Product Design for Recycling and Recycling Industry

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ABSTRACT

Because of the fear of resource extinction and worsening of natural environment, companies and households have been gradually promoting the activities of reducing, reusing, and recycling of natural resources by the slogan '3Rs' representing those activities. We need to achieve building an efficient recycling system to reduce the burden of the environmental cost in production as well as consumption. In the production side, producers become conscious of the importance of renewable resource use and recycled material use in addition to the effort to make more efficient use of natural resources. For promoting recycling of end-of-life products and making efficient use of resources, one important method is to adopt the designs of produced commodities which make easier to recycle the commodities after their use, so that waste disposal could be decreased.

We investigate a recycling model on the basis of Eichner (2005). Our paper is different from his model in three aspects. First, in his paper it is the recycling firm rather than the producers that determines the level of the product design. Since the recycling firm determines the level of product design so that recycling cost is minimized, the social optimum level of product design can be achieved in the market economy. Hence, external diseconomies cannot be caused by product design. But our paper employs more realistic model in which the producers determine the level of product design. In this case, the producers decide the design level so as to minimize production cost. Therefore, we cannot achieve the efficient level of product design because recycling costs increase and thus external diseconomies appear. Second, since policy variables have been introduced in an arbitrary manner in Eichner (2005), it is hard to understand which policy can take care of which market failure. In our model there are three kinds of market failures, that is, monopoly, environmental externality, and product design externality. These three types of market failures are related to the production amount of a consumption good, the level of product design, and the recycling ratio, respectively. As policy instruments to resolve these failures, we can consider a production subsidy for the recycling firm as a monopolist, a waste tax imposed on the discarded waste to promote recycling, and a material subsidy to encourage the product design suitable to recycling. Third, we provide some comparative statics analysis so as to examine how the changes of the degree of an environmental damage caused by waste, the waste disposal cost of landfilled goods, and the price of the recycled materials affect the level of production, the product design, and the recycling ratio.

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1. Model and Social Optimum

We employ the model which is partial equilibrium in nature. The amount of a consumption good is denoted by y which is produced by the use of recycled materials, virgin materials and labor. The producers determine the attribution of the consumption good in addition to production level. The attribution of the consumption good is expressed by an index of product design q. It is assumed that the waste good can be recycled by a lower cost according to a greater q. The cost function of the producer is given by

$$C(y,q) = yF(q), \tag{1}$$

where $F(q)$ is the unit production costs of the consumption good with recyclability degree q and we suppose that $F_q > 0$, and $F_{qq} > 0$. For any consumption amount of the good, the same amount of the waste good is supposed to be generated. We assume that the producers collect the waste good and bring them into a recycling firm. The recycling firm produces recycled materials by the use of a part of the waste and discards the remaining by landfilling.

Then, for consumed amount of the consumption good y, we have

$$y = r + w, \tag{2}$$

where r and w are the recycled and discarded amounts of the waste good, respectively. Let α represent the recycling ratio of the wasted good. Then the followings hold:

$$r = \alpha y, \tag{3}$$

$$w = (1-\alpha)y. \tag{4}$$

Next we define the cost structure of a recycling firm. We assume that the recycling cost function is represented by the following function:

$$N = yG(q,\alpha), \tag{5}$$

where N is the cost to produce $r(=\alpha y)$ units of recycle materials from y units of the waste good. As for the function $G(q,\alpha)$, we assume that $G_\alpha \equiv \partial G/\partial\alpha > 0$, $G_{\alpha\alpha} \equiv \partial G_\alpha/\partial\alpha > 0$, $G_q \equiv \partial G/\partial q < 0$ and $G_{qq} \equiv \partial G_q/\partial q > 0$.

The consumption good market is supposed to be perfectly competitive and the producers of the consumption good determine the quality of the product design and produce the good by the use of recycled and virgin materials. These producers have an obligation to collect the used consumption good from households and hand bring them into a recycling firm. In the recycling market, only one firm exists so that the firm can act as a monopolist. This recycling firm receives the used consumption good from the consumption good producers and produce recycled materials which will be reused in the consumption good production. The non-recycled parts of the used consumption good are landfilled as waste. Finally the resource and material market is supposed to be perfectly competitive.

The linear inverse demand function of the consumption good is represented by $P(y)=\beta-\delta y$ where β and δ are strictly positive parameters. The landfilling of waste is supposed to cause an environmental damage. We assume that the marginal landfilling cost of end-of-life products is c^w and the marginal environmental damage by landfilling waste is c^d. Both c^w and c^d are positive and constant. Then the social welfare is

$$W(y,q,\alpha)=\int_0^y(\beta-\delta s)ds-yF(q)-yG(q,\alpha)-(c^w+c^d)(1-\alpha)y+\alpha yp^r\ , \qquad (6)$$

where p^r is the price of resources and materials for production.

Our first task is to demonstrate the socially optimal allocation which follows from the maximization of (6) with respect to y, q and α. Then the first-order conditions are obtained as

$$\beta-\delta y^*=F(q^*)+G(q^*,\alpha^*)+(c^w+c^d)(1-\alpha^*)-\alpha^*p^r, \qquad (7)$$

$$F_q+G_q=0, \qquad (8)$$

$$G_\alpha=c^w+c^d+p^r. \qquad (9)$$

where y^*, q^* and α^* are those of optimal values. If $G(q,\alpha)$ is convex for (q,α), the second-order condition is satisfied. (See Appendix for this.)

The efficient allocation of the consumption good is determined by equation (7). It means that the consumers' marginal payment for the consumption good which is the LHS of (7) equals the sum of its unit production cost, the net unit recycling cost ($G(q^*,\alpha^*)-\alpha^*p^r$), the marginal landfilling cost and the marginal environmental damage. Equation (8) shows that, for the recycling activity, the marginal cost of the design expressed by F_q should be equal to the marginal benefit from saving the recycling cost exhibited by $-G_q$. Equation (9) implies that the marginal cost to raise the recycling ratio is equal to the sum of the marginal landfilling cost, the marginal environmental damage, and the price of the recycled materials.

2. Market Equilibrium

In this section we investigate the market equilibrium. Our model introduces the concept that the consumption good producers have a responsibility to collect the-end-of life consumption good from households after consumption and to bring it to the recycling firm. When the collected end-of-life consumption good is brought into the recycling firm, the consumption good producers must pay a fee to the recycling firm for recycling service provided by the recycling firm. Japan and some countries in Europe, for example, adopt this system.

Since perfect competition prevails in the consumption good market, the profit maximizing behavior of a typical consumption good producer is formulated as

$$\max_{y,q} \Pi^y = (p^y - p)y - yF(q) + \sigma^m qy, \tag{10}$$

where p^y is the price of the consumption good, p is the price of the wasted good brought into the recycling firm and σ^m is a product design subsidy. The first-order conditions are given by

$$p^y - p - F(q) + \sigma^m q = 0, \tag{11}$$

$$F_q = \sigma^m. \tag{12}$$

The second-order condition also holds. The amount of the produced consumption good and the quality of product design are determined from (11) and (12). Especially the level of product design is determined as $q^m \equiv q(\sigma^m)$ by (12). Then, in view of (11) and the demand equation $p^y = \beta - \delta y$, the price of the recycling service is determined as

$$p = \beta - \delta y - F(q^m) + \sigma^m q^m \equiv P(y, q^m). \tag{13}$$

Next we consider the behavior of the recycling firm as a monopolist. The behavior of the firm is to maximize its profit with respect to y and α subject to (13), so that the optimization problem of the firm is described as

$$\max_{y,\alpha} \Pi^r = [(P(y, q^m) - \tau^y]y - yG(q, \alpha) - (p^w + \tau^w)(1-\alpha)y + p^r \alpha y, \tag{14}$$

where p^w is a landfilling charge, τ^y is a subsidy for recycling service and τ^w is a waste tax. Local government plays a role of discarding the non-recycled wastes by landfilling, so that the government charges p^w to the recycling firm for this one unit of cost. This means $p^w = c^w$. The first-order conditions for maximizing profit of the recycling firm are given by

$$\beta - 2\delta y = F(q^m) + G(q^m, \alpha) + \tau^y - \sigma^m q^m + (p^w + \tau^w)(1-\alpha) - p^r \alpha, \tag{15}$$

$$G_\alpha = p^w + \tau^w + p^r.$$

(16)

By virtue of (16), α is determined. This, together with (15), determines y. Then p^y is obtained from (11).

In this market equilibrium, there are three types of external diseconomies. First is the monopoly power of the recycling firm. Second is the environmental damage caused by landfilling the non-recycled waste. Third is the low quality of the product design to reduce the production cost. These three types of failures reveal that production, y, the level of product design, q, and the recycling ratio, α, tend to be lower under the market equilibrium than the socially optimal levels. In order to attain the socially optimal levels of these variables under the decentralized economy, we can use three policy instruments. They are a subsidy τ^y for the recycling service, a product design subsidy σ^m, and a waste tax, τ^w to reduce the land filling of the waste good. If these policies are appropriately introduced, economic efficiency is achieved in the decentralized economy. The following proposition presents the levels of these policies for the market equilibrium to be efficient.

3. Propositions

PROPOSITION 1. *If we set*

$$\tau^y = \delta y - G_q q^m - \alpha p^r,$$

$$\tau^w = c^d > 0,$$

$$\sigma^m = -G_q > 0,$$

then the market equilibrium becomes efficient, implying that the welfare can be maximized.

PROPOSITION 2. *The market equilibrium level of the product design is lower than that that of the social optimal level. And, if $G_{\alpha q} \leq 0$, the market equilibrium recycling ratio is lower than that of the social optimum.*

PROPOSITION 3. *For the market economy to be efficient, τ^y should be a subsidy (tax) when the undersupply due to monopoly power is larger (smaller) than the oversupply due to free riding on the environment in the recycling service and landfilling.*

PROPOSITION 4. *Concerning the socially optimum, increases in the landfilling cost and the environmental damage lessen the production level of the consumption good* y^**, and raise the level of the product design* q^* *and the recycling ratio* α^**.*

PROPOSITION 5. *At the social optimum, a rise in the price of the recycled material enhances the consumption good production* y^**, the level of the product design* q^**, and the recycling ratio* α^**.*

PROPOSITION 6. *In the market equilibrium, an increase in the landfilling cost of the waste decreases the amount of the consumption good* y^m*, and increases the recycling ratio* α^m*, but does not affect the quality of product design* q^m*.*

PROPOSITION 7. *In the market equilibrium, a rise in the price of the recycled material expands the consumption good supply* y^m*, as well as the recycling ratio* α^m*, but does not influence the level of product design* q^m*.*

4. Conclusion

In our paper, we construct a model where the perfectly competitive producers of the consumption good choose the product design which affects the recycling cost and the monopolistic recycling producer determine the volume of the recycling service and recycling ratio of the used consumption good. Economic efficiency cannot be attained since there are three types of market failures which are the lower level of the product design, and the smaller recycling ratio and the over or under supply of the recycling service. Thus we introduced three types of policy instruments, each of which corresponds to each type of the market failures and investigated how these market failures are solved by these policy instruments.

Then we examined the comparative static analysis on how changes in the recycling cost, the landfilling cost and the price of the recycled materials affect the consumption good supply, the recycling ratio and the level of the product design. By the analysis we showed that increases in the landfilling cost and the environmental damage by the waste reduce the socially optimal amount of the consumption good while an increase in the price of the recycled material expands it. We also showed that the increases of these exogenous variables necessarily raise the socially optimal levels of the recycling ratio and the product design. In the market equilibrium, the environmental damage by the waste has no effect on the equilibrium. The effects of the landfilling cost and the recycled material price have the same effect to the consumption good supply and the recycling ratio as in the case of the social optimum. However, these exogenous variables have no impact on the level of product design.

We can extend the present analysis to a various cases. For example, we consider the case where the consumption good producer is a monopolist and the case where there is a cost of the collection of the used up consumption good and thus only a part of the consumed amount of the consumption good is collected. More importantly, we should extend the model to a general equilibrium framework. These are our future topics.

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