IDEC DP² Series Vol. 2 No. 6

Developmnet
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February, 2012

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# What is the socially desirable formation of environmental R&D ?

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**Abstract**

This paper presents an examination of the socially desirable formation of environmental R&D in Cournot duopoly in a setting where a regulator has no precommitment ability for an emissions tax. The results reveal that if environmental damage is sufficiently small, alternatively if there is severe environmental damage and large inefficiency in environmental R&D costs, then environmental research joint venture (ERJV) cartelization is socially desirable. However, if environmental damage is sufficiently extensive, and if a firm's environmental R&D costs are sufficiently limited, then, in contrast to previous studies, environmental R&D competition is socially more desirable than environmental R&D cartelization and ERJV cartelization, although R&D competition is the case of "NO information sharing" and "NO R&D coordination."

**JEL Classification**: O32; L13; Q55; Q58.

**Keywords**: Environmental research joint venture; Environmental R&D; Time-consistent emission tax; Competition policy; Cournot duopoly

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# 1 Introduction

Innovation drives economic growth. As macroeconomic growth theory and empirical studies prove, scientific technological advances are a key component of long-term economic growth. Economic policies are justified if they can foster a competitive market of research and development (R&D) that rewards innovation and improves social welfare. In the framework of partial equilibrium analysis, many previous studies have examined R&D subsidies, intellectual property rights, R&D tax credits and other innovation promotion policies in oligopolistic markets.[1] Unlike the government designing public policies for socially beneficial R&D, firms invariably desire privately beneficial R&D formation. Considering firms' decision making, an effective R&D scheme is to form a research joint venture (RJV). The guidelines for RJV affect market efficiency, and the accumulation of R&D activities influences economic growth.

Nowadays, RJVs are motivated not only by traditional business demands for cost reductions, better quality, and new product development but also by current social concerns such as health care interests, food security, and environmental issues. In particular, environmental issues and environmental consciousness require firms to reduce emissions to a marked degree, but it is difficult to engage in environmental R&D efforts aimed at emissions reduction for individual firms because of the associated cost and uncertainty. This is a principal reason that each firm forms environmental research joint ventures (ERJVs) with other firms. Moreover, when taking action on behalf of the environment, most efforts tend to be welcomed. Many people might agree recklessly that the promotion of ERJV is socially necessary, but is ERJV truly socially efficient? Our primary purpose is to explore this question carefully. This motivation plays a large part in forming the theoretical foundation of competition policy because, sooner or later, a regulator will be necessary to clarify guidelines for RJV in the previously described new fields. Incidentally, the ERJV literature is quite inadequate compared with cost-reducing RJV studies in spite of the appearance of new RJV fields. As another purpose of this paper, to fill that void of knowledge, we analyze the welfare performance of ERJV from the viewpoint of antitrust policy, and derive related policy implications.

Technology spillover leads to inappropriability of the fruits of R&D. Therefore, in the presence of spillover effects, RJV is a privately beneficial instrument for innovation. Caloghirou *et al.* (2003) point out that a firm's incentives to form an RJV are R&D cost sharing, reduction of R&D duplication, spillover internalization, and so on. However, RJV might generate inefficiencies of the final output market. Suetens (2008) shows, from the experimental side, that R&D

[1] For example, see Lahiri and Ono (1999), Hinloopen (1997, 2000), Cassiman (2000), and Toshimitsu (2003).

cooperation supports price collusion.[2] Therefore, even in the case of ERJV undertaken for reducing emissions, it is necessary to judge carefully whether an ERJV is socially allowable.

Economic research into environmental technology and regulation has greatly increased in the past several decades. Jaffe *et al.* (2002) and Requate (2005) provide excellent surveys of the related literature.[3] However, there remain unsolved topics. In particular, a regulator's precommitment ability with regard to policy variables is the theme that attracts the greatest attention.[4] Corresponding to this research stream, Poyago-Theotoky (2007) examines whether polluting Cournot duopolists' coordination behavior in emission-reducing R&D is socially allowable when a regulator has no precommitment ability for emissions taxes. Her research represents an excellent contribution to policy implications for environmental R&D and emissions tax policy. In this study, following the well-known definition of R&D scenarios by Kamien *et al.* (1992), we introduce two incremental scenarios: ERJV competition and ERJV cartelization.[5] Furthermore, we compare these two cases with the equilibrium outcomes of the two cases of environmental R&D competition and environmental R&D cartelization explored by Poyago-Theotoky (2007). This paper uses the definition presented by Kamien *et al.* (1992) to provide consistent theoretical arguments and comparisons with related papers subsequent to their seminal work. Our investigation here leads to increased contributions for establishment of better competition rules.

This paper proceeds as follows. The next section introduces the model and the equilibrium outcomes. The third section examines which R&D regime has social superiority and derives policy implications. The final section presents conclusions.

## 2 The model and equilibrium outcomes

This section presents the model developed by Poyago-Theotoky (2007) and its equilibrium outcomes.

[2] Anticompetitive dangers from RJVs are explained in Section 4.2 (pp. 323–325) of Grossman and Shapiro (1986).

[3] As some representative studies from the empirical side, for example, see Scott (1996, 1997, 2003, 2005) and Horbach (2008).

[4] For example, see Poyago-Theotoky and Teerasuwannajak (2002), Requate (2005) and Hepburn (2006).

[5] Kamien *et al.* (1992) define RJV as the full information-sharing (perfect spillover) of R&D findings. Subsequent to their research, numerous theoretical R&D studies have employed their definition.

## 2.1 The model

We assume an industry comprising two homogeneous firms – firm $i$ and firm $j$ – engaging in a quantity competition with the same cost structure and emissions-reducing technology. Then $q_i$ denotes firm $i$'s output. Demand is given as $p(q_i, q_j) = a - (q_i + q_j)$, $(i, j = 1, 2;\ i \neq j)$, where $a(> 0)$ is a market size parameter.

The value of each firm's emissions per unit output is one. Firm $i$'s environmental R&D effort is captured by $z_i$. Both firms use end-of-pipe technology for pollution abatement. Although this technology is insufficient for reducing emissions per unit output, it mitigates emissions by adsorbing pollution at the end of the production process.

Firm $i$ receives benefits not only from its own environmental R&D effort but also from the effort of its rival. When firm $i$'s production level is $q_i$, then the R&D expenditure $(\gamma/2)z_i^2, (\gamma > 0)$ enables firm $i$ to abate its emissions from $q_i$ to $e_i(q_i, z_i) \equiv q_i - z_i - \beta z_j$. A lower value of $\gamma$ implies higher efficiency of the R&D cost. Symmetric parameter $\beta \in [0, 1]$ denotes the spillover effects of R&D. Firm $i$'s positive externalities from a rival's R&D effort is captured by $\beta z_j$. No fixed costs for pollution abatement are necessary. In addition, firm $i$'s total cost function is additively separable with respect to production costs and R&D expenditures: $C(q_i, z_i) = cq_i + (\gamma/2)z_i^2, (c > 0, A \equiv a - c > 0)$.

Firm $i$'s net emissions $e_i(q_i, z_i)$ depend on both the output and environmental R&D effort. Total emissions $E \equiv \sum_{i=1}^{2} e_i(q_i, z_i)$ cause environmental damage $D(E) \equiv dE^2/2$; $d(> \underline{d} \equiv (-1 + \sqrt{3})/2)$ is the damage coefficient.[6]

Social welfare $SW$ is defined as the sum of consumers' surplus and producer's surplus less $D(E)$ and total R&D expenditures, $\sum_{i=1}^{2} (\gamma/2)z_i^2$. The regulator has no precommitment ability for an emissions tax rate $t$. The time structure is as follows.

*Stage 1*: Firm $i$ determines $z_i$ to maximize its own profit $(\pi_i)$ or joint profits $(\pi_i + \pi_j)$.
*Stage 2*: The regulator determines $t$ to maximize $SW$.
*Stage 3*: Firm $i$ determines $q_i$ noncooperatively to maximize its own profit.

## 2.2 Equilibrium outcomes

Poyago-Theotoky (2007) investigates two environmental R&D regimes – R&D competition and R&D cartelization – and presents the subgame-perfect Nash equilibrium (SPNE) under a time-consistent emissions tax. A brief sketch of solution procedures and results follows.

[6] An interior solution for environmental R&D is guaranteed by the following assumption: $d > \underline{d} \equiv (-1 + \sqrt{3})/2$. For details, see Ouchida and Goto (2011).

### 2.2.1 Environmental R&D competition

In the last stage, firm $i$'s profit is $\pi_i(q_i, q_j) = \{a - (q_i + q_j)\}q_i - cq_i - t\{q_i - z_i - \beta z_j\}\} - (\gamma/2)z_i^2$. From the first-order conditions for profit maximization, the symmetric equilibrium output is derived as $q(t) = (A - t)/3$. Consequently, social welfare in Stage 2 is $SW(t) = 2Aq(t) - 2[q(t)]^2 - (d/2)\{2q(t) - (1+\beta)\{z_i + z_j\}\}^2 - \sum_{i=1}^{2}(\gamma/2)z_i^2$. The subgame equilibrium tax rate is obtained as

$$t(z_i, z_j) = \frac{(2d-1)A - 3d(1+\beta)\{z_i + z_j\}}{2(1+d)}. \tag{1}$$

Therefore, firm $i$'s profit during the first stage is $\pi_i(z_i, z_j) = [q(t(z_i, z_j))]^2 + t(z_i, z_j)\{z_i + \beta z_j\} - (\gamma/2)z_i^2$. Each firm determines its environmental R&D efforts noncooperatively. The first-order conditions $\partial \pi_i(z_i, z_j)/\partial z_i = 0,\ (i, j = 1, 2; i \neq j)$ generate the following equilibrium R&D efforts.[7]

$$z_{\mathrm{N}} = \frac{[(1+d)(2d-1) + d(1+\beta)]A}{2\gamma(1+d)^2 + d(1+\beta)[3(3+\beta) + d(7+\beta)]}. \tag{2}$$

The equilibrium levels of emissions tax rate, output level for each firm, profit, and social welfare are derived as follows.

$$t_{\mathrm{N}} = \frac{[d(2d-3)(1+\beta)^2 + 2\gamma(2d^2 + d - 1)]A}{4\gamma(1+d)^2 + 2d(1+\beta)[3(3+\beta) + d(7+\beta)]}, \tag{3}$$

$$q_{\mathrm{N}} = \frac{[2(1+d)\gamma + d(1+\beta)(7 + 4d + 3\beta)]A}{4\gamma(1+d)^2 + 2d(1+\beta)[3(3+\beta) + d(7+\beta)]}, \tag{4}$$

$$\pi_{\mathrm{N}} = q_{\mathrm{N}}^2 + t_{\mathrm{N}}(1+\beta)z_{\mathrm{N}} - (\gamma/2)z_{\mathrm{N}}^2, \tag{5}$$

$$SW_{\mathrm{N}} = 2Aq_{\mathrm{N}} - 2q_{\mathrm{N}}^2 - 2d\{q_{\mathrm{N}} - (1+\beta)z_{\mathrm{N}}\}^2 - \gamma z_{\mathrm{N}}^2. \tag{6}$$

Full information sharing of the fruits of R&D is characterized by $\beta = 1$. When $\beta = 1$, the above SPNE outcomes (Equations (2)–(6)) show the equilibrium values for the case of ERJV competition. In particular, we provide the following definition: $SW_{\mathrm{NJ}} \equiv SW_{\mathrm{N}}|_{\beta=1}$.[8] We assume that no fixed costs for ERJV are necessary.

### 2.2.2 Environmental R&D cartelization

However, environmental R&D cartelization implies that each firm determines its environmental R&D effort to maximize joint profits during the first stage.

[7] The subscript "N" stands for the case of R&D competition. This paper follows the scheme employed by Kamien *et al.* (1992).

[8] The subscript "NJ" stands for the case of ERJV competition. This subscript also applies to the other equilibrium values.

Then, the equilibrium levels of the SPNE outcomes are derived as follows.[9]

$$z_{\rm C} = \frac{(1+\beta)[(1+d)(2d-1)+2d]A}{2\gamma(1+d)^2+4d(3+2d)(1+\beta)^2}, \quad (7)$$

$$t_{\rm C} = \frac{[d(2d-3)(1+\beta)^2+\gamma(2d^2+d-1)]A}{2\gamma(1+d)^2+4d(3+2d)(1+\beta)^2}, \quad (8)$$

$$q_{\rm C} = \frac{[d(5+2d)(1+\beta)^2+\gamma(1+d)]A}{2\gamma(1+d)^2+4d(3+2d)(1+\beta)^2}, \quad (9)$$

$$\pi_{\rm C} = q_{\rm C}^2 + t_{\rm C}(1+\beta)z_{\rm C} - (\gamma/2)z_{\rm C}^2, \quad (10)$$

$$SW_{\rm C} = 2Aq_{\rm C} - 2q_{\rm C}^2 - 2d\{q_{\rm C} - (1+\beta)z_{\rm C}\}^2 - \gamma z_{\rm C}^2. \quad (11)$$

When $\beta = 1$, the above SPNE outcomes (Equations (7)–(11)) show equilibrium values for the ERJV cartelization scenario. Preliminary to the welfare comparison in Section 3, we set the following definition: $SW_{\rm CJ} \equiv SW_{\rm C}|_{\beta=1}$.[10] Poyago-Theotoky (2007) shows that for $\beta = 1$, $SW_{\rm CJ} > SW_{\rm NJ}$. Therefore, the equilibrium social welfare under ERJV cartelization dominates that under ERJV competition.[11] Hereafter, we do not analyze the case of ERJV competition and, instead, concentrate on the welfare performance of the other R&D regimes.

# 3 R&D regimes and social superiority

This section presents an examination of whether equilibrium social welfare under ERJV cartelization dominates that under the other two R&D scenarios: environmental R&D competition and environmental R&D cartelization.

## 3.1 Environmental R&D cartelization versus ERJV cartelization

Comparing the equilibrium social welfare under environmental R&D cartelization, $SW_{\rm erc}$, with that under ERJV cartelization, $SW_{\rm CJ}$, engenders the following proposition.

**Proposition 1.** $SW_{\rm CJ} \geq SW_{\rm C}$ *for all* $d > \underline{d}$, $\gamma > 0$ *and* $\beta \in [0, 1]$.

**Proof**: See Appendix A. □

[9] The subscript "C" denotes the case of environmental R&D cartelization.
[10] The subscript "CJ" stands for the case of ERJV cartelization. This subscript is also applicable to the other equilibrium values.
[11] See Equation (14), Corollary 1 and Proof of Proposition 2 in Appendix A in Poyago-Theotoky (2007).

This proposition states that, in terms of social-welfare maximization, ERJV cartelization invariably dominates environmental R&D cartelization. Full information sharing generates welfare superiority compared with the case of R&D cartelization. This result is consistent with our intuition.

### 3.2 Environmental R&D competition versus ERJV cartelization

We now compare the two equilibrium social welfare levels. The difference between $SW_{\mathrm{CJ}}$ and $SW_{\mathrm{N}}$ is given as follows:

$$SW_{\mathrm{CJ}} - SW_{\mathrm{N}} = \frac{J(d,\gamma;\beta)A^2}{[\Delta^{\beta=1}]^2\Gamma^2} \gtreqless 0. \tag{12}$$

Appendix B explains details of equation (12). Figure 1 reports a graphical analysis of this comparison. As shown by Poyago-Theotoky (2007), in the region above (below) the curve $\gamma_\varphi$ in Figure 1, $SW_{\mathrm{C}} \geq (<) SW_{\mathrm{N}}$ and $z_{\mathrm{C}} \geq (<) z_{\mathrm{N}}$.[12] In addition, when $\beta = 1$, then $SW_{\mathrm{CJ}} > SW_{\mathrm{NJ}}$.

Let us specifically examine the case of imperfect spillover ($\beta \neq 1$). Then, as new findings, we can observe the following. When $\underline{d} < d \leq 3/2$, then $J(d,\gamma;\beta) \geq 0$; *i.e.*, ERJV cartelization is always socially superior to environmental R&D competition irrespective of the value of $\gamma$. However, if $d > 3/2$, then ERJV cartelization is superior (inferior) to environmental R&D competition for all $\gamma \geq (<) \gamma_{JV}$.[13] In the region above (below) the curve $\gamma_{JV}$ in Figure 1, $SW_{\mathrm{CJ}} \geq (<) SW_{\mathrm{N}}$. These results are summarized as Proposition 2.

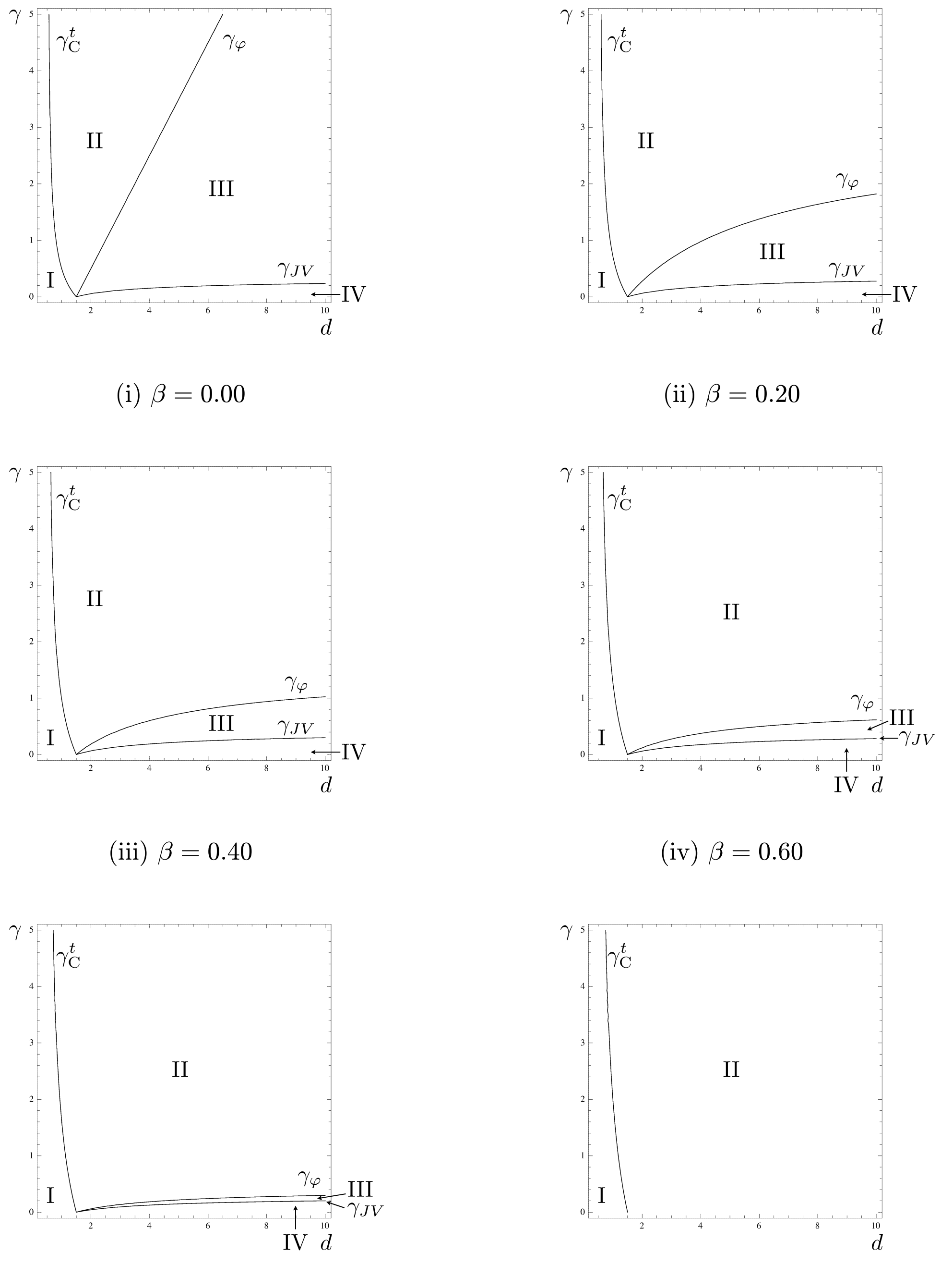
**Proposition 2.** *Presuming that $\beta < 1$, new findings are as described below.*
*(i) If $\underline{d} < d \leq 3/2$, then $SW_{\mathrm{CJ}} \geq SW_{\mathrm{N}}$ for all $\gamma > 0$ and $\beta \in [0, 1)$.*
*(ii) If $d > 3/2$ and $\gamma \geq \gamma_{JV}$, then $SW_{\mathrm{CJ}} \geq SW_{\mathrm{N}}$ for all $\beta \in [0, 1)$.*
*(iii) If $d > 3/2$ and $\gamma < \gamma_{JV}$, then $SW_{\mathrm{CJ}} < SW_{\mathrm{N}}$ for all $\beta \in [0, 1)$.*

Poyago-Theotoky (2010) points out that negative emissions taxes (emissions subsidies) might be socially justified. When $d$ is in the interval $(\underline{d}, 3/2)$, and also $\gamma$ is strictly smaller than $\gamma^t_{\mathrm{C}}$, then the regulator can mitigate the market inefficiency through emissions subsidy and ERJV cartelization irrespective of the value of the spillover parameter.[14] In fact, in Region I below the curve $\gamma^t_{\mathrm{C}}$ in

[12] $\varphi$ is defined in Poyago-Theotoky (2007, p. 69). $\gamma_\varphi \equiv \{\gamma > 0 | \varphi \equiv d(3-2d)(1+\beta)^2(1-\beta) + 2\gamma(2d^2\beta + 2d\beta - \beta + d) = 0, d > 3/2\}$. $\gamma_\varphi$ in Figure 1 is identical to the borderline in Figure 1 of Poyago-Theotoky (2007). $\gamma_\varphi$ has the following property: $\lim_{d \to +\infty} \gamma_\varphi = (1+\beta)^2(1-\beta)/2\beta$. Therefore, when $\beta = 1$, $\gamma_\varphi$ disappears. Her investigation reveals that $\mathrm{sign}\{\varphi\} = \mathrm{sign}\{z_{\mathrm{C}} - z_{\mathrm{N}}\} = \mathrm{sign}\{SW_{\mathrm{C}} - SW_{\mathrm{N}}\}$.

[13] $\gamma_{JV} \equiv \{\gamma(>0) | J(d,\gamma;\beta) = 0, d > 3/2\}$. It is straightforward to verify the existence and uniqueness of $\gamma_{JV}$. However, it is extremely difficult to obtain $\gamma_{JV}$ explicitly by solving the cubic equation $J(d,\gamma;\beta) = 0$.

[14] $\gamma^t_{\mathrm{C}} \equiv d(3-2d)(1+\beta)^2/(2d^2+d-1)$ is derived from $t_{\mathrm{C}} = 0$.




(i) $\beta = 0.00$ (ii) $\beta = 0.20$

(iii) $\beta = 0.40$ (iv) $\beta = 0.60$

(v) $\beta = 0.80$ (vi) $\beta = 1.00$

Figure 1. Environmental R&D competition versus ERJV cartelization.

Figure 1, $t_{\mathrm{C}} < 0$ and $SW_{\mathrm{CJ}} > SW_{\mathrm{C}} > SW_{\mathrm{N}}$. Region I expands monotonously in $\beta \in [0, 1]$.[15] Propositions 1 and 2 show that, even in the case of ERJV cartelization, not only its desirability but also a negative emissions tax (emissions subsidy) might still be socially justified. However, only when $\gamma < \gamma_{\mathrm{N}}^{t} (< \gamma_{\mathrm{C}}^{t})$, then $t_{\mathrm{N}} < 0$.[16] Therefore, in Region IV below the curve $\gamma_{JV}$, $t_{\mathrm{N}}$ is always positive. In Figure 1, Regions II and III denote the region between $\gamma_{\mathrm{C}}^{t}$ and $\gamma_{\varphi}$, and the region between $\gamma_{\varphi}$ and $\gamma_{JV}$, respectively. Whereas Poyago-Theotoky (2007) shows that $\gamma_{\varphi}$ that represents the borderline of sign$\{SW_{\mathrm{C}} - SW_{\mathrm{N}}\}$, this research newly reveals the existence of $\gamma_{JV}$, which plays key roles in Proposition 2. As Figure 1 clarifies, when $\beta = 1$, then Regions III and IV disappear.[17]

| Region | Emission tax | Welfare ranking |
|---|---|---|
| I | $t_{\mathrm{C}} < 0$ | $SW_{\mathrm{CJ}} > SW_{\mathrm{C}} > SW_{\mathrm{N}}$ |
| II | $t_{\mathrm{C}} > 0$ | $SW_{\mathrm{CJ}} > SW_{\mathrm{C}} > SW_{\mathrm{N}}$ |
| III | $t_{\mathrm{C}} > 0$ | $SW_{\mathrm{CJ}} > SW_{\mathrm{N}} > SW_{\mathrm{C}}$ |
| IV | $t_{\mathrm{N}} > 0$ | $SW_{\mathrm{N}} > SW_{\mathrm{CJ}} > SW_{\mathrm{C}}$ |

Table 1. Welfare ranking and the sign of emission tax rate

Table 1 presents the welfare ranking and the sign of an emissions tax rate in each region of Figure 1. Figure 1 and Table 1 show that, in Regions I, II, and III, the implementation of ERJV cartelization yields an improvement in social welfare. However, particularly addressing the existence of Region IV, it seems clear that ERJV cartelization is not necessarily better than any other scenario. Particularly with sufficiently small $\gamma$ and sufficiently large $d$, environmental R&D competition is socially efficient. In other words, Proposition 2(iii) shows that ERJV cartelization is socially harmful in Region IV. Therefore, it is apparent that a social incentive for ERJV cartelization does not always exist. Proposition 2 is partially different from the results of Chiou and Hu (2001) showing that, in an R&D model of cleaner production type, ERJV cartelization maximizes social welfare.[18] Additionally, it is important to compare the cost-reducing R&D literature with our result to enrich the theoretical argument in relation to competition policy. Welfare ranking in Region IV is inconsistent with the findings of Kamien *et al.* (1992), Atallah (2005a) and Lambertini and Rossini (2009) and others, who show the social superiority of RJV cartelization.[19] Moreover,

[15] In fact, $\partial \gamma_{\mathrm{C}}^{t} / \partial \beta > 0$ for all $d \in (\underline{d}, 3/2)$ because the ratchet effect becomes large as the spillover effect becomes large. The ratchet effect is explained in the following paragraph.

[16] $\gamma_{\mathrm{N}}^{t} \equiv d(3 - 2d)(1 + \beta)^2 / 2(2d^2 + d - 1)$ is derived from $t_{\mathrm{N}} = 0$.

[17] See Appendix B and footnote 12 in this paper.

[18] The footnote 2 of Poyago-Theotoky (2007, p. 64) provided the essential explanation about the structure of the Chiou and Hu (2001) model.

[19] Atallah (2005a) examines the case of asymmetric spillover. His analysis includes the

the result of Proposition 2(iii) differs greatly from the typical textbook (Belleflamme and Peitz (2010, pp. 498–499)), demonstrating that RJV cartelization yields a socially superior performance to that obtained through noncooperative R&D.

It is possible to interpret the reason for the existence of Region IV as follows. Greater R&D efforts decrease the emissions tax rate determined during the second stage.[20] In Hepburn (2006) and Puller (2006), this is called a "ratchet effect". If $\gamma$ is sufficiently small, then the joint-profit maximization effect is dominated by the profit-enhancing effect through the ratchet effect. For that reason, $z_{\mathrm{CJ}}(\equiv z_{\mathrm{C}}|_{\beta=1}) < z_{\mathrm{N}}$.[21] Greater environmental R&D efforts increase production levels and consumer surplus. When the damage is severe and when R&D costs are sufficiently small, greater R&D efforts generated through R&D competition results in a large increasing effect on consumer surplus and a large mitigating effect on environmental damage. These effects dominate the effect of increasing R&D costs. Therefore, the equilibrium social welfare under R&D competition is greater than in the case of ERJV cartelization. However, when the damage coefficient is sufficiently small, the equilibrium social welfare under R&D competition is dominated by that under ERJV cartelization because of the small mitigating effect of environmental damage.

## 3.3 Firm profitability

ERJV cartelization is, in fact, not implemented without firm profitability. This subsection actually examines whether ERJV cartelization yields firm profitability. With regard to private incentive of R&D cooperation, Poyago-Theotoky (2007) shows that $\pi_{\mathrm{C}} > \pi_{\mathrm{N}}$.[22] Comparing the equilibrium profit under ERJV cartelization, $\pi_{\mathrm{CJ}}(\equiv \pi_{\mathrm{C}}|_{\beta=1})$, with that under environmental R&D cartelization, $\pi_{\mathrm{C}}$, engenders the following proposition.

**Proposition 3.** $\pi_{\mathrm{CJ}} \geq \pi_{\mathrm{C}} > \pi_{\mathrm{N}}$ *for all* $d > \underline{d}$, $\gamma > 0$ *and* $\beta \in [0, 1]$.

**Proof**: See Appendix C. □

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results of the case of symmetric perfect spillover. Therefore, it is easy to ascertain the social superiority of RJV cartelization under symmetric perfect spillover. For details, see Figure 7 of Atallah (2005a, p. 933). Furthermore, in the literature related to cost-reducing innovation, some works reveal that industry-wide RJV cartelization is not necessarily socially efficient. As examples, see Yin (1999), Amir (2000) and Yun *et al.* (2000). The models constructed in those studies differ from the model presented here.

[20]See, Equation (1). In fact, $\partial t(z_i, z_j)/\partial z_i < 0$.

[21]$z_{\mathrm{CJ}} \geq (<) z_{\mathrm{N}}$ for all $\gamma \geq (<) \hat{\gamma}_{\mathrm{N}} \equiv d(1-\beta)\delta/\mu$, where $\mu \equiv (1+d)^2[2d^2 + (4-\beta)d - 1] (> 0)$ and $\delta \equiv 18d^3 + 41d^2 + 12d - 15 + \beta(d+3)(d^2 + 3d - 1) (> 0)$. Therefore, if $\gamma$ is sufficiently small, then $z_{\mathrm{CJ}} < z_{\mathrm{N}}$. This result differs from that reported by d'Aspremont and Jacquemin (1988, 1990) that cost-reducing R&D efforts under RJV cartelization are invariably larger than under any other scenario.

[22]See Equation (16) in Poyago-Theotoky (2007).

This proposition states that ERJV cartelization between symmetric Cournot duopolists always yields firm profitability. Consequently, in Regions I, II, and III in Figure 1, ERJV cartelization is socially beneficial and feasible. The intuitive explanation here is that, under ERJV cartelization, each firm is able to avoid R&D competition and to enjoy the highest free-rider effect and joint-profit maximization effect. However, in Region IV, firms cannot enjoy the higher profits because the welfare-maximizing regulator allows neither R&D coordination nor information sharing.

In the literature related to cost-reducing R&D, Atallah (2005a, 2005b), Lambertini and Rossini (2009) and other papers reveal that RJV cartelization is privately beneficial for each firm. Proposition 3 signifies that, irrespective of the difference of the theoretical framework between the emission-reducing R&D model and the cost-reducing R&D model, there exists a private incentive of RJV cartelization.[23]

### 3.4 Policy implication

The category of pollution abatement technology in this model is called "end-of-pipe". Measures of this category achieve reduction of the amount of emissions by absorption at the end of production processes. Flue gas desulfurization equipment and activated carbon adsorption equipment are examples of this type. As an example of the oligopolistic market corresponding to this model, we can mention oil refinery firms and firms with huge chemical plants. In fact, such oligopolistic firms use end-of-pipe technology and also invest in R&D for quality improvement of catalysts. The results presented in this paper provide an important policy implication related to whether ERJV cartelization in horizontal relation is allowed socially. Our investigation reveals the possibility of the superiority of ERJV cartelization. In Regions I, II, and III shown in Figure 1, no intervention for ERJV cartelization is necessary. However, in contrast to the well-known result of cost-reducing R&D, we obtain that environmental R&D competition is socially efficient (*i.e.,* socially desirable) when the efficiency of pollution abatement costs is sufficiently high, and also when the environmental damage coefficient is sufficiently high.

In the last two decades, although the importance of environmental R&D has been increasingly socially recognized, there have been only a few studies of the welfare performance of ERJV.[24] Competition policies of many countries are designed to elicit detailed and practical policy suggestions on ERJV.[25] As an ex-

[23] Yakita and Yamauchi (2011) examined the Cournot duopolists' environmental R&D to improve the environmental quality of products. In their model, it is straightforward to show that both firms invariably have some private incentive for RJV cartelization.

[24] For example, see Chiou and Hu (2001) and Katsoulacos *et al.* (2001).

[25] The EU's antitrust guidelines for the horizontal cooperation agreements are "Guidelines

ample, the Japanese guidelines for RJV (Japan Fair Trade Commission [JFTC] (1993) and its amended versions) are ambiguous and frail.[26] Unfortunately, the Japanese antitrust authorities (JFTC) have formed detailed policy guidelines for ERJV to only a slight degree.[27] This fact signifies that the Japanese antitrust authorities' discretionary power on ERJV is too strong. Under such regulatory circumstances, the ERJV participants might be faced with the risk of becoming a noncompliant (or administratively sanctioned) firm involuntarily because the rules are not enacted definitely. The lack of detailed rules might generate the disincentive to forming an ERJV. This paper provides the theoretical findings to improve such weak points.

In Japan, 20 major firms involved in petroleum and chemical industries established "the Research Association of Refinery Integration for Group-Operation (RING)" in May 2000.[28] The main purpose of RING is to encourage RJV projects for cost-effective plant operation and emissions reduction among participants to enhance a competitive advantage and to survive in the international market. In particular, with respect to RING's ERJV projects, the striking character is that the research consortia consist of firms belonging to different industries. Apparently, the participating firms have intentionally avoided a horizontal ERJV in order not to be exposed to a violation of antitrust laws. Is a horizontal ERJV socially harmful, or beneficial? At least the Japanese antitrust authorities have not earnestly considered the question. Other such countries might exist. The results presented in this paper are important for the design of a practical competition policy for ERJV.[29]

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on the applicability of Article 101 of the Treaty on the Functioning of the European Union to horizontal co-operation agreements". These appear on the European Commission's website (URL: http://ec.europa.eu/competition/antitrust/legislation/horizontal.html). However, with regard to the US guidelines for JV, the Federal Trade Commission (FTC) and the U.S. Department of Justice (DOJ) issued "Antitrust Guidelines for Collaborations Among Competitors" on the FTC's website (URL: http://www.ftc.gov/os/2000/04/ftcdojguidelines.pdf). Caloghirou *et al.* (2003), Caloghirou *et al.* (2004) and Motta (2004, Chapters 1 and 4) reported historical, legal, and economic explanations for RJV. Grossman and Shapiro (1986) provided important arguments related to RJV and antitrust guidelines. These studies are useful for understanding the antitrust policies of influential countries and regions.

[26] For details, see the website of JFTC (URL: http://www.jftc.go.jp/en/).

[27] In Japan, the guidelines for RJV for recycling and consumer safety are ambiguous as well as those for ERJV.

[28] For details, see RING's website (URL: http://www.ring.or.jp/).

[29] As described in this paper, $d$ is assumed as an exogenous damage parameter. Strictly speaking, however, the value of $d$ should be derived from the scientific findings of environmental epidemiology and public health. Therefore, more interdisciplinary studies are necessary to produce effective ERJV guidelines.

# 4 Concluding remarks

We investigated the socially desirable formation of symmetric Cournot duopolists' environmental R&D activity. This paper provides the following facts and policy implications. If the damage parameter is sufficiently large, and if environmental R&D costs are sufficiently small, then environmental R&D competition is socially desirable. Surprisingly, our analysis reveals the social superiority of environmental R&D competition, although that scenario is the case of "NO information sharing" and "NO R&D coordination". In such circumstances, the antitrust authorities should disallow not only ERJV cartelization but also environmental R&D cartelization. This result is fairly counterintuitive and differs from the well-known conclusions of the existing literature. However, if environmental damage is sufficiently small, or alternatively if there is severe environmental damage and high inefficiency of environmental R&D costs, then ERJV cartelization is socially desirable. Under those circumstances, firms should be allowed to form an ERJV cartelization. Such cooperative behavior yields improved social welfare. Furthermore, each firm has an incentive for ERJV cartelization.

Some directions for future research are described below. First, the case of an asymmetric spillover parameter must be analyzed in line with Atallah's (2005a, 2005b, 2007) examinations. Second, we should explore the case of price competition in a differentiated duopoly. Third, it is important to examine environmental R&D cooperation in a vertical relation.


# Acknowledgements

The authors are grateful to Takao Ohkawa, Makoto Okamura, Akira Yakita, Akihiko Yanase, Masatomo Itakura, and Hirofumi Fukuyama for their constructive comments. Any remaining errors are the sole responsibility of the authors. The authors are also grateful for a Research Grant for Environmental Policy Studies of the Ministry of the Environment of Japan, No. 6, 2009–2011. In addition, this research is partially supported by a Grant-in-Aid for Young Scientists (b), No. 22730200, from the Ministry of the Education, Culture, Sports, Science and Technology of Japan.


# Appendix A

**Proof of Proposition 1**: After some manipulation, the difference between $SW_{\mathrm{CJ}}$ and $SW_{\mathrm{C}}$ is derived as shown below.

$$SW_{\mathrm{CJ}} - SW_{\mathrm{C}} = \frac{4(1-\beta)(3+\beta)LA^2}{[\Delta^{\beta=1}]^2\Delta^2} \geq 0,$$

where

$$
\begin{aligned}
L &\equiv 32d^3(3+2d)^2(5+2d)(1+\beta)^2 + 8d^2(3+2d)[4(1+d)(3+2d) \\
&\quad +(1+\beta)^2(48d^5+216d^4+292d^3+76d^2-51d+5)]\gamma \\
&\quad +2d(1+d)^2[64d^5+446d^3+155d^2-64d+3 \\
&\quad +(1+\beta)^2(2d^2+3d-1)(8d^3+26d^2+21d+1)]\gamma^2 \\
&\quad +(1+d)^4(2d^2+3d-1)(2d^2+5d+1)\gamma^3 > 0, \\
\Delta &\equiv 2\gamma(1+d)^2 + 4d(3+2d)(1+\beta)^2 > 0, \\
\Delta^{\beta=1} &\equiv 2\gamma(1+d)^2 + 16d(3+2d) > 0.
\end{aligned}
$$

Therefore, $SW_{\mathrm{CJ}} \geq SW_{\mathrm{C}}$ for all $d > \underline{d}$, $\gamma > 0$ and $\beta \in [0,1]$. $\square$

# Appendix B

**Welfare comparison**: We obtain the following result.

$$
SW_{\mathrm{CJ}} - SW_{\mathrm{N}} = \frac{J(d,\gamma;\beta)A^2}{[\Delta^{\beta=1}]^2\Gamma^2} \gtreqless 0,
$$

where

$$
\begin{aligned}
J(d,\gamma;\beta) &\equiv y + 8\gamma[k_0 + k_1\gamma + k_2\gamma^2], \\
y &\equiv -64d^3(1-\beta)(1+\beta)^2(1+d)^2(2d-3)[21+51d+26d^2 \\
&\quad +\beta(3+13d+6d^2)] \gtreqless 0, \\
\lambda_3 &\equiv 32d^5+201d^4+324d^3+154d^2-12d+9 > 0, \\
\lambda_2 &\equiv 768d^5+2457d^4+2924d^3+994d^2-180d+81 > 0, \\
\lambda_1 &\equiv 2720d^5+7735d^4+8172d^3+2278d^2-452d+279 > 0, \\
\lambda_0 &\equiv 1216d^5+2023d^4+132d^3-1666d^2-156d+687 > 0, \\
k_0 &\equiv d^2\{(1-\beta)[4(1+\beta)[16(3+\beta)+(1+\beta)(1-\beta)]d^6+\lambda_3\beta^3+\lambda_2\beta^2 \\
&\quad +\lambda_1\beta+\lambda_0] + 128(1+d)^2(2d+1)(2d+3)(2d^2+3d-1)\} > 0, \\
k_1 &\equiv 2d(1+d)^2\{(1-\beta)[d^2(d+1)(d+2)\beta^3 + d(1+d)(2d^3+14d^2 \\
&\quad +16d-1)\beta^2 + d(8d^4+101d^3+200d^2+91d-19)\beta + 94d^5 \\
&\quad +406d^4+499d^3+72d^2-112d+5\beta+27] \\
&\quad +4[20d^5+144d^4+170d^3+50d^2-2d-9]\} > 0, \\
k_2 &\equiv (1+d)^4\{(1-\beta)[8d^2+4(5+\beta)d+7+3\beta]d^2 \\
&\quad +4d^4+4d^3+d^2+2(4+\beta)d-3\} > 0, \\
\Gamma &\equiv 2\gamma(1+d)^2 + d(1+\beta)[3(3+\beta)+d(7+\beta)] > 0.
\end{aligned}
$$

In addition, $\Delta^{\beta=1}(>0)$ is defined in Appendix A. It is straightforward to verify the sign of each of the definitions presented above.

If $\underline{d} < d \leq 3/2$, then $y \geq 0$ for all $\beta \in [0,1)$. Therefore, when $\underline{d} < d \leq 3/2$, then $J(d,\gamma;\beta) \geq 0$; *i.e.*, $SW_{\text{CJ}} \geq SW_{\text{N}}$ irrespective of the value of $\gamma$. However, when $d > 3/2$, then $y < 0$ for all $\beta \in [0,1)$. Therefore, when $d > 3/2$, then $J(d,\gamma;\beta) \gtreqless 0$. As portrayed in Figure 1, $SW_{\text{CJ}} \geq (<) SW_{\text{N}}$ for all $\gamma \geq (<) \gamma_{JV} \equiv \{\gamma(>0) | J(d,\gamma;\beta) = 0, d > 3/2\}$. From the definition of $J(d,\gamma;\beta)$, verifying the existence and uniqueness of $\gamma_{JV}$ is straightforward.

Furthermore, assuming that $d > 3/2$, only when $\beta = 1$, $y = 0$; *i.e.* $SW_{\text{CJ}} > SW_{\text{NJ}}$. This observation readily implies that there invariably exists some Region IV unless $\beta = 1$.

# Appendix C

**Proof of Proposition 3**: Differentiation between $\pi_{\text{CJ}}$ and $\pi_{\text{C}}$ is given as:

$$\pi_{\text{CJ}} - \pi_{\text{C}} = \frac{2\gamma(1-\beta)BA^2}{\Delta^2[\Delta^{\beta=1}]^2} \geq 0, \tag{13}$$

where $B \equiv [2d^2+3d-1]^2[8d(3+2d)+\gamma(1+d)^2][2d(2d+3)(1+\beta)^2+\gamma(1+d)^2] > 0$. $\Delta(>0)$ and $\Delta^{\beta=1}(>0)$ are both defined in Appendix A. Only when $\beta = 1$, then $\pi_{\text{CJ}} = \pi_{\text{C}}$. Equation (13) shows that each firm invariably has an incentive for ERJV cartelization. Poyago-Theotoky (2007) describes that $\pi_{\text{C}} > \pi_{\text{N}}$.[30] Therefore, $\pi_{\text{CJ}} \geq \pi_{\text{C}} > \pi_{\text{N}}$ for all $d > \underline{d}$, $\gamma > 0$ and $\beta \in [0,1]$. □

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