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THE RECYCLED CONTENT STANDARD WITH DIFFERENTIATED PRODUCTS

By TAKESHI IIDA*

Many countries recommend the use of a recycled content standard, however there are few studies investigating its design. In this paper, we analyze a recycled content standard for differentiated products and derive the optimal recycled content rate. In particular, we focus on two factors that affect a firm's production activity. The first is the quality of a product, which is affected by the rate of recycled content. The second is the consumer's brand preference, which affects the firm's market power. We find that depending on the marginal cost of recycling, the regulator sets a high recycled content rate when the degree of horizontal product differentiation (HPD) is small. Moreover, in such a case, the amount of waste is less than when the degree of HPD is large.

JEL classification: L51; Q53; Q58

Key words: Vertical/Horizontal product differentiation; Recycled content standards

1. Introduction

A regulator adopts various recycling policies to reduce waste, such as levying taxes on the use of virgin materials, providing subsidies for recycling activities, introducing a deposit-refund system, and implementing recycled content standards. Many studies on recycling policies focus on efficiency, thereby determining which recycling policies achieve an optimal amount of waste reduction (e.g., see Palmer and Walls 1997; Sigman 1995 and Calcott and Walls 2005).

The recycled content standard is one of the more popular recycling policies. It requires firms to use a certain percentage of recycled material as input. In Japan, a regulatory agency must purchase a recycled good, which is regulated by the law of Green Purchasing. For example, the law requires that copy paper contain 100% recycled paper. The U.S. Environmental Protection Agency (U.S. EPA) recommends copy paper to contain 30% recycled paper. The U.S. EPA also listed recycled-content recommendations for 8 other items, such as, construction, landscaping, transportation products, etc. Although, many countries recommend the implementation of recycled content standards, there are few studies investigating their design.

Higashida and Jinji (2006) analyse the strategic use of recycled content standards between two countries. They compare the strategic relationships that arise when there is a trade in recycled materials with those that occur when there is no trade in recycled materials. However, they do not investigate the optimal recycled content rate from the perspective of domestic policy. Palmer and Walls (1997) and Sigman (1995) also analyze recycled content standards. Their focus is not on the design of recycled content standards but rather on which recycling policies can achieve the first best amount of waste reduction.

Previous studies have not focused on the design for the recycled content standard as an

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independent policy. Therefore, our objective is to fill this gap in the literature. We investigate how high a recycling standard should be set from the perspective of social welfare, including consumer surplus, producer surplus, and environmental damage caused by waste. We also derive the optimal recycled content rate. In previous studies, discussion about the market structure that will be regulated seems inadequate. Because the waste problem is caused by consumption and production activities, it is important to consider the market structure. Therefore, we chiefly focus on two factors that affect a firm's production activity: the quality of the product and the consumer's brand preference.

The use of recycled material reduces the quality of the product relative to that which has been produced entirely from virgin material. This phenomenon is typically observed in the paper industry. The recycling process lowers the quality and weakens the strength of the paper. Because consumers prefer white paper to brown paper and paper of poor quality cannot be used with copy machines, recycling activity may lead to a loss in demand. With regard to the recycled content standard, because a regulator sets the recycled content rate, there is a direct effect on the quality of the product. Although a high recycled content rate reduces waste, it lowers the quality of the product. Therefore, a regulator faces a trade-off between environmental quality and product quality when setting the recycled content rate. Even if the recycling activity reduces waste, it may not be wise to set a high recycled content rate from the perspective of social welfare.

The other factor in firm's production activity is the consumer's brand preference, which affects the firm's market power. For example, in a market with strong consumer brand preference, firms have their own market and strong market power. On the other hand, a market with weak consumer brand preference is more competitive than a market where brand preference is strong. Because the level of competition affects a firm's production activity, and in turn the amount of waste generated, a regulator must consider the consumer's brand preference. Our objective is to investigate the manner in which a regulator sets the recycled content rate with regard to both product quality and consumer's brand preference.

We investigate this issue using the framework of Symeonidis (2003), which models both vertical and horizontal product differentiation (HPD). Therefore, adopting his model, we can incorporate two factors. Vertical product differentiation relates to the quality of the product and HPD relates to consumer's brand preference. Two firms are engaged in quantity or price competition, both producing one variety of a differentiated product. Firms are regulated and must use a set proportion of recycled material, which has been established by a regulator. Firms incur additional cost when using recycled material, for example, the cost of dissolving old paper to make textiles, the cost of removing dust, etc. Therefore, in our model, the cost of using recycled material is higher than that of using virgin material. Moreover, the quality of the product decreases as the recycled content rate increases. We assume that the consumer has a preference not for environmental quality, but for product quality. For example, this means that consumers prefer white paper to brown paper even if the color of the brown paper is the result of recycling activity. Of course, there are consumers who value recycling or recycled commodities, and literature exists that assumes that recycling activity directly increases a consumer's utility (e.g., see Lusk, 1975., 1976., and Smith, 1972). However, when one

considers whether a consumer would buy a product, it seems that the important determinant of product preference is not environmental factors but quality or function. From the above, firms have no incentive to use recycled material unless a regulator obliges them to do so.

Several studies have examined the relationship between environmental policy and HPD. Lange and Requate (1999) analyze the optimal environmental tax under HPD with a price-setting duopoly. They show that when the product is more differentiated and asymmetry is large, policy makers set the optimal tax rate higher than the Pigouvian tax because of the larger output.

While Lange and Requate (1999) focus on the level of environmental tax rather than the relationship between the environmental tax and the degree of HPD, Fujiwara (2009) analyzes this relationship, allowing for free entry. He shows that the relationship between the optimal environmental tax and the degree of HPD in the presence of free entry may be the inverse of their relationship in the absence of entry.

In addition to environmental taxation, McGinty and Vries (2009) and Poyago-Theotoky (2003) analyze the optimal subsidy for environmental technology with HPD. McGinty and Vries (2009) analyze the relationship between the environmental subsidy and the degree of HPD, and its effect on the diffusion of clean technology. They show that the subsidy enhances the diffusion of clean technology, the effect being larger when the product is more homogenous.

Poyago-Theotoky (2003) compares the optimal tax and subsidy under Cournot competition with those under Bertrand competition. He shows that although the optimal tax under Bertrand competition is always higher than that under Cournot competition, the optimal subsidy under Bertrand competition is lower than that under Cournot competition when the product is more differentiated.

Further, there are other studies focusing on the degree of HPD. Lee and Park (2005) compare tradable emission permits with command and control; Wang and Chen (2007) compare the optimal environmental tax under pure oligopoly with that under mixed oligopoly; Poyago-Theotoky and Teerasuwannajak (2002) investigate the incentives for the firm's voluntary environmental investment.

Although the above literature focuses on horizontal product differentiation, none of these studies allows for vertical product differentiation in addition to HPD. As mentioned above, the specific utility function considered by Symeonidis (2003) gives us a new perspective on the analysis of environmental policy with differentiated products. Therefore, we extend his utility function and analyze recycling policy, focusing on the trade-off between product quality and the recycling rate.

Our model is constructed based on a two stage game. In the first stage, a regulator sets the recycled content rate in order to maximize social welfare. In the second stage, firms observe the recycled content rate and simultaneously choose quantity or price.

We will now discuss the main results of our investigation. In our model, an increase in the recycled content rate has two effects on social welfare. One is the benefit, which arises with waste reduction. The other is the cost, which arises from the loss of consumer surplus; the higher recycled content rate increases the distortion of imperfect competition and lowers the quality of the product. If the benefit is larger than the cost, the regulator raises the recycled

content rate.

When the marginal cost of recycling is high, the regulator sets a low recycled content rate, as the high marginal cost causes firms suppress their output, leading to a loss in consumer surplus. Thus, to modify the damage to consumer surplus, the regulator reduces the recycled content rate in order to promote production. Further, the relationship between the recycled content rate and the degree of HPD depends on the marginal cost of recycling. In the case of Cournot competition, if the marginal cost of recycling is low (resp. high), the regulator sets a high (resp. low) recycled content rate when the degree of HPD is small. When the degree of HPD is small, competition between firms intensifies. In our model, this means that the two markets become one when the degree of HPD is small. Therefore, the overall amount of waste is always small when the degree of HPD is small. In this case, however, competition generates excessive waste from the perspective of social welfare. Thus, the regulator sets a high recycled content rate when the degree of HPD is small.

We also compare the case of Cournot competition with that of Bertrand competition. In the case of Bertrand competition, the effect of competition is strong; thus, the regulator sets a higher recycled content rate in the case of Bertrand competition than that of Cournot competition.

This paper is organized as follows. The next section describes the model of the recycled content standard of differentiated products. Section 3 analyzes the behavior of firms and regulators, and the final section concludes the paper.

2. The Model

There are consumers who have a preference for product quality. We use a specific form of utility function that is slightly different from that of Symeonidis (2003). The utility function is given by

$$U = (1 + q_i - \sigma q_j)x_i + (1 + q_j - \sigma q_i)x_j - \frac{1}{2}(x_i^2 + 2\sigma x_i x_j + x_j^2) + M, \quad (1)$$

where x_i and q_i represent the quantity and quality of good i , and M is expenditure on other goods. The exogenous parameter $\sigma \in (0, 1)$ represents the degree of HPD. The products are independent as $\sigma \rightarrow 0$ and perfect substitutes as $\sigma \rightarrow 1$, when $q_i = q_j$. We define quality as $1 + \varepsilon - \alpha$ and $1 - \alpha$. We denote the degree of efficiency of technology that enhances the quality of the product as ε and the recycled content rate that is set by a regulator as α . If $\varepsilon > 0$, firm i 's technology is more efficient than firm j 's. We assume that the upper bound of ε , $\bar{\varepsilon}$ is not so large. The quality of recycled material is lower than that of virgin material; thus, we assume that the use of recycled material reduces the quality of the final product according to the proportion of α . From the utility function and expenditure constraint $Y = p_i x_i + p_j x_j + M$, the inverse demand function for product i is derived as follows:

$$p_i = 1 + q_i - \sigma q_j - x_i - \sigma x_j, \quad i = 1, 2. \quad (2)$$

In this inverse demand function, the relationship between firm i 's quality and firm j 's quality is substituted. The segment of this inverse demand function is denoted as $1 + q_i - \sigma q_j$. The superior quality of firm j can deprive firm i of its market, the degree of this varying according to the level of HPD. Thus, in this model, x_i and x_j are substitutes.¹⁾ We denote waste by following Higashida and Jinji (2006). The total amount consumed in period $t - 1$ is $x_{i,t-1} + x_{j,t-1} = X_{t-1}$. Products X_{t-1} are wasted after consumption. If wasted goods X_{t-1} are recycled, they are used in period t as inputs; if they are not recycled, they are disposed of. The amount of recycled materials produced from wasted goods is αX_{t-1} , and cannot exceed X_{t-1} . Therefore, the amount of waste in period t is denoted as $X_{t-1} - \alpha X_{t-1}$. The landfill capacity is limited and disposing of waste may generate environmental harm. Thus, unrecycled waste causes environmental damage. We focus on the steady state equilibrium to simplify the analysis, $X_{t-1} = X_t = X$. Environmental damage is denoted as follows:

$$ED = [(1 - \alpha)X]^2, \quad (3)$$

where $X = x_i + x_j$.

Consider two firms producing differentiated products. These firms are engaged in either quantity competition or price competition. The product inputs that firms can use are virgin material, recycled material, or a mixture of the two. One unit of material bears one unit of product. To produce x_i units of the product using recycled and virgin materials, αx_i units of recycled material and $(1 - \alpha)x_i$ units of virgin material are needed. We denote the marginal cost of a product produced with virgin material and with recycled material by c_v and c_r , respectively. The cost of recycled material is higher than that of virgin material because it is costly to produce recycled material from waste. Therefore, firms have no incentive to use recycled materials unless the regulator obliges them to do so. We assume $c_r > c_v$ and c_v to be zero. Firm i 's profit is denoted as follows:

$$\pi_i = p_i x_i - \alpha c_r x_i, \quad i = 1, 2, \quad (4)$$

where x_i and p_i represent the quantity and the price of product i , respectively. The regulator maximizes social welfare (SW) by choosing the proportion of recycled material α . Social welfare is constructed from the sum of consumer's surplus (CS) and producer's surplus (PS) minus environmental damage (ED):

$$SW = CS + PS - ED. \quad (5)$$

1) See Appendix. A. 1 for more detail on the utility function used by Symeonidis (2003).

3. Cournot competition

3.1 The equilibrium in the second stage

In this section, we consider the case where firms are engaged in quantity competition. In the second stage, firm i chooses x_i to maximize its own profit. The Cournot equilibrium can be derived as follows:

$$x_i^C = \frac{(2 - \sigma)(1 - \alpha c_r) + (2 + \sigma^2)q_i - 3\sigma q_j}{4 - \sigma^2}, \quad i = 1, 2. \quad (6)$$

From equilibrium quantity, we obtain equilibrium price and profit, respectively, as

$$p_i^C = \frac{2 - \sigma + \alpha c_r(2 + \sigma - \sigma^2) + (2 + \sigma^2)q_i - 3\sigma q_j}{4 - \sigma^2}, \quad i = 1, 2, \quad (7)$$

$$\pi_i^C = \left(\frac{(2 - \sigma)(1 - \alpha c_r) + (2 + \sigma^2)q_i - 3\sigma q_j}{4 - \sigma^2} \right)^2, \quad i = 1, 2. \quad (8)$$

Here, we consider the manner in which the regulator's choice of α affects a firm's behavior. The quality of the product is denoted as $q_i = 1 + \varepsilon - \alpha$, $q_j = 1 - \alpha$. Thus, we substitute it into the equilibrium quantity, the price, and the profit and we obtain the following:

$$x_i^C = \frac{(2 - \sigma)^2 + \varepsilon(2 + \sigma^2) - \alpha A_1}{4 - \sigma^2}, \quad x_j^C = \frac{4 - \sigma(4 + 3\varepsilon - \sigma) - \alpha A_1}{4 - \sigma^2}, \quad (9)$$

$$p_i^C = \frac{(2 - \sigma)^2 + \varepsilon(2 + \sigma^2) + \alpha A_2}{4 - \sigma^2}, \quad p_j^C = \frac{4 - \sigma(4 + 3\varepsilon - \sigma) + \alpha A_2}{4 - \sigma^2}, \quad (10)$$

$$\pi_i^C = \left(\frac{(2 - \sigma)^2 + \varepsilon(2 + \sigma^2) - \alpha A_1}{4 - \sigma^2} \right)^2, \quad \pi_j^C = \left(\frac{4 - \sigma(4 + 3\varepsilon - \sigma) - \alpha A_1}{4 - \sigma^2} \right)^2, \quad (11)$$

where $A_1 = (2 - \sigma)(1 + c_r - \sigma)$ and $A_2 = (2 - \sigma)\{\sigma(1 + c_r) - (1 - c_r)\}$.

If the regulator increases the recycled content rate, the marginal cost of the product rises and quality decreases. Therefore, the firm suppresses its output. This effect is denoted as

$$\frac{\partial x^C}{\partial \alpha} = -\frac{c_r}{2 + \sigma} - \frac{1 - \sigma}{2 + \sigma} < 0. \quad (12)$$

The first term is the effect that is caused by increased marginal cost and the second term is due to decreased quality. These effects decrease when σ is larger. This means that in a market with a σ large, firms do not reduce their output further owing to a strong strategic relationship between the firms, as compared to that of a weaker one. In particular, the second

term becomes 0 as $\sigma \rightarrow 1$. In this case, because quality competition is strong, the effect of the regulation becomes small. Therefore, the regulator may increase the recycled content rate when the degree of HPD is small rather than when it is large.

3.2 The equilibrium in the first stage

In the first stage, the regulator chooses α to maximize social welfare. From (8), (9), (10) and (11), we obtain social welfare (the derivations of CS , PS and ED are provided in Appendix. A.2) as follows:

$$SW^C = \frac{-8\alpha^4(1+c_r-\sigma)^2(2-\sigma)^2 - A_3 + A_4}{2(4-\sigma^2)^2}, \quad (13)$$

where

$$A_3 = \left\{ \begin{array}{l} 2(2-\sigma)^3(1-\sigma)[(2-\sigma) + \varepsilon(1-\sigma)] \\ -2\alpha(2-\sigma)^2[2(2-\sigma) + \varepsilon(1-\sigma)][(c_r+2\varepsilon)(1-\sigma) + (3-\sigma)^2] \\ -8\alpha^3(1+c_r-\sigma)(2-\sigma)^2[2 + (4+\varepsilon)(1-\sigma)] \\ -\varepsilon^2(4+24\sigma+\sigma^2+12\alpha^3-5\sigma^4) \end{array} \right\}$$

and

$$A_4 = \left\{ \begin{array}{l} 2\alpha^2(2-\sigma)^2[-49 - c_r^2(1-\sigma) - \varepsilon^2(1-\sigma)^2 + 67\sigma - 23\sigma^2 + \sigma^3] \\ -4\varepsilon(4-7\sigma+3\alpha^2) - c_r(8\varepsilon(1-\sigma) + 2(17-10\sigma+\sigma^2)) \end{array} \right\}.$$

We obtain the optimal recycled content rate α^C as follows:

$$\alpha^C = \frac{20 + 12c_r + 2\varepsilon(1-\sigma) - 16\sigma - A_5}{16(1+c_r-\sigma)}, \quad (14)$$

where $A_5 = 2[-8(1+c_r-\sigma)((c_r+2\varepsilon)(1-\sigma) + (3-\sigma)^2) + (10+6c_r-8\sigma+\varepsilon(1-\sigma))^2]^{\frac{1}{2}}$. The second order condition, $\frac{\partial^2 SW}{\partial \alpha^2} < 0$, is satisfied for $c_r \in (0, 1)$, $\sigma \in (0, 1)$ and $\varepsilon \in [0, \bar{\varepsilon}]$. We consider the manner in which the optimal α^C changes, depending on the marginal cost of recycling and the degree of HPD. First, the regulator sets a low recycled content rate when the marginal cost of recycling is high. This is confirmed, as the partial derivation of α^C with respect to c_r is negative, $\frac{\partial \alpha^C}{\partial c_r} < 0$. The interpretation of this result is as follows. The benefit of increasing the recycled content rate is the reduction of waste that is caused by the decrease in firm output. However, because a high recycled content rate imposes a burden on firms, firms suppress their production activity, leading to a loss of consumer surplus, which is the cost of increasing the recycled content rate. Moreover, when the marginal cost of recycling is high, firms suppress production activity regardless of the degree of regulation. Therefore, the regulator does not need to set a high recycled content rate when the marginal cost of recycling is high. Next, we examine the manner in which the optimal α^C changes depending on the degree of HPD. In this case, we must consider three cases depending on the marginal cost of recycling. Thus, we obtain Proposition 1.

Proposition 1. We consider the case where ε is quite small but takes a positive value. In this case, (a) the range $(0, \underline{c}_r^C)$ (resp. $(\overline{c}_r^C, 1)$) yields $\partial \alpha^C / \partial \sigma > (<) 0$ for $\sigma \in (0, 1)$, and (b) the range $[\underline{c}_r^C, \overline{c}_r^C]$ yields $\partial \alpha^C / \partial \sigma < 0$ for $\sigma \in (0, \sigma^*)$ and $\partial \alpha^C / \partial \sigma \geq 0$ for $\sigma \in [\sigma^*, 1)$.

Proposition 1 is illustrated in Fig. 1. The horizontal and the vertical axes are represented by c_r and σ respectively. This result also supports $\varepsilon \in [0, \bar{\varepsilon}]$, as shown in Appendix. A.3.

The interpretation of (a) in this proposition is as follows. The low marginal cost of recycling induces firms to increase their output, resulting in an increase in environmental damage. The regulator increases the recycled content rate to suppress firm activity. When the degree of HPD is small, the effect of the regulation is weak because the effect of the strategic relationship is large; thus, the regulator enhances the regulation when the degree of HPD is large. Of course, an increased recycled content rate is a burden for firms and consumers; therefore, $CS + PS$ decreases. However, in this case, the benefit of the increase in the recycled content rate and the decrease in environmental damage dominate the cost of increasing the recycled content rate. There are two markets in our model that become a single market when the degree of HPD is small. Such a situation is a result of $\sigma \rightarrow 1$. Therefore, the overall amount of waste is

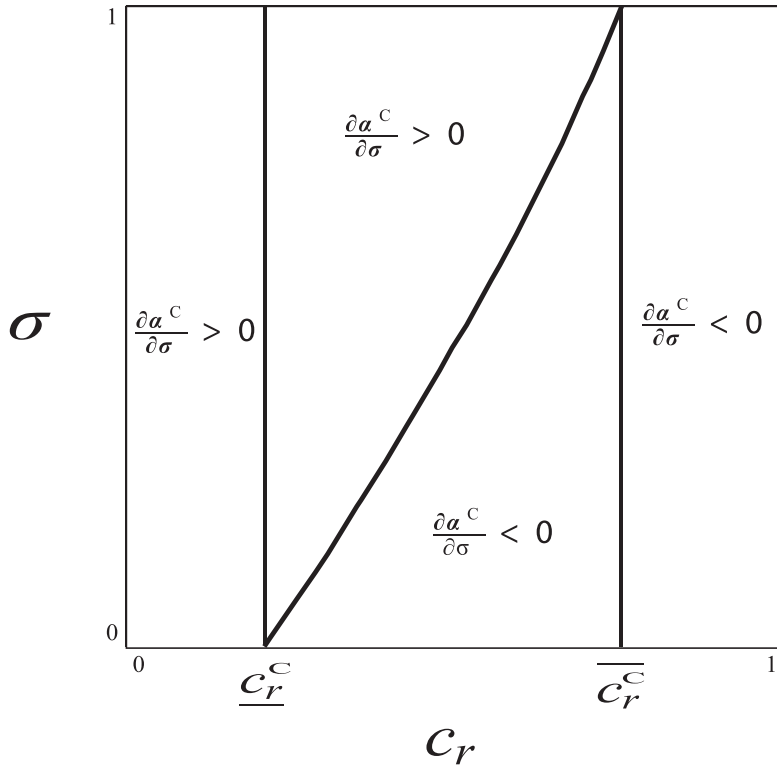


Figure 1: Illustration of Proposition 1

greater when the degree of HPD is large. Thus, intuitively, the regulator will set a low recycled content rate when the degree of HPD is small. In the case where the marginal cost of recycling is small, however, the effect of competition induces the regulator to set a high recycled content rate.

In contrast, in the case where the marginal cost of recycling is large, $c_r \in (\bar{c}_r^C, 1)$, firms suppress production activity. This results in consumer surplus damage. Hence, the regulator reduces the recycled content rate to enhance firms' production activity, which supports the consumer surplus. When the degree of HPD is smaller, the overall amount of production is small; hence, the regulator sets a low recycled content rate to enhance firm activity. In this case, the cost of increasing the recycled content rate dominates the benefit of the increase in the recycled content rate.

Finally, in the case of (b), which is in the range of $\sigma \in (0, \sigma^*)$, the benefit of increasing the recycled content rate is smaller than its cost; thus, the regulator sets a low recycled content rate to promote firm activity. In the range of $\sigma \in [\sigma^*, 1)$, the effect of Cournot competition is strong, and reduces the effect of the regulation, resulting in excessive production activity from the perspective of SW . Therefore, the regulator sets a high recycled content rate to reduce environmental damage (Fig. 2.c). In our model, there are two effects that arise from increasing the recycled content rate. One is increasing firms' marginal cost (the first term of (12)). The other is decreasing market size and reducing the segment of the inverse demand curve by lowering quality (the second term of (12)). These two effects are weak when the degree of HPD is small. In particular, with regard to the second effect, the segment is not affected as much as $\sigma \rightarrow 1$. Hence, when the degree of HPD is small, owing to the first effect, the regulator will set a high (low) recycled content rate to reduce waste (to promote firms' production activity).

4. Comparison of Bertrand and Cournot Competition

In this section, we consider firms engaged in price competition. In the first stage, the regulator sets the recycled content rate at a level that maximizes social welfare. In the second stage, firms simultaneously observe the recycled content rate and choose their prices. The equilibrium concept used in this game is the subgame perfect equilibrium (SPE). Thus, we solve this game by employing backward induction.

We obtain the demand function from the utility function (1) as follows:

$$x_i = \frac{1 - p_i + q_i - \sigma + p_j\sigma - 2q_j\sigma + q_i\sigma^2}{1 - \sigma^2}, \quad i = 1, 2. \quad (15)$$

The profit of firm i is

$$\pi_i = (p_i - \alpha c_r) \left(\frac{1 - p_i + q_i - \sigma + p_j\sigma - 2q_j\sigma + q_i\sigma^2}{1 - \sigma^2} \right), \quad i = 1, 2. \quad (16)$$

Therefore, we obtain the optimal recycled content rate that is chosen by the regulator (a derivation is proved in Appendix. A.4) as

$$\alpha^B = \frac{20 + 12c_r + 2\varepsilon(1 - \sigma) - 16\sigma - A_6}{16(1 + c_r - \sigma)}, \quad (17)$$

where

$$A_6 = \left\{ \begin{array}{l} 4[10 + 6c_r - 8\sigma + \varepsilon(1 - \sigma)]^2 \\ -32(1 + c_r - \sigma)[9 + c_r(1 - \sigma + 2\sigma^2) + 2\varepsilon(1 - \sigma) - \sigma(6 - 3\sigma + 2\sigma^2)]. \end{array} \right\}^{\frac{1}{2}}$$

Thus, we obtain Proposition 2 from this result.

Proposition 2. We consider the case where ε is quite small but takes a positive value. In this case, (a) the range $(0, \underline{c}_r^B)$ yields $\partial\alpha^B/\partial\sigma > 0$ for $\sigma \in (0, 1)$, and (b) the range $\in [\underline{c}_r^B, 1)$ yields $\partial\alpha^B/\partial\sigma < 0$ for $\sigma \in (0, \sigma^{**})$ and $\partial\alpha^B/\partial\sigma \geq 0$ for $[\sigma^{**}, 1)$.

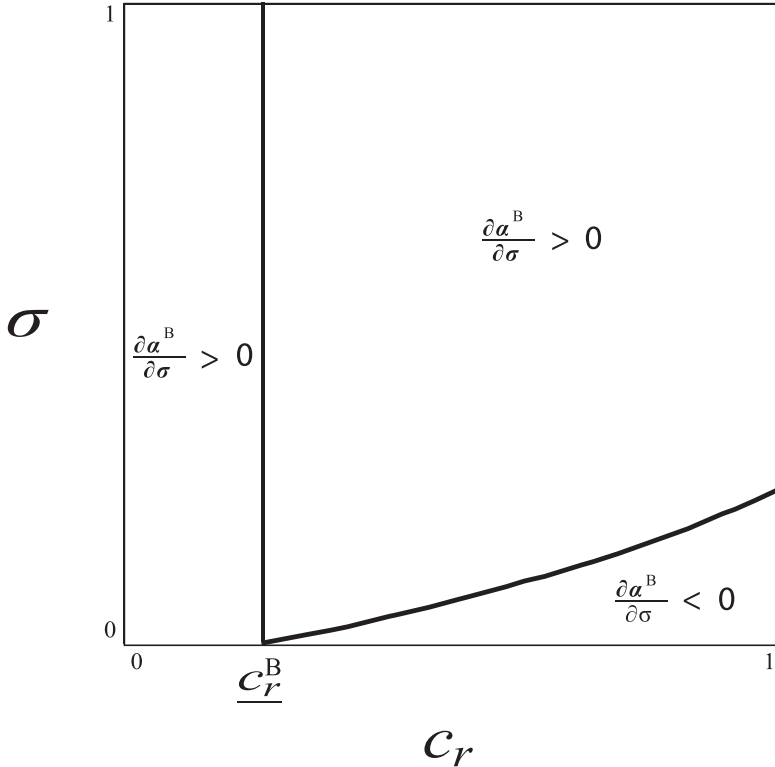


Figure 2: Illustration of Proposition 2

Proposition 2 is illustrated in Fig. 2. The horizontal and vertical axes are represented by c_r and σ , respectively. Unlike in Cournot competition, in the case where c_r is large, the regulator does not set a low recycled content rate when the degree of HPD is small for $\sigma \in (0, 1)$, as the competition effect is stronger under Bertrand competition. Therefore, the benefit of increasing the recycled content rate, which reduces waste, always dominates the cost of increasing recycling when the degree of HPD is small. We compare the optimal recycled content rates under Cournot competition and Bertrand competition. The result is quite intuitive. The Competition effect is stronger under Bertrand competition than under Cournot competition. Thus, the amount of waste is greater under Bertrand competition if the regulator chooses the same recycled content rate. Therefore, the regulator will choose a high recycled content rate to achieve as large an amount of waste as that under Cournot competition. This suggests that $\alpha^B > \alpha^C$.

Thus, we obtain Proposition 3.

Proposition 3. The optimal recycled content rate is higher under Bertrand competition than under Cournot competition; therefore, $\alpha^B > \alpha^C$ for $\sigma \in (0, 1)$, $c_r \in (0, 1)$ and $\varepsilon \in [0, \bar{\varepsilon}]$.

Proof. From the optimal recycled content rates under Cournot competition and Bertrand competition, we obtain,

$$\alpha^B - \alpha^C = \frac{A_5 - A_6}{16(1 + c_r - \sigma)}. \quad (18)$$

The sign of this condition is determined by $D - O$. We calculate $A_5^2 - A_6^2$ and obtain $A_5^2 - A_6^2 = 64(1 + c_r - \sigma)^2 \sigma^2 > 0$, implying that $A_5 > A_6$. Therefore, $\alpha^B > \alpha^C$.

5. Conclusion

In this paper, we studied the recycled content standard with differentiated products by focusing on two factors that affect production activity, resulting in waste. The first factor is the quality of the product. The second is the consumer's brand preference. A high recycled content standard is good for the environment because of reduced waste. However, from the perspective of consumers and producers, it may not be good since the use of recycled material reduces product quality relative to that of virgin material. Also, the consumer's brand preference affects the market power of the firm. In a market where consumers have a strong preference for a particular brand, each firm will have its own market, and thus, act as a monopoly. The amount of waste and consumer surplus depends on the firm's market power. Therefore, when a regulator sets a recycled content standard, it must consider not only environmental damage but also consumer and producer surpluses, including the consumer's preferences for products.

Our main finding concerns the relationship between the recycled content rate, which is set by a regulator, and the degree of horizontal product differentiation(HPD), which depends on

the marginal cost of recycling. In the case of Cournot competition, when the marginal cost of recycling is small, production activity is excessive from the perspective of social welfare. Moreover, because the effect of competition between firms reduces the rate of the regulation, the regulator enhances the recycled content standard when the degree of HPD is small. In contrast, when the marginal cost of recycling is large, firms suppress production activity, resulting in a loss of consumer surplus. Therefore, the regulator reduces the recycled content standard to promote firms' production activity when the degree of HPD is small. The findings from our model are a result of a substitution of the relationship between firms' quality and the low product quality arising from recycling activity. In such a scenario, there are two ways in which firms' behavior is affected by raising the recycled content rate. One is through the marginal cost of recycling and the other is through product quality. These effects are weak when the degree of HPD is small. With regard to the substitution of the relationship between firms' quality, firms scramble for market share when the degree of HPD is small; hence, the effect of competition is strong.

We also compare the optimal recycled content rates under Cournot competition and Bertrand competition. The optimal recycled content rate is higher under Bertrand competition than under Cournot competition, as competition has a greater effect on production activity under Bertrand competition than under Cournot competition. Based on our results, it is desirable for a regulator to consider the properties of the product and the cost of recycling activity when setting the recycling standard. Moreover, a regulator must determine the type of competition that firms are engaged in. For example, in the case of copy paper, it seems that consumers have less preference for brands; therefore, the degree of HPD is small and the marginal cost of recycling is high. In addition, firms are engaged in Cournot competition; hence, our results suggest that it is desirable for a regulator to set a low recycled content rate.

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Appendix

A. 1

The utility function used by Symeonidis (2003) is

$$U^S = x_i + x_j - \frac{x_i^2}{q_i^2} - \frac{x_j^2}{q_j^2} - \sigma \frac{x_i x_j}{q_i q_j} + M.$$

The partial derivatives of this utility function are $\frac{\partial^2 U^S}{\partial x_i \partial q_j} = \sigma \frac{x_j}{q_i q_j^2} > 0$. This means that there is a complementary relationship between the quality of firms i and j .

A. 2

From (9), (10) and (11), we obtain CS , PS and ED in the first stage as follows:

$$CS = \frac{(1 + \sigma)[-2\alpha(2(2 - \sigma) + \varepsilon(1 - \sigma))(1 + c_r - \sigma)(2 - \sigma)^2 + B_1]}{2(4 - \sigma^2)^2}, \quad (19)$$

$$PS = \frac{(4 - \alpha(1 + c_r - \sigma)(2 - \sigma) - \sigma(4 + 3\varepsilon - \sigma))^2 + B_2}{(4 - \sigma^2)^2}, \quad (20)$$

$$ED = \frac{(1 - \alpha)^2(2\alpha(1 + c_r - \sigma) - 2(2 - \sigma) - \varepsilon(1 - \sigma))^2}{(2 + \sigma)^2}, \quad (21)$$

where

$$B_1 = \left\{ \begin{array}{l} (2 - \sigma)^2[2\alpha^2(1 + c_r - \sigma) + 2(2 - \sigma)^2 + 2\varepsilon(2 - \sigma)(1 - \sigma)] \\ + \varepsilon^2(4 + 5\sigma^2)(1 - \sigma) \end{array} \right\},$$

and

$$B_2 = \{(2 - \sigma)[(2 - \sigma) - \alpha(1 + c_r - \sigma)] + \varepsilon(2 + \sigma^2)\}^2.$$

A. 3

In the case of Cournot competition, we show that Proposition 2 is robust for $\varepsilon \in [0, \bar{\varepsilon}]$. The upper bound of ε is the value such that $\partial U / \partial q_j = x_j - \sigma x_i \geq 0$. Thus, we obtain Proposition 4,

Proposition 4. In the case of Cournot competition, (a) the range $(0, \underline{c}_r)$ (resp. $(\bar{c}_r, 1)$) yields $\partial \alpha^C / \partial \sigma > (<) 0$ for $\sigma \in (0, 1)$, and (b) the range $[\underline{c}_r, \bar{c}_r]$ yields $\partial \alpha^C / \partial \sigma < 0$ for $\sigma \in (0, \sigma^{***})$ and $\partial \alpha^C / \partial \sigma \geq 0$ for $\sigma \in [\sigma^{***}, 1)$.

Proof. At first, we differentiate the optimal recycled content rate α^C with the respect to σ :

$$\frac{\partial \alpha^C}{\partial \sigma} = \frac{A_5(2 - c_r(2 + \varepsilon)) - B_3}{8A_5(1 + c_r - \sigma)^2}, \quad (22)$$

where

$$B_3 = \left\{ \begin{array}{l} 2(4 + 6\sigma^2 + \varepsilon) + 4c_r^3 + 2c_r^2(8 - 6\sigma + \varepsilon) \\ + c_r(4 + 2\varepsilon\sigma + \varepsilon^2\sigma + 12\sigma^2) - [2\sigma(6 + 2\sigma^2 + \varepsilon) + c_r(24\sigma + 4\varepsilon + \varepsilon^2)] > 0 \end{array} \right\}$$

for $\sigma \in (0, 1)$, $c_r \in (0, 1)$ and $\varepsilon \in [0, \bar{\varepsilon}]$. Therefore,

$$\text{sign} \left[\frac{\partial \alpha^C}{\partial \sigma} \right] = \text{sign}[A_5(2 - c_r(2 + \varepsilon)) - B_3]. \quad (23)$$

If $A_5(2 - c_r(2 + \varepsilon)) > (<) B_3$, then $\frac{\partial \alpha^C}{\partial \sigma} > (<) 0$. Obviously, if $(2 - c_r(2 + \varepsilon)) < 0$, then $\frac{\partial \alpha^C}{\partial \sigma} < 0$.

In this case, as we assume the value of ε to be small, the value of c_r is quite large. We consider the case where $(2 - c_r(2 + \varepsilon)) > 0$. After calculating, we obtain

$$[A_5(2 - c_r(2 + \varepsilon))]^2 - B_3^2 = -8(1 + c_r - \sigma)^2 \{\gamma(\sigma) - \psi(\sigma)\}, \quad (24)$$

where

$$\gamma(\sigma) = \left\{ \begin{array}{l} c_r[2c_r(c_r^2 + c_r(6 + \varepsilon) + 12\sigma^2) \\ + 4(7 + 6\sigma^2 - 2\sigma^3) + \varepsilon^2(2 - \sigma) + 2\varepsilon(5 + 4\sigma - \sigma^2)] \\ + 2[\varepsilon(1 + \sigma^2) + \sigma^2(6 - 4\sigma + \sigma^2)], \end{array} \right\}$$

and

$$\psi(\sigma) = [6 + c_r\varepsilon^2 + 2c_r^2(2 + 7\varepsilon + 2\varepsilon^2) + 2\sigma(4(2 + c_r) + 2c_r^2(8 + 2c_r + \varepsilon) + 2\varepsilon)]. \quad (25)$$

From (23) and (24), if $\gamma(\sigma) > (<) \psi(\sigma)$, then $\frac{\partial \alpha^C}{\partial \sigma} < (>) 0$. At first, we consider the case where c_r is quite small, $c_r \in (0, \underline{c}_r)$. In this case, we show that $\gamma(\sigma) > \psi(\sigma)$ for $\sigma \in (0, 1)$. The two functions $\gamma(\sigma)$ and $\psi(\sigma)$ are monotonically increasing at a rate of σ . Moreover, the slope of ψ is steeper than that of γ for any $c_r > 0$ and $\varepsilon > 0$. Therefore, if the segment of ψ is larger than that of γ , then $\psi > \gamma$ for $\sigma \in (0, 1)$, and this implies $\frac{\partial \alpha^C}{\partial \sigma} > 0$. This relationship is depicted in Fig.A.1. The segment is obtained when $\sigma = 0$;

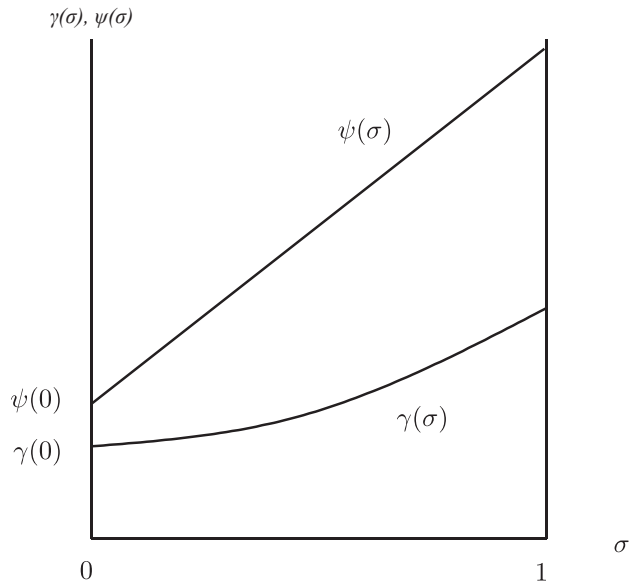
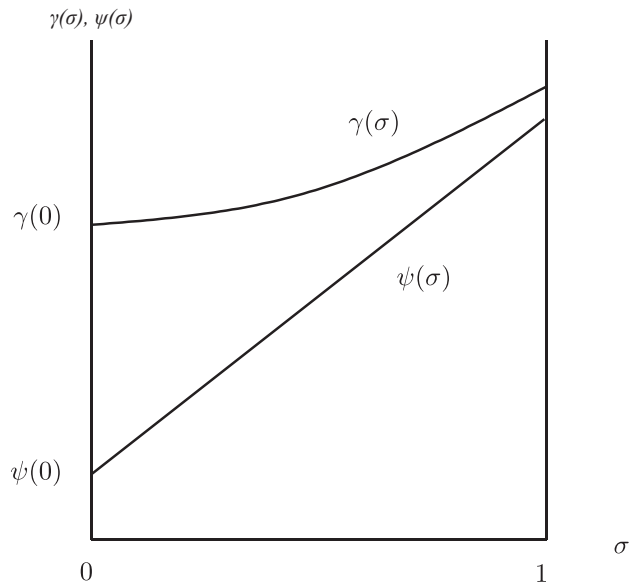
and we obtain

$$\gamma(0) - \psi(0) = -2(3 - \varepsilon) + c_r(28 + 10\varepsilon - \varepsilon^2) - 2c_r^2(2 + 7\varepsilon + 2\varepsilon^2) + 2c_r^3((6 + \varepsilon) + c_r). \quad (26)$$

Because we now consider c_r to be quite small, if the sign of $-2(3 - \varepsilon)$ is negative, then $\gamma(0) < \psi(0)$. The upper bound of ε that satisfies $\frac{\partial U}{\partial q_j} = x_j - \sigma x_i \geq 0$ for $\sigma \in (0, 1)$ is very small. If $\sigma \rightarrow 1$, then this condition is satisfied when ε is almost zero. Hence, the upper bound of ε is very small and $\bar{\varepsilon} < 3$. Therefore, $\gamma(0) < \psi(0)$ for $\sigma \in (0, 1)$ and $\varepsilon \in [0, \bar{\varepsilon}]$. Next, we consider the case where c_r is quite large, $c_r \in (\bar{c}_r, 1)$. If $c_r \rightarrow 1$ then $\gamma(0) - \psi(0) = 32 - 5\varepsilon^2 > 0$. Here, we consider the maximum values of γ and σ . The maximum value is obtained when $\sigma = 1$. If $\gamma(0) > \psi(0)$ and $\gamma(1) < \psi(1)$, then γ is larger than ψ for $\sigma \in (0, 1)$; therefore, $\frac{\partial \alpha^C}{\partial \sigma} < 0$. This relationship is depicted in Fig.A.2. We obtain

$$\gamma(1) - \psi(1) = 2(-8 + c_r^4 + c_r^3(2 + \varepsilon) + 2c_r(9 + 4\varepsilon) - c_r^2(12 + 9\varepsilon + 2\varepsilon^2)). \quad (27)$$

If $c_r \rightarrow 1$, then $\gamma(1) - \psi(1) = 2 - 4\varepsilon^2$. Hence, if $\varepsilon < 0.707$, then the sign is always positive. As mentioned above, the upper bound of ε is very small and $\bar{\varepsilon} < 0.707$. Therefore, $\frac{\partial \alpha^C}{\partial \sigma} < 0$ for $\sigma \in (0, 1)$. Finally, in the case where $c_r \in [\underline{c}_r, \bar{c}_r]$, the relationship between γ and ψ is denoted in Fig.A.3. Hence, there exists σ^{***} such that $\gamma \leq (>) \psi$ for $\sigma \in (0, \sigma^{***}]$ (resp. $\sigma \in (\sigma^{***}, 1)$) and $\varepsilon \in [0, \bar{\varepsilon}]$.

Fig. A.1: Relationship between γ and ψ for $c_r \in (0, \bar{c}_r)$.Fig. A.2: Relationship between γ and ψ for $c_r \in (\bar{c}_r, 1)$.

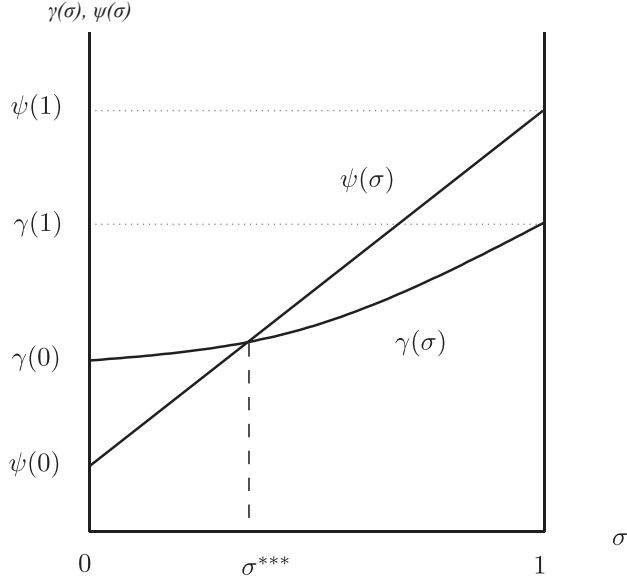


Fig. A.3: Relationship between γ and ψ for $c_r \in [\underline{c}_r, \bar{c}_r]$.

In the case of Bertrand competition, the robustness is ambiguous.

A. 4

Under Bertrand competition, we obtain equilibrium output, price, and profit in the second stage as follows:

$$x_i^B = \frac{(4 - \sigma^2)(1 - \sigma) + 2\varepsilon - \alpha B_4}{(4 - \sigma^2)(1 - \sigma^2)}, \quad x_j^B = \frac{(4 - \sigma^2)(1 - \sigma) - \varepsilon\sigma(3 - \sigma^2) - \alpha B_4}{(4 - \sigma^2)(1 - \sigma^2)}, \quad (28)$$

$$p_i^B = \frac{(4 - \sigma^2)(1 - \sigma) + 2\varepsilon - \alpha B_5}{4 - \sigma^2}, \quad p_j^B = \frac{(4 - \sigma^2)(1 - \sigma) - \varepsilon\sigma(3 - \sigma^2) - \alpha B_5}{4 - \sigma^2}, \quad (29)$$

$$\pi_i^B = \frac{((4 - \sigma^2)(1 - \sigma) + 2\varepsilon - \alpha B_4)^2}{(4 - \sigma^2)^2(1 - \sigma^2)}, \quad \pi_j^B = \frac{((4 - \sigma^2)(1 - \sigma) - \varepsilon\sigma(3 - \sigma^2) - \alpha B_4)^2}{(4 - \sigma^2)^2(1 - \sigma^2)}, \quad (30)$$

where $B_4 = (1 + c_r - \sigma)(2 - \sigma - \sigma^2)$ and $B_5 = \{2 - 3\sigma + \sigma^3 - c_r(2 + \sigma)\}$.

From this, we obtain CS^B , PS^B and ED^B ,

$$CS^B = \frac{-2\alpha[2(2 - \sigma) + \varepsilon(1 - \sigma)](1 + c_r - \sigma)(1 - \sigma)(2 + \sigma)^2 + B_6}{2(4 - \sigma^2)^2(1 - \sigma^2)}, \quad (31)$$

$$PS^B = \frac{4 + 2\varepsilon - 4\sigma - \sigma^2 + \sigma^3 - \alpha(1 + c_r - \sigma)(2 - \sigma - \sigma^2)]^2 + B_7}{(4 - \sigma^2)^2(1 - \sigma^2)}, \quad (32)$$

$$ED^B = \frac{(1 - \alpha)^2[2\alpha(1 + c_r - \sigma) - 2(2 - \sigma) - \varepsilon(1 - \sigma)]^2}{(2 + \sigma - \sigma^2)^2}, \quad (33)$$

where

$$B_6 = \left\{ \begin{array}{l} 2\alpha^2(1 + c_r - \sigma)^2(1 - \sigma)(2 + \sigma)^2 + 2(1 - \sigma)(4 - \sigma^2)^2 \\ + 2\varepsilon(2 - \sigma)(2 - \sigma - \sigma^2)^2 + \varepsilon^2(4 + \sigma^2 - \sigma^4) \end{array} \right\},$$

and

$$B_7 = [4 - (4 + 3\varepsilon)\sigma - \sigma^2 + (1 + \varepsilon)\sigma^3 - \alpha(1 + c_r - \sigma)(2 - \sigma - \sigma^2)]^2. \quad (34)$$

In the first stage, the regulator chooses the recycled content rate to maximize $SW^B = CS^B + PS^B - ED^B$. Subsequently, we obtain the optimal recycled content rate (17).

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