the profit allocated to the home and foreign firm with $\widehat{v}_h$ and $\widehat{v}_f$ respectively, so we have $v_h \equiv \delta\widehat{\Pi}, v_f \equiv (1-\delta)\widehat{\Pi}$.

The countries' welfare functions take the forms:

$$W_h(s_h, s_f) = \delta\widehat{\Pi}(s_h, s_f) - \frac{s_h(\widehat{x}_h(s_h, s_f))^2}{2\theta_h}; \quad (12)$$

$$W_f(s_h, s_f) = (1-\delta)\widehat{\Pi}(s_h, s_f) - \frac{s_f(\widehat{x}_f(s_h, s_f))^2}{2\theta_f}. \quad (13)$$

The corresponding FOCs[24] give governments' reaction functions:

$$s_h = -\frac{(1-\delta)}{(1+\delta)}\left(\frac{(1-s_f)(9-2\theta_h(5\beta^2-8\beta+5)) - 2\theta_f(5\beta^2-8\beta+5) + 4\theta_h\theta_f(1-\beta^2)^2}{[9(1-s_f) - 2\theta_f(5\beta^2-8\beta+5)]}\right),$$

$$s_f = -\frac{\delta}{(2-\delta)}\left(\frac{(1-s_h)(9-2\theta_f(5\beta^2-8\beta+5)) - 2\theta_h(5\beta^2-8\beta+5) + 4\theta_h\theta_f(1-\beta^2)^2}{[9(1-s_h) - 2\theta_h(5\beta^2-8\beta+5)]}\right)$$

with and[25] $\frac{ds_h}{ds_f}$ and $\frac{ds_f}{ds_h} > 0$, that is the two R&D policies are strategic complements. The above reaction functions do have constant slope and cross twice in the (s_h, s_f) space, the unstable equilbrium is discarded due to the condition imposed for s.o.c., stability, and interior solution in the R&D subgame: $\theta_h < \frac{1}{2}$ and $\theta_f < \frac{1}{2}$. Solving for equilibrium R&D policies, we have:

$$s_i^{CT} = \frac{9\delta(I+M) + L - \sqrt{9(1+\delta)(1-\delta)H_iH_j(I+M) + \{9\delta(I+M)+L\}^2}}{9(1+\delta)H_j};$$

$$s_j^{CT} = \frac{9(1-\delta)I - 9\delta M + J - \sqrt{9\delta(2-\delta)H_iH_j(I+M) + \{9(1-\delta)I - 9\delta M + J\}^2}}{9(2-\delta)H_i},$$

where $H_i \equiv 9 - 2\theta_i(5-8\beta+5\beta^2) > 0$, $H_j \equiv 9 - 2\theta_j(5-8\beta+5\beta^2) > 0$, $I \equiv 9 - 2\theta_i(5-8\beta+5\beta^2) - 2\theta_j(5-8\beta+5\beta^2)$, $M \equiv 4\theta_i\theta_j(1-\beta^2)^2 > 0$, $J \equiv 4\theta_i\theta_j(17 - 40\beta + 48\beta^2 - 40\beta^3 + 17\beta^4)$, $L \equiv 8\theta_i\theta_j(2-\beta)^2(1-2\beta)^2$. The equilibrium R&D policies are *R&D taxes* ($s_i^{CT}, s_j^{CT} < 0$).

Consider the case where $\delta = \frac{1}{2}$, it can be easily deduced that *h is taxed more heavily compared to f* (i.e. $s_h^{CT} < s_f^{CT}$)[26]. The condition: $\frac{(1-s_h^{CT})}{\theta_h} > \frac{(1-s_f^{CT})}{\theta_f}$ always holds at equilibrium, therefore $x_f^{CT} > x_h^{CT}$, and $q_f^{CT} > q_h^{CT}$ are always true in this case.

24 $\frac{dW_i}{ds_i} = \frac{\delta d\widehat{\Pi}}{ds_i} - \frac{(\widehat{x}_i)^2}{2\theta_i} - s_i\frac{\widehat{x}_i}{\theta_i}\frac{d\widehat{x}_i}{ds_i} = 0.$

25 $\frac{ds_i(s_i)}{ds_j} = \frac{(1-\delta)16\theta_i\theta_j(2-\beta)^2(1-2\beta)^2}{(1+\delta)[9(1-s_j)-2\theta_j(5-8\beta+5\beta^2)]^2} > 0, \frac{ds_j(s_i)}{ds_i} = \frac{16\delta\theta_h\theta_f(2-\beta)^2(1-2\beta)^2}{(2-\delta)[9(1-s_j)-2\theta_j(5-8\beta+5\beta^2)]^2} > 0.$

26 With $\delta = 0.5$,we have $s_i^{CT} = \frac{1}{27}(H_i - \frac{1}{H_j}\sqrt{H_i^2H_j^2 + 27H_iH_j(I+M)}) < 0$. Since $\theta_h < \theta_f, H_h > H_f$; and $I + M > 0$ thus $s_h^{CT} < s_f^{CT}$.

One of this paper's main contribution to the R&D literature is the analysis in the next step. We investigate the rationale behind the optimal R&D tax by disentangling the effects of R&D tax on country i's welfare. To make the following analysis applicable for both countries, let $\widehat{\delta}_i$ denote the proportion of $\widehat{\Pi}$ allocated to firm i, i.e $\widehat{\delta}_h = \delta$, and $\widehat{\delta}_f = (1-\delta)$. From (12) and (13), the corresponding FOC is

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

The first term on the RHS can be written as:

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

where $\widehat{\widehat{\pi}}_i = f(\widehat{x}_i, \widehat{x}_j; s_i, s_j)$. Substituting (15) back in (14), we have

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

Rearranging above, we attain

$$\begin{aligned} s_i^{CT} \frac{\widehat{x}_i}{\theta_i}\frac{d\widehat{x}_i}{ds_i} &= -\frac{(1-\widehat{\delta}_i)(\widehat{x}_i)^2}{2\theta_i}; \\ s_i^{CT} &= -\frac{(1-\widehat{\delta}_i)\widehat{x}_i}{2} / \frac{d\widehat{x}_i}{ds_i} < 0. \end{aligned} \tag{16}$$

As $\frac{d\widehat{x}_i}{ds_i} > 0$, *R&D tax* is an optimal policy.

Similar to that in the case of R&D competition, the term $\frac{\partial\widehat{\widehat{\pi}}_i}{\partial x_j}\frac{d\widehat{x}_j}{ds_i}$ in (15) represents the combined effect of the rent-shifting and the spill-back motives. In the case of R&D cartel, G_i considers $\widehat{\Pi}$ when choosing s_i; the rent shifting and spill-back motives are therefore internalized. In other words, the effect of s_i on x_j and subsequently on π_i is fully internalized. G_i anticipates that any subsidy provided to firm i will be shared among the cartel members, and the direct benefit accrued to its own firm is only $\widehat{\delta}_i \frac{\partial\widehat{\widehat{\pi}}_i}{\partial s_i}$. It is as if G_i subsidizes firm j via the cartel agreement, while the cost of subsidy falls entirely on G_i. Therefore, it is wiser for G_i to tax its national firm i; any additional tax cost to firm i will be shared within the cartel, while only G_i has the claim on tax revenue. The s^{CT} is reached when the marginal cost of R&D tax borne by firm i (i.e. $\widehat{\delta}_i \frac{(\widehat{x}_i)^2}{2\theta_i}$) is equal to the marginal benefit of such tax policy accrued to G_i (i.e. which is $\frac{(\widehat{x}_i)^2}{2\theta_i} + s_i \frac{\widehat{x}_i}{\theta_i} \frac{d\widehat{x}_i}{ds_i}$). Although G_i desires as large tax revenue as possible, it cannot keep increasing the tax rate. The higher the tax, the lower the R&D level firm i will be assigned to conduct; most of the R&D task will be allocated to its partner and that results in lower tax revenue to be collected from firm i. *It should be noted that, the governments' motives to intervene through R&D tax remain unaffected by the variation in level of spillovers as long as this sharing rule is in use as the government has to take the R&D cartel's joint profit into account when maximizing welfare. Furthermore, the variation of the sharing proportion, $\widehat{\delta}_i$, although has no effect on the rationale behind and form of the intervention, it does affect the magnitude of such intervention*[27].

These findings are summarized in the following proposition:

Proposition 1 *Whenever firms agree to share the sum of cartel joint profit according to the adopted fixed percentage profit- sharing rule, government' s intervention through R&D tax is always optimal. Also, an optimal rate is determined by equating marginal cost of R&D tax borne by firm i with the marginal benefit of such tax accrued to government i.*

The magnitude of tax decreases as $\widehat{\delta}_i$ increases, *ceteris paribus* . The higher $\widehat{\delta}_i$ increases the tax burden (marginal cost of R&D tax) borne by firm i, the optimal tax size decreases to match the marginal benefit of tax with its marginal cost.

The comparative statics results of the R&D tax when firms form cartel agreement ($s_i^{CT} < 0$) under various specifications[28] are summarized in table 3.

Specification	*Comparative Statics*
1. $s_i^{CT}\|_{\theta_i=\theta_j}$	$\frac{ds_i^{CT}}{d\beta} < 0$ for most β $\frac{ds_i^{CT}}{d\beta} > 0$ for very high β $\frac{ds_i^{CP}}{d\theta} > 0$
2. $s_i^{CT}\|_{\beta=0}$	$\frac{ds_i^{CT}}{d\theta_i} > 0, \frac{ds_i^{CT}}{d\theta_j} > 0$
3. $s_i^{CT}\|_{\beta=1}$	$\frac{ds_i^{CT}}{d\theta_i} > 0, \frac{ds_i^{CT}}{d\theta_j} > 0$ -

[27] Variation of the sharing proportion would affect the stability of the alliance and the firms' willingness to cooperate, however those are outside the scope of our study.

[28] Detailed investigations are available from the authors upon request.

In the case of symmetry ($\theta_i = \theta_j$), we have $\frac{ds_i^{CT}}{d\beta} > 0$ for very high β, and the reverse is true for lower level of β. The intuition is straightforward. Recall that $\frac{d^2R_i}{dx_i^2} > 0$; as firm i delivers more R&D output, its corresponding R&D expenditure rises at an increasing rate. With coordinated R&D decision, firm i has incentive to increase x_i as β rises because it knows that firm j would benefit from x_i too. G_i can take advantage of the situation by increasing the tax rate to seek higher tax revenue. However, when β is very high, coordinated actions encourage high investment from both partners and put them on relatively steep section of R_i. Firm i will delegate some of its R&D tasks to the foreign partner if it finds the imposed tax rate too burdensome. In such case, G_i may lose out from a fall in tax revenue. Thus, it is wiser for G_i to lower the tax rate when the spillovers are quite high, so it stands to gain from tax revenue.

In the specific case of $\beta = 0$, we find that any increase in θ_i or θ_j reduces R&D tax . As θ_i increases, firm i conducts more x_i but incurs larger unit cost of R&D output ($\frac{d^2R_i}{dx_i^2} > 0$). G_i chooses to lower the tax rate so as to induce firm i to keep on investing, not to delegate part of its R&D task to its foreign partner. Although, like in Barros and Nilssen (1999), the firm receives more favourable tax treatment once it becomes more efficient, our rationale behind this result is completely different from theirs[29]. In the case where θ_j increases, firm i responds by reducing its x_i. G_i then prevents a fall in its tax revenue by reducing the tax rate to induce firm i to keep investing in R&D[30].

With the absence of spillovers, our *R&D cartel* shares the same characteristics with Qui and Tao (1998)'s *R&D coordination* case. They consider the appropriate R&D policies imposed by home (i) and foreign (j) governments when their national firms choose to coordinate decisions but not to share information. To maximize the joint profit, each firm would *underinvest* in R&D. However, as firms are symmetric in their setting, an issue of transfer payment among firms is irrelevant. Each firm's net profit is its sales profit net of R&D cost (i.e. $\widehat{\widehat{\pi}}_i$ in our analysis). Consequently, when G_i chooses R&D policy, it considers only $\widehat{\widehat{\pi}}_i$, not $\widehat{\widehat{\pi}}_j$. Hence, the government's motives for intervention is captured by[31] $\frac{\partial\widehat{\widehat{\pi}}_i}{\partial x_i}\frac{d\widehat{x}_i}{ds_i} + \frac{\partial\widehat{\widehat{\pi}}_i}{\partial x_j}\frac{d\widehat{x}_j}{ds_i}$. 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 advocates R&D subsidy. In other words, the government does not help its national firm commit to its coordination agreement to underinvest in R&D and wish to change the firm's behaviour by providing R&D subsidy. On the contrary, in this paper, G_i considers the effect of its s_i on $\widehat{\pi}_j$ so as to maximize Π; the only motive for intervention is to maximize gain from tax revenue. So, in a way, the governments help their national firms commit to their coordination

[29] In their setting where domestic competition exists, the more efficient firm is relatively more successful in shifting rent from foreign firms; thus imposing a smaller negative external effect on other domestic firms. So it faces lower tax.

[30] In the case where $\beta = \frac{1}{2}$, $\frac{ds_i^{CT}}{d\theta_j} = 0$, because at this level of β, an increase in x_j does not induce firm i to invest more, thus government i does not need to alter its R&D policy to accommodate any change θ_j.

[31] There is no spill-back motive in Qui and Tao (1998) as spillovers are absent.

agreement.

In the case of $\beta = 1$, we find that $\frac{ds_i^{CT}}{d\theta_i} > 0$, and $\frac{ds_i^{CT}}{d\theta_j} > 0$. The intuition behind $\frac{ds_i^{CT}}{d\theta_i} > 0$ is similar to that in the case $\beta = 0$, while that of $\frac{ds_i^{CT}}{d\theta_j} > 0$ is slightly different. When θ_j increases, it induces a rise x_j. This in turn induces x_i due to the strategic complementability of firms' R&D. As firm i will be on a steeper section of R_i, a reduction of tax rate can prevent it from delegating its R&D task to firm j.

The matter of transfer payment is crucial so as to make the cartel sustainable. The size and the direction of the transfer depend on the agreed sharing rule and level of spillovers. Consider a simple case where $\widehat{\delta}_i = \frac{1}{2}$ and $s_h^{CT}, s_f^{CT} = 0$. We first find that $\pi_f^{CT} < \pi_h^{CT}$, when β is relatively high[32]. Why is that? Although $x_h^{CT} < x_f^{CT}$ due to h's lower R&D efficiency, h benefits significantly from x_f^{CT} via spillovers. Hence, both firms experience similar reductions in marginal costs, while f carries a larger burden of R&D expenditure. As a result, π_f^{CT} tends to be lower than π_h^{CT}. Nonetheless, the payment of $\frac{\pi_h^{CT} - \pi_f^{CT}}{2}$ has to be transfered from h to f to satisfy the 50% profit sharing rule. On the other hand, when spillovers are relatively low, c_f is significant lower than c_h.That 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 f to h. Firm f is willing to do so as long as coordination is more beneficial than no coordination at all. Using this system of transfer payment, the cartel can arrange profit evenly to its member.

To make further analysis tractable, we assume henceforth that the cooperating firms **adopt a 50% profit sharing rule** to facilitate the coordination. Note also that, due to the complexity of the closed form solutions of equilibrium tax, firms' R&D, quantities, profits and countries' welfare, we have to resort to numerical simulation when making comparison of the profit and welfare variables across firms and countries. The comparison results are summarized in table 4.

[32] 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 $\beta \gtrsim 0.7$.

	equibrium values	*comparison results*
x_i^{CT}	$\frac{18\theta_i(1+\beta)K[1-s_j^{CT}-2\theta_j(1-\beta)^2]}{\Omega_{CT}}$	$x_h^{CT} < x_f^{CT}$
q_i^{CT}	$\frac{K+(2-\beta)x_i^{CT}+(2\beta-1)x_j^{CT}}{3}$	$q_h^{CT} < q_f^{CT}$ for $\beta \neq 1$, $q_h^{CT} = q_f^{CT}$ for $\beta = 1$
π_i^{CT}	$(q_i^{CT})^2 - \frac{(1-s_i^{CT})(x_i^{CT})^2}{2\theta_i})$	$\pi_h^{CT} < \pi_f^{CT}$ for most β, $\pi_h^{CT} > \pi_f^{CT}$ for very high β
v_i^{CT}	$\frac{\widehat{\Pi}}{2} = \frac{\sum_{i \neq j} \pi_i^{CT}}{2}$	$v_h^{CT} = v_f^{CT}$
W_i^{CT}	$\frac{\widehat{\Pi}}{2} - \frac{s_i^{CT}\left(x_i^{CT}\right)^2}{2\theta_i}$	$W_h^{CT} < W_f^{CT}$

,

Undoubtedly, the more R&D efficient firm who is imposed with lower tax rate has higher incentive to perform R&D. This results in f's higher effective R&D, X and larger quantity supplied except when β are at their maximum which allows h to match its superior partner with equal quantity supplied in the market. As far as π_i^{CT} is concerned, f experiences higher π for most level of β except when β are relative high. Although both firms overinvest compared to their efficient level when they coordinate their decisions in an environment of pervasive spillovers, h is at advantageous position as it gets free and easy access to x_f. However, due to the 50% profit sharing rule, a certain amount of transfer payment will have to be made from h to f to ensure equal net profit, v_h^{CT}, to both firms. As for welfare comparison, G_h attains lower welfare for all levels of β, this is mainly due to the lower levels of tax revenue collected and its national firm's profit compared to its foreign counterpart.

3.4 RJV Cartel (RJVCT)

This scenerio combines the important features of RJV and R&D cartel: complete sharing of information and coordinating R&D decisions; it is simply the R&D cartel with $\beta \equiv 1$. In this case, firm i tends to overinvest compared to the efficient level to utilize the complete flow of information. The optimal R&D policy takes the form:

$$s_i^{RJVCT} = \frac{9\delta I + L - \sqrt{9(1+\delta)(1-\delta)H_iH_jI + (9\delta I + L)^2}}{9(1+\delta)H_j} < 0;$$

$$s_j^{RJVCT} = \frac{9(1-\delta)I + J - \sqrt{9\delta(2-\delta)H_iH_jI + (9(1-\delta)I + J)^2}}{9(2-\delta)H_i} < 0,$$

where $H_i \equiv 9 - 4\theta_i > 0$, $H_j \equiv 9 - 4\theta_j > 0$, $I \equiv 9 - 4\theta_i - 4\theta_j > 0$ and $J \equiv L \equiv 8\theta_i\theta_j > 0$.

In the case where $\widehat{\delta} = 0.5$, we have $s_f^{RJVCT} > s_h^{RJVCT}$, $\frac{ds_i^{RJVCT}}{d\theta_i} > 0$ and $\frac{ds_i^{RJVCT}}{d\theta_j} > 0$. The intuition behind these comparative statics are as given in the case of R&D cartel with $\beta = 1$. Furthermore, we can deduce from table 3 that at $\beta \equiv 1$, $x_f^{RJVCT} > x_h^{RJVCT}$; $q_f^{RJVCT} = q_f^{RJVCT}$; $\pi_h^{RJVCT} > \pi_f^{RJVCT}$, and a transfer payment is to be made from h to f to share R&D cost, thus the 50% sharing rule is fulfilled. This payment is equal to $\frac{1}{2}\left(\frac{(x_f^{RJVCT})^2}{2\theta_f} - \frac{(x_h^{RJVCT})^2}{2\theta_h}\right)$.

3.5 Choosing R&D regime

To address this question, we move to the first stage of the game where firms are allowed to make decision on what form of cooperative agreement they want to tie themselves into so as to maximizes their profits, taking into account the governments' policy stance for each R&D regime. To make analysis in this stage of game tractable, $\widehat{\delta} = 0.5$ is set for the cases of R&D cartel and RJV cartel.

We know from the governments' subgame that G_h and G_f will intervene through R&D subsidies in cases where firms compete in R&D and when firms agree to form research joint venture. On the other hand, they will impose R&D tax if the firms engage in R&D cartel and RJV cartel. Although, simultaneous interventions may not be beneficial from societal welfare standpoint (both countries welfare could be worsen)[33], a choice to intervene is optimal from each government's point of view (i.e. intervention is a dominant strategy for each government) and it does not want to deviate from that chosen action, ex post[34].

The profit levels are compared for given θ_i, θ_j and β. To help explain what drives the profit comparison results, we make comparison of each firm's R&D level under different R&D regimes. Due to the complexity of equilibrium profit and R&D expressions, we resort to graphic simulations. Figure 1 and 2 show examples of those simulations, where K and θ_f fixed at 1, and 0.49 respectively and θ_h is set at three values: 0.49; 0.3; and 0.15 so that the firms' relative R&D efficiency can be brought into the picture. The net profit levels of h's and f's are respectively shown in panel 1) to 3) and panels 4) to 6) of figure 1, while figure 2 and figure 3 shows the firms' autonomous R&D and effective R&D levels respectively.

Claim 2 *Given a 50% profit -sharing rule, and governments' intervention through R&D subsidy when firms compete in R&D or form RJV, and through R&D tax when firms form R&D cartel or RJV cartel, the RJV cartel may no longer be*

[33] The detailed analysis of effects of simultaneous interventions on welfare including example of simulation results are available from the authors upon request.

[34] In the case of unilateral intervention, an intervention always enhances the country's welfare. This policy stance can be easily deduced from welfare maximization procedure. $s_i^* \neq 0$, is an optimal choice. See detail analysis of this case in Teerasuwannajak (2004).

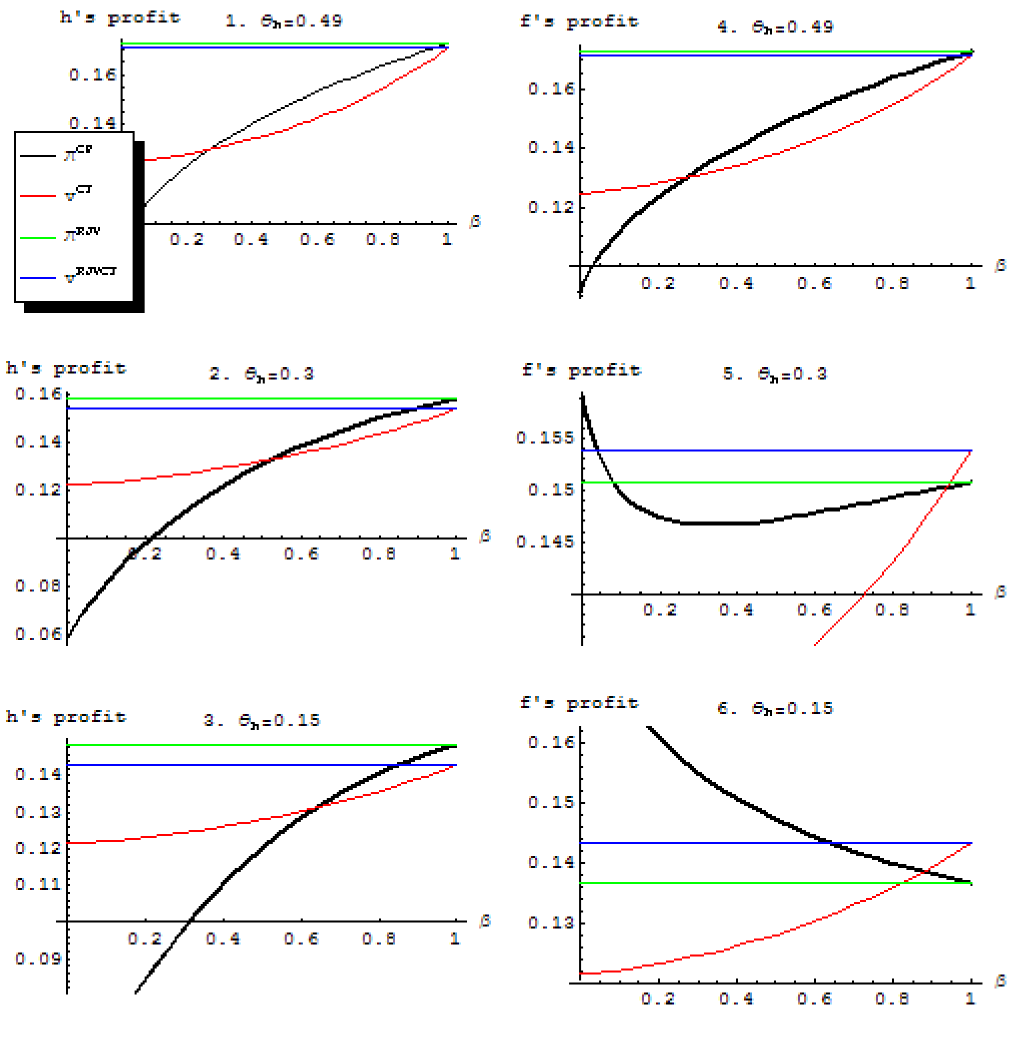

Figure 1: Firm h and firm f 's equilibrium profits under different R&D regimes.

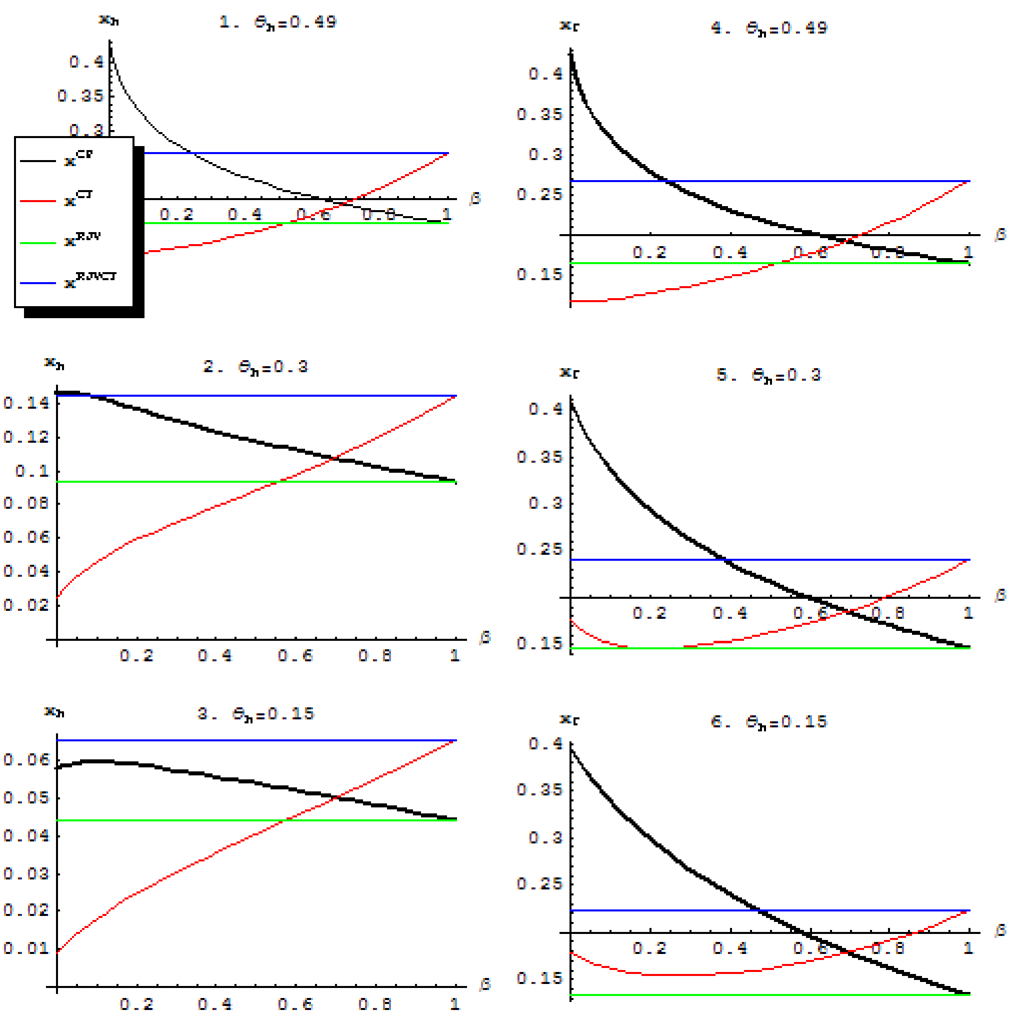

Figure 2: Firm h and firm f 's R&D under different R&D regimes.

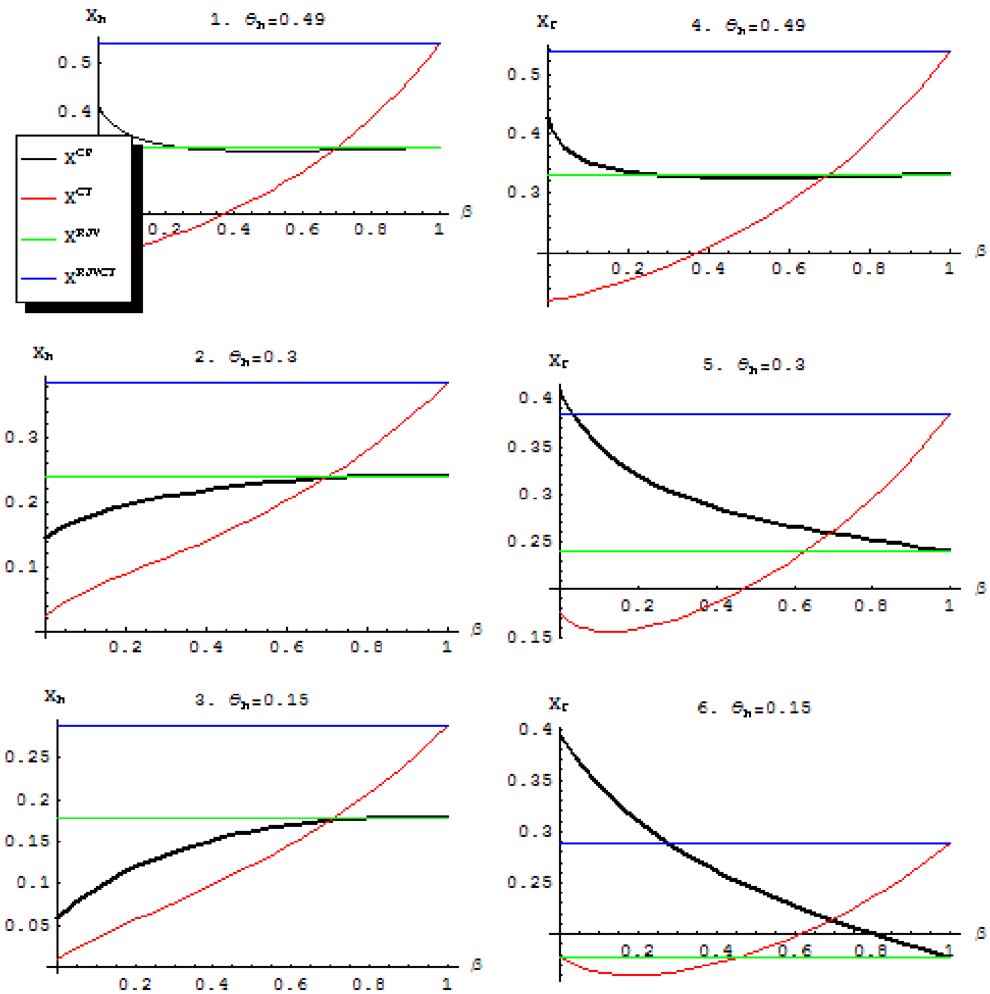

Figure 3: Firm h and firm f's effective R&D under different R&D regimes

the most beneficial form of R&D cooperation[35]*. From an inferior firm's point of view, the RJV agreement always outperform other forms of R&D configurations, whereas the more superior firm may still find 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 R&D competition regime otherwise.*

Although in most cases the inferior firm's own R&D and its effective R&D are highest under RJV cartel compared to other regimes, the effect of simultaneous interventions through R&D tax significantly affect the cartel joint profit. This make the RJV agreement, which entitles the inferior firm to both R&D knowledge of the superior firm and government's R&D subsidy, the most attractive regime. Interestingly, in the case where firms are symmetric, intervention through taxes also make RJV cartel less agreeable than RJV from the foreign firm's point of view.

As for the more superior foreign firm, the degree of inferiority of its partner does affect the potential benefit and viability of RJV cartel. Although we find that R&D tax imposed under RJV cartel has impact on firms' incentive to perform autonomous R&D, but f's effective R&D is still highest under 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 RJV cartel in terms of profits. With relatively low β, coordinating firms underinvest in their R&D compared to their efficient levels, and have to bear imposition of tax under RJV cartel. This results in low effective R&D compared to that in the case of R&D competition and that is why profit could be higher if firms compete in R&D. However, as spillovers become more pervasive. The internalization of the free-rider problem that results in relatively high effective R&D under RJV cartel makes this regime more attractive again.[36]. The bigger the gap between firms' R&D efficiency, the more likely for the foreign firm to prefer R&D competition regime as the inferior partner cannot contribute much in terms of R&D, thus profit to the cartel.

In sum, given the prospect of governments' intervention, a concensus on R&D regime may not be easily reached among asymmetric partners under a 50% profit sharing rule. However, by adjusting the ratio of profit sharing to take into account of the gap between firms' efficiency, both firms may find that a certain form of cooperation fares better in terms of profits compared to other regimes A concensus on potential form of R&D configuration could then be reached in such case.

4 Government Coordination

In this section, we further explore a form of government's intervention under different R&D configurations when the home and foreign governments cooperate

[35] 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.

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

in setting R&D policy and *harmonizing* the form of R&D policy across the two countries. In doing so, we first assume $s_h = s_f = s$, and each government chooses s to maximize the sum of both countries' welfare: $W_h + W_f$. Since the nature of games played by firms in the R&D stage and the output stage when governments cooperate are the same as those portrayed in the case of government competition, we can deduce the third- stage equilibria of R&D, quantities and profits under each R&D configurations by substituting s_i and s_j with s. We avoid making unnecessary repetitions in this section by starting our analysis at the second stage of the game (the government stage). The scenerio where firms compete in R&D will be considered first, and some inference will then be drawn for the case of research joint venture (RJV). We then move to consider the case of R&D cartel, and lastly RJV cartel.

Due to the complexity of the closed form solutions of s derived for each R&D regime, the following analysis address only the form of and the rationale behind governments' intervention, the equilibrium value of s, will not be explicitly shown.

4.1 R&D competition (CP-C)

From (2) and (3), by setting $s_h = s_f = s$, we have $x_i^* = \frac{6\theta_i(2-\beta)K[3(1-s)-2\theta_j(2-\beta)(1-\beta)]}{\Omega_{CP}}$; $q_i^{**} = \frac{9(1-s)K[3(1-s)-2\theta_j(2-\beta)(1-\beta)]}{\Omega_{CP-C}} > 0$; $\pi_i^{**} = (q_i^{**})^2 - \frac{(x^*)^2}{2\theta_i}$ where $\Omega_{CP-C} \equiv [9(1-s) - 2\theta_i(2-\beta)^2][9(1-s) - 2\theta_j(2-\beta)^2] - 4\theta_i\theta_j(2-\beta)^2(2\beta-1)^2 > 0$ and $i, j \in \{h, f\}, i \neq j$. It is straightforward to show that $\frac{dx_i^*}{ds} > 0$ and $\frac{dx_j^*}{ds} > 0$. Since $W_i = \pi_i^{**} - s\frac{(x_i^*)^2}{2\theta_i}$, the cooperative government problem is to maximize the sum of both countries' welfare; that is to

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

Its corresponding FOC gives

$$\begin{aligned}
\frac{d\Psi}{ds} &= \frac{d\pi_i^{**}}{ds} + \frac{d\pi_j^{**}}{ds} - \frac{1}{2}\left(\frac{(x_i^*)^2}{\theta_i} + \frac{(x_j^*)^2}{\theta_j}\right) - \frac{s}{2}\left(\frac{2x_i^*}{\theta_i}\frac{dx_i^*}{ds} + \frac{2x_j^*}{\theta_j}\frac{dx_j^*}{ds}\right) \\
&= \frac{\partial\pi_i^{**}}{\partial x_i^*}\frac{dx_i^*}{ds} + \frac{\partial\pi_i^{**}}{\partial x_j^*}\frac{dx_j^*}{ds} + \frac{\partial\pi_i^{**}}{\partial s} + \frac{\partial\pi_j^{**}}{\partial x_i^*}\frac{dx_i^*}{ds} + \frac{\partial\pi_j^{**}}{\partial x_j^*}\frac{dx_j^*}{ds} + \frac{\partial\pi_j^{**}}{\partial s} \\
&\quad -\frac{1}{2}\left(\frac{(x_i^*)^2}{\theta_i} + \frac{(x_j^*)^2}{\theta_j}\right) - s\left(\frac{x_i^*}{\theta_i}\frac{dx_i^*}{ds} + \frac{x_j^*}{\theta_j}\frac{dx_j^*}{ds}\right) \\
&= 0
\end{aligned}$$

Since $\frac{\partial\pi_i^{**}}{\partial x_i^*}$ and $\frac{d\pi_j^{**}}{dx_j^*}$ are both zero from the third stage FOCs, and $\frac{\partial\pi_i^{**}}{\partial s}$ 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, the above equation becomes

$$\frac{d\Psi}{ds} = \frac{\partial \pi_i^{**}}{\partial x_j^*}\frac{dx_j^*}{ds} + \frac{\partial \pi_j^{**}}{\partial x_i^*}\frac{dx_i^*}{ds} - s\left(\frac{x_i^*}{\theta_i}\frac{dx_i^*}{ds} + \frac{x_j^*}{\theta_j}\frac{dx_j^*}{ds}\right) = 0$$

Consider the term $\frac{\partial \pi_i^{**}}{\partial x_j^*}$ and $\frac{\partial \pi_j^{**}}{\partial x_i^*}$, they can be respectively elaborated as:

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

Thus, $\frac{d\Psi}{ds}$ can be rewritten as:

$$\begin{aligned}
s\left(\frac{x_i^*}{\theta_i}\frac{dx_i^*}{ds} + \frac{x_j^*}{\theta_j}\frac{dx_j^*}{ds}\right) &= \left(\frac{\partial \pi_i^*}{\partial q_j^*}\frac{dq_j^*}{dx_j}\right)\frac{dx_j^*}{ds} + \frac{\partial \pi_i^*}{\partial x_j}\frac{dx_j^*}{ds} + \left(\frac{\partial \pi_j^*}{\partial q_i^*}\frac{dq_i^*}{dx_i}\right)\frac{dx_i^*}{ds} + \frac{\partial \pi_j^*}{\partial x_i}\frac{dx_i^*}{ds} \\
&= \frac{2}{3}(2\beta - 1)\left(q_i^*\frac{dx_j^*}{ds} + q_j^*\frac{dx_i^*}{ds}\right)
\end{aligned}$$

It was established earlier that $\frac{dx_j^*}{ds} > 0$ and $\frac{dx_i^*}{ds} > 0$, hence $s^{CP-H} \gtreqless 0$ if $\beta \gtreqless \frac{1}{2}$. The optimal policy is R&D subsidy (tax) when the firms' R&D are strategic complements (substitutes). The rationale behind is straightforward. Under R&D competition, firms tend to underinvest when spillovers are pervasive. However, given these large spillovers, firms' R&D indeed strategically complement each other, each firm's profit increases with the other firm's R&D. When both governments cooperate to maximize total welfare, they want to encourage more R&D investments by both firms. So R&D subsidy is optimally chosen. On the contrary, when spillovers are small, firms tend to overinvest in order to strategically manipulate its counterpart's R&D decision. These actions do harm to both countries welfare, so both governments agree to impose R&D tax on their firms to deter too much R&D.

Certain analytical results can be drawn for the case of research joint venture. When $\beta \equiv 1$, firms agree to share full information, the form of optimal R&D policy is R&D subsidy.

4.2 R&D cartel (CT-C)

Following the same procedure that was done in the previous case, from (10) and (11), we set $s_h = s_f = s$, so that we have $\widehat{x}_i = \frac{18\theta_i(1+\beta)K[(1-s)-2\theta_j(1-\beta)^2]}{\Omega_{CT-C}}$; $\widehat{\widehat{q}}_i = \frac{9k(1-s)[3(1-s)-2(1-\beta)(\theta_j(2-\beta)-\theta_i(1-2\beta))]}{\Omega_{CT-C}} > 0$; $\widehat{\pi}_i = (\widehat{\widehat{q}}_i)^2 - \frac{(\widehat{\widehat{x}})^2}{2\theta_i}$ where $\Omega_{CT-C} \equiv [9(1-s)-2\theta_i(2-\beta)^2][9(1-s)-2\theta_j(2-\beta)^2] - 4\theta_i\theta_j(2-\beta)^2(2\beta-1)^2 > 0$ and

$i, j \in \{h, f\}, i \neq j$. With lengthy algebraic manipulation, it is possible to show that $\frac{d\widehat{x}_i}{ds} > 0$ and $\frac{d\widehat{q}_i}{ds} > 0$. From $W_i = \delta\widehat{\Pi} - \frac{s(\widehat{x}_j(s))^2}{2\theta_i}$; $W_j = (1-\delta)\widehat{\Pi} - \frac{s(\widehat{x}_j(s))^2}{2\theta_j}$, where $\widehat{\Pi}$ stands for cartel joint profit, the cooperative government's problem is:

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

Its corresponding FOC gives:

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

However, $\frac{\partial\widehat{\widehat{\pi}}_i}{\partial\widehat{\widehat{x}}_i}\frac{d\widehat{\widehat{x}}_i}{ds} + \frac{\partial\widehat{\widehat{\pi}}_j}{\partial\widehat{\widehat{x}}_i}\frac{d\widehat{\widehat{x}}_i}{ds} = 0$ and $\frac{\partial\widehat{\widehat{\pi}}_i}{\partial\widehat{\widehat{x}}_j}\frac{d\widehat{\widehat{x}}_j}{ds} + \frac{\partial\widehat{\widehat{\pi}}_j}{\partial\widehat{\widehat{x}}_j}\frac{d\widehat{\widehat{x}}_j}{ds} = 0$ from the third-stage optimization, thus the above equation can be rewritten as:

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

Given the term $\frac{\widehat{\widehat{x}}_i}{\theta_i}\frac{d\widehat{\widehat{x}}_i}{ds} + \frac{\widehat{\widehat{x}}_j}{\theta_j}\frac{d\widehat{\widehat{x}}_j}{ds}$ is not equal to zero, we can then conclude that the optimal R&D policy for both governments in this case is *no intervention,* $s^{CT-C} = 0$. Why is that? It is as if the cartel arrangement between firms acts on behalf of the cooperative governments. The cartel optimization help internalize the rent shifting and spill-back motives. Also, any revenue gained by the governments is the firms' loss and vice versa, this gain and loss are cancelled out in the total welfare optimization. The net result suggests laissez fair policy in both R&D cartel and RJV cartel.

5 Concluding Remarks

Our paper investigates the forms of governments' interventions via R&D policy when their national firms who are asymmetric in their R&D efficiency may have formed certain type of cooperative agreement such as R&D cartel , research joint venture (RJV) and RJV cartel. Firms coordinate their R&D decisions when they form R&D cartel while they merely share their R&D information if they form RJV, and they agree to both info-sharing and coordination of R&D decisions in RJV cartel. The important feature of our model is the adoption of a particular form of profit sharing rule whenever firms coordinate their R&D decisions. This feature has significantly altered the motives behind a government's intervention from what conventionally established; and questioned the viability of such interventions.

We start 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 international RJV. Two traditional motives drive this form of intervention: the rent-shifting and the spill-back motives. The former is from the government's intention to help its national firm extract certain profit from its rival, while the latter captures its intention to boost the amount of the rival firm's R&D which, via spillovers, would spill back to benefit its national firm. Regardless of the level of spillovers, the interactions of the two motives always suggests R&D subsidy.

The novelty of our study arises from the analysis of R&D cartel and RJV cartel where an exogenously determined profit- sharing rule is employed in their decision making process. Since the alliance's net profit is to be redistributed among asymmetric members in the manner governed by the sharing rule, the alliance's net profit, not just its national firm's profit, is the main concern for each government when making decision to intervene. That means under these two forms of agreements, the effects of one government's R&D policy on the other country's national firm's profit are completely internalized in the welfare maximizing process such that the traditional rent-shifting and spill-back motives disappear, and the optimal policy is R&D tax. The reason is that the home government anticipates that effect of R&D tax on its national firm would later on be processed by the cartel's profit maximizing procedure. So it is as if the tax incidence is borne by all members in the cartel, while only the home government has the right to collect tax revenue. The optimal tax rate is reached when a further rise in R&D tax would cause too large reduction in the firm's R&D which consequently leads to a fall in total tax revenue.

When it comes to the firms' business of choosing R&D regime, we address this issue by comparing the firm's equilibrium net profits under four different R&D regimes, taking into account governments' competition through R&D policy. In order to make the analysis tractable, we assume a 50% profit-sharing rule is employed whenever firms coordinate their decisions. We show that given the prospect of governments' intervention, a concensus on R&D regime may not be easily established by these asymmetric firms under a 50% profit sharing rule. The impositions of R&D taxes when firms coordinate affects firms' perception towards cartel arrangement a great deal. The inferior home firm prefers RJV to other regimes as it can get easy access to its partner R&D while at the same time getting support from its government through R&D subsidy. The more superior foreign firm may even find R&D competition most beneficial especially when its partner R&D efficiency is significantly below its own and spillovers are relatively low. The RJV cartel may outperform others only when involuntary spillovers are relatively high that the internalization of free-rider problem under RJV cartel makes the regime most appealing again.

We further extend the model to explore the case where governments coordinate by harmonizing their form of interventions, this indeed gives us very interesting results. We find that under R&D competition regime, R&D subsidy is an optimal policy only when spillovers are pervasive as both governments want to encourage more R&D investments by both firms when their R&D incentives are lacking due to free-riding problem. On the contrary, when spillovers are relatively small, R&D tax is to be chosen.This is because both firms tend to overinvest in R&D which harm both countries' welfare. So R&D tax is imposed to deter too much R&D activities. In the case where firms form R&D cartel or RJV cartel, the governments' interventions are redundant. The cartel arrangement between firms has acted on behalf of the coordinating governments, it has internalized the governments' rent shifting and spill-back motives. Also any revenue gained by the governments is the firms' loss and vice versa, so this gain and loss are cancelled out in the total welfare optimization.

These results help emphasize the fact that the business of choosing an appropriate R&D policy can be tricky. Even in the simplest case of asymmetric duopolist, the nature of optimal R&D policy is very sensitive to the form of relationship forged between its national firm and the foreign counterpart. An expectation of governments' interventions through R&D policy may act as deterrence, not a catalyst, to asymmetric firms forming cooperative agreement.

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