Environmental R&D, Monopoly Recycling Markets, and Recycled Content Standards

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Abstract

In this paper, we construct a model consisting of an upstream monopoly recycler and a downstream polluting firm with environmental research and development (ER&D) to study the impact of a recycled content standard (RCS) on the recycling rate. In this framework, we show that a stricter RCS decreases the price of recycled materials and increases the output and the level of ER&D of the final goods firm. Then, the RCS increases the profit of the final goods firm, clearly. On the other hand, the impact on the monopoly recycler's profit depends on whether the two positive effects derived from an increase in the demand for recycled materials and a decrease in her marginal cost dominate the negative effect caused by a decrease in the recycled materials price. Moreover, even though the output of final goods increases, the total amount of waste may decrease if the level of ER&D is sufficiently high.

Keywords: Environmental R&D, Recycled content standard, Recycling rate, Monopoly

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1. Introduction

To eliminate waste pollution, many countries have put in practice the 3Rs (reduce-reuse - recycle). For example, under the 2001 Home Appliances Recycling Law, the Japanese home electronics industry is required to maintain a recycling rate of at least 50%, while the US state of California requires that manufacturers of polyethylene terephthalate (PET) packaging must meet a minimum of 10% recycled content to stimulate the use of recycled materials. In addition to these recycling measures, firms affected must also improve the eco-friendly design (green design) of their products through environmental research and development (ER&D).

Here, we construct a model consisting of an upstream monopoly recycler and a downstream polluting firm with ER&D to consider the impact of a recycled content standard (RCS).[1] RCSs require firms to use a certain percentage of recycled materials as inputs, with the intention of reducing waste by stimulating their use. The existing literature analyzing the use of RCSs includes Palmer and Walls (1997), Higashida and Jinji (2006) and Iida (2011). However, none of these studies considers how the strengthening of an RCS impacts upon the ER&D for promoting the recycling of final products. To do this, we adopt a model including ER&D in the downstream firm à la Katsoulacos and Xepapadeas (1996), Chiou and Hu (2001), and Tsai et al. (2015).[2] Through applying this model, we treat the recycling rate as an endogenous variable, where the rate is the ratio of the recovered amounts of recycled materials to the output of final goods. Hence, in our model, an increase in the recycling rate means that the final goods become easier to recycle.[3] Though we simply assume that the downstream and upstream sectors are both monopolies, the model reveals the relationship between the RCS and firm decisions on ER&D.[4]

One distinctive feature of our model is an assumption concerning an imperfectly competitive market for recycled materials, along with the final goods market. As indicated by Eichner (2005) and Sugeta and Shinkuma (2012, 2014), some recycling markets reach the stage where only one or a few recyclers operate and determine the price of recycled materials. However, this literature does not examine the impact of RCSs. We assume a monopoly recycler

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[1] It is possible for upstream eco-industry firms outside the polluting sector to undertake ER&D. For example, Greaker and Rosendahl (2008) and Nimubona and Benchekroun (2015) analyze cost-reducing ER&D in the oligopolistic eco-industry.

[2] Katsoulacos and Xepapadeas (1996) show that when polluting duopoly firms undertake ER&D and spillovers exist between firms, the optimal emission tax is then less than the marginal damage. Chiou and Hu (2001) investigate ER&D competition or cooperation through environmental research joint ventures under emission taxes. Tsai et al. (2015) examine the relationship between the optimal environmental tax and tariff in the situation where only a home firm can undertake ER&D, and show that these policies may be a strategic substitute.

[3] Eichner (2005), Tsai et al. (2013), and Sugeta and Shinkuma (2014) consider the case where the government regulates the recycling rate as a policy variable.

[4] E.g., the Japanese markets of home appliances are imperfectly competitive and then mainly consists of some representative multinational firms; Panasonic, Sony, etc. In this paper, as a first step to examine such a relationship, we suppose that the final goods market is monopoly.

and a downstream polluting firm, where the polluting firm can undertake ER&D for improving her recycling rate. We then clarify the effect of a stricter RCS on this rate and on the price of recycled materials, and examine the direct and indirect impacts of the RCS through the change in these variables in a recycling economy.

By using this model, we show that a stricter RCS decreases the price of recycled materials, and then increases the output and the level of ER&D of the final goods firm. Then, the RCS increases the profit of the final goods firm, while the impact on the monopoly recycler's profit does not determine, definitely. Moreover, even though the output of final goods increases, the total amount of waste may decrease if the level of ER&D is sufficiently high.

The remainder of this paper is organized as follows. Section 2 describes the model. In Section 3, we investigate the economic and environmental impacts of a stricter RCS. Section 4 provides a brief discussion of the optimal RCS, and Section 5 gives some concluding remarks.

2. Model

There are two markets in this economy: an upstream monopoly market for recycled materials and a downstream monopoly market for final goods. Let x be the output of the downstream firm, and p denote the price of the final goods. Then, the inverse demand function is $p(x) = a - bx$. On the other hand, we express the output of recycled materials as y. In the following analysis, we define the recycling rate $e \equiv y / x$. That is, the recycling rate denotes the extracted ratio as recycled materials among consumed final goods. Then, the observed wastes are expressed as $E(e,x) = (1-e)x$. If the goods are not recycled, they cause environmental damage.[5] Therefore, the individual consumer treats E as a public bad which does not affect individual actions. It follows that the externality does not affect the equilibria of the downstream and upstream markets.

We assume that the government of the country implements two environmental policies: (I) an RCS ($\mu \in (0,1)$) to stimulate the using of recycled materials; and (II) an environmental tax (t) to reduce waste products by encouraging the final goods producer to promote ER&D, and then, to improve the recycling rate.

The downstream firm uses recycled and raw materials to produce one unit of the final good x because the government implements RCS regulation, irrespective of whether the price of recycled materials is higher than that of raw materials. In this case, the derived demand of recycled materials is μx. Therefore, the recycled materials balance is subjected to[6]

[5] We assume that final goods wasted at time T–1 are recycled as recycled materials at time T. However, along with Higashida and Jinji (2006), we focus only on the steady-state equilibrium.

[6] For our analytical purpose, we simplify the recovery process of scrap goods (especially, the input demand for the goods by the monopoly recycler). As closely analyzed in Palmer et al.(1997) and Kaffine (2014), scrap prices which are determined from the market clearing condition for scrap goods play an important role as a determinant of waste and recycling policies' costs.

$$ex \geq \mu x. \quad (1)$$

If the supply of the material is equal to the demand in (1), it means that the level of a RCS and the recycling rate is identical. However, we are interested in the relation between an increase in the RCS and the recycling rate. Hence, in the following analysis, we suppose that the downstream sector targeted for the RCS is very small relative to the aggregate recycling market, thus; $ex > \mu x$.

Next, we provide that the marginal costs of the final goods firm (c) and the recycler (c^R). The final goods firm is subject to the environmental tax if its product cannot be recycled. Moreover, we assume that the price of the raw materials (w) is fixed at the world level, and then the price of raw materials (r) is lower than that of recycle materials ($r > w$).[7] In this case, the marginal cost of the final goods firm is expressed as follows:[8]

$$c(e, r, \mu, t) = \mu r + (1-\mu)w + t(1-e). \quad (2)$$

As explained above, we consider the case where the supply of recycled materials is not binding. In this meaning, the loop of resources recycling is not closed, completely. However, when the final goods firm improves the recycling rate, further, the extraction of recycled materials from wasted final goods should be easier. Hence, in order to incorporate this influence, we assume that the marginal cost of the recycler is decreased with an increase in the recycling rate. In particular, we express the recycler's marginal cost as

$$c^R(e) = 1/e, \quad (3)$$

where $c^{R'}(e) = -e^{-2} < 0,\ c^{R''}(e) = 2e^{-3} > 0$.

2.1 Profit maximization of the final good firm

To achieve a higher recycling rate, the downstream firm spends on ER&D. The ER&D cost is assumed to be a quadratic function regarding this rate, that is, $ke^2/2$, where $k(>0)$ is an investment efficiency parameter. Considering the inverse demand function and (2), the profit of the final goods firm is written as follows:[9]

$$\max_{x,e}\ \pi(x, e, r, \mu, t) = \{p(x) - c(e, r, \mu, t)\}x - ke^2/2. \quad (4)$$

Then, from the first-order conditions for (4), we obtain the firm's own output and the

[7] As in Higashida and Jinji (2006), if $\mu=0$, the monopoly recycler cannot operate because recycled materials are not demanded. That is, with RCS regulation, the downstream home firm is obligated to purchase relatively expensive recycled materials. On the other hand, Sugeta and Shinkuma (2012, 2014) assumed that the price of recycled materials supplied by the monopoly recycler is lower than that of the raw materials. Thus, in their model, $w > r > c^R$.

[8] In our model, the price of raw materials is exogenously given. Hence, we omit "w" in the corresponding function.

[9] We assume, in this model, that the downstream firm cannot exercise any monopsony power in the recycling market. The firm takes the price of recycled materials as given.

level of ER&D to maximize her profit:[10]

$$\tilde{x}(r,\mu,t) = k(\phi - \mu r)/A, \quad \tilde{e}(r,\mu,t) = t(\phi - \mu r)/A, \tag{5}$$

where $A \equiv 2bk - t^2$. The second-order condition for maximizing the profit with respect to e is written as $\partial^2\pi/\partial e^2 = (t^2 - 2bk)/2b < 0$. Hence, $A > 0$. In addition, we define the net profit of the final goods producer without the cost of recycling as $\phi \equiv a - (1-\mu)w - t$. From (5), $\phi > 0$ must be satisfied in order to keep the positive output and ER&D levels.

We find that the level of ER&D hinges on (I) the primal surplus without recycling ($a - w$), (II) the cost-push effect of the RCS ($-\mu(r-w)$), and (III) the environmental tax level. Noting $r > w$ from our assumption, the second effect weakens the incentive for ER&D if r is given.

2.2 Profit maximization of the recycler

Here, we consider the profit maximization of the monopoly recycling firm. Cinsidering that the marginal cost of the recycler hinges on the level of ER&D, the profit maximization of this recycler is expressed as

$$\max_r \ \pi^R(r,\mu,t) = \{r - c^R(\tilde{e}(r,\mu,t))\}\mu\tilde{x}\,(r,\mu,t) = \{r - 1/\tilde{e}(r,\mu,t)\}\mu\tilde{x}\,(r,\mu,t). \tag{6}$$

Then, noticing the definition regarding A and ϕ, from the first-order condition for (6), we obtain the price of recycled materials to maximize her profit:

$$r^*(\mu,t) = \phi/2\mu. \tag{7}$$

Therefore, substituting (7) into (5), we get the output of final goods and the level of ER&D in equilibrium:

$$x^*(\mu,t) = k\phi/2A, \quad e^*(\mu,t) = t\phi/2A. \tag{8}$$

Because of $A > 0$, both the output and the recycling rate are positive as long as the net profit ϕ is positive.

3. Comparative statics of an RCS

3.1 The effect on the price of recycled materials and the level of ER&D

First, we check the impact on the price of recycled materials. Differentiating (7) with respect to μ, we obtain

$$\partial r^*/\partial\mu = -(a - w - t)/2\mu^2 < 0. \tag{9}$$

When the parameter a in the inverse-demand function is sufficiently large, the size of the final goods market is also large, and then the demand for recycled material is brisk. However, the price of recycled materials may fall even though the demand for this material increases.

As an intuitive explanation, if we represent the demand for recycled materials as $D^R \equiv \mu\tilde{x}$, the relation between r and D^R is expressed as $r = \phi/\mu - AD^R/\mu^2 k$. Thus; when μ is strengthened, the demand curve becomes flatter with the fall in its ordinate intercept and the expansion in its horizontal intercept. Then, since the marginal cost of the recycler is

[10] If the downstream firm choose the output, then the level of ER&D, sequentially, we can obtain same solution.

constant in terms of the materials' output, the price that attains the profit maximization may fall even in the case where the marginal cost stays constant.

Moreover, the marginal cost is the decreasing function with respect to the recycling rate in our model. As we show right after this, an increase in μ swells the level of ER&D. That is, the recycling rate improves, and then the marginal cost decreases. This effect also contributes the fall in the materials' price.[11]

Next, we confirm that, from (8), the effect of a stricter RCS on the output of the final goods and the recycling rate is

$$\partial x^* / \partial \mu = kw / 2A > 0, \quad \partial e^* / \partial \mu = tw / 2A > 0 . \tag{10}$$

An increase in the RCS decreases the price of raw materials. Then, as shown in Appendix 1, the equilibrium marginal cost of the downstream firm is written as (A1). From this equation, we can show that a stricter RCS lowers the marginal cost of the downstream firm. Hence, the RCS intensifies the cost advantage of the final goods firm. As a result, the firm can raise both her output and recycling rate.

3.2 The effect on profits

Here, we investigate the impact of a stricter RCS on the profits of the downstream and upstream firms.[12] First, the equilibrium profit of the downstream final goods firm is written as (A5) in Appendix 1. We, then, show that the effect of the RCS on the profit as

$$\partial \pi^* / \partial \mu = kw\phi / 4A > 0 . \tag{11}$$

Namely, the firm gains from an increasing RCS because the price of raw materials falls. Although the investment cost of ER&D rises along with the higher recycling rate, the marginal cost of the firm becomes lower. Therefore, the output expands, and then, the profit of the firm increases with a stricter RCS.

Next, the equilibrium profit of the upstream monopoly recycler is written as (A6) in Appendix 1. From (A6), we have the following equation:

$$\partial \pi^{R*} / \partial \mu = k(tw\phi - 2A) / 2tA . \tag{12}$$

As shown in (9), a stricter RCS decreases the price of recycled materials. This impact directly causes a reduction of the recycler's revenue, then the recycler's profit. On the other hand, the output and the recycling rate of the final goods firm increase via this price reducing effect. Then, an increase in the output of final goods swells the recycler's revenue. Moreover, an improvement in the level of ER&D reduces her marginal cost. The later two effects augment the recycler's profit. Therefore, the recycler's profit may increases if the price reducing effect of the materials is not too large, more specifically, if the two positive effects derived from an

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[11] Suppose that we still assume the linear demand function regarding the final goods. In this case, we can obtain the same sign in (9) even if we do not specify the function $c^R(e)$, as long as $c^R{}''(e) \geq 0$ and the parameter a is sufficiently large.

[12] We provide the specific equilibrium equations for the endogenous variables regarding profits and total waste in Appendix 1.

increase in the demand for recycled materials and a decrease in her marginal cost dominate the negative effect caused by a decrease in the recycled materials price.

3.3 The effect on the total amount of waste

Next, we focus on the environmental impact of a stricter RCS. At the equilibrium, the total waste is represented as (A7) in Appendix 1. Thus, the impact of the RCS on the total waste becomes

$$\partial E^* / \partial \mu = (1-e^*)(\partial x^* / \partial \mu) - x^*(\partial e^* / \partial \mu) = kw[2bk - t\{a-(1-\mu)w\}]/2A^2 . \qquad (13)$$

The effect of $\partial E^* / \partial \mu$ depends on the sign of. The RCS increases the output of the polluting firm and improves the recycling rate. The former effect provides a negative impact on total waste as against the latter. Then, we find that total waste decreases if the net profit without the tax payment of the polluting firm multiplied by the environmental tax rate are larger relative to the cost of ER&D.

Hence, we summarize comparative static results in this section as follows:

Proposition: *(I) A stricter RCS decreases the price of recycled materials, then increases the output and the level of ER&D of the final goods firm. (II) The profit of the final goods firm clearly increases. On the other hand, the profit of the recycling firm may augment if the two positive effects derived from an increase in the demand for recycled materials and a decrease in her marginal cost dominate the negative effect caused by a decrease in the recycled materials price. (III) The total amount of waste may decrease if the cost of ER&D is smaller than the net profit without the tax payment of the polluting firm multiplied by the environmental tax rate, that is,* $2bk < t\{a-(1-\mu)w\}$.

We only analyzed the impact of a tighter RCS in this paper. However, both of the upstream and downstream markets are monopoly in our model, and then there is a negative externality caused by the wastes, too. This means that, e.g., as denoted in Palmer and Walls (1997), some other policies are required to reduce the waste and to reform distortions from imperfect competition, even though the RCS is effective in promoting resource circulation.

4. A note on the optimal RCS

In this section, we consider the optimal RCS. When we assume that the environmental tax revenue is transferred in a lump-sum fashion to domestic consumers, the welfare of the country at the equilibrium (W^*) is expressed as

$$W^*(t,\mu) = CS^*(t,\mu) + \pi^*(t,\mu) + \pi^{R*}(t,\mu) + (t-\Omega)E^*(t,\mu), \qquad (14)$$

where $CS*$ is the consumer surplus at the equilibrium and Ω is the social valuation of environmental damage associated with the waste products. Hence, the effect of a stricter RCS on welfare is represented as follows:[13]

$$\partial W^* / \partial \mu = k[-4A^2 + tw\phi(bk+3A) + 2tw(t-\Omega)\{2bk - t(a-w+\mu w)\}]/4tA^2 = 0 . (15)$$

[13] See Appendix 2 for details of the calculation given in this section.

In addition, the second-order partial derivative of welfare with respect to μ is given as

$$\partial^2 W^* / \partial\mu^2 = kw^2 D / 4A^2, \qquad (16)$$

where $D \equiv 7bk - t(5t - 2\Omega)$. As shown in (16), the second-order derivative with respect to μ may be negative or positive depending on the sign of *D*, where *D* includes the marginal social damage, the environmental tax, and the investment efficiency parameter. Therefore, we identify the optimal RCS for two cases.

<u>*Case 1:*</u> $\Omega > (5t^2 - 7bk)/2t$ or $\Omega \geq 5t/2$, that is, $D > 0$

In this case, it is clear that $\partial^2 W^* / \partial\mu^2 > 0$. Hence, the optimal RCS is infinitely close to 1, (I) if the first-order derivative with respect μ is positive when $\mu \to 0$, or (II) even if the derivative is negative when $\mu \to 0$ and is positive when $\mu \to 1$ as long as the welfare level in $\mu \to 1$ is higher than that in $\mu \to 0$. Given that the higher is the recycling rate, the less is waste pollution, almost all the waste being recycled is the preferred measure of this economy when the marginal social damage is sufficiently high.

<u>*Case 2:*</u> $\Omega < (5t^2 - 7bk)/2t$, that is, $D < 0$

In the case where the marginal damage is considerably smaller than the environmental tax level, we obtain $\partial^2 W^* / \partial\mu^2 > 0$. In such a case, by setting the right-hand side of (15) equal to zero, we derive the optimal RCS as

$$\mu^*(t) = [4A^2 - tw\{(a-w)D - 4bk\Omega + 3t(t^2 - bk)\}] / tw^2 D. \qquad (17)$$

However, noting $D < 0$, the optimal RCS may not be located in the interval (0,1) as long as the environmental tax level is so high, then, the last term of the numerator in (17) takes great value, considerably.

5. Concluding remarks

To consider the effectiveness of an RCS for creating a recycling society, we employed a model consisting of a monopoly recycler and a polluting downstream firm, where the polluting firm can undertake ER&D for improving the recycling rate, and we analyzed the economic and environmental effects of an RCS. In our model, a stricter RCS reduces the price of the materials and increases the recycling rate. The RCS then may increase the profits of the downstream firm and the recycler. Moreover, if the level of ER&D is sufficiently high, the RCS may decrease total waste, even though the output of final goods increases.

Further research is required to address the following points. First, we simply assume that the downstream and upstream sectors are both monopolies. However, the recycling industry in most developing countries comprises formal and/or informal recyclers. Hence, we could extend our model in the direction of oligopolistic (or perfect) competition among the upstream recyclers. Second, our model does not include recycling in a foreign country. By adding this to our model, we could consider trade in recycled materials, and thus whether the promotion of international resource circulation improves the environment. Hence, a future research task would be to introduce foreign recycling into this model.

Appendix 1: Specific equilibrium equations

Here, we provide the specific equilibrium equations with respect to marginal costs, profits and total waste. First, considering (7) and (8), at the equilibrium, the marginal cost of the final goods firm is represented as

$$c^*(\mu,t) = [(bk - t^2)a + bk\{(1-\mu)w + t)\}]/A. \tag{A1}$$

Hence, the impact of a RCS on c^* is as follows:

$$\partial c^* / \partial\mu = -bkw/A < 0. \tag{A2}$$

Next, from (8), the marginal cost of the recycler is expressed as

$$c^{R*}(\mu,t) = 1/e^*(\mu,t) = 2A/t\phi. \tag{A3}$$

Hence, the impact of a RCS on c^{R*} is as follows:

$$\partial c^{R*} / \partial\mu = -2wA/t\phi^2 < 0. \tag{A4}$$

Considering (4), (8), and (A1), the profit of the downstream firm is represented as

$$\pi^*(\mu,t) = \{p(x^*(\mu,t)) - c^*(\mu,t)\}x^*(\mu,t) - ke^{*2}(\mu,t)/2 = k\phi^2/8A. \tag{A5}$$

On the other hand, the effect of the RCS on the monopoly recycler is analogously calculated. From (6), (7), (8), and (A3), this is represented as

$$\pi^{R*}(\mu,t) = \{r^*(\mu,t) - c^{R*}(\mu,t)\}\mu x^*(\mu,t) = k(t\phi^2 - 4\mu A)/4tA. \tag{A6}$$

Hence, we can find that $t\phi^2 > 4\mu A$ if $r > c^R$, then, the recycler accrue the positive profit.

Finally, noting (8), total waste at the equilibrium is

$$E^*(\mu,t) = \{1 - e^*(\mu,t)\}x^*(\mu,t) = k\phi(2A - t\phi)/4A^2, \tag{A7}$$

where $2A - t\phi > 0$ as long as the recycling rate does not attain 1.

Appendix 2: Welfare effect of an RCS

From (14), the welfare effect of a stricter RCS is expressed as

$$\partial W^*/\partial\mu = \partial CS^*/\partial\mu + \partial\pi^*/\partial\mu + \partial\pi^{R*}/\partial\mu + (t-\Omega)\partial E^*/\partial\mu, \tag{A8}$$

where the partial derivative of consumer surplus is given as

$$\partial CS^*/\partial\mu = -x^*(\partial p^*/\partial\mu) = -(k\phi/2A)(-bkw/2A) = bk^2w\phi/4A^2. \tag{A9}$$

Then, substituting (11), (12), (13), and (A9) into (A8), we obtain the following first order condition:

$$\begin{aligned}\partial W^*/\partial\mu &= bk^2w\phi/4A^2 + kw\phi/4A + k(tw\phi - 2A)/2tA \\ &\quad + kw(t-\Omega)\{2bk - t(a - w + \mu w)\}/2A^2 \\ &= k[bktw\phi + tw\phi A + 2A(tw\phi - 2A) + 2tw(t-\Omega)\{2bk - t(a - w + \mu w)\}]/4tA^2 \quad \text{(A10)} \\ &= k[-4A^2 + tw\phi(bk + 3A) + 2tw(t-\Omega)\{2bk - t(a - w + \mu w)\}]/4tA^2 \\ &= 0.\end{aligned}$$

Moreover, by differentiating (A10) with respect to μ, the second-order partial derivative is derived as

$$\partial^2 W^*/\partial\mu^2 = kw^2D/4A^2, \tag{A11}$$

where $D \equiv 7bk - t(5t - 2\Omega)$. If the second order condition is satisfied, $D < 0$.

Hence, if $D < 0$, the optimal RCS may be located in the interval (0,1). Actually, solving

(A10) with respect to μ and considering $A \equiv 2bk - t^2$, the optimal RCS is represented as follows:

$$\begin{aligned}\mu^* &= [4A^2 - tw(bk+3A)(a-w-t) - 2tw(t-\Omega)\{2bk - t(a-w)\}] \\ &\quad / tw^2\{bk + 3A - 2t(t-\Omega)\} \\ &= [4A^2 - tw\{(a-w)(7bk - 5t^2 + 2t\Omega) - (3bkt - 3t^3 + 4\Omega bk)\}] \\ &\quad / tw^2(7bk - 5t^2 + 2t\Omega) \\ &= [4A^2 - tw\{(a-w)D - 4bk\Omega + 3t(t^2 - bk)\}] / tw^2 D.\end{aligned} \tag{A12}$$

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