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Asymmetric Innovation Agreements under Environmental Regulation

Abstract

In a domestic market, a duopoly produces a homogeneous final good, pollution, pollution abatement and R&D. One of the firms (foreign) has superior technology. The government regulates the duopoly by levying a pollution tax to maximize domestic welfare. We consider the potential implementation of three innovation agreements: cooperative research joint venture (RJV), non-cooperative RJV and licensing. In the cooperative (non-cooperative) RJV, the firms (do not) internalize R&D spillovers. We show that, for the domestic firm, the cooperative RJV dominates and licensing is the least desirable alternative. Although licensing is dominant for the foreign firm, it is not implementable. Both RJVs are implementable. While the non-cooperative RJV is more likely the greater the degrees of asymmetry (in terms of efficiency and R&D spillover rates) between the firms, the cooperative RJV is more likely the lower the degrees of asymmetry. Implementation of both types of RJVs improve the competitiveness of the domestic firm and welfare. A subsidy policy that induces the foreign firm to accept a feasible cooperative RJV when it strictly prefers a feasible non-cooperative RJV is always welfare improving.

JEL-Codes: D430, D620, F230, L130, L240, L510, Q550, Q580.

Keywords: environmental regulation, innovation, research joint ventures, licensing.

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1. Introduction

Innovation agreements abound and take various forms.[1] Two important examples are research joint ventures (RJVs) and licensing.[2] Many innovation agreements are international (mostly, North-North and North-South) and some international agreements occur as a natural consequence of foreign direct investment.[3] While innovation agreements in clean and perfectly competitive markets are socially desirable because they increase efficiency, their social desirability in dirty oligopolistic industries depends on their impacts on market power and environmental degradation.[4] As different types of innovation agreements typically generate divergent welfare impacts, one should consider each type of innovation agreement very carefully in order to prevent unfortunate tradeoffs.

Improvement in environmental performance appears to be one of the main reasons why firms form RJVs. According to Scott (1996), one third of the first RJVs filed after the enactment of the National Cooperation Research Act (NCRA) of 1984 in the

[1] Hagedoorn (1990) presents a detailed overview of six forms of interfirm cooperation: (i) joint ventures and research corporations; (ii) joint R&D; (iii) technology exchange agreements; (iv) customer-supplier relationships; (v) direct investment; and (vi) one-directional technology flows. RJVs and technology exchange agreements represent nearly 34.6% of the total. For further evidence of RJVs, see, e.g., Greenlee (2005) and Hagedoorn (2002). According to a survey for the Intellectual Property Owners Association in the U.S., 17.6% of respondents licensed out their patents (Cockburn and Henderson (2003)).

[2] "A license is an agreement whereby the owner of intellectual property authorizes another party to use it." Scotchmer (2004), p. 161.

[3] See, e.g., Caloghirou et al. (2003), Song (2011) and Xu (2000) for evidence of North-North innovation agreements. See, e.g., Asano and Matsushima (2014), Borensztein et al (1998), Kokko (1994), Müller and Schnitzer (2006), Vishwasrao (1994) and Yang and Maskus (2009) for evidence of North-South innovation agreements. According to Tan et al (2010), China acquires technologies through joint ventures or by purchasing technological licenses. For example, the Shanghai Electric Group acquired the designs for turbine technology by purchasing a license from Alstom and obtained access to boiler and generator technologies through a joint venture with Siemens. Watson et al (2011) shows that RJV and licensing are important sources of international knowledge transfers in low carbon technology between the United Kingdom and China.

[4] Miyagiwa (2009) shows that a cooperative RJV facilitates collusion. Duso et al. (2014) finds strong evidence that cooperative RJVs among competitors in the same industry leads to collusion, while cooperative RJVs among non-competitors enhance efficiency. We rule out collusion. It is an interesting topic for future research.

U.S. and one third of RJVs within a period of 21 months after the enactment of the Clean Air Act Amendments (CAAA) of 1990 relate to environmental issues. The objectives of Japan's Research Association of Refinery Integration for Group-Operation (RING) are to improve its participants' competitiveness and environmental performance. The goals of Canada's Oil Sands Innovation Alliance (COSIA) are to improve its members' environmental performances in four environmental impact areas: toxic tailings ponds, greenhouse gas emissions, water pollution and ground and biodiversity disturbance.[5]In great part, COSIA emerged in response to an increase in the stringency of an environmental standard in 2009, whose objective was to reduce environmental damages caused by toxic tailings ponds.[6] However, as COSIA's joint R&D activities encompass three additional areas of environmental impacts, its formation rationale, just like the phenomenon that Scott (1996) describes (i.e., formation of environmental RJVs prior to CAAA), suggests that some polluting industries may form RJVs in anticipation of new (or more stringent) environmental regulations.

In this paper, we consider the endogenous formation of innovation agreements in a duopoly where there is a technological gap between the firms. Technological gaps are common in dynamic industries that experience frequent technological improvement. They are also common in international markets where entrants (foreign firms) have superior technology (see, e.g., Asano and Matsushima (2014) and Müller and Schnitzer

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[5] RING and COSIA are examples of industrywide RJVs. RING and COSIA started their operations in 2000 and 2012, respectively. For more details, see http://www.ring.or.jp/ and http://www.cosia.ca. Recent papers investigate the determinants of participation in RJVs. According to Hernan et al. (2003), sectorial R&D intensity, industry concentration, firm size, technological spillovers, past participation in R&D join venture (RJV) and the effectiveness of patents influence the probability of forming RJVs. According to Roller et al. (2007), the determinants of participation in RJVs are R&D cost sharing, firm size differences, the number of firms in the R&D project, the industries and the impact of R&D investments.

[6] Alberta's former environmental regulator, called Energy Resources Conservation Board (ERCB) implemented Directive 074 ("Tailings Performance Criteria and Requirements for Oil Sands Mining Schemes") on February 3, 2009.

(2006)). In keeping with the latter, we consider a duopoly consisting of domestic and foreign firms in which the foreign firm has superior technology.

We examine four settings: (i) status quo (no innovation); (ii) cooperative RJV; (iii) non-cooperative RJV; and (iv) licensing. Under the cooperative RJV, the firms coordinate their R&D efforts and internalize R&D spillovers. Under the non-cooperative RJV, the firms enjoy R&D spillovers but do not internalize them. In the setting with licensing, the foreign firm charges a royalty fee to allow the domestic firm to have access to its superior technology knowing how it affects competition in the output's market.

The firms select a feasible agreement (RJV or licensing), if any is available, in the first stage of a multistage game of complete but imperfect information that they play with a domestic government. An innovation agreement is feasible if it represents a (weak) Pareto improvement relative to the status quo. If there is a single feasible agreement, this is the firms' choice. If there are multiple feasible innovation agreements, the firms announce their preference rankings to each other. If the first choices coincide, the firms choose the dominant one. If the first choices do not coincide, the firms utilize a random device (e.g., flip a fair coin if there are two alternatives) in their selection procedure. The government observes the first stage's outcome and then sets the pollution tax in the second stage before the firms make choices of abatement, output and R&D efforts.

We show that the cooperative RJV dominates the non-cooperative RJV and licensing is the least preferable alternative (including the status quo) for the domestic firm and the government. For the foreign firm, however, licensing dominates and the non-cooperative RJV is generally second best. Referring to a feasible innovation scheme as "implementable" if it is adoptable, we can say that licensing is not implementable and both RJVs are implementable under different technological circumstances.

To our knowledge, this is the first paper that examines the endogenous formation of different types of innovation agreements in the presence of a technological gap and environmental regulation. We believe this is quite important because firms are typically asymmetric, RJVs and licensing are common, one of the main reasons for the formation of innovation agreements is to improve the participants' environmental performances and some polluting firms may have been forward looking when they formed RJVs.

Our paper contributes to several branches of the literature. There is a large literature that investigates various circumstances under which environmental regulation promotes incentives for innovation in pollution abatement (see, e.g., Carrión-Flores and Innes (2010), Denicolo (1999), Fischer et al. (2003), Laffont and Tirole (1996), Malueg (1989), Monner-Colonques and Rubio (2016), Montero (2002a), and Requate (1995, 1997, 2005b)). Requate (2005a) provides an excellent review of the early theoretical literature. Particularly relevant for this paper are the contributions that study innovation efforts supplied by firms that are imperfectly competitive in the output market (see, e.g., Chiou and Hu (2001), Innes and Bial (2002), Katsoulacos and Xepapadeas (1996), Montero (2002b), Ouchida and Goto (2014, 2016a, 2016b), Poyago-Theotoky (2007)). Unlike these papers, we consider settings in which innovation *agreements* are endogenous, there is a technological gap in the industry and (domestic) welfare does not take the producer surplus of the (foreign) firm that has superior technology into account. As Innes and Bial (2002), we assume the firms' R&D effort levels are unobservable by each other and by the government.[7] The firms observe each other's R&D effort if they cooperate.

[7] See Sappington (1982) for a discussion of the difficulty faced by regulators to observe the regulated firms' R&D efforts. Sappington (1982) considers a game of incomplete and imperfect information. We analyze games of complete but imperfect information. Extending our framework to examine the impacts of informational asymmetry is an interesting avenue for future research.

As we analyze the effects of (anticipated) environmental regulation on potential innovation adoption and improvement of the domestic firm's competitiveness, we contribute to the vast literature on the Porter hypothesis (see, e.g., Greaker (2006), Greaker and Rosendhal (2008), Jaffe and Palmer (1997), Lanoie et. al (2011), Mohr (2002), Porter (1991), Xexapadeas and De Zeeum (1999)). We depart from most works in this literature in that innovation adoption, if it occurs, takes place prior to environmental regulation. However, the anticipated costs of environmental regulation play an important role. Innovation occurs when the firms join a feasible RJV. The costs of environmental regulation that the firms face in a RJV are lower than in the status quo, and the anticipated savings in environmental regulatory costs are one of the key drivers of innovation. The other key driver is improvement in the domestic firm's competitiveness. The firms' perfect foresight results in an outcome that supports the Porter hypothesis. The credible threat of higher environmental regulatory costs produce adoption of Pareto-improving innovation and improvement in domestic competitiveness.

Asano and Matsushima (2014) examine the incentives that a foreign firm faces to transfer its superior and clean technology to a domestic firm, which utilizes a dirty technology, in the presence of an emission tax. Our framework differs from theirs in many respects, including allowing for cost-reducing R&D in the licensing agreement, considering RJVs and examining the endogenous formation of innovation agreements.

The paper is as follows. Section 2 describes the basic model. Section 3 examines the subgame perfect equilibria for the four settings. Section 4 evaluates the impacts of the implementable innovation agreements on domestic competitiveness and welfare. It also shows that a subsidy policy that induces the foreign firm to accept a feasible cooperative RJV is always welfare improving. Section 5 offers concluding remarks.

2. Basic Model

Suppose that a duopoly, containing domestic and foreign firms, produce a homogeneous final good in an economy where the market for the final good is closed. The production process is dirty. The foreign firm possesses an advanced technology. In the absence of a licensing agreement, the domestic firm utilizes a basic technology.

Firm i, $i = 1, 2$, produces q_i units of output, a_i units of abatement and r_i units of cost-reducing R&D effort.[8] Let $y_i \equiv a_i + q_i$ denote firm i's joint production level of abatement and output. We assume that abatement and output are perfect substitutes in production; that is, these two production activities compete equally in terms of usage of costly inputs. R&D effort increases the effectiveness of inputs. Following Kamien et al. (1992), we postulate that, due to information sharing, R&D efforts produce higher spillovers in RJVs than in the alternative settings where R&D efforts are undertaken independently. To simplify exposition, we assume that independent R&D activities do not generate spillovers.

In general, the foreign firm may produce abatement, output and R&D at a lower cost than the domestic firm. Let firm 1 be the foreign firm and let t and $e_i = q_i - a_i$ denote the pollution tax and firm i's pollution emission, respectively. We initially consider the case where the firms exert R&D efforts independently from each other. We assume that firm i's total cost of producing abatement, output and R&D (including the regulatory cost) is $C(a_i, q_i, r_i; \theta_i) + te_i = \theta_i c(x_i, r_i) + t(q_i - a_i)$, where

[8] See, e.g., d'Aspremont and Jacquemin (1988), Kamien et al. (1992) and Ziss (1994) for early models of cost-reducing R&D. The issues we consider here also overlap with those studied in the literature on R&D sharing (e.g., Morasch (1995), Pastor and Sandonis (2002), Fabrizi and Lippert (2007, 2012)). None of these papers, however, compares different forms of RJV in the presence of environmental regulation.

$x_i \equiv y_i - r_i = a_i + q_i - r_i$, $\theta_i \in [\underline{\theta}, \overline{\theta}]$ is firm i 's efficiency parameter and $\Delta\theta \equiv \overline{\theta} - \underline{\theta} > 0$ is the maximum technological gap between firms. Since the foreign firm has superior technology, $\theta_2 \geq \theta_1$. For simplicity, we let $\theta_2 = \overline{\theta} = 1$ and $\theta_1 \equiv \theta$ in what follows.[9] We assume that $c(.)$ is increasing at an increasing rate in x_i and r_i and separable in x_i and r_i; namely, $c^i_{xr} \equiv \partial^2 c / \partial x_i \partial r_i = 0$, $i = 1, 2$.

Let $Q = \sum_{i=1}^{2} q_i$ be the total output supply and let $P = P(Q)$ be the inverse market demand function, where $P'(Q) < 0$ and $P''(Q) \leq 0$. Let $A = \sum_{i=1}^{2} a_i$ and $E = \sum_{i=1}^{2} e_i = Q - A$ be the industry's total abatement and pollution level, respectively. Pollution causes a monetary damage, $D(E)$, where $D'(E) > 0$ and $D''(E) > 0$.

The government regulates the industry by choosing the pollution tax level that maximizes domestic welfare, $W = U(Q) + \Pi_2 + tE - D(E)$, which is the sum of consumer surplus, $U(Q)$, firm 2's profit, Π_2 , and the social surplus from environmental taxation: that is, pollution tax revenue, tE, minus the monetary cost of environmental damage, $D(E)$. We assume that $U'(Q) > 0$ and $U''(Q) > 0$.[10] We also assume that the government distributes the tax revenue to consumers in a lump-sum

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[9] In Sections 3.4 and 4, we assume that the cost and damage functions are quadratic and the demand function for output is linear to facilitate comparisons. Letting $\theta_2 = \overline{\theta} = 1$ and $\theta_1 = \theta$, we find that an interior Nash equilibrium in the status quo requires $\theta > 0.5934$. Hence, in Sections 3.4 and 4, we assume that $\underline{\theta} = 0.6$. We carry out the analysis with general demand, cost and damage functions in Sections 3.1 – 3.3 to demonstrate that our most important results do not depend on the functional form assumptions that we make for comparison purposes.

[10] If, for example, $P(Q) = 1 - Q$, we have $U(Q) = Q^2/2$.

fashion. We neglect regulations to deter collusive behavior in the choices of output. We assume that the government can ensure full compliance with such regulations.[11]

The firms and government play a multistage game. In the first stage, the firms select an innovation agreement, if any. In the second stage, the government sets the pollution tax after observing the first stage's outcome. The subsequent actions and timing depend on the first stage's outcome. If the first stage outcome is either the status quo or the non-cooperative RJV, the firms in the third stage choose abatement, output and R&D efforts.[12] If the first stage outcome is the cooperative RJV, in the third stage, the firms choose R&D efforts to maximize joint profit. In the fourth stage, they choose abatement and output. If the first stage outcome is the licensing agreement, the foreign firm chooses the royalty fee in the third stage. In the fourth stage, the firms choose abatement, output and R&D efforts. The equilibrium concept is subgame perfection.

3. Subgame Perfect Nash Equilibria

3.1. Status quo

As a benchmark, we first consider a setting in which there is no innovation agreement.

The players' payoff functions are as follows:

$$\Pi_i = P\left(q_i + q_{-i}\right)q_i - \theta_i c\left(a_i + q_i - r_i, r_i\right) - t\left(q_i - a_i\right), \qquad i = 1, 2, \tag{1}$$

$$W = U\left(Q\right) + \Pi_2 + tE - D\left(E\right), \tag{2}$$

where $q_{-i} = q_2$ if $i = 1$ and vice versa, $\theta_1 = \theta$ and $\theta_2 = 1$. Consider the third stage.

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[11] See, e.g., Silva et al. (2007) for regulatory regimes with costly enforcement that yield such outcomes.

[12] We deviate from papers in the R&D literature, including Kamien et al. (1992), which consider settings in which there is strategic commitment with R&D, following Brander and Spencer (1983). The critical assumption underlying strategic commitment with R&D is that each firm can observe the other firms' R&D efforts prior to making output or price choices. As we pointed out before, we follow Innes and Bial (2002) in assuming that a firm's R&D effort is not observable by the other firm or the government. Firms observe each other's R&D effort when they coordinate their R&D efforts. This occurs in the cooperative RJV only.

An interior Nash equilibrium satisfies the following conditions, for $i = 1, 2$:

$$t = \theta c_x^1 = c_x^2 , \tag{3}$$

$$P(Q) + P'(Q) q_i = \theta c_x^1 + t = c_x^2 + t , \tag{4}$$

$$c_x^i = c_r^i , \tag{5}$$

where $c_x^i \equiv \partial c(x_i, r_i) / \partial x_i$ and $c_r^i \equiv \partial c(x_i, r_i) / \partial r_i$, $i = 1, 2$. For each i , equation (3) informs us that firm i chooses abatement at the level that equates its marginal revenue from abatement provision to its marginal cost of abatement provision. The marginal revenue from abatement provision is the pollution tax rate, since this represents the amount of regulatory cost that the firm saves per unit of abatement. From equations (3), we know that marginal costs of abatement provision are equalized. For each i , equation (4) shows that the optimal level of output produced by firm i is determined by the equality of this firm's marginal revenue and its total marginal cost from production of output. The total marginal cost associated with production of output is the sum of the marginal technological cost and the marginal regulatory cost. For each i , equation (5) states that firm i chooses R&D effort at the level that equates its marginal benefit from R&D effort to its marginal R&D effort's cost. The marginal benefit from R&D effort is the marginal production cost. Given the modelling assumptions, the sufficient second order conditions are satisfied in the maximization problems in the third stage.

It is important to note that the following conditions hold in equilibrium:

$$P(Q) + P'(Q) q_i = 2t , \qquad i = 1, 2 . \tag{6}$$

Equations (6) follow from equations (3) and (4). The right sides of equations (6) inform us that both companies face the same effective marginal cost (measured in terms of a multiple of the pollution tax) in the production of output. Interestingly, this implies that the firms supply the same output quantity in equilibrium despite the technological gap. Proposition 1 captures this result as well as other implications of the conditions that characterize the equilibrium in the third stage.

Proposition 1. In the status quo, the interior equilibrium in the third stage yields

$$a_1 \geq a_2\,; \qquad q_1 = q_2\,; \qquad r_1 \geq r_2\,; \qquad x_1 \geq x_2\,. \tag{7}$$

Proof. See Appendix A.

The last three results in (7) inform us that the foreign firm produces quantities of joint output and R&D that are at least as large as the quantities that the domestic firm produces in equilibrium: $y_1 \geq y_2$ and $r_1 \geq r_2$. Since $q_1 = q_2$, we find that the foreign firm provides at least as much abatement in equilibrium $\left(a_1 \geq a_2\right)$.

Since the sufficient second order conditions for maximization are satisfied in the third stage, equations (3) – (5) allow us to implicitly define the response functions, $a^i\left(t\right)$, $q^i\left(t\right)$ and $r^i\left(t\right)$, $i = 1, 2$. For $i = 1, 2$, the marginal responses are as follows:

$$q_t^i = \frac{2}{3P'\left(Q\right) + QP''\left(Q\right)} < 0\,, \tag{8}$$

$$a_t^1 = \frac{c_{xx}^1 + c_{rr}^1}{\theta c_{xx}^1 c_{rr}^1} - q_t^1 > 0, \quad a_t^2 = \frac{c_{xx}^2 + c_{rr}^2}{c_{xx}^2 c_{rr}^2} - q_t^2 > 0, \tag{9}$$

$$r_t^1 = \frac{1}{\theta c_{rr}^1} > 0, \quad r_t^2 = \frac{1}{c_{rr}^2} > 0\,, \tag{10}$$

where $a_t^i \equiv da_i / dt$, $q_t^i \equiv dq_i / dt$ and $r_t^i \equiv dr_i / dt$, $i = 1, 2$. Equations (8) – (10) are intuitive. An increase in the pollution tax reduces output and increases both abatement and R&D efforts.

Consider the second stage. The government chooses $t \in [0,1]$ to maximize (2) subject to the policy responses, equations (8) – (10), $i = 1, 2$. Assuming an interior solution, the first order condition is

$$U'(Q)\sum_{i=1}^{2} q_t^i + \Pi_t^2 + E + \left(t - D'(E)\right)E'(t) = 0, \tag{11}$$

where $\Pi_t^2 \equiv d\Pi_2/dt$. According to equation (11), the optimal tax accounts for the marginal effects on consumer surplus (decreases), domestic producer surplus (ambiguous sign) and the social surplus from taxation (ambiguous sign). Combining equations (8) – (11), equation (11) reduces to a more intuitive expression:

$$\frac{2\left[2U'(Q) + P'(Q)q_2\right]}{3P'(Q) + Q(t)P''(Q)} + e_1 + \left[t - D'(E)\right]\left[\frac{8}{3P'(Q) + QP''(Q)} - \frac{c_{xx}^1 + c_{rr}^1}{\theta c_{xx}^1 c_{rr}^1} - \frac{c_{xx}^2 + c_{rr}^2}{c_{xx}^2 c_{rr}^2}\right] = 0. \tag{12}$$

The numerator of the first term on the left hand side has an ambiguous sign because $U'(Q) > 0$ and $P'(Q) < 0$. If, for example, $U(Q) = Q^2/2$ and $P(Q) = 1 - Q$, the numerator is positive and the denominator is negative. The bracketed term that multiplies $\left[t - D'(E)\right]$ has a negative sign. Hence, the optimal pollution tax equals the marginal pollution damage if and only if the first two terms on the left hand side add up to zero. If the sum of these two terms is negative (positive), then the optimal pollution tax is lower (higher) than the marginal pollution damage. This is intuitive, since the first term represents the marginal effect on consumer surplus and the second term is the net marginal revenue from taxation. If the marginal effect on consumer surplus is higher (lower) in absolute value than the net marginal revenue from taxation, the optimal pollution tax is lower (higher) than the marginal pollution damage.

3.2. RJVs

We now turn our attention to RJVs. We assume that the formation of RJVs involve no setup or coordination costs in order to focus on the key competitiveness incentives that may lead a firm to prefer one type of RJV to the other.[13]

3.2.1. Non-cooperative RJV

If the RJV is not cooperative, the timing of the game played by firms and the government is identical to the game played in the status quo. The firms' payoff functions are as follows:

$$\Pi_1 = P(Q)q_1 - \theta c\left(q_1 + a_1 - \left(r_1 + \beta_1 r_2\right), r_1\right) - t\left(q_1 - a_1\right), \tag{13}$$

$$\Pi_2 = P(Q)q_2 - c\left(q_2 + a_2 - \left(r_2 + \beta_2 r_1\right), r_2\right) - t\left(q_2 - a_2\right), \tag{14}$$

where $0 \le \beta_1 \le \beta_2 \le 1$. The parameter β_i is the R&D spillover rate that firm i enjoys, $i = 1, 2$.[14] Since the foreign firm has superior technology, it seems logical to postulate that it has also superior R&D capability. For simplicity, we assume that $\beta_2 = 1$ and let $\beta_1 \equiv \beta$. Equation (2), again, provides us with the government's payoff function.

Plug $\beta_1 \equiv \beta$ and $\beta_2 = 1$ into payoffs (13) and (14), respectively. Assuming interior solutions for the firms' maximization problems, the equilibrium in the third stage satisfies conditions (3) – (5). The marginal responses are equations (8), (10) and

$$a_t^1 = \left[\frac{c_{xx}^1 + c_{rr}^1}{\theta c_{xx}^1 c_{rr}^1} + \frac{\beta}{c_{rr}^2}\right] - q_t^1 > 0, \quad a_t^2 = \left[\frac{c_{xx}^2 + c_{rr}^2}{c_{xx}^2 c_{rr}^2} + \frac{1}{\theta c_{rr}^1}\right] - q_t^2 > 0. \tag{15}$$

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[13] See, e.g., Falvey et al. (2013) for a setting with market imperfection, RJVs and coordination costs.

[14] As in Kamien et al. (1992), RJVs produce higher R&D spillover rates than independent R&D efforts because there is information sharing within RJVs. In the settings with independent R&D efforts, $\beta_1 = \beta_2 = 0$. Unlike Kamien et al. (1992), we consider asymmetric firms. Hence, it seems reasonable to assume that the spillover rates are also asymmetric.

Equations (15) inform us that the R&D spillover rates influence the firms' abatement response rates under the non-cooperative RJV.

In the first stage, the government chooses $t \in [0,1]$ to maximize (2) subject to the firms' optimal responses. Assuming an interior solution, we obtain the following first order condition, which determines the optimal tax:

$$\frac{2\left[2U'(Q)+P'(Q)q_2\right]}{3P'(Q)+QP''(Q)}+\frac{c_x^2}{\theta c_{rr}^1}+e_1+\left[t-D'(E)\right]\left[\frac{8}{3P'(Q)+QP''(Q)}-\frac{2c_{xx}^1+c_{rr}^1}{\theta c_{xx}^1 c_{rr}^1}-\frac{(1+\beta)c_{xx}^2+c_{rr}^2}{c_{xx}^2 c_{rr}^2}\right]=0. \quad (16)$$

Equation (16) differs from equation (12) in two significant ways: (i) there is an extra positive term on the left hand side $\left(c_x^2/\theta c_{rr}^1\right)$ and (ii) the last two ratios inside of the bracketed term that multiplies $\left[t-D'(E)\right]$ differ from their counterparts in the previous equation. These changes correspond to the strategic interactions between R&D spillovers.

3.2.2. Cooperative RJV

If the RJV is cooperative, each firm observes the government's pollution tax and, in the third stage, chooses its R&D effort to maximize joint profit. In the fourth stage, the firms choose abatement and output levels simultaneously.

The payoff functions for the government, foreign firm and domestic firm are (2), (13) and (14), respectively. The joint profit is

$$\hat{\Pi} \equiv \Pi_1+\Pi_2 = PQ-tE-\theta c\left(q_1+a_1-\left(r_1+\beta r_2\right),r_1\right)-c\left(q_2+a_2-\left(r_1+r_2\right),r_2\right). \quad (17)$$

In the fourth stage, an interior equilibrium satisfies conditions (3) and (4). Note that these equations again imply $q_1=q_2$. The first and second order conditions allow us to define the implicit response functions, $a^i\left(t,r_1,r_2\right)$ and $q^i\left(t,r_1,r_2\right)$, $i=1,2$. For $i=1,2$, the set of the marginal responses are given by (8) and the following equations:

$$a_t^1 = \frac{1}{\theta c_{xx}^1} - q_t^1 > 0, \;\; a_t^2 = \frac{1}{c_{xx}^2} - q_t^2 > 0, \tag{18}$$

$$q_{r_1}^i = q_{r_2}^i = 0\,, \tag{19}$$

$$a_{r_i}^i = 1 > 0\,, \tag{20}$$

$$a_{r_2}^1 = \beta > 0, \;\; a_{r_1}^2 = 1 > 0\,, \tag{21}$$

where $q_{ri}^i \equiv \partial q_i / \partial r_i$, $a_{ri}^i \equiv \partial a_i / \partial r_i$ and $a_{r-i}^i \equiv \partial a_i / \partial r_{-i}$, $i = 1,2$ and $i \neq j$. Equations (18) differ from equations (15) because in this case the firms take the R&D efforts as given in the last stage. Equations (19) show that outputs do not change with the firms' R&D efforts. These results follow from our assumption that $c(.)$ is separable in x_i and r_i: $c_{xr}^i \equiv \partial^2 c / \partial x_i \partial r_i = 0$, $i = 1,2$. For each i, equation (20) shows that firm i increases its abatement supply at a one-to-one rate with its R&D effort. Equations (21) capture the marginal spillover effects that R&D efforts create in the industry. The abatement supply of firm 2 (1) rises at one-to-one (β) rate with an increase in firm 1's (2's) R&D effort.

In the third stage, firm i chooses r_i to maximize (17) subject to the firms' responses. Assuming an interior solution, the first order conditions yield

$$2c_x^1 = c_r^1 \;\text{ and }\; (1+\beta)c_x^2 = c_r^2\,. \tag{22}$$

Equations (22) reveal that the firms choose R&D effort levels that equate the sum of marginal benefits to marginal costs. The R&D efforts internalize R&D spillovers. Assuming that the sufficient second order conditions hold in the maximization of joint profit, equations (22) allow us to implicitly define the response functions, $r^i(t)$, $i = 1,2$. The marginal responses are as follows:

$$r_t^1 = \frac{2}{\theta c_{rr}^1} > 0 \text{ and } r_t^2 = \frac{(1+\beta)}{c_{rr}^2} > 0. \tag{23}$$

Plugging the R&D response functions in (23) into the response functions for abatement and output, we have $a^i\left(t, r^1(t), r^2(t)\right)$ and $q^i\left(t, r^1(t), r^2(t)\right)$, $i = 1, 2$.

In the second stage, the government chooses $t \in [0,1]$ to maximize (2) subject to the firms' response functions. Assuming an interior solution, we obtain the first order condition that determines the optimal tax:

$$\frac{2\left[2U'(Q)+P'(Q)q_2\right]}{3P'(Q)+QP''(Q)} + c_x^2\left[\frac{\theta(1+\beta)c_{rr}^1 + 2c_{rr}^2}{\theta c_{rr}^1 c_{rr}^2} - \frac{(1+\beta)c_r^2}{c_x^2 c_{rr}^2}\right] + e_1$$
$$+\left[t - D'(E)\right]\left[\frac{8}{3P'(Q)+QP''(Q)} - \frac{4c_{xx}^1 + c_{rr}^1}{\theta c_{xx}^1 c_{rr}^1} - \frac{(1+\beta)^2 c_{xx}^2 + c_{rr}^2}{c_{xx}^2 c_{rr}^2}\right] = 0. \tag{24}$$

Equation (24) is more complex than equation (16). The increase in the degree of complexity comes from the fact that the industry internalizes R&D spillovers.

3.3. Licensing

Having examined RJVs, we now turn our attention to licensing. Suppose that licensing is the outcome in the first stage. As we discussed before, we examine a setting in which the foreign firm sets the licensing royalty fee after it observes the pollution tax. After observing the pollution tax and the royalty fee, the firms choose abatement, output and R&D levels in the last stage, taking each other's choices as given.

Let $\phi \geq 0$ denote the foreign firm's royalty fee. The firms' payoffs are

$$\Pi_1 = P(Q)q_1 + \phi(q_2 + a_2) - \theta c(q_1 + a_1 - r_1, r_1) - t(q_1 - a_1), \tag{25}$$

$$\Pi_2 = P(Q)q_2 - \theta c(q_2 + a_2 - r_2, r_2) - t(q_2 - a_2) - \phi(q_2 + a_2). \tag{26}$$

Observe that we write payoffs (25) and (26) with both firms having the same technology.

The foreign firm earns profits from supplying output and selling the license. The domestic firm faces the additional cost from purchasing the license.

The equilibrium in the fourth stage satisfies the following conditions:

$$a_1\left(t-\theta c_x^1\right)=0,\ \ a_1\ge 0,\ \ t-\theta c_x^1\le 0\,, \tag{27}$$

$$a_2\left(t-\phi-\theta c_x^2\right)=0,\ \ a_2\ge 0,\ \ t-\phi-\theta c_x^2\le 0\,, \tag{28}$$

$$q_1\left(P(Q)+P'(Q)q_1-\theta c_x^1-t\right)=0,\ \ q_1\ge 0,\ \ P(Q)+P'(Q)q_1-\theta c_x^1-t\le 0\,, \tag{29}$$

$$q_2\left(P(Q)+P'(Q)q_2-\theta c_x^2-t-\phi\right)=0,\ \ q_2\ge 0,\ \ P(Q)+P'(Q)q_2-\theta c_x^2-t-\phi\le 0\,, \tag{30}$$

$$r_1\left(c_x^1-c_r^1\right)=0,\ \ r_1\ge 0,\ \ c_x^1-c_r^1\le 0\,, \tag{31}$$

$$r_2\left(c_x^2-c_r^2\right)=0,\ \ r_2\ge 0,\ \ c_x^2-c_r^2\le 0\,. \tag{32}$$

Since we cannot guarantee that the Nash equilibrium is interior, we write the Kuhn-Tucker conditions (27) – (32). As we demonstrate in Appendix B, if we assume that $c(x_i,r_i)=\left[x_i^2+r_i^2\right]/2$, $P(Q)=1-Q$, $U(Q)=Q^2/2$ and $D(E)=E^2/2$ (as we do in Sections 3.4 and 4), an interior equilibrium requires $\theta<0.3275$, which is inconsistent with our assumption that $\theta\in[0.6,1]$. Maintaining this assumption implies that $a_2=0$ in the equilibrium with licensing. The other quantities are positive. Thus, in what follows we consider the case in which $a_1>0,\ a_2=0,\ q_i>0,\ r_i>0,\ i=1,2$:

$$t=\theta c_x^1\,, \tag{33}$$

$$t<\phi+\theta c_x^2\ \ \Rightarrow\ \ a_2=0\,, \tag{34}$$

$$P(Q)+P'(Q)q_1=\theta c_x^1+t\,, \tag{35}$$

$$P(Q)+P'(Q)q_2=\theta c_x^2+t+\phi\,, \tag{36}$$

$$c_x^i = c_r^i,\quad i = 1,2. \tag{37}$$

Conditions (33) – (37) enable us to state the following important results:

Proposition 2. Suppose that $\theta \in [0.6,1]$, $c(x_i, r_i) = [x_i^2 + r_i^2]/2$, $P(Q) = 1 - Q$, $U(Q) = Q^2/2$ and $D(E) = E^2/2$. Then, in the equilibrium with licensing, we have

$$a_1 > a_2 = 0; \qquad q_1 > q_2; \qquad r_1 > r_2; \qquad x_1 > x_2. \tag{38}$$

Proof. See Appendix B.

Unlike the previous scenarios, the foreign firm's share in the output market exceeds the domestic firm's share. By charging a license fee, the foreign firm has market advantage in the supply of output. The license fee also deters the domestic firm from supplying a positive amount of abatement.

Assuming that the sufficient second order conditions hold in the maximization problems in the fourth stage, conditions (33) – (37) enable us to implicitly define the response functions, $a^1(t,\phi)$, $q^i(t,\phi)$ and $r^i(t,\phi)$, $i = 1,2$. For $i = 1,2$, the marginal responses with respect to ϕ are as follows:

$$a_\phi^1 = -q_\phi^1 = \frac{\left(c_{rr}^2 + c_{xx}^2\right)\left[P'(Q) + P''(Q)q_1\right]}{P'(Q)\left(c_{rr}^2 + c_{xx}^2\right)\left[3P'(Q) + P''(Q)Q\right] - \theta c_{rr}^2 c_{xx}^2\left[2P'(Q) + P''(Q)q_1\right]} < 0, \tag{39}$$

$$q_\phi^2 = \frac{\left(c_{rr}^2 + c_{xx}^2\right)\left[2P'(Q) + P''(Q)q_1\right]}{P'(Q)\left(c_{rr}^2 + c_{xx}^2\right)\left[3P'(Q) + P''(Q)Q\right] - \theta c_{rr}^2 c_{xx}^2\left[2P'(Q) + P''(Q)q_1\right]} < 0, \tag{40}$$

$$r_\phi^1 = 0, \tag{41}$$

$$r_\phi^2 = \frac{c_{rr}^2\left[2P'(Q) + P''(Q)q_1\right]}{P'(Q)\left(c_{rr}^2 + c_{xx}^2\right)\left[3P'(Q) + P''(Q)Q\right] - \theta c_{rr}^2 c_{xx}^2\left[2P'(Q) + P''(Q)q_1\right]} < 0. \tag{42}$$

Equations (39) reveal that the foreign firm increases output and reduce abatement in response to an increase in the license fee. Equation (40) informs us that the domestic firm reduces output in response to an increase in the license fee. Equation (41) shows that foreign firm's R&D effort is unaffected by changes in the license fee. The same, however, is not true for the R&D effort supplied by the domestic firm. Equation (42) shows that this firm's R&D effort decreases with the license.

Before we proceed with the analysis of the third stage, it is useful to present the marginal responses with respect to the pollution tax. They are as follows:

$$q_t^1 = \frac{\left(c_{rr}^2 + c_{xx}^2\right)\left[3P'(Q) - P''(Q)\left(q_1 - 2q_2\right)\right] - 2\theta c_{rr}^2 c_{xx}^2}{P'(Q)\left(c_{rr}^2 + c_{xx}^2\right)\left[3P'(Q) + P''(Q)Q\right] - \theta c_{rr}^2 c_{xx}^2\left[2P'(Q) + P''(Q)q_1\right]}, \tag{43}$$

$$q_t^2 = \frac{\left(c_{rr}^2 + c_{xx}^2\right)P''(Q)\left(q_1 - 2q_2\right)}{P'(Q)\left(c_{rr}^2 + c_{xx}^2\right)\left[3P'(Q) + P''(Q)Q\right] - \theta c_{rr}^2 c_{xx}^2\left[2P'(Q) + P''(Q)q_1\right]}, \tag{44}$$

$$a_t^1 = \frac{c_{rr}^1 + c_{xx}^1}{\theta c_{rr}^1 c_{xx}^1} - q_t^1, \tag{45}$$

$$r_t^1 = \frac{1}{\theta c_{rr}^1} > 0, \tag{46}$$

$$r_t^2 = \frac{c_{xx}^2 P''(Q)\left(q_1 - 2q_2\right)}{P'(Q)\left(c_{rr}^2 + c_{xx}^2\right)\left[3P'(Q) + P''(Q)Q\right] - \theta c_{rr}^2 c_{xx}^2\left[2P'(Q) + P''(Q)q_1\right]}. \tag{47}$$

As equations (43) – (45) and (47) make it clear, we are unable to sign q_t^1, q_t^2, a_t^1 and r_t^2 because we do not know, a priori, the sign of $q_1 - 2q_2$. As before, equation (46) informs us that the foreign firm increases its R&D effort in response to an increase in the pollution tax. Note that if $P''(Q) = 0$, $q_t^1 < 0$, $a_t^1 > 0$ and $q_t^2 = r_t^2 = 0$.

In the second stage, the foreign firm chooses $\phi \geq 0$ to maximize (25) subject to the optimal responses from the third stage. Assuming that the solution is interior, the first order condition is

$$q_2 + q_\phi^2 \left[P'(Q) q_1 + \phi \right] = 0 . \tag{48}$$

Since $q_2 > 0$ and $q_\phi^2 < 0$ (see (40)), equation (48) requires that $P'(Q) q_1 + \phi > 0$.[15] Equation (48) reveals that the optimal license satisfies the equalization of the slope of the domestic firm's reaction function, q_ϕ^2, to the slope of the foreign firm's iso-profit curve, $-q_2 / \left[P'(Q) q_1 + \phi \right]$.

Assuming that the sufficient second order condition (i.e., $\Pi_{\phi\phi}^1 < 0$) is satisfied, equation (48) defines the implicit function $\phi(t)$, the foreign firm's best response in terms of its license choice with respect to the pollution tax. We obtain:

$$\phi_t = -\frac{q_t^2 + q_{\phi t}^2 \left[P'(Q) q_1 + \phi \right] + q_\phi^2 \left[P''(Q) q_1 Q_t + P'(Q) q_t^1 \right]}{\Pi_{\phi\phi}^1}, \tag{49}$$

where $\Pi_{\phi\phi}^1 = q_\phi^2 \left[2 + P''(Q) q_1 Q_\phi + P'(Q) q_\phi^1 \right] + q_{\phi\phi}^2 \left[P'(Q) q_1 + \phi \right]$.[16]

In the first stage, the government chooses the pollution tax accounting for all response functions. Assuming an interior solution, the first order condition yields

$$\begin{aligned} &\left[U'(Q) Q_t + q_2 \left(P'(Q) q_t^1 - 1 \right) + E + \left(t - D'(E) \right) E_t \right] \\ &\qquad + \phi_t \left[U'(Q) Q_\phi + q_2 \left(P'(Q) q_\phi^1 - 1 \right) + \left(t - D'(E) \right) E_\phi \right] = 0. \end{aligned} \tag{50}$$

Combining equations (39) – (47) and (50), we obtain:

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15 As we demonstrate in Appendix B, this requirement is satisfied if $P(Q) = 1 - Q$ and $c(x_i, r_i) = \left(x_i^2 + r_i^2 \right)/2$. Given these assumptions, the sufficient second order condition is also satisfied.

16 The sign of the ratio on the right hand side of (49) is ambiguous in general. However, it is straightforward to show that the sign is negative if $P(Q) = 1 - Q$, $U(Q) = Q^2/2$, $c(x_i, r_i) = \left(x_i^2 + r_i^2 \right)/2$, $D(E) = E^2/2$ and $\theta \in [0.6, 1]$. Given these assumptions, we obtain the following results: $\phi = \left\{ 1 - t\left[1 + 1/(5 + 4\theta) \right] \right\}/2$ and $\phi_t = -\left[1 + 1/(5 + 4\theta) \right] < 0$.

$$\left\{\frac{\left[U'(Q)+q_2P'(Q)\right]\left[3\left(c_{rr}^2+c_{xx}^2\right)P'(Q)-2\theta c_{rr}^2c_{xx}^2\right]-q_2P'(Q)P''(Q)(q_1-2q_2)\left(c_{rr}^2+c_{xx}^2\right)}{\Psi}\right.$$

$$\left.+e_1+\left[t-D'(E)\right]\left[\frac{\left[6P'(Q)-P''(Q)(q_1-2q_2)\right]\left(c_{rr}^2+c_{xx}^2\right)-4\theta c_{rr}^2c_{xx}^2}{\Psi}-\frac{c_{rr}^1+c_{xx}^1}{\theta c_{rr}^1c_{xx}^1}\right]\right\} \quad (51)$$

$$+\phi_t\left\{\frac{\left[U'(Q)-q_2\left[4P'(Q)+P''(Q)(2q_1+q_2)\right]\right]P'(Q)\left(c_{rr}^2+c_{xx}^2\right)}{\Psi}\right.$$

$$\left.+\frac{q_2\left[2P'(Q)+q_1P''(Q)\right]\theta c_{rr}^2c_{xx}^2-q_1P''(Q)\left(c_{rr}^2+c_{xx}^2\right)\left[t-D'(E)\right]}{\Psi}\right\}=0,$$

where $\Psi\equiv P'(Q)\left(c_{rr}^2+c_{xx}^2\right)\left[3P'(Q)+P''(Q)Q\right]-\theta c_{rr}^2c_{xx}^2\left[2P'(Q)+P''(Q)q_1\right]>0$.

To get some intuition for equation (51), one should contrast it to equation (12), the equation that determines the optimal tax in the status quo. Even though the status quo involves firms with different technologies but identical output supplies and the current setting involves firms with identical technologies but different output supplies, the crucial difference between equations (12) and (51) is the extra component in equation (51), which relates to the effect of the pollution tax on the license fee. The terms in equation (12) capture the effects of the pollution tax on consumer surplus, tax revenue and producer surplus for the domestic firm. Likewise, the first term on the left side of equation (51) captures the effects of the pollution tax on consumer surplus, tax revenue and producer surplus for the domestic firm. The second term on the left side of equation (51) is the extra net marginal social benefit of the pollution tax through its impact on the license fee. Since the license fee hurts the domestic firm and reduces its output and abatement supplies (relative to the status quo), the government has an incentive to set the pollution tax at a level that surpasses the optimal pollution tax in the status quo. In fact, if one considers the particular quadratic functional forms described in Proposition 2, the optimal pollution tax in the license agreement is higher than in the status quo (see section 4).

3.4. Agree to innovate?

We now compare the equilibria and examine which, if any, innovation agreement is implementable. For comparison purposes, we need to make functional form assumptions. Let $P(Q)=1-Q$, $U(Q)=Q^2/2$, $c(x_i,r_i)=\left(x_i^2+r_i^2\right)/2$ and $D(E)=E^2/2$. Let the superscripts "*S*", "*N*", "*C*" and "*L*" denote equilibrium quantities in the status-quo, non-cooperative RJV, cooperative RJV and licensing settings, respectively. Remember that an innovation agreement is feasible if and only if it satisfies both firms' participation constraints: the agreement must represent a Pareto improvement relative to the status quo.

To derive some intuition for the results, let us consider the firms' payoffs for two efficiency rates, $\theta=0.6$ and $\theta=0.8$, as functions of β . Figures 1 and 2 show payoffs under the four possible scenarios.

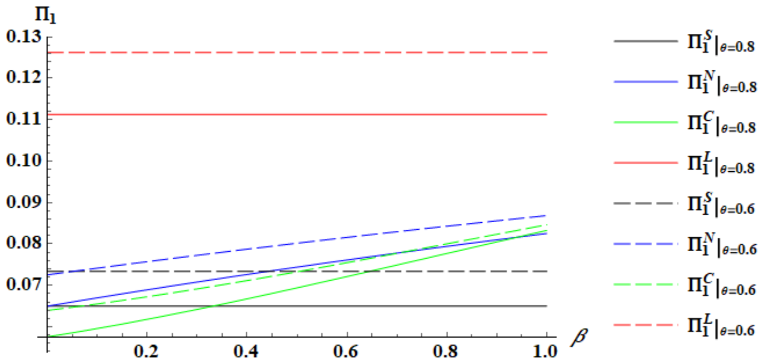

Figure 1. Foreign firms' payoffs, $\theta\in\{0.6,0.8\}$ and $\beta\in[0,1]$.

As Figure 1 reveals, for the foreign firm, the licensing agreement dominates all alternatives, the non-cooperative RJV is generally second best and the cooperative RJV dominates the non-cooperative RJV for sufficiently high spillover values if $\theta=0.8$. In addition, the status quo dominates the non-cooperative (and the cooperative) RJV for small spillover values ($\beta<0.1$) if $\theta=0.6$. The status quo dominance relative to the cooperative RJV increases as theta increases. The payoffs under the RJVs increase with the spillover rate that this firm enjoys.

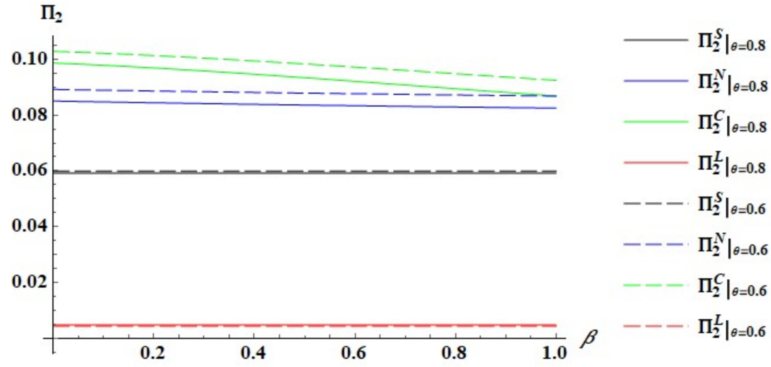

Figure 2. Domestic firms' payoffs, $\theta \in \{0.6, 0.8\}$ and $\beta \in [0,1]$.

Figure 2 informs us that, for the domestic firm, cooperative RJV dominates non-cooperative RJV, both RJVs dominate the status quo and the status quo dominates the licensing agreement. The payoffs under the RJVs decrease with the spillover rate enjoyed by the foreign firm, but they fall at a faster rate under the cooperative RJV.

We now show that the licensing agreement is not implementable because it violates the participation constraint for the domestic firm. Figure 3 reveals that this firm's profit in the status quo is higher than in the licensing agreement for $\theta \in [0.6,1]$.

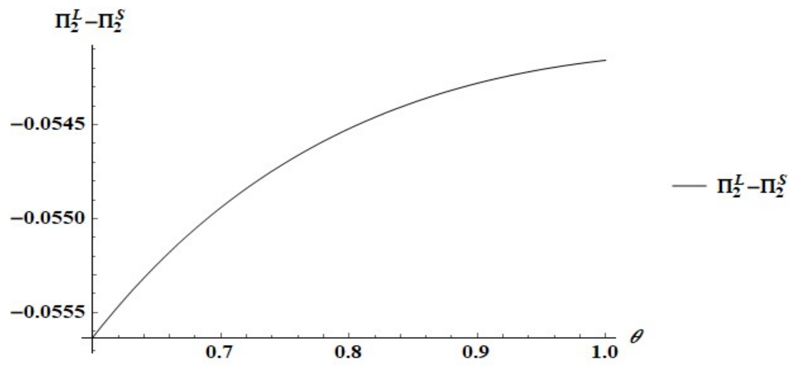

Figure 3. Domestic firm prefers the status quo to the licensing agreement.

As it is apparent in Figure 2, the domestic firm always prefer either type of RJV to the status quo. Figure 4 compares the domestic firm's payoffs under the RJVs to its payoff in the status quo when $\beta = 1$. These are the domestic firm's lowest payoffs as functions of the parameters. Thus, the domestic firm prefers any RJV to the status quo.

Figure 5 shows that, for the domestic firm, the cooperative RJV dominates the non-cooperative RJV for $\theta \in [0.6,1]$ and $\beta \in [0,1]$.

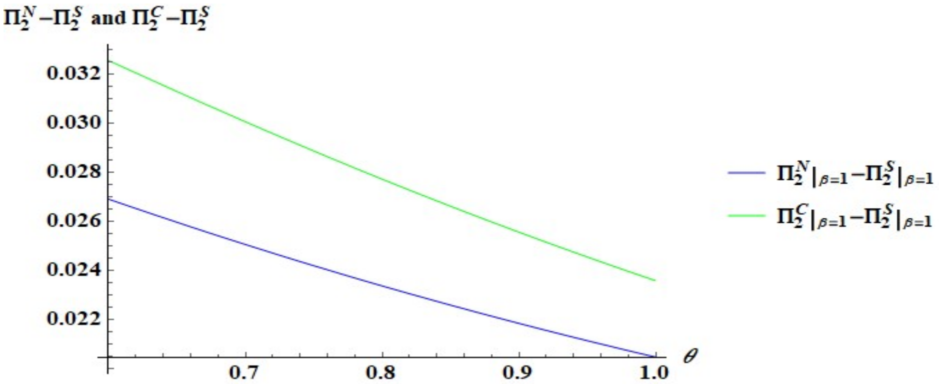

Figure 4. Domestic firm's innovation premia, $\beta = 1$.

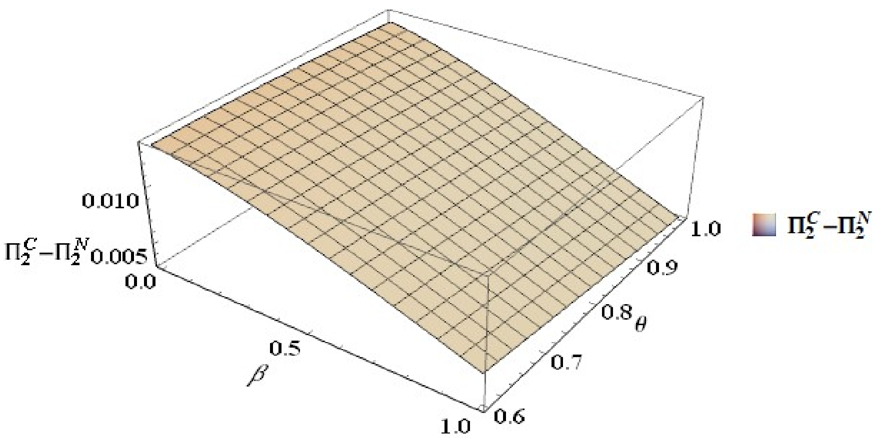

Figure 5. The cooperative RJV dominates the non-cooperative RJV for the domestic firm

Let us now examine the foreign firm's incentives to enter into a RJV with the domestic firm. As we pointed out above, the foreign firm prefers the status quo to either form of RJV if the efficiency and spillover parameters are sufficiently low. From Figure 1, it is apparent that the innovation premium that this firm obtains under each type of RJV (i.e., the difference between its payoff under each type of RJV and its payoff in the status quo) increases with both parameters' values. Indeed, as Figure 6 reveals, if we restrict our analysis to parameter combinations that satisfy $\theta \in [0.6,1]$ and $\beta \in [0.1,1]$, the innovation premium under the non-cooperative RJV is always positive.

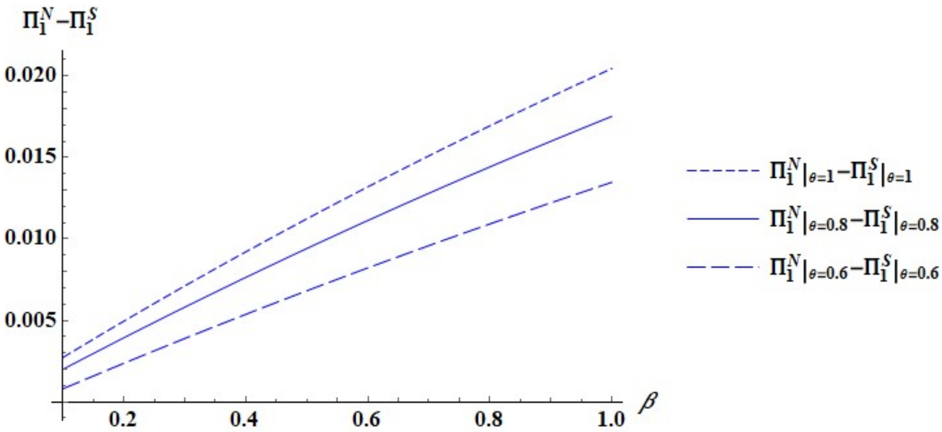

Figure 6. Foreign firm's innovation premium (non-cooperative RJV).

Given the results that Figures 1 and 6 present, we now expect that, whenever both RJVs are feasible, the foreign firm prefers the non-cooperative RJV for most combinations of efficiency and spillover parameter values. In the relevant range, where both firms' participation constraints are satisfied for at least one type of RJV, Figure 7 shows that the foreign firm rejects the cooperative RJV in an area with low values for the parameters. In addition, the foreign firm prefers the non-cooperative (cooperative) RJV in an area of intermediary (high) values for the parameters.

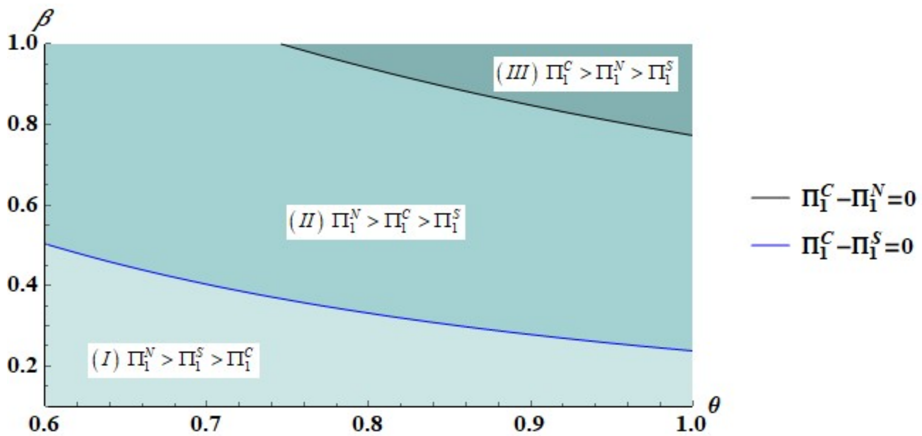

Figure 7. Foreign firm's innovation acceptance areas.

We summarize the outcomes in the first stage in the following proposition.

Proposition 3. Suppose that $\theta \in [0.6,1]$ and $\beta \in [0.1,1]$. Then, for parameter values in

(i) area I of Figure 7, both firms select the non-cooperative RJV;

(ii) area II of Figure 7, the choice of RJV is random;

(iii) area III of Figure 7, both firms select the cooperative RJV.

Proof. Consider Figure 7. For parameters' values in area I, the cooperative RJV is not feasible because it violates the foreign firm's participation constraint. Hence, both firms select the feasible, non-cooperative RJV. For parameters' values in areas II and III, both RJVs are feasible. In area II, the selection is random because the firms disagree about the top choice. In area III, the cooperative RJV dominates for both firms. *Q.E.D.*

The more efficient the foreign firm is relative to the domestic firm and the lower the spillover rate that the foreign firm enjoys the more likely it is that the outcome in the first stage is the non-cooperative RJV. The lower the asymmetry between the firms (both in terms of efficiency and spillover rates) the more likely it is that the outcome in the first stage is the cooperative RJV.

4. Domestic Competitiveness and Welfare

Having examined the circumstances under which each type of RJV is implementable, we now turn our attention to improvements in the competitiveness of the domestic firm and domestic welfare that the implementable RJVs may promote. We first consider the effects on domestic competitiveness.

The competitiveness of the domestic firm improves whenever innovation occurs. We are not able to capture such an improvement if we compare the firms in terms of their shares of the output market in the settings with innovation and without innovation. Since the firms produce the same output quantity in the subgame perfect equilibria for the status quo and the RJVs, they have the same share of the output market. As both firms produce multiple products (abatement and output) and exert R&D efforts, one should compare their performances in terms of their shares of the industry's profit. Since the firms face the same output price and the same price incentive to produce abatement (i.e., the pollution tax), a comparison of profit shares yields a precise competitiveness measure.

Let $\sigma(\beta,\theta) \equiv \Pi_2(\beta,\theta) / \hat{\Pi}(\beta,\theta)$ denote the domestic firm's profit share as a function of the foreign firm's spillover and efficiency rates, respectively. Figure 8 shows that the domestic firm's profit share in the status quo increases as the technological gap decreases and it equals half in the absence of a technological gap. Interestingly, we also see that the domestic firm's profit share equals half despite the existence or not a technological gap in the non-cooperative RJV if the firms are identical in terms of the R&D spillover rates (i.e., $\beta = 1$). For a lower R&D spillover rate enjoyed by the foreign firm ($\beta = 0.4$), the domestic firm's profit share in the non-cooperative RJV is always higher than the foreign firm's share. In the cooperative RJV, the domestic firm's profit share equals half only if there is no technological gap and both firms are identical in terms of R&D spillover rates. As the R&D spillover rate enjoyed by the foreign firm decreases from $\beta = 1$ to $\beta = 0.4$, the domestic firm's profit share in the cooperative RJV increases given the foreign firm's efficiency rate, θ.

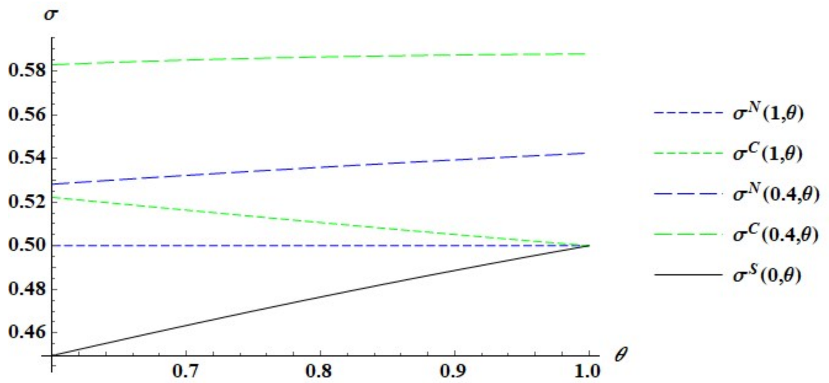

Figure 8. Domestic firm’s profit shares (status quo and RJVs)

As Figures 2, 4 and 8 reveal for some particular efficiency and spillover rates, it appears that the greater the degrees of asymmetry between the firms (in terms of efficiency and spillover rates), the greater the domestic firm’s relative benefit from engaging in a RJV. Figures 9 and 10 confirm this intuition for $\theta \in [0.6,1]$ and $\beta \in [0.1,1]$.

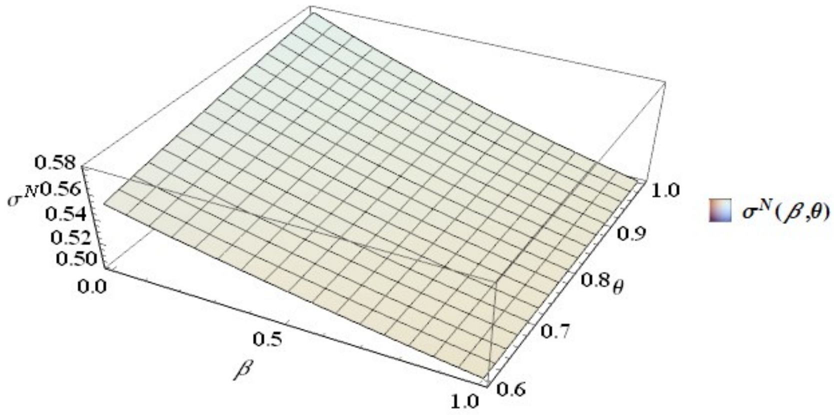

Figure 9: Domestic firm’s profit share in the non-cooperative RJV.

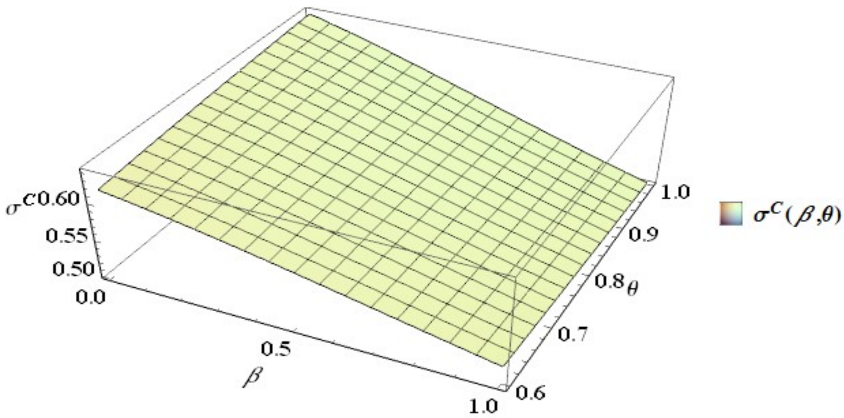

Figure 10: Domestic firm’s profit share in the cooperative RJV.

Relative to the status quo, a feasible RJV yields an increase in the domestic firm's profit share because the R&D spillovers enable the domestic firm to reduce its environmental regulatory cost. The cost savings produced by the innovation would occur even if the firm faced the same pollution tax in both scenarios. However, the costs savings are more substantial because the government's optimal response to the implementation of an innovation agreement is to reduce the pollution tax, as Figure 11 reveals. It is also evident that the pollution tax in the non-implementable licensing agreement is higher than in the status quo in each case.

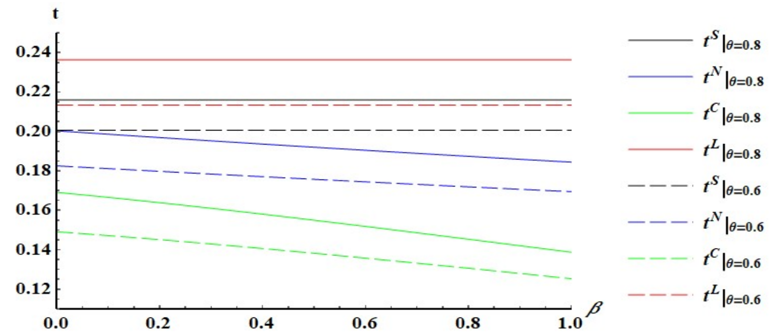

Figure 11. Pollution taxes, for $\theta \in \{0.6, 0.8\}$.

One may worry that the lower pollution tax is associated with a higher amount of pollution. However, consistent with the previous argument that an implementable RJV improves environmental performance, we see in Figure 12 that pollution levels under the RJVs are lower than in the status quo and in the licensing agreement.

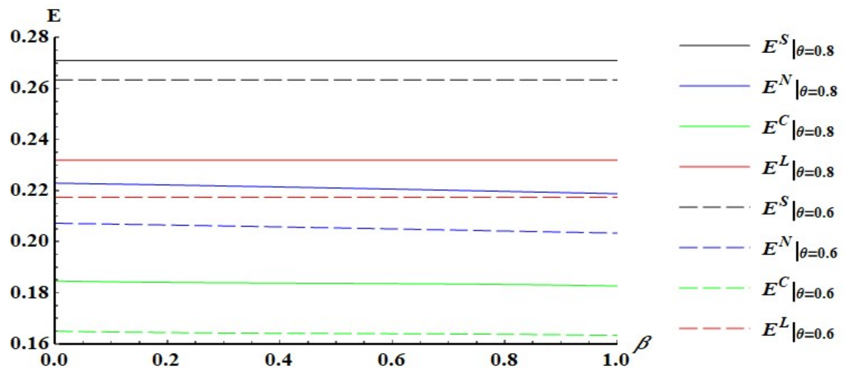

Figure 12. Pollution levels, for $\theta \in \{0.6, 0.8\}$.

Let us now examine the welfare effects. It is straightforward to show that the settings with RJVs are dominant in terms of welfare. As before, for illustration purposes, we plot welfare as a function of β for two efficiency rates, $\theta \in \{0.6, 0.8\}$. Figure 13 shows that, in each case, welfare is highest under the cooperative RJV, second best under the non-cooperative RJV and lowest under licensing. Fortunately, the licensing agreement is not implementable. Figure 14 shows that the cooperative RJV dominates the non-cooperative RJV not only in the particular cases examined in Figure 13, but in general.

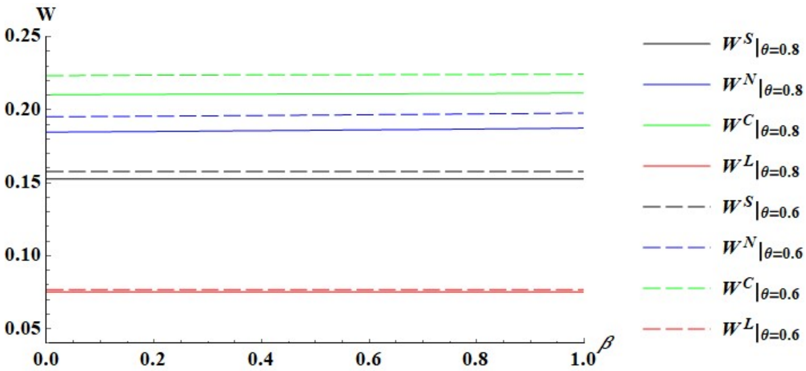

Figure 13. Domestic welfare, $\theta \in \{0.6, 0.8\}$.

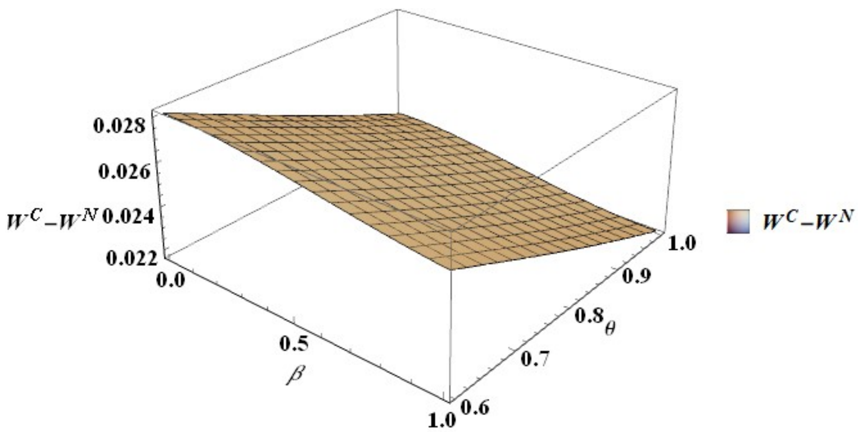

Figure 14. The cooperative RJV is dominant in terms of welfare.

Since the cooperative RJV dominates the non-cooperative RJV in terms of welfare, a potential welfare improving policy that the government may undertake is to “bribe” the foreign firm to select a feasible cooperative RJV whenever it strictly prefers a feasible non-cooperative RJV. Remember that this occurs in areas I and II of Figure 7. Let $\tau(\beta,\theta) \equiv \Pi_1^N(\beta,\theta) - \Pi_1^C(\beta,\theta)$ for all $\beta \in [0.1,1]$ and $\theta \in [0.6,1]$ such that $\Pi_1^N(\beta,\theta) \geq \Pi_1^C(\beta,\theta)$ denote the lump-sum transfer payment (subsidy) that the government makes to the foreign firm to induce it to accept the cooperative RJV when it prefers the non-cooperative RJV. Assume that $\tau(\beta,\theta) = 0$ if $\Pi_1^C(\beta,\theta) > \Pi_1^N(\beta,\theta)$. Let $W^N(\beta,\theta)$ and $W^T(\beta,\theta) \equiv W^C(\beta,\theta) - \tau(\beta,\theta)$ denote the welfare levels under the non-cooperative RJV and under the cooperative RJV net of the subsidy $\tau(\beta,\theta)$, respectively. Figure 15 shows that such a subsidy policy is, indeed, welfare improving because $W^T(\beta,\theta) > W^N(\beta,\theta)$ for $\theta \in [0.6,1]$ and $\beta \in [0.1,1]$.

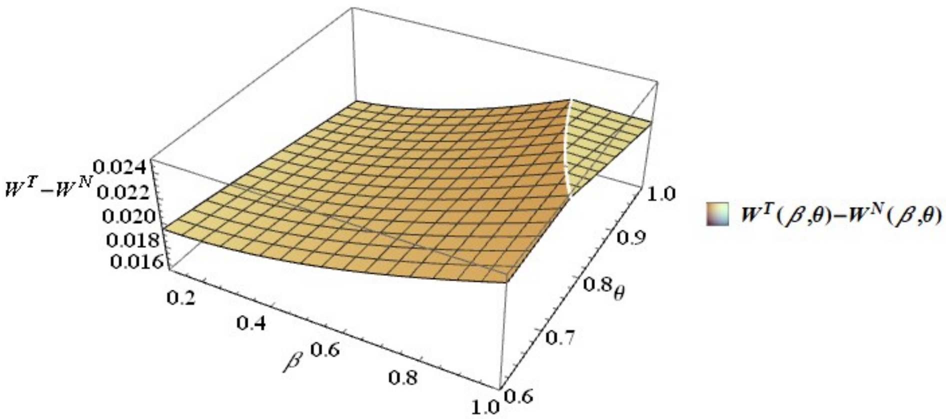

Figure 15. Welfare improving subsidy policy.

5. Conclusion

RJVs and licensing are common innovation agreements. These agreements occur in many nations, developed and developing, and, in several instances, they feature participation of international firms. A substantial share of such agreements derives its motivation from attempts of its participants to improve their environmental performances. There is evidence that in some cases the firms that form RJVs display forward-looking behavior with respect to the occurrence of new (or more stringent) environmental regulations.

This paper examines the potential formation of RJVs when, imperfectly competitive, asymmetric firms anticipate the effects that the interaction between each of three different forms of innovation agreements and environmental regulation produce. The duopoly contains domestic and foreign firms. The regulator (domestic government) cares about domestic welfare, which ignores the producer surplus that the foreign firm enjoys.

We obtain several important results. First, we show that licensing is not implementable because it makes the domestic firm worse off relative to the status quo. Second, we demonstrate that both forms of RJVs are implementable: the non-cooperative RJV is more likely the greater the degrees of asymmetries (in terms of efficiency and R&D spillover rates) between the firms while the cooperative RJV is more likely the lower the degrees of asymmetries. Third, we find that implementation of both RJVs improve the domestic firm's competitiveness and domestic welfare. Welfare improvements are larger under the cooperative RJV. Finally, we show that a subsidy policy that induces the foreign firm to accept the cooperative RJV when it strictly prefers the non-cooperative RJV is welfare improving.

Appendix

We provide the proofs for Propositions 1 and 2 in Appendix A and B, respectively. In Appendix C, we show the conditions that characterize the equilibria in the status quo and joint R&D arrangements under the particular quadratic functional forms described in Proposition 2. In all equilibria, $a_2 > 0$ for $1 \geq \theta \geq 0.6$.

Appendix A.

Proof of Proposition 1. Combining equations (3) and (4), we obtain equations (6), which imply $P'(Q)(q_1 - q_2) = 0$. Then, $q_1 = q_2$ because $P'(Q) < 0$. Equations (3) imply $c_x^1 \geq c_x^2$ because $1 \geq \theta$ and c is increasing at an increasing rate in x_i and separable in x_i and r_i. Hence, $x_1 \geq x_2$. Combining $c_x^1 \geq c_x^2$ with equations (5) yields $c_r^1 \geq c_r^2$, which implies $r_1 \geq r_2$ because c is increasing at an increasing rate in r_i and separable in x_i and r_i. Then, $x_1 \geq x_2$, $r_1 \geq r_2$ and $q_1 = q_2$ imply $a_1 \geq a_2$. Q.E.D

Appendix B.

Proof of Proposition 2. In this proof, we first show that $a_2 = 0$ for $\theta \in [0.6, 1]$. Suppose that $a_2 > 0$. In this case, the equilibrium conditions are as follows, $i = 1, 2$:

$$t = 8\theta(9+16\theta)/\mathrm{E};\ \phi = 4\theta(9+16\theta)/\mathrm{E};\ q_1 = q_2 = [27+\theta(81+32\theta)]/\mathrm{E};$$

$$Q = 2[27+\theta(81+32\theta)]/\mathrm{E};\ P(Q) = 9[3+\theta(25+32\theta)]/\mathrm{E};\ a_1 = [45+\theta(47-32\theta)]/\mathrm{E};$$

$$a_2 = [9-\theta(17+32\theta)]/\mathrm{E};\ r_1 = (36+64\theta)/\mathrm{E};\ r_2 = (18+32\theta)/\mathrm{E};$$

$$e_1 = 2[\theta(17+32\theta)-9]/\mathrm{E};\ e_2 = 2[9+\theta(49+32\theta)]/\mathrm{E};\ E = 4\theta(33+32\theta)/\mathrm{E};$$

$$\Pi_1 = \{729+\theta[8262+\theta(22113+64\theta(273+16\theta))]\}/\mathrm{E}^2;$$

$$\Pi_2 = \{81+\theta[270+\theta(217+\theta(217+32\theta))]\}/(9+32\theta)\mathrm{E};\ W = [27+\theta(41+32\theta)]/\mathrm{E}.$$

where $\mathrm{E} \equiv (9+11\theta)(9+32\theta) > 0$. Hence, $a_2 > 0$ if and only if $\theta < 0.3275$.

Since $a_2 > 0$ is infeasible, the equilibrium conditions are as follows, $i = 1,2$:

$$t = \theta(5+4\theta)\left[5+\theta(17+10\theta)\right]/\Gamma;\ \phi = \left[5+2\theta(5+3\theta)\right]\left[5+2\theta(11+6\theta)\right]/2\Gamma;$$

$$q_1 = \left[25+2\theta\left(65+2\theta\left(47+\theta(31+8\theta)\right)\right)\right]/2\Gamma;\ q_2 = 2\theta\left(5+\theta(17+10\theta)\right)/\Gamma;$$

$$Q = \left[25+2\theta\left(75+2\theta\left(64+\theta(41+8\theta)\right)\right)\right]/2\Gamma;\ P(Q) = \left[25+2\theta\left(115+2\theta\left(152+\theta(149+48\theta)\right)\right)\right]/2\Gamma;$$

$$a_1 = \left[25+4\theta\left(20+\theta\left(12-\theta(11+8\theta)\right)\right)\right]/2\Gamma;\ a_2 = 0;\ r_1 = (5+4\theta)\left[5+\theta(17+10\theta)\right]/2\Gamma;$$

$$r_2 = \theta\left[5+\theta(17+10\theta)\right]/\Gamma;\ e_1 = \theta\left[25+2\theta\left(35+2\theta(21+8\theta)\right)\right]/\Gamma;$$

$$e_2 = 2\theta\left[5+\theta(17+10\theta)\right]/\Gamma;\ E = \theta(7+4\theta)\left[5+4\theta(3+2\theta)\right]/\Gamma;$$

$$\Pi_1 = \left\{625+2\theta\left[4125+\theta\left(20850+\theta\left(53505+4\theta\left(19408+\theta\left(16321+2\theta\left(3829+876\theta+64\theta^2\right)\right)\right)\right)\right)\right]\right\}/4\Gamma^2;$$

$$\Pi_2 = 2\theta^2(2+\theta)\left[5+\theta(17+10\theta)\right]^2/\Gamma^2;\ W = \left\{25+2\theta\left[55+2\theta\left(65+\theta(55+16\theta)\right)\right]\right\}/8\Gamma;$$

where $\Gamma \equiv 25+2\theta\left[95+2\theta\left(108+\theta(95+28\theta)\right)\right] > 0$.

We see that the result $a_1 > a_2 = 0$ holds in the relevant range, $\theta \in [0.6,1]$. Combining conditions (33) – (36), we obtain $P'(Q)(q_2 - q_1) > 0$, which implies $q_1 > q_2$. The inequalities $a_1 > a_2$ and $q_1 > q_2$ imply that $y_1 > y_2$. Now, suppose that $x_2 \geq x_1$. This implies that $c_x^2 \geq c_x^1$. Combining this inequality with conditions (37), we obtain $c_r^2 \geq c_r^1$, which yields $r_2 \geq r_1$. Now, note that $x_2 \geq x_1$ yields $y_2 - r_2 \geq y_1 - r_1$, which implies that $y_2 - y_1 \geq r_2 - r_1 \geq 0$. But, this contradicts $y_1 > y_2$. Hence, we must have $x_1 > x_2$, which implies $r_1 > r_2$. QED

Appendix C.

1. In the status quo, the subgame perfect equilibrium for the game played by firms and the government is determined by the following conditions, $i=1,2$:

$$t=4\theta(3+11\theta)/\mathrm{A};\quad q_1=\left[3+2\theta(10+11\theta)\right]/\mathrm{A};\ q_2=\left[3+2\theta(10+11\theta)\right]/\mathrm{A};$$

$$Q=2\left[3+2\theta(10+11\theta)\right]/\mathrm{A};\ P(Q)=\left[3+22\theta(2+5\theta)\right]/\mathrm{A};\ a_1=\left[9+2\theta(12-11\theta)\right]/\mathrm{A};$$

$$a_2=\left[2\theta(11\theta-4)-3\right]/\mathrm{A};\ r_1=2(3+11\theta)/\mathrm{A};\ r_2=2\theta(3+11\theta)/\mathrm{A};$$

$$e_1=2\left[2\theta(11\theta-1)-3\right]/\mathrm{A};\ e_2=2(14\theta+3)/\mathrm{A};\ E=4\theta(6+11\theta)/\mathrm{A};$$

$$\Pi_1=\left\{9+4\theta\left[48+\theta\left(265+11\theta(42+11\theta)\right)\right]\right\}/\mathrm{A}^2;$$

$$\Pi_2=\left\{9+4\theta(5+11\theta)\left[6+\theta(17+33\theta)\right]\right\}/\mathrm{A}^2;\ W=\left[3+2\theta(6+11\theta)\right]/\mathrm{A}.$$

where $\mathrm{A}\equiv 9+14\theta(6+11\theta)>0.$ Note that $a_2>0$ if $\theta>0.5934$.

2. In the non-cooperative joint R&D arrangement, the subgame perfect equilibrium satisfies the following conditions, $i=1,2$:

$$t=8\theta\left(9+\theta(22+3\beta)\right)/\mathrm{B};\quad q_i=\frac{1}{3}\left\{1-\frac{16\theta\left[9+\theta(22+3\beta)\right]}{\mathrm{B}}\right\};$$

$$Q=\frac{2}{3}\left\{1-\frac{16\theta\left[9+\theta(22+3\beta)\right]}{\mathrm{B}}\right\};\ P(Q)=\frac{1}{3}\left\{1+\frac{32\theta\left[9+\theta(22+3\beta)\right]}{\mathrm{B}}\right\};$$

$$a_1=\left\{45+\theta(42\beta+68)+\theta^2\left(9\beta^2+48\beta-88\right)\right\}/\mathrm{B};$$

$$a_2=\left\{9+\theta\left[52+88\theta-\beta\left(6+\theta(16+3\beta)\right)\right]\right\}/\mathrm{B};\ r_1=4\left(9+(22+3\beta)\theta\right)/\mathrm{B};$$

$$r_2=4\theta\left(9+(22+3\beta)\theta\right)/\mathrm{B};\ e_1=2\left\{\theta\left[\theta\left(88-\beta(4+3\beta)\right)+4(5-3\beta)\right]-9\right\}/\mathrm{B};$$

$$e_2=2(1+\theta\beta)\left[\theta(28+3\beta)+9\right]/\mathrm{B};\ E=16\theta\left(6+\theta(11+3\beta)\right)/\mathrm{B};$$

$$\Pi_1 = \frac{1}{\mathrm{B}^2}\Big\{\theta^4\Big[7744+\beta\Big(22528+\beta\big(6352+528\beta+9\beta^2\big)\Big)\Big]$$
$$+4\theta^3\Big[8624+3\beta\big(2392+9\beta(38+\beta)\big)\Big]+18\theta^2\Big[1616+9\beta(64+3\beta)\Big]$$
$$+324\theta(26+3\beta)+729\Big\};$$

$$\Pi_2 = \frac{1}{\mathrm{B}^2}\Big\{\theta^4\Big[23232+\beta\Big(11264+\beta\big(2416+3\beta(80+3\beta)\big)\Big)\Big]$$
$$+4\theta^3\Big[11792+3\beta\big(1480+9\beta(22+\beta)\big)\Big]+18\theta^2\Big[1760+27\beta(16+\beta)\Big]$$
$$+324\theta(26+3\beta)+729\Big\};$$

$$W = \Big\{27+\theta\Big[92+88\theta+3\beta\big(6+\theta(8+\beta)\big)\Big]\Big\}\Big/\mathrm{B}.$$

where $\mathrm{B} \equiv 81+18\theta(3\beta+26)+\theta^2\left(9\beta^2+168\beta+616\right)>0$ and $a_2>0$ for $\beta\in[0,1]$.

3. In the cooperative joint R&D arrangement, the subgame perfect equilibrium satisfies the following conditions, $i=1,2$:

$$t=8\theta\Big[15+\theta\big(22+3\beta(2+\beta)\big)\Big]\Big/\mathrm{X};\quad q_i=\frac{1}{3}\left\{1-\frac{16\theta\Big[15+\theta\big(22+3\beta(2+\beta)\big)\Big]}{\mathrm{X}}\right\};$$

$$Q=\frac{2}{3}\left\{1-\frac{16\theta\Big[15+\theta\big(22+3\beta(2+\beta)\big)\Big]}{\mathrm{X}}\right\};\ P(Q)=\frac{1}{3}\left\{1+\frac{32\theta\Big[15+\theta\big(22+3\beta(2+\beta)\big)\Big]}{\mathrm{X}}\right\};$$

$$a_1=\Big\{105+\beta\theta\Big[8(\theta+9)+3\beta\Big(22+\theta\big(18+\beta(8+3\beta)\big)\Big)\Big]+88\theta(1-\theta)\Big\}\Big/\mathrm{X};$$

$$a_2=\Big\{45+6\theta(10-\beta)(2+\beta)+\theta^2\Big[88+\beta\big(56-10\beta-3\beta^3\big)\Big]\Big\}\Big/\mathrm{X};$$

$$r_1=\Big[120+8\theta\big(22+3\beta(2+\beta)\big)\Big]\Big/\mathrm{X};\ r_2=4\theta(1+\beta)\Big[15+\theta\big(22+3\beta(2+\beta)\big)\Big]\Big/\mathrm{X};$$

$$e_1=2\Big\{\theta\Big[44(1+2\theta)-\beta\Big(6(1-6\theta)+\beta\big(18+\theta(3\beta(2+\beta)-2)\big)\Big)\Big]-15\Big\}\Big/\mathrm{X};$$

$$e_2=2\Big\{\theta\Big[28+\beta\Big(6(1+2\theta)+\beta\big(18+\theta(3\beta(2+\beta)+34)\big)\Big)\Big]+15\Big\}\Big/\mathrm{X};$$

$$E=8\theta\Big(18+\theta\big(3\beta(4+3\beta)+22\big)\Big)\Big/\mathrm{X};$$

$$\Pi_1 = \frac{1}{X^2}\Big\{\theta^4\Big[7744+\beta\Big(29568+\beta\Big(40544+\beta\Big(25216+\beta\Big(12340+3\beta\Big(1104+\beta\big(260+3\beta(8+\beta)\big)\Big)\Big)\Big)\Big)\Big)\Big]$$
$$+4\theta^3\Big[9680+\beta\Big(16016+\beta\Big(16216+45\beta\Big(140+\beta\big(50+\beta(6+\beta)\big)\Big)\Big)\Big)\Big]$$
$$+\theta^2\Big[54736+450\beta\big(96+\beta\big(70+3\beta(4+\beta)\big)\big)\Big]+\theta\big(30000+4500\beta(2+\beta)\big)+5625\Big\};$$

$$\Pi_2 = \frac{1}{X^2}\Big\{\theta^4\Big[23232+\beta\Big(22528+\beta\Big(14240+\beta\Big(8320+\beta\Big(3412+3\beta\Big(432+\beta\big(116+3\beta(8+\beta)\big)\Big)\Big)\Big)\Big)\Big)\Big]$$
$$+4\theta^3\Big[20768+\beta\Big(15344+\beta\Big(9592+9\beta\Big(428+\beta\big(142+5\beta(6+\beta)\big)\Big)\Big)\Big)\Big]$$
$$+\theta^2\Big[93616+90\beta\big(496+\beta\big(278+15\beta(4+\beta)\big)\big)\Big]+\theta\big(40800+4500\beta(2+\beta)\big)+5625\Big\};$$

$$W = \Big\{75+\theta\Big[160+30\beta(2+\beta)+\theta\Big(88+\beta\Big(48+\beta\big(26+3\beta(4+\beta)\big)\Big)\Big)\Big]\Big\}\Big/X.$$

where $X \equiv 225+6\theta\big[98+15\big(2+\beta(2+\beta)\big)\big]+\theta^2\Big[352+9\big(2+\beta(2+\beta)\big)^2+6\big(38+\beta(44+25\beta)\big)\Big]>0.$

Note that $a_2 > 0$ for $\beta \in [0,1]$.

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