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Eco-Firms and Sequential Adoption of Environmental Corporate Social Responsibility in the Managerial Delegation

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This article investigates the strategic environmental corporate social responsibility (ECSR) of polluting firms in the presence of eco-firms. When the firms decide ECSR sequentially within the framework of the managerial incentive design and then face simultaneous price competition, we show that firms will adopt ECSR and purchase abatement goods to mitigate competition if the products are more substitutable, but the late adopter chooses lower ECSR and thus earns higher profit. It can partially explain the current expansive adoption of ECSR as an industry-wide wave.

JEL classification code : L1, L2, M2
Keywords: environmental corporate social responsibility; eco-firms; abatement goods; late adopter advantage

1. Introduction

Nowadays increasing attention has been paid to environmental corporate social responsibility (ECSR) in both practice and academia. A large number of polluting companies recently participate in greenhouse gas reduction programs and issue various ECSR statements and activities in their annual reports.[1] The ECSR wave, the trend of sequential expansion of ECSR, is now more popular and getting expanding.[2] Then, why do firms actively and sequentially adopt ECSR even though the adoption of ECSR increases the company's own cost and thus causes a cost disadvantage?

Since Porter and van der Linde (1995) ignited the environment-competitiveness relationship to introduce the concept of creating shared value of ECSR, a growing interest in strategic

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[1] Lyon and Maxwell (2004) and Kitzmueller and Shimshack (2012) provided fruitful discussions on the practical and academic issues on ECSR.

[2] CSR trend report by PriceWaterhouseCoopers (2010/2011) suggested that the number of companies with CSR statements on their websites increased to 81% at the end of July 2010 from 75% at the end of July 2009. KPMG (2008/2013), nearly 80% of the 250 largest companies worldwide issued CSR reports in 2008 and more than 30% (71%, 90%) companies of US (UK, Japan, respectively) adopted CSR in 2013. For more descriptions, see Bian, et al. (2016) and Hirose, et al. (2017).

ECSR has been characterizing the recent business and economics literature. Recently, from the viewpoint of instrumental ECSR, Lambertini and Tampieri (2015), Liu *et al*. (2015), and Hirose *et al*. (2016, 2017) explained how ECSR is desirable for both polluting firms and the society when firms adopt ECSR strategically. In particular, Hirose *et al*. (2017) employed the strategic managerial incentive design, in which the separation of ownership and management exists and shareholders can induce managers to operate their firm based on certain managerial incentives, and showed that the ECSR can enhance the profitability of polluting firms.[3] However, they examined a simultaneous choice on ECSR and thus provided limited explanations about the recent ECSR wave.

On the other hand, the current global concerns on climate change and the subsequent tighter environmental policies have induced the emergence of eco-firms, which produce pollution abatement goods in the eco-industry.[4] Previous literature on the eco-industry is focused on the relationship with mandatory policy instruments such as emission taxes and abatement subsidies rather than voluntary participation by the firms.[5] Therefore, this compliance approach is not much useful to explain how the eco-firms contribute to the recent voluntary adoption of ECSR.

In this article, we incorporate eco-firms and polluting firms in order to formulate the model of managerial incentive design in a duopolistic market and investigate the strategic interaction in the sequential adoption of ECSR. We show that both firms will adopt ECSR sequentially and purchase abatement goods from the eco-firms to increase their profits if the two products are more substitutable under price competition. This is because the choices of profitable ECSR are strategic complements, which induce to mitigate price competition and thus increase the equilibrium prices, which can serve to earn more profits. We also show that the late adopter sets lower ECSR than that of the early adopter and thus, earns a higher profit, i.e., late adopter advantage exists. It can partially explain the current expansive adoption of ECSR as an industry-wide wave.

The organization of this paper is as follows: We construct a basic model in section 2 and provide an analysis in section 3. We conclude in the final section.

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[3] Concerning CSR-related incentives, Kopel and Brand (2012), Brand and Grothe (2015) and Bian, et al. (2016) also considered the managerial incentive design and showed that the emergence of a CSR firm can enhance its profitability, compared to pure profit-seeking firms.

[4] The importance of the eco-industry has been recognized by policy reports in international institutions. According to Environmental Business International (2012), the global market size of the eco-industry was approximately US$838 billion in 2010 and is expected to reach US$992 billion by 2017.

[5] See, for example, David and Sinclair-Desgagne (2005), Canton, et al. (2008) and Lee and Park (2011) in the literature of eco-industry.

2. The Model

Consider a vertically related market where polluting duopoly firms sell consumption goods to consumers and an eco-firm sells abatement goods to polluting firms. Following Singh and Vives (1984), we assume the quasi-linear utility function of the representative consumer given by

$$U(q_1, q_2) = A(q_1 + q_2) - \frac{1}{2}(q_1{}^2 + 2\beta q_1 q_2 + q_2{}^2) \tag{1}$$

where $\beta \in (0,1)$ represents the degree of product differentiation: a small number indicates a larger degree of product differentiation. Then, the inverse demand function is linear given by

$$P_i = A - q_i - \beta q_j,\ i = 1,2\ \ (i \neq j) \tag{2}$$

where P_i and q_i are firm i's price and quantity, respectively.

Both firms produce differentiated products but emit the same pollutants. They can also reduce the emission level by purchasing abatement goods, a_i, produced by the eco-firm. We assume an end-of-pipe technology in which an emission function is linear,

$$e_i(q_i, a_i) = q_i - a_i \tag{3}$$

We also assume that damage function is quadratic:

$$D = d\left(\sum_{i=1}^{2} e_i(q_i, a_i)\right)^2 \tag{4}$$

where d (> 0) is the coefficient of environmental damage function.

We assume that two polluting firms are characterized by separate ownership and management. In a managerial delegation model,[6] each firm consists of an owner who owns the firm and manager who makes decisions based on the incentive contract designed by the corresponding firm owner. In particular, each manager's compensation structure is proportional to a linear combination of profit and the ECSR incentive. In particular, the pay-off function of the manager of the polluting firm is given by:

$$T_i = \pi_i - \theta_i d(q_i - a_i)^2 \tag{5}$$

[6] See, for example, Fershtman (1985) and Sklivas (1987) in the literature of managerial delegation game.

where π_i is firm i's profit and θ_i (≥ 0) is the internal emission price on the damage it produced, which represents the degree of ECSR, determined by the owner of firm i. Without loss of generality, we assume that marginal production cost is zero. Then, the owner of firm i maximizes its profit, which is given by

$$\pi_i = P_i q_i - r a_i \tag{6}$$

where r is the unit price of abatement goods, determined by the eco-firm.
Then, the eco-firm maximizes the following profit function:

$$\pi_U = r a_U \tag{7}$$

where $a_U = \sum_{i=1}^{2} a_i$. The production cost of abatement goods is also assumed at zero.
The timing of the game is as follows: In the first and second stages, respectively, the owner of each polluting firm decides the degree of ECSR to maximize its own profit in (6) sequentially. The owner of firm 1 chooses its ECSR in the first stage and the owner of firm 2 follows in the second stage, without loss of generality. In the third stage, the eco-firm sets the price of abatement goods to maximize its own profit in (7). Finally, each polluting firm faces price competition and the manager of each firm decides the price of consumption goods and the amount of abatement goods to maximize its own objective function in (5). All games are solved by backward induction.

3. The Analysis

In the fourth stage, assuming interior solutions on prices, the first-order Kuhn-Tucker conditions of each polluting firm with respect to P_i and a_i are as follows:

$$\frac{\partial T_i}{\partial P_i} = q_i + P_i \frac{\partial q_i}{\partial P_i} - 2d\theta_i (q_i - a_i) \frac{\partial q_i}{\partial P_i} = 0, \tag{8}$$

$$\frac{\partial T_i}{\partial a_i} = -\mathrm{r} + 2d\theta_i (q_i - a_i) \leq 0, \;\; a_i \geq 0 \;\; \text{and} \;\; a_i \frac{\partial T_i}{\partial a_i} = 0 \tag{9}$$

There are four possible cases, depending on the choices of the two firms on the purchase of abatement goods. In particular, imposing interior solutions, i.e., $a_i = q_i - \frac{r}{2d\theta_i} > 0$ from (9), yields the following equilibrium outcomes of fourth stage:[7]

$$P_i = \frac{A(1-\beta)+r}{2-\beta} \tag{10}$$

$$a_i = \frac{2d\theta_i(A-r)-r(2-\beta)(1+\beta)}{2d(2-\beta)(1+\beta)\theta_i} \tag{11}$$

$$q_i = \frac{A-r}{2+\beta-\beta^2} \tag{12}$$

$$Q = \frac{2(A-r)}{2+\beta-\beta^2} \tag{13}$$

Note that we have $a_i > 0$ and $q_i > \frac{r}{2d\theta_i}$ if $\theta_i > \frac{r(2-\beta)(1+\beta)}{2d(A-r)} \equiv \widehat{\theta_i}$.

Using $a_U = \sum_{i=1}^{2} a_i$, the profit of firm i in (6) and that of the eco-firm in (7) is as follows, respectively:

$$\pi_i = \frac{r^2(2-\beta)^2(1+\beta)+2d(A-r)^2(1-\beta)\theta_i}{2d(2-\beta)^2(1+\beta)\theta_i} \tag{14}$$

$$\pi_U = ra_U = \frac{r(4d(A-r)\theta_1\theta_2-r(2-\beta)(1+\beta)(\theta_1+\theta_2))}{2d(2-\beta)(1+\beta)\theta_1\theta_2}. \tag{15}$$

In the third stage, the eco-firm decides the following optimal price of abatement goods, which maximizes its profit in (15):

$$r = \frac{2Ad\theta_1\theta_2}{(2-\beta)(1+\beta)(\theta_1+\theta_2)+4d\theta_1\theta_2}. \tag{16}$$

Note that r is always positive as long as θ_i is positive. Note also that both polluting firms' ECSR levels positively affect the price of abatement goods, $\frac{\partial r}{\partial \theta_i} > 0$, which increases the equilibrium price of consumption goods in (10).

The equilibrium price as follows:

$$P_i = \frac{A((2-\beta)(1-\beta)(1+\beta)(\theta_i+\theta_j)+2d(3-2\beta)\theta_i\theta_j)}{(2-\beta)((2-\beta)(1+\beta)(\theta_i+\theta_j)+4d\theta_i\theta_j)} \tag{17}$$

where $\frac{\partial P_i}{\partial \theta_i} > 0$. That is, the adoption of ECSR increases the equilibrium price of consumption goods. From (11), we also have:

[7] We can show that the analysis with interior solutions provides a subgame perfect Nash equilibrium when $\beta \in (0.8,1)$. See Proposition 1 and the proof in Appendix I.

$$a_i = \frac{A\theta_i((2-\beta)(1+\beta)+2d\theta_j)}{(2-\beta)(1+\beta)((2-\beta)(1+\beta)(\theta_i+\theta_j)+4d\theta_i\theta_j)} \tag{18}$$

Thus, $a_i > 0$ as far as $\theta_i > 0$.[8]

The profit of polluting firm *i* in (14) can be rewritten as follows:

$$\pi_i = \frac{A^2\Big((1-\beta)(2-\beta)^2(1+\beta)^2\theta_j^2+(1-\beta)\theta_i^2\big((2-\beta)(1+\beta)+2d\theta_j\big)^2+2(2-\beta)(1+\beta)\theta_i\theta_j\big((1-\beta)(2-\beta)(1+\beta)+d(4-3\beta)\theta_j\big)\Big)}{(2-\beta)^2(1+\beta)\big((2-\beta)(1+\beta)(\theta_i+\theta_j)+4d\theta_i\theta_j\big)^2} \tag{19}$$

In the second stage, the owner of firm 2, late adopter, decides the degree of ECSR that will maximize its profit by observing firm 1's ECSR. The reaction function of firm 2 is as follows:

$$\theta_2 = \frac{\beta(1+\beta)(2-\beta)\theta_1}{(2-\beta)(1+\beta)(4-3\beta)+4d(3-2\beta)\theta_1} \tag{20}$$

Note that θ_2 is positive as far as θ_1 is positive. Thus, firm 2 is not willing to participate in ECSR as far as firm 1 does not adopt ECSR. Note also that the slope of the reaction function of firm 2 is positive but smaller than one, i.e., $0 < \frac{\partial\theta_j(\theta_i)}{\partial\theta_i} < 1$. It implies that the choices regarding ECSR are strategic complements. Thus, when firm 1 increases its ECSR, firm 2 is also willing to increase its ECSR, which will increase the equilibrium prices. But, firm 2's ECSR is lower than that of firm 1.

In the first stage, the owner of firm 1, early adopter, considers the reaction function of firm 2 in (19) in its profit function and decides its optimal degree of ECSR as follows:

$$\theta_1^* = \frac{(2-\beta)^2(1+\beta)(5\beta-4)}{2d(12-5(3-\beta)\beta)} \tag{21}$$

Note that θ_1^* is positive only if $\beta \in (0.8,1)$. It implies that if the two products are not much differentiated, firm 1 will engage in ECSR and choose $a_i > 0$. Subsequently, we also have a positive ECSR of late adopter, i.e., firm 2.

$$\theta_2^* = \frac{(2-\beta)^2(1+\beta)(5\beta-4)}{2d(20-(21-5\beta)\beta)} \tag{22}$$

Thus, we have $\theta_1^* > \theta_2^* > 0$ if $\beta \in (0.8,1)$. Then, the equilibrium outcomes are:

$$q_1^* = q_2^* = \frac{A(12-5\beta)}{8(2-\beta)(1+\beta)}, \quad P_1^* = P_2^* = \frac{A(4-3\beta)}{8(2-\beta)}, \quad a_1^* = \frac{A(12-7\beta)}{8(2-\beta)^2(1+\beta)} > a_2^* = \frac{A(4-\beta)}{8(2-\beta)^2(1+\beta)},$$

[8] It implies that $\widehat{\theta}_i = 0$ at the equilibrium price of abatement goods.

$r^* = \frac{A(5\beta-4)}{8}$ and $\pi_2{}^* - \pi_1{}^* = \frac{A^2(4-3\beta)(5\beta-4)}{32(2-\beta)^2(1+\beta)} > 0$.

Then, we have the following proposition.[9]

Proposition 1. *Both firms adopt ECSR sequentially and purchase abatement goods when* $\beta \in (0.8,1)$. *But, late adopter chooses a lower degree of ECSR and earns a higher profit than early adopter (i.e., late adopter advantage exists).*

We can provide an economic explanation: Due to the fact that price competition leads to intense competition, both owners have incentives to lower the degree of competition. Thus, the firm *i* adopts ECSR to penalize its manager with the purpose of inducing higher prices to mitigate competition. The increase in a firm *i*'s ECSR will increase firm *j*'s ECSR because the choices of ECSRs are strategic complements. Then, the increase in firm *i*'s price will increase firm *j*'s price as well because the choices of prices are also strategic complements. Therefore, when the two products are more substitutable, the sequential adoption of ECSR is profitable and thus ensures higher profit rather than that without ECSR. Further, early adopter induces late adopter to participate in ECSR wave by choosing a higher degree of ECSR. Thus, late adopter chooses a lower degree of ECSR, which yields a higher profit than early adopter. It indicates that late adopter advantage exists in a sequential adoption of ECSR.[10]

Remark 1: We can consider the case where the eco-firm does not exist or/and both polluting firms do not purchase abatement goods.[11] We then show that both firms adopt ECSR sequentially and late adopter advantage still exists. (See Appendix II)

Remark 2: We can endogenize the timing of choosing the sequence of ECSR, suggested by Hamilton and Slutsky (1990), in which the owner of each firm faces the observable delay game. We then show that sequential equilibrium emerges in this game; one firm decides early adaptation and the other firm decides late adaptation, in which the former chooses a higher degree of ECSR and the latter chooses a lower degree of ECSR. (See Appendix III)

Remark 3: We can consider the market structure of eco-industry where multiple eco-firms

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[9] Appendix I provides a proof of Proposition 1.

[10] Gal-Or (1985) considers a differentiated Bertrand duopoly with cost symmetry and shows that a second-mover advantage prevails under general conditions while Amir and Stepanova (2006) show that this holds true with asymmetric cost.

[11] From the proof of Proposition 1, it also happens when $\beta \in (0,0.8)$.

compete in producing abatement goods. We then show that both firms will adopt ECSR sequentially and purchase abatement goods from the eco-firms to mitigate competition if the two products are very much substitutable. We also show that as the number of eco-firms increases, total purchases of the abatement goods decrease. (See Appendix IV)

4. Conclusion

The adoption of ECSR can be generally thought of strategic substitutes because it increases the company's own cost while its rivals who do not adopt ECSR have a competitive advantage. We showed that this trade-off may not be true because the choices of ECSR are strategic complements in the strategic managerial incentive design. We showed that the sequential adoption of ECSR mitigates price competition and thus, increases their profits if the two products are more substitutable. It explains why profit-maximizing firms adopt ECSR and may explain why the degree of ECSR is different among firms.

As a future research, we can consider environmental policies such as subsidies on abatement facilities, emission taxes and tradable permits, and investigate the strategic interactions between the profitable ECSR and environmental regulations. Further, we can consider a form of two-part tariffs with subsidy and unit price on abatement goods. Then, the eco-firm can construct optimal two-part tariff scheme to maximize its profits with/without government subsidy on abatement goods.[12] These challenging issues are left to future research.

Appendix I: The proof of Proposition 1

It is sufficient to show that no firm will deviate from the equilibrium outcome with interior solutions in choosing the prices and abatement goods at the fourth stage. In particular, we will compare T_i in the corner solutions with zero abatement goods ($a_i = 0$). Let the equilibrium outcomes with interior solutions be $T_i^* = T_i(a_i^*, a_j^*, P_i^*, P_j^*)$ and the deviation outcomes with corner solutions with zero abatement goods be $T_i^d = T_i(0, a_j^*, P_i^d, P_j^*)$. Then, we can show that $T_i^* > T_i^d$ for $\beta \in (0.8,1)$ and $i = 1,2$. That is, each manager can get higher payoffs under the interior solutions with positive abatement ($a_i > 0$) than deviation to zero abatement ($a_i = 0$) at the fourth stage. Therefore, when $\beta \in (0.8,1)$, the outcomes of interior solutions are on the equilibrium path as a subgame perfect equilibrium.

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[12] For example, see David and Sinclair-Desgagne (2005) and Lee and Park (2011) in the literature of eco-industry.

Appendix II: The equilibrium without abatement goods

We will consider the outcomes of corner solutions, $a_i = 0$ in (9), when $\beta \in (0,0.8)$. Then, in the third stage, the equilibrium price, which maximizes the objective function of each manager in (5) is:

$$P_i = \frac{A(1-\beta^2+2d\theta_i)((1-\beta)(2+\beta)+2d\theta_j)}{(4-\beta^2)(1-\beta^2)+2d(2-\beta^2)(\theta_i+\theta_j)+4d^2\theta_i\theta_j}$$

In the first stage, the profit of firm 2 is:

$$\pi_2 = P_2 q_2 = \frac{A^2(1-\beta^2+2d\theta_2)((1-\beta)(2+\beta)+2d\theta_1)^2}{((4-\beta^2)(1-\beta^2)+2d(2-\beta^2)(\theta_1+\theta_2)+4d^2\theta_1\theta_2)^2}$$

The first-order condition with respect to the degree of ECSR yields:

$$\theta_2(\theta_1) = \frac{\beta^2(1-\beta^2)+2d\beta^2\theta_1}{2d(2-\beta^2+2d\theta_1)}$$

Then, we have $\theta_2(0) > 0$ and $\frac{\partial\theta_2(\theta_1)}{\partial\theta_1} > 0$. This shows that θ_2 is positive as far as θ_1 is positive, i.e., $\theta_2 > 0$ when $\theta_1 > 0$. We also have $\frac{\partial^2\theta_2(\theta_1)}{\partial\theta_1^2} < 0$. This implies that $\theta_1 = \theta_2 = \bar{\theta} = \frac{\sqrt{(1-\beta^2)}-(1-\beta^2)}{2d} > 0$. Thus, we have the following relations: $\theta_1 \lesseqgtr \theta_2$ when $\theta_1 \lesseqgtr \bar{\theta}$.

In the first stage, the profit of firm 1 is:

$$\pi_1 = \frac{A^2(1-\beta^2+2d\theta_1)(4-2\beta-3\beta^2+\beta^3+2d(2-\beta)\theta_1)^2}{16(2-\beta^2+2d\theta_1)^2(1-\beta^2+d\theta_1)^2}$$

Differentiating this profit function with respect to the degree of ECSR yields:

$$\left.\frac{\partial\pi_1}{\partial\theta_1}\right|_{\theta_1=0} = \frac{A^2 d\beta^2(4+2\beta-\beta^2)}{4(1+\beta)(2-\beta^2)^3} > 0 \text{ and } \left.\frac{\partial\pi_1}{\partial\theta_1}\right|_{\theta_1=\theta_2=\bar{\theta}} > 0.$$

Then, we have ${\theta_1}^{**} > {\theta_2}^{**} > 0$. Therefore, both firms adopt ECSR sequentially, but late adopter advantage exists.

Appendix III: The endogenous timing game

We endogenize the timing of the game by adopting the observable delay game, a variant of Hamilton and Slutsky (1990). In this game, firm i $(i = 1,2)$ simultaneously chooses whether to move early (t_i = 1) or late (t_i = 2). The ECSR decision stage is played simultaneously if both firms decide the same time, sequentially or otherwise.

First, suppose that $\theta_i > 0$ at the equilibrium in simultaneous choice game. Then, from the profit function of firm i in (6), both firms have the symmetric reaction functions in (19), which yields the following results of ECSR:

$$\theta_i{}^S = -\frac{(2-\beta)(1-\beta)(1+\beta)}{d(3-2\beta)} < 0 \text{ for } \beta \in (0,1).$$

This is a contradiction. It implies that no firm engages in ECSR activities in a simultaneous choice game. That is, $\theta_i{}^S = 0$ and $a_i{}^S = 0$, which yields:

$$P_i{}^S = \frac{A(1-\beta)}{2-\beta},\ q_i{}^S = \frac{A}{(2-\beta)(1+\beta)} \text{ and } \pi_i{}^S = \frac{A^2(1-\beta)}{(2-\beta)^2(1+\beta)}.$$

Finally, we have the profit rankings, which support the sequential choice game as a subgame perfect equilibrium:

$$\pi_i{}^* - \pi_i{}^S = \frac{A^2(4-5\beta)^2}{32(2-\beta)^2(1+\beta)} > 0 \text{ and } \pi_j{}^* - \pi_j{}^S = \frac{A^2\beta(5\beta-4)}{16(2-\beta)^2(1+\beta)} > 0 \Leftrightarrow \beta \in (0.8,1)$$

Appendix IV: The market structure of eco-industry

Suppose that $m(\geq 1)$ eco-firms compete in producing abatement goods with Cournot fashion and two polluting firms purchase the abatement goods under ECSR. Following the analysis of Canton *et al.* (2008), we assume that the market price of eco-industry is determined by total demand of the two polluting firms and total supply of the productions of m eco-firms. That is, we have $a_U = a_E$ at equilibrium where $a_E = \sum_{e=1}^{m} a_e = \sum_{i=1}^{2} a_i$.

Then, assuming interior solutions of abatement goods, from (11), we have the inverse demand function of the abatement goods:

$$r = \frac{4Ad\theta_1\theta_2}{(2+\beta-\beta^2)(\theta_1+\theta_2)+4d\theta_1\theta_2} - \frac{2d\theta_1\theta_2(2-\beta)(1+\beta)}{(2+\beta-\beta^2)(\theta_1+\theta_2)+4d\theta_1\theta_2} a_U$$

Using the first order condition of each eco-firm with respect to its abatement goods, $\frac{\partial \pi_e}{\partial a_e} = 0$, and the symmetric equilibrium in the eco-industry, $a_U = \sum_{e=1}^{m} a_e = m a_e$, we have:

$$a_e = \frac{2A}{(1+m)(2+\beta-\beta^2)},\ r = \frac{4Ad\theta_1\theta_2}{(1+m)((2+\beta-\beta^2)(\theta_1+\theta_2)+4d\theta_1\theta_2)} \text{ and}$$

$$a_i = \frac{A((m-1)(2+\beta-\beta^2)\theta_j+\theta_i((1+m)(2+\beta-\beta^2)+4dm\theta_j))}{(1+m)(2+\beta-\beta^2)((2+\beta-\beta^2)(\theta_i+\theta_j)+4d\theta_i\theta_j)}.$$

Note that as m increases, a_e decreases.

Finally, from the profit of polluting firm 2, we have the reaction function of firm 2:

$$\theta_2 = \frac{(1-m(1-\beta))(2-\beta)(1+\beta)\theta_1}{(2-\beta)(1+\beta)(3+m(1-\beta)-2\beta)+4d(2+m(1-\beta)-\beta)\theta_1}$$

When $\beta > \frac{m-1}{m}$, θ_2 is positive as far as $\theta_1 > 0$.

Then, from the first order conditions for maximizing the profits, we have

$$\theta_1{}^* = \frac{(2-\beta)^2(1+\beta)(\beta(2+3m)-(1+3m))}{2d(7-7\beta+2\beta^2+m(5-8\beta+3\beta^2))} \quad \text{and} \quad \theta_2{}^* = \frac{(2-\beta)^2(1+\beta)(\beta(2+3m)-(1+3m))}{2d(13-11\beta+2\beta^2+m(7-10\beta+3\beta^2))}.$$

Note that the degree of ECSR is positive when $\beta > \underline{\beta} = \frac{1+3m}{2+3m}$, where $\underline{\beta}$ is increasing in m and $\underline{\beta} = 0.8$ if m =1. Thus, as m approaches infinity, no firms purchase abatement goods in the eco-industry even though both polluting firms adopt ECSR. Also, we can show that the outcomes of interior solutions are on the equilibrium path as a subgame perfect equilibrium.

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