Environmental Research Joint Venture under the Emission Tax

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Abstract. The effect of environmental policy depends crucially on the strategic behavior of firms. Firms can undertake pollution abatement innovation cooperatively through environmental R&D joint ventures (RJVs). Environmental RJVs have not only environmental but also economic impacts. Two types of environmental RJV are discussed in this paper: coordination-RJVs which are designed to maximize joint profit, and collaboration-RJVs which are designed to spill over the pollution abatement technology. Coordination-RJVs minimize output quantities, maximize total emission, and minimize the social surplus. Collaboration-RJVs minimize R&D costs, minimize total emission, and maximize the social surplus. Environmental RJVs are socially desirable only if there is technological spillover among parties to the RJV.

Key words: pollution abatement, R&D joint venture, coordination, collaboration, Cournot competition, strategic effect

JEL classification: N50, L11, L51

I. Introduction

In light of the earth's very limited resources, economic development may one day reach its limits. Sustainable development was announced as a global policy at the landmark 1992 Rio Earth Summit (United Nations 1996). The concept of environmental innovation, including pollution abatement, energy saving, etc., is an effective and efficient way of sustaining economic development in an environment of limited resources. Firms can undertake environmental innovation alone or in concert. It should be noted, however, that environmental innovation decisions have not only environmental but also economic impacts.

Being different from other types of autonomous innovation, environmental innovation is often induced to meet legal emission requirements. Therefore, government regulation plays an important role in promoting environmental R&D. However, once an environmental policy is imposed, as their best response firms can either reduce their output or increase pollution abatement (e.g., Keeler, Spence and Zeckhauser 1971, Baumol and Oates 1988, Damania 1996, etc.). Thus, it is well known that environmental policy may actually fail to encourage environmental innovation. For this reason, the environmental policy needs to be designed to encourage environmental R&D instead of output reduction (e.g., Carraro and Siniscalco 1992, Jung, Krutilla and Boyd 1996, Katsoulacos and Xepapadeas 1996).

Environmentally innovative firms compete in both R&D and output quantity. The first stage R&D competition has a *strategic effect* on the second stage quantity competition and hence on the consumer surplus. Katsoulacos and Xepapadeas (1996) initiate research on the duopolistic environmental R&D competition with the spillover of environmental technology. They show that firms have an incentive to undertake R&D only if their emissions are taxed, implying that environmental R&D efforts are often not autonomous but are in fact induced by government regulations. They also prove that the privately optimal environmental R&D level deviates from the socially optimal level since firms do not take the consumer surplus into account. Therefore, the government can correct inefficient environmental R&D efforts by imposing an R&D subsidy or tax.

In addition to environmental R&D competition, two firms can also form a research joint venture (RJV) before undertaking R&D. An RJV is a type of strategic behavior among firms. An RJV has two effects: technological spillover, and collusion in output quantities. The former enhances R&D efficiency while the latter decreases the consumer surplus. For cost-reducing innovation, Kamien et al. (1992) show that an RJV with product that cooperate in its R&D decision yields the highest consumer plus producer surplus under Cournot competition, provided that the technological spillover rate is sufficiently high.

In many countries, the antitrust laws allow collusion in R&D activities but not in quantities and pricing. This is because the former may increase the social surplus if it enhances technological spillover, while the latter hurts the consumer and social surpluses in most of the cases. Choi (1993) does a study on cooperative R&D with duopolistic product market competition. He finds that the social incentive for cooperative R&D is higher than the private incentive when the spillover rate is high. In addition to the benefit technological spillover, RJV is also an instrument for sharing R&D risk and improving R&D cost effectiveness.

Although there are so many journal and book articles on RJV issues, little work has specifically focused on environmental RJVs.[1] Scott (1996) pioneers an empirical research on environmental RJVs in the U.S. According to an earlier paper of Scott (1988), for overall RJV filings in the U.S. from January 1985 to June 1986, twenty out of the sixty-one RJVs reported under the National Cooperative Research Act (NCRA) were related to environmental issues. Meanwhile, Scott (1996) finds that from February 15, 1991 to August 15, 1992, thirty-five out of the ninety-six RJVs reported under NCRA were related to environmental issues. Therefore, during these two periods at least one third of the RJVs in the NCRA sample pools were environmental RJVs! Hence, it can be strongly affirmed that environmental RJVs are in no way a trivial type of RJV. Scott (1996) concludes that environmental RJVs may well promote economic efficiency in terms of R&D cost effectiveness, risk, and spillover. However, firms' second market competition decision is effectively affected by the first stage R&D competition and cooperation decision. If firms can cooperate in environmental R&D, they can implicitly cooperate in market competition. Thus, an environmental RJV may have both negative environmental and economic impacts. We agree with Scott (1996) that environmental RJVs may improve R&D cost efficiency. However, in this paper we try to address the argument that collusive environmental R&D behavior may also reduce output quantities and emission abatement.

Recently, theoretic analysis of strategic collusion among firms in response to environmental policies has begun to receive considerable attention. For example, in a setup without technological spillover, Damania (1996) establishes an infinitely repeated game to show that an emission tax on pollution may facilitate collusion between duopolists. Instead of undertaking pollution abatement in order to reduce emission tax payments, the two firms in the model can reduce output quantities collusively in order to raise the price and to lower the taxable emission amount. Thus, an emission tax may fail to promote pollution abatement.

Damania comes up with an interesting question: What if the firms collusively reduce output quantities instead of doing pollution abatement? Following Damania's question, we would like to further inquire, "If the quantity collusion effect dominates technology spillover effect in an environmental RJV, will an environmental RJV be as socially desirable as Scott (1996) described?" Damania (1996), however, is not exactly a counter point to Scott (1996), since the former does not consider technological spillover within a strategic environmental coalition. Therefore, in this paper, we compare two types of environmental RJV: (1) an RJV without technological spillover which attempts to maximize the firms' joint profit (called the "coordination-RJV"); and (2) an RJV with technological spillover which attempts to maximize each firm's own profit (called the "collaboration-RJV"). This study shows that such environmental coalitions can encourage pollution abatement only if there is technological spillover.

The world economy is still comprised of small and medium sized enterprises (SMEs) with very limited funds for pollution abatement.[2] For instance, in the EU member economies, SMEs employ 66% of the task workforce and represent 99.8% of all enterprises excluding those in the agricultural and non-market sectors (EU 1999). One may wonder if environmental RJVs between SMEs promote pollution abatement. According to the "Rule of Reason", a strategic coalition should be allowed only if the production efficiency gained dominates the associated distributive inefficiency. Our finding show that environmental RJVs are beneficial to the social surplus improvement only if there is technological spillover.

This paper is organized as follows. In Section II, we investigate a duopoly without environmental RJV. In Section III, we discuss two types of environmental RJV: coordination-RJVs and collaboration-RJVs. In Section IV, numerical results are used to compare the social surpluses under a duopoly without RJV, a coordination-RJV, and a collaboration-RJV. Section V concludes the study.

II. A Duopoly without RJV

In this section, we analyze the duopoly case. We index the two firms by 1 and 2, respectively. The two firms produce homogeneous goods and engage in Cournot competition in the market, and both firms generate pollution during production.

There are two stages in the game. In the first stage, the two firms choose their pollution abatement level r_i (i = 1, 2) in order to lower their own emission per unit of output. For simplicity, the pollution abatement R&D functions are assumed to be identical:

$$R_i(r_i) = \frac{R}{2} r_i^2, \ i = 1, 2, \tag{1}$$

where $R > 0$. In the second stage, the two firms choose their outputs simultaneously, given the abatement level determined in the first stage. The solution concept of the subgame-perfect Nash equilibrium (SPNE) is applied to solve this game (see Osborne and Rubinstein 1994); that is, the solution to the game is obtained by backward induction.

The inverse demand function of the market is simply assumed to be linear:[3]

$$P = a - bQ, \tag{2}$$

where P is the market price; and $Q = q_1 + q_2$; q_1, q_2 are the quantities produced by firms 1 and 2, respectively. In order to focus on the strategic use of pollution abatement, we assume that the marginal production costs of the two firms are zero.[4] Therefore, the profit functions of the two firms are,

$$\pi_i = (a - bQ)q_i - t(\bar{e} - r_i)q_i - \frac{R}{2} r_i^2, \ i, j = 1, 2, \ i \neq j. \tag{3}$$

In the second stage, firm i's output can be solved as

$$q_i = \frac{1}{3b}\left[a - t\bar{e} + 2tr_i - tr_j\right], \ i, j = 1, 2, \ i \neq j. \tag{4}$$

By the above equation, we have $\frac{\partial q_i}{\partial r_i} = \frac{2t}{3b} > 0$ and $\frac{\partial q_i}{\partial r_j} = -\frac{t}{3b} < 0$. This implies that given the emission tax rate, firm i can reduce its emission tax payment by increasing its pollution abatement level and that a reduction in firm i's emission tax payment will increase its output. Meanwhile, a reduction in firm i's emission tax payment through increasing its abatement level will decrease the opponent's output.

Hence, in the first stage, firm i's profit function can be rewritten as

$$\pi_i = \pi_i(q_1(r_1, r_2), q_2(r_1, r_2), r_i),\ i = 1, 2. \tag{5}$$

In the first stage, the two firms choose abatement level r_i to maximize profits. The first order conditions are,

$$\frac{\partial \pi_i}{\partial r_i} = \frac{\partial \pi_i}{\partial r_i} + \frac{\partial \pi_i}{\partial q_i}\frac{\partial q_i}{\partial r_i} + \frac{\partial \pi_i}{\partial q_j}\frac{\partial q_j}{\partial r_i} = 0,\ i, j = 1, 2,\ i \neq j. \tag{6}$$

In Equation (6), the term $\frac{\partial \pi_i}{\partial q_i}$ is zero due to the optimum choice of output. Therefore, the first order condition for profit maximization in Equation (6) can be rewritten as

$$\frac{\partial \pi_i}{\partial r_i} = \underbrace{\frac{\partial \pi_i}{\partial r_i}}_{\text{profit effect}} + \underbrace{\frac{\partial \pi_i}{\partial q_j}\frac{\partial q_j}{\partial r_i}}_{\text{strategic effect}} = 0,\ i, j = 1, 2,\ i \neq j. \tag{7}$$

It is clearly shown in Equation (7) that the total effect of a firm's pollution abatement level can be decomposed into two effects: the profit effect and the strategic effect. The profit effect stems from the fact that pollution abatement allows a firm to increase its profits by lowering its emission tax payments. The strategic effect indicates that a firm's pollution abatement indirectly affects its profit by affecting its rival's output. Since $\frac{\partial \pi_i}{\partial q_j} = -bq_i < 0$ and $\frac{\partial q_i}{\partial r_i} = -\frac{t}{3b} < 0$, the second term on the right-hand side of Equation (7) must be positive. That is, the strategic effect gives firm i an incentive to further increase its pollution abatement level in order to increase its own profit by decreasing its opponent's output. Note that when the market structure is monopoly or perfect competition, such a strategic effect does not appear.

The necessary second order condition for the existence of a solution under a duopoly without RJV is $9bR > 4t^2$. Simultaneously solving the two firms' maximization problem, we obtain the SPNE pollution abatement level as $r_1^* = r_2^* = r^* = \frac{4t(a - t\bar{e})}{9bR - 4t^2}$, the SPNE outputs as $q_1^* = q_2^* = q^* = \frac{3R(a - t\bar{e})}{9bR - 4t^2}$, and the SPNE total emission amount as $E^* = Q^*(\bar{e} - r^*) = \frac{6R(a - t\bar{e})(9bR\bar{e} - 4at)}{(9bR - 4t^2)^2}$. Note that the equilibrium pollution abatement levels are zero if an emission tax is not adopted by the government, that is, if $r^*(t = 0) = 0$. This is illustrates that environmental R&D is often not autonomous but is induced by government regulation.

III. A Duopoly with RJV

We now allow the two firms to form an environmental RJV before undertaking R&D. Following Qiu and Tao (1998), we consider two types of RJV here. The first type of RJV is a "pollution abatement coordination" RJV; that is, in the first stage, the two firms coordinate in the environmental abatement level in order to maximize their joint profit, although there is no spillover of the abatement technology.[5] In the second stage, the two firms engage in Cournot quantity competition. The second type of RJV is a "pollution abatement collaboration" RJV; that is, in the first stage, the two firms spill over abatement technology to each other in order to maximize their own profits rather than joint profit. In the second stage, the two firms engage in Cournot quantity competition. We do not consider the firms' collusion in the output stage, since in many countries collusion in quantity and pricing decisions violates the antitrust laws. However, the first stage pollution abatement has a *strategic effect* on second stage quantity competition.

3.1 Pollution Abatement Coordination

The second stage of the game is as described in Section 2, while in the first stage the firms' problem is to maximize their joint profit by choosing an abatement level when the two firms are coordinating in abatement R&D. The joint profit function in the first stage can be expressed as

$$V = \sum_{i=1}^{2} \pi_i \, (q_1(r_1, r_2), q_2(r_1, r_2), r_i), \; i = 1, 2, \tag{8}$$

or

$$V = \sum_{i=1}^{2} \pi_i = (a-bQ)Q - \sum_{i=1,2} \left[t(\bar{e} - r_i)q_i + \frac{Rr_i^2}{2} \right], \; i, j = 1, 2, \; i \neq j. \tag{9}$$

In Equations (8) and (9), firm i's output is the same as that described in Equation (4).

The first order condition of firm i's maximization can be written as

$$\frac{\partial V}{\partial r_i} = \frac{\partial V}{\partial r_i} + \frac{\partial V}{\partial q_i}\frac{\partial q_i}{\partial r_i} + \frac{\partial V}{\partial q_j}\frac{\partial q_j}{\partial r_i} = 0,\ i, j = 1, 2,\ i \neq j. \tag{10}$$

In the first stage, the two firms choose individual abatement level in order to maximize the joint profit. Because $\frac{\partial \pi_i}{\partial q_i} = 0$ (the first order condition in the second stage), the first order condition for profit maximization in Equation (11) can be rewritten as

$$\frac{\partial V}{\partial r_i} = \underbrace{\frac{\partial \pi_i}{\partial r_i}}_{\text{profit effect}} + \underbrace{\frac{\partial \pi_i}{\partial q_j}\frac{\partial q_j}{\partial r_i}}_{\text{strategic effect}} + \underbrace{\frac{\partial \pi_j}{\partial q_i}\frac{\partial q_i}{\partial r_i}}_{\text{coordination effect}} = 0,\ i, j = 1, 2,\ i \neq j. \tag{11}$$

The necessary second order condition for maximization is $4bR > t^2$. Compared to Equation (7), there is the extra term of the coordination effect, $\frac{\partial \pi_j}{\partial q_i}\frac{\partial q_i}{\partial r_i}$, in Equation (11). Since $\frac{\partial \pi_j}{\partial q_i} < 0$ and $\frac{\partial q_i}{\partial r_i} < 0$, the coordination effect is negative. This implies that the firms have an incentive to reduce their pollution abatement levels when they are engaged in coordination. This is because in addition to the profit and strategic effects, an increase in firm *i*'s pollution abatement will also reduce its opponent's profit. In order to maximize joint profit, each firm under an RJV will reduce its pollution abatement levels in order to avoid reducing the other firm's profit and hence joint profit.

Simultaneously solving both firms' maximization problem, we obtain the SPNE pollution abatement level as $r_1^{**} = r_2^{**} = r^{**} = \frac{t(a - t\bar{e})}{4bR - t^2}$, the SPNE output quantities as $q_1^{**} = q_2^{**} = q^{**} = \frac{R(a - t\bar{e})}{4bR - t^2}$, and the SPNE total emission amount as $E^{**} = Q^{**}(\bar{e} - r^{**})$ $= \frac{2(4bR\bar{e} - at)R(a - t\bar{e})}{4bR - t^2}$. Comparing the equilibrium results under the coordination-RJV with those under duopoly, we have the following proposition.

[Proposition 1] *Given the same emission tax rate, a coordination-RJV induces lower pollution abatement levels and output quantities than a duopoly without RJV.*

[Proof] From the analytical solutions and second order conditions, we have $q^{**} = \frac{R(a - t\bar{e})}{4bR - t^2} < q^* = \frac{3R(a - t\bar{e})}{9bR - 4t^2}$, which implies that $Q^{**} < Q^*$. Moreover, $r^{**} = \frac{t(a - t\bar{e})}{4bR - t^2}$

$$< r^* = \frac{4t(a - t\bar{e})}{9bR - 4t^2}.$$

When two firms form a coordination-RJV, they can coordinate their pollution abatement levels. Such coordination has an indirect effect on their output quantities. Through an environmental RJV, though two firms can produce less with less pollution abatement, they can increase marginal revenues by reducing their output quantities collusively. Therefore, it is possible that total emissions can be reduced by a pollution coordination-RJV even though the per output pollution abatement is less. This result is consistent with Damania's (1996) setup without technological spillover that a collusive reduction in output quantities without pollution abatement can also reduce the total emissions. Consequently, the *coordination effect* of a coordination-RJV increases the firms' joint profit by reducing both environmental R&D costs and output quantities. Meanwhile, a coordination-RJV under emission tax results in higher per unit emissions, a lower total output, and a lower consumer surplus.

3.2 Pollution Abatement Collaboration

In this subsection, we discuss another environmental RJV type, namely pollution abatement collaboration. Under the collaboration RJV, one firm's pollution abatement R&D can reduce its own per output pollution and it can also be spilled over to the other firm. To simplify the analysis, we here assume that the spillover effects are symmetric. In the second stage, the two firms choose their output quantities simultaneously. Therefore, the profit functions of the two firms are,

$$\pi_i = (a - bQ)q_i - t(\bar{e} - r_i - \beta r_j)q_i - \frac{R}{2}r_i^2,\ i, j = 1, 2,\ i \neq j, \tag{12}$$

where β is the spillover rate, $0 \leq \beta < 1$. The coefficient β represents the degree to which the pollution abatement technology spills over from one firm to the other. In the second stage, firm i's output can be resolved as

$$q_i = \frac{1}{3b}\left[a - t\bar{e} + t(2 - \beta)r_i + t(2\beta - 1)r_j\right],\ i, j = 1, 2,\ i \neq j. \tag{13}$$

From the above equation, we know that $\frac{\partial q_i}{\partial \beta} = \frac{t}{3b}\left(-r_i + 2r_j\right)$. This implies that as long as the difference in abatement levels is not too large, pollution abatement collaboration increases firm i's output quantities. Moreover, $\frac{\partial q_i}{\partial r_i} = \frac{t}{3b}(2-\beta) > 0$. This means that firm i's pollution abatement R&D lowers its per output emission tax payments and thus increases its output. However, as the spillover effect increases, the marginal effect of the abatement level on q_i decreases. This is because as the spillover effect increases, the opponent's tax payments also decrease with firm i's pollution abatement level.

Firm i's pollution abatement R&D has two opposite effects. First, firm i's pollution abatement reduces its own emission tax payments and thus reduces the opponent's output. Second, firm i's pollution abatement R&D spills over to the opponent, making the opponent's emission tax payments decrease and thus the opponent's output increase. From Equation (13), we know that $\frac{\partial q_i}{\partial r_j} = \frac{t}{3b}(2\beta - 1)$. This implies that when the spillover effect is small (β is less than $\frac{1}{2}$), the first effect dominates the second effect; thus, firm i's pollution abatement R&D makes its opponent's output decrease. Contrarily, when the spillover effect is large (β is larger than $\frac{1}{2}$), the second effect dominates the first one; and thus firm i's pollution abatement R&D makes its opponent's output increase.

Substituting Equation (13) into Equation (14), we obtain firm i's profit function in the first stage:

$$\pi_i = \pi_i(q_1(r_1, r_2), q_2(r_1, r_2), r_i), \qquad i = 1, 2. \tag{14}$$

The two firms choose abatement level r_i to maximize individual profits in the first stage. The first order condition of firm i is,

$$\frac{\partial \pi_i}{\partial r_i} = \frac{\partial \pi_i}{\partial r_i} + \frac{\partial \pi_i}{\partial q_i}\frac{\partial q_i}{\partial r_i} + \frac{\partial \pi_i}{\partial q_j}\frac{\partial q_j}{\partial r_i} = 0,\ i, j = 1, 2,\ i \neq j. \tag{15}$$

The necessary second order condition for the existence of a solution under a collaboration-RJV is $9bR > 2(2-\beta)(1+\beta)t^2$. Because $\frac{\partial \pi_i}{\partial q_i} = 0$ (the first order condition in the second stage), the first order condition for profit maximization in Equation (15) can be rewritten as

$$\frac{\partial \pi_i}{\partial r_i} \;=\; \underbrace{\frac{\partial \pi_i}{\partial r_i}}_{\text{profit effect}} + \underbrace{\frac{\partial \pi_i}{\partial q_j}\frac{\partial q_j}{\partial r_i}}_{\text{strategic effect}} = 0, \quad i, j = 1, 2, i \neq j. \tag{16}$$

Being different from the situations under the coordination RJV, there is no coordination effect under the collaboration RJV since the firms' objective is not to maximize joint profit. Thus, in Equation (16), there are only profit and strategic effects. Because $\frac{\partial q_i}{\partial r_i} \genfrac{}{}{0pt}{}{<}{>} 0$ if $\beta \genfrac{}{}{0pt}{}{<}{<} \frac{1}{2}$, the strategic effect is positive [negative] if β is less than [larger than] $\frac{1}{2}$. Under the strategic concern, each firm under the collaboration RJV will have an incentive to increase [decrease] its abatement level if β is less than [larger than] $\frac{1}{2}$. That is, the firms' abatement levels strictly decrease with the spillover effect.

Simultaneously both firms' maximization problem, we obtain the SPNE pollution abatement level as $r_1^{***} = r_2^{***} = r^{***} = \frac{2(2-\beta)t(a-t\bar{e})}{9bR-2(2-\beta)(1+\beta)t^2}$, the SPNE outputs as $q_1^{***} = q_2^{***} = q^{***} = \frac{3R(a-t\bar{e})}{9bR-2(2-\beta)(1+\beta)t^2}$, and the SPNE total emission amount as $E^{***} = Q^{***}(\bar{e} - (1+\beta)r^{***}) = \frac{6R(a-t\bar{e})[9bR\bar{e}-2(2-\beta)(1+\beta)at]}{\left[9bR-2(2-\beta)(1+\beta)t^2\right]^2}$. With these analytical solutions, we derive the following proposition.

[Proposition 2] *Given the same emission tax rate, a collaboration-RJV induces lower R&D costs than a duopoly without RJV, for 0 ≤ β < 1.*

[Proof] By assuming that the second-order condition holds, we must have $\frac{dr^{***}}{d\beta} = \frac{-2t(a-t\bar{e})}{\left[9bR-2(2-\beta)(1+\beta)t^2\right]^2}\left[9bR-2(2-\beta)^2t^2\right] < 0$, for $0 \leq \beta < 1$. Moreover, the R&D costs are strictly decreasing in r^{***}.

Thus, the two types of environmental RJV both lead to a reduction in pollution abatement levels. Therefore, the effect of a collaboration-RJV is twofold. The first effect is that the duopolists can save pollution abatement costs through the spillover of technology, as depicted in Proposition 2. The second effect is that collusive abatement has a strategic effect on quantity competition. Therefore, to compare the welfare effects of an RJV, we need to construct the social surplus equation.

IV. Welfare Comparison

We measure the social welfare level by the social surplus (*SS*), in which a higher social surplus represents a higher welfare level. The social surplus is equal to the consumer surplus (*CS*) plus the producer surplus (*PS*) minus environmental damage (*D*) in monetary units. That is,

$$SS = PS + CS - D. \tag{17}$$

The producer surplus is the sum of the firm's profits, $\pi_1 + \pi_2$. Because of the linear demand curve assumption (Equation (1)), the consumer surplus is simply $\frac{1}{2}bQ^2$. Following the conventional setup, we assume that environmental damage is a strictly convex function of total emission, $D(E)$, with $D(0) = 0$, $D' > 0$, $D'' > 0$. To find analytical solutions, the quadratic function form is adopted, that is, $D = \frac{d}{2}E^2$ with $d > 0$. We then can go on to calculate the social surpluses under a duopoly without RJV, pollution abatement coordination, and pollution abatement collaboration. Numerical examples under a set of parameters for the three scenarios are listed in Table 1. As long as the second order conditions of all three cases are satisfied, the ordering of the SPNE outcomes under the three scenarios will not change with parameters.

As is shown in Table 1, a coordination-RJV results in the lowest social surplus. Moreover, a coordination-RJV results in the highest producer surplus, the highest total emissions, and the lowest consumer surplus. This is because in a coordination-RJV, the two firms collusively reduce the abatement levels and output quantities in order to increase their profits. Therefore, both the economic and environmental impacts under a coordination-RJV are negative. This result is consistent with Damania (1996); that is, without technological spillover, the two firms can reduce output quantities collusively in order to raise the price and they may not engage in pollution abatement.

Since the coordination-RJV has the highest total emissions, an increase in marginal environmental damage (*d*) enlarges the difference in the social surplus between a coordination-RJV and a collaboration-RJV or a duopoly without RJV. That is, as the environmental damages of the product get higher, the social surplus under a coordination-RJV falls behind more. An increase in the emission tax rate will reduce the differences but it will not change the ordering of the SPNE outcomes under these three scenarios.

A collaboration-RJV results in a strictly higher social surplus than a duopoly without RJV if the spillover rate is strictly positive. Meanwhile, a collaboration-RJV results in the highest consumer surplus, the lowest R&D costs, and the lowest total emissions. The firms save their R&D costs by sharing information with each other. Information sharing is also beneficial to consumers and to pollution abatement. Moreover, the social surplus increases and then decreases in $\beta \in [0,1)$. This result is consistent with Kamien et al. (1992), that is, that an RJV cooperating in R&D decisions yields the highest consumer surplus and producer surplus under Cournot competition, as long as the spillover rate is sufficiently high.

Under the same emission tax rate, the ranking of social surpluses always goes from high social surplus collaboration-RJVs, through duopoly without RJVs, to low social surplus coordination-RJVs. Therefore, if the government sets up an emission tax optimally within each scenario, the order of the highest social surplus achievable down to the lowest still runs from collaboration-RJVs, duopoly without RJV, to coordination RJVs.

According to our analytical and numerical results, a collaboration-RJV is socially desirable while a coordination-RJV is not. The government should encourage collaboration-RJVs and ban coordination-RJVs. It is a fact, however, that an environmental RJV can be both a coordination-RJV and a collaboration-RJV at the same time. In that case, the government should check if there is indeed the sharing of pollution abatement technology within the RJV. R&D efficiency and social surplus will improve only if there is spillover of pollution abatement technology. Otherwise, such an environmental RJV merely serves as an instrument of collusion and should definitely be outlawed.

Table 1: Numerical Examples of the Equilibrium Outcomes

(t = 0.2, a = 20, b = 0.2, $\bar{e}$ = 1, R = 10, d = 0.5)

	r	Q	E	PS	CS	D	SS
Duopoly without RJV	0.887892	66.5920	7.46546	435.564	443.448	13.9333	865.08
Coordination RJV	0.497487	48.7488	24.9994	492.512	247.494	156.242	583.764
Collaboration RJV (β = 0)	0.887892	66.5920	7.46546	435.564	443.448	13.9333	865.08
Collaboration RJV (β = 0.1)	0.843838	66.6188	4.78176	435.924	443.807	5.7163	874.013
Collaboration RJV (β = 0.5)	0.66667	66.6666	0	436.560	444.444	0	881.005
Collaboration RJV (β = 0.7)	0.577674	66.6546	1.19673	436.402	444.285	0.358039	880.328
Collaboration RJV(β = 0.9)	0.488538	66.6188	4.78176	445.924	443.807	5.7163	874.013

V. Concluding Remarks

In this paper, it is shown that a coordination-RJV minimizes the social surplus. Firms in a coordination-RJV can strategically reduce their environmental R&D and output quantities in order to obtain the highest joint profit. This result matches that of Damania (1996) in which there is no technological spillover between the two collusive firms.

Our theoretical model verifies the findings of Scott (1996) that an environmental RJV may improve R&D efficiency in terms of R&D cost effectiveness and spillover, etc. Thus, an environmental RJV is socially desirable only if there is technology spillover under such a coalition.

In many countries in the world, R&D cooperation is legal under the antitrust laws, as long as its effect in promoting R&D and production efficiency outweighes the inefficiency resulting from the reduction in competition. A coordination-RJV has negative effects on total output, per output abatement and social surplus. Moreover, a collaboration-RJV with environmental technology spillover is social surplus maximizing. Thus, antitrust law enforcers should scrutinize whether the members of an environmental RJV are substantially sharing environmental innovations. Furthermore, an environmental RJV should be allowed only if there is technological spillover within.

Environmental RJVs under other types of environmental instruments, such as emission quotas, marketable permits, etc., should also be taken into account. Even under different policy instrument, the spillover of technology will continue to play a key role in determining whether an environmental RJV is socially desirable. An environmental RJV is socially desirable if and only if the benefits from spillover outweigh the social surplus loss from collusion among the firms.

In this paper, we assume that the market structure is a duopoly. However, the number of firms in an RJV can be more than two. In that case, the environmental RJV problem will be an endogenous coalition problem under a fixed number oligopoly. There can be many symmetric or asymmetric coalitions in equilibrium. In addition, the market structure can also be endogenous (Katsoulacos and Xepapadeas 1995). An endogenous coalition problem would be a worthy topic for future research.

Notes

1. After conducting an overall search on 1969-1998 economic literature, we found that Professor John T. Scott's empirical studies were the only series specifically focusing on environmental RJVs.
2. The Small and Medium Development Organization in Turkey (WWW homepage address: http://www.kosegeb.com) summarizes an international comparison to show the importance of SMEs in the world economy. According to its statistics, the rate of SMEs to total number of enterprises is 99.9% in France, 99.8% in Germany, 97.0% in Italy, 99.4% in Japan, 97.8% in South Korea, 98.8% in Turkey 97.2%, in the U.S., and 96.0% in the U.K. Moreover, the production rate of SMEs is 54% in France, 49.0% in Germany, 53.0% in Italy, 52.0% in Japan, 34.5% in South Korea, 37.7% in Turkey, 36.2% in the U.S., and 25.1% in the U.K.

3. The properties of the equilibrium outcomes under Cournot competition are the same for both the linear and nonlinear demand curves, provided that the nonlinear curve is concave or not too convex; i.e., that the value of p'' is not too large. The condition that p'' is not too large guarantees that the reaction curves in quantity are both negatively sloping, i.e., that the two firms' quantity strategies are strategic substitutes (See Bulow, Geanakoplos and Klemperer (1985)).
4. The assumption does not affect the ensuing qualitative discussion.
5. Kamien et al. (1992) refer to this kind of RJV as "R&D cartelization"; that is, the firms coordinate in R&D activities to maximize joint profit.

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