E C O N O M I C S   B U L L E T I N

Economic Instruments and Resource Use in a Recyclable Product Market

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Abstract

By constructing a static model of a recyclable product market where the product can be manufactured by using both a recycled material and a harvested natural resource, we examine how different types of economic policy instruments affect resource harvesting activities of individual producers. In particular, we show that an increase in a recycling subsidy for consumers and an increase in a waste disposal fee on consumers can respectively lead to an increase in the resource harvest level. We explore the conditions under which these economic instruments are likely to backfire in terms of natural resource conservation.

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1 Introduction

It is often argued that an important objective of recycling activities is to reduce the society's demand for natural resources such as virgin timber and raw minerals (Kinnaman, 2006). As examples of economic instruments to facilitate recycling activities, environmental economists have studied the functions of policy measures that range from direct subsidies for recycling activities to more indirect policies such as taxes on the extractions of natural resources and volume-based disposal fees in collecting solid household wastes.

Existing studies on these economic instruments have mainly focused on demonstrating how a certain combination of policy instruments is able to attain the first-best, or the second-best result by considering the social cost of depleting natural resources as well as the costs of garbage disposal and landfill.[1] The scope of this note is rather limited, and we focus on examining how an individual economic policy measure affects the amount of a natural resource harvested by individual producers. Our main finding is that an increase in recycling subsidy for consumers and an increase in garbage disposal fee on consumers can respectively lead to an increase in the amount of a natural resource harvested by producers. Hence, under certain circumstances, these economic instruments can indeed accelerate the depletion of a natural resource stock.

2 The Model

Our static model of an economy with a recyclable product consists of L households and N producers ($L > 1$ and $N > 1$). We assume that both households and producers behave as price-takers. Let us start by describing a representative household's behavior.

2.1 The Behavior of a Household

A representative household consumes two kinds of consumer products, a recyclable product, q, and, a numeraire, z. We suppose that the consumption of q units of the recyclable product yields q units of waste to be disposed of by a household while the consumption of the numeraire generates no waste, for simplicity. Each household is rational or far-sighted

[1] Kinnaman and Fullerton (2000) concisely summarize the main findings of both theoretical and empirical studies on the economics of household waste management.

in the sense that, in determining how much of the goods it purchases, it takes into account the eventual waste disposal cost following its consumption. In disposing of its own waste, each household has two options. One is to use regular household garbage disposal service, and the other is to resort to municipal collection service specifically designed for subsequent recycling of household waste into a productive input.[2] We consider that the latter way of disposal causes some disutility to the household in sorting and treating its waste properly, as well as inconvenience involved in its temporary storage and the transportation of the waste to a proper collection site at a pre-specified date. The household must pay a volume-based fee, δ, per unit of its waste intended for recycling, r_S, to the collector of the recyclable waste.[3] On the other hand, the household must pay a fixed handling charge of τ per unit of garbage, g, for regular garbage disposal service. Note that we always have $g = q - r_S$. We assume that δ is strictly smaller than τ.

Under these settings, a representative household's problem is to solve the following constrained utility maximization problem with respect to the demand for the recyclable product, q_D, the supply of the recyclable waste, r_S, and the consumption level of the numeraire z:

$$\underset{q_D, r_S, z}{Max} \; U = u(q_D, r_S) + z, \tag{1}$$

$$s.t. \quad pq_D + z + \delta r_S + \tau g \leq w \tag{2}$$

$$q_D \geq r, \tag{3}$$

where p and w are the output price of the recyclable product and the household's total income, respectively. In (1), $u(q_D, r_S)$ is a part of the household's utility level that is associated with the recyclable product. We suppose that it has the following properties: $u_{q_D} > 0, u_{q_D q_D} < 0, u_{r_S} < 0, u_{r_S r_S} < 0$, and $u_{r_S q_D} = 0$.[4]

[2] Municipal collection service of general and recyclable garbages are quite prevalent (Walls, Macauley and Anderson, 2005). We assume that neither a household nor a producer do not take into account the potential impacts of profit or loss incurred by a waste collecting municipality.

[3] We consider here that the actual collectors of the recyclable waste are municipal governments, which can sell the waste to the producers afterwards and distribute the profit in a lump-sum manner. Also, note that a household does not receive any monetary payment from the producer, as opposed to what is typically assumed in existing studies. We have confirmed that the inclusion of the monetary payment for supplying the recycling input into the household's budget constraint does not alter the qualitative results of the comparative statics significantly.

[4] The last property on the cross-partial term implies that the utility function is additively-separable,

The first-order conditions for the utility maximization problem are

$$u_{q_D}(q_D, r_S) - p - \tau = 0, \tag{4}$$

$$u_{r_S}(q_D, r_S) - \delta + \tau = 0. \tag{5}$$

These are fairly straight-forward marginal conditions. In particular, (5) implies that the amount of the recyclable input supply is determined by a household in such a way that the marginal disutility of treating its waste for the recycling purpose is equal to the difference between the collection fees of regular waste and of the recyclable input.

2.2 The Behavior of a Producer

Now we turn to a representative firm's behavior. A firm's objective is to maximize its profit by selling the recyclable product, q. Each producer can process the recyclable waste it obtains to create an input which can be used for producing the original output.[5] The producer also uses a virgin input harvested from its own natural resource stock as an input. The production function of the recyclable product is $q(h, r_D)$, where h is the amount of the harvested natural resource and r_D is the amount of the recyclable input which the firm obtains. We suppose that this production function has the following properties: $q_h > 0, q_{hh} < 0, q_{r_D} > 0, q_{r_D r_D} < 0$, and $q_{hr_D} > 0$.[6]

The profit maximization problem of a representative firm can be written as

$$\underset{h,r_D}{Max}\ \Pi\left(h, r_D\right) = pq(h, r_D) - C(h) - th - p_r r_D, \tag{6}$$

where the convex function $C(h)$ signifies the cost of harvesting and processing the virgin natural resource for the production purpose, t is the per-unit tax on the harvested

which is a standard assumption when the cost of treating recyclable wastes is explicitly incorporated.

[5]Although quite unrealistic, we suppose, for the sake of simplicity, that the firm can transform the recyclable waste into the production input costlessly. The inclusion of such a cost will not alter any qualitative results of this study.

[6]The last property implies that the marginal product of the recyclable input increases as the use of the harvested input rises. Indeed, utilizing a recycled input exclusively in a production process tends to become very costly or even impossible as the production level increases, as is exemplified by some cases of paper and plastic products where their production and consumption processes significantly alter the qualities of the inputs. As a result, it becomes increasingly difficult to produce a quality product by more disproportional use of a recycled input.

resource, and p_r is the price per unit of the recyclable input, which is determined within the recyclable input market.

The first-order conditions for profit maximization are

$$pq_h(h, r_D) - C_h(h) - t = 0, \tag{7}$$

$$pq_{r_D}(h, r_D) - p_r = 0. \tag{8}$$

2.3 Market Equilibrium

Finally, as both the product and input markets need to clear in equilibrium, we have the following two market equilibrium conditions:

$$Lq_D = Nq(h, r_D), \tag{9}$$

$$Lr_S = Nr_D, \tag{10}$$

where (9) is for the output market and (10) is for the recyclable input market. The market equilibrium is described by (4), (5), (7), (8), (9) and (10).

3 Comparative Statics

Totally differentiating (4), (5), (7), (8), (9) and (10) with respect to the endogenous variables and policy variables, we are able to conduct comparative statics analysis of our model. The main finding can be summarized in the following proposition:

Proposition 1. *An increase in a recycling subsidy for households and an increase in a disposal fee on household waste respectively have ambiguous impacts on the level of the natural resource harvested by firms, whereas the increase in the tax on the resource harvest necessarily discourages the firm's harvesting effort.*

Proof. See the comparative statics results in Appendix. **Q.E.D.**

This proposition hints a rather alarming possibility that an attempt to encourage the recycling activities by way of an increase in a recycling subsidy for consumers as well as an increase in a garbage disposal fee actually leads to a detrimental consequence in the light of natural resource conservation.

We can explain the mechanisms behind Proposition 1 as follows. On the one hand, an increase in the subsidy encourages the households to conduct more recycling activities and raises the availability of the recyclable input in this input market, which induces the firms' input substitution toward this recyclable input. On the other hand, due to an increase in this subsidy, the consumers' demand for the recyclable output rises, which can raise the firm's input demand for the natural resource. Proposition 1 indicates the possibility that the interactions of these effects in the output and input markets may result in an increase in the resource harvesting activities. It is also intriguing to note that the sign of the change in the price of the recyclable input with respect to the increase in a recycling subsidy is ambiguous because of the hike in the firm's production level.

The impacts of an increase in the volume-based garbage fee work quite differently. Its increase certainly dampens the household's demand for the output as it implies an increase in its overall disposal cost. At the same time, it encourages the recycling activities by the households as this mode of disposal becomes economically more attractive, which has a favorable impact on the firm's production through an increase in the availability of the recyclable input. These two considerations produce ambiguous results not just in the output quantity and recyclable input price levels but also in the firm's demand for the natural resource input.

Let us look more closely into the comparative statics results in order to obtain the conditions under which an economic measure backfires in terms of inducing greater resource harvesting efforts by the firms. As for the effect of providing a recycling subsidy for households upon the natural resource harvest, we can obtain the following proposition:

Proposition 2. *An increase in a recycling subsidy for households is more likely to increase the natural resource harvested by firms when 1) the marginal utility of the recyclable product, q, diminishes slowly, 2) the marginal product of the recycled input, r, is lower, 3) the number of households in an economy, L, is sufficiently larger relative to the number of resource-owning firms, N, and 4) the magnitude of the cross-partial derivative, q_{hr_D}, is more significant.*

Proof. Through the examination of the comparative statics result of h with respect to δ, i.e., (A2) in Appendix, we can derive the above conditions that contribute to making its overall sign turns out to be negative. **Q.E.D.**

The first condition concerns the household's preference for the recyclable output. When the household possesses less risk-averse preference with respect to the recyclable product, such a situation is more likely to occur. In addition, this is likely to be the case when the absolute consumption level is relatively small. These situations are probably more applicable to developing countries rather than developed countries.

Secondly, lower productivity of the recyclable input tends to increase the firms' reliance on the natural resource input in order to cater to the increased consumers' demand for the product after the increase in the recycling subsidy. This case is more plausible in an industry where a recycling-related production technology is still in its infancy.

The third condition can be interpreted in the context of the abundance of the concerned natural resource in an economy in relation to its population size. It implies that, when the population size is relatively larger, given a fixed number of resource owning firms, the increase in the recycling subsidy is more likely to contribute to the depletion of the natural resource stock. This suggests that the government of such a resource scarce nation needs to be more careful in their choices of economic instruments.

Finally, the last condition states that this backfire case is likely to occur when the marginal productivity of the recyclable input can be enhanced greatly by the concurrent use of the natural resource input. This is presumably the case in paper and plastic industries where it becomes increasingly more difficult to produce a high quality product with the disproportional use of a recycled input.

Furthermore, we can obtain the following proposition concerning the effects of imposing a disposal fee on household waste:

Proposition 3. *An increase in a garbage disposal fee on households is more likely to increase the natural resource harvested by firms when 1) the marginal utility of the recyclable product, q, diminishes slowly, 2) the marginal product of the recycled input, r, is* *lower, 3) the number of households in an economy, L, are large relative to the number of resource-owning firms, N, 4) the magnitude of the cross-partial derivative, q_{hr_D}, is more significant, and 5) the marginal disutility of recycling increases slowly.*

Proof. By closely examining the comparative statics result of h with respect to τ, i.e., (A3) in Appendix, we can derive the above favorable conditions that make its overall sign negative. **Q.E.D.**

This proposition identifies the conditions under which an increase in the volume-based garbage fee on consumers backfires in terms of inducing greater resource harvesting efforts by firms. Indeed, the first four observations coincide with those obtained in Proposition 2 for the recycling subsidy whereas the ways in which these two policies function are not exactly the same as we have seen above. As for the last condition, one possible explanation can be provided in the context of the opportunity cost of time for households. This condition is applicable when the opportunity cost of time increases rather slowly, which is again typical of households in developing nations where good employment opportunities are rather limited.

4 Concluding Remarks

In this note, we have found that an increase in a recycling subsidy for consumers and an increase in a disposal fee on household waste can respectively contribute to an increase in the harvesting efforts of a natural resource input by firms. Overall, our investigations indicate that a resource-scarce developing nation is more liable to witness those backfire cases. Our finding calls for, at least, more careful implementations of these economic instruments.

As a direction of future studies, an important extension of our static model is to incorporate dynamic aspects of recycling activities and natural resource use, especially taking into account the evolution of a resource stock. Also, it would be interesting to examine how the presence of market power can alter our analytical outcomes.

References

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Appendix: Comparative Statics Results

Based on this system of equations, (4), (5), (7), (8), (9), and (10), we can obtain the so-called comparative statics equation as follows:

$$\begin{bmatrix} u_{q_D q_D} & u_{q_D r_S} & 0 & 0 & -1 & 0 \\ u_{r_S q_D} & u_{r_S r_S} & 0 & 0 & 0 & 0 \\ 0 & 0 & pq_{hh} - C_{hh} & pq_{hr_D} & q_h & 0 \\ 0 & 0 & pq_{r_D h} & pq_{r_D r_D} & q_{r_D} & -1 \\ -L & 0 & Nq_h & Nq_{r_D} & 0 & 0 \\ 0 & L & 0 & -N & 0 & 0 \end{bmatrix} \begin{bmatrix} dq_D \\ dr_S \\ dh \\ dr_D \\ dp \\ dp_r \end{bmatrix} = \begin{bmatrix} d\tau \\ d\delta - d\tau \\ dt \\ 0 \\ 0 \\ 0 \end{bmatrix},$$

where the sign of the determinant of the Jacobian matrix, J, can be found eventually as:

$$|J| = (-L)u_{r_S r_S}(pq_{hh} - C_{hh})(-N) - Nq_{hh}u_{r_S r_S}(-N) > 0. \tag{A1}$$

Given (A1) and the assumptions on the household's utility and firm's production functions described in the text, we can obtain the following comparative statics results with respect to the three different types of economic instruments:

$$\frac{\partial q_D}{\partial \delta} = \frac{(pq_{hh} - C_{hh})Nq_D L - pq_{hr_D}Nq_h L}{|J|} < 0,$$

$$\frac{\partial r_S}{\partial \delta} = \frac{(-1)[-(pq_{hh} - C_{hh})(-L)(-N)] - q_h u_{q_D q_D} Nq_h(-N)}{|J|} < 0,$$

$$\frac{\partial h}{\partial \delta} = \frac{(-L)Lpq_{hr_D} + q_h(-u_{q_Dq_D}LNq_{r_D})}{|J|} \gtreqless 0, \tag{A2}$$

$$\frac{\partial p}{\partial \delta} = \frac{u_{q_Dq_D}(pq_{hh} - C_{hh})Nq_{r_D}L}{|J|} > 0,$$

$$\frac{\partial p_r}{\partial \delta} = \frac{Lu_{q_Dq_D}[q_{hh}pq_{r_Dr_D}N + q_{r_D}(pq_{hh} - C_{hh})N(1 + q_{r_D})] + L^2(pq_{hh} - C_{hh})pq_{r_Dr_D}}{|J|} \gtreqless 0,$$

$$\frac{\partial q_D}{\partial \tau} = \frac{-(pq_{hh} - C_{hh})Nq_{r_D}L - (-pq_{hr_D}Nq_hL) - q_hu_{r_Sr_S}Nq_h(-N)}{|J_1|} \gtreqless 0,$$

$$\frac{\partial r_S}{\partial \tau} = \frac{-(pq_{hh} - C_{hh})(-N)(-L) + q_hu_{q_Dq_D}Nq_h(-N)}{|J_1|} > 0,$$

$$\frac{\partial h}{\partial \tau} = \frac{-(-L)Lpq_{hr_D} - q_h[-u_{r_Sr_S}(-L)(-N)] - q_h(-u_{q_Dq_D}LNq_{r_D})}{|J|} \gtreqless 0, \tag{A3}$$

$$\frac{\partial p}{\partial \tau} = \frac{(-L)Nu_{q_Dq_D}[(pq_{hh} - C_{hh}) + (pq_{hh} - C_{hh})q_{r_D} - pq_{hr_D}q_h]}{|J|} < 0,$$

$$\frac{\partial p_r}{\partial \tau} = \frac{-Lu_{r_Sr_S}[pq_{r_Dh}(-N)q_h - q_{r_D}(pq_{hh} - C_{hh})] + L^2[-(pq_{hh} - C_{hh})pq_{r_Dr_D} + pq_{hr_D}pq_{hr_D}]}{|J|}$$

$$+\frac{Lu_{q_Dq_D}[pq_{hr_D}q_{r_D}Nq_h + pq_{hr_D}Nq_{r_D}q_h - q_hpq_{r_Dr_D}Nq_h - (pq_{hh} - C_{hh})Nq_{r_D}q_{r_D}]}{|J|} \gtreqless 0,$$

$$\frac{\partial q_D}{\partial t} = \frac{-u_{r_Sr_S}Nq_h(-N)}{|J|} < 0,$$

$$\frac{\partial r_S}{\partial t} = \frac{0}{|J|} = 0,$$

$$\frac{\partial h}{\partial t} = \frac{(-1)[-u_{r_Sr_S}(-L)(-N)]}{|J|} < 0.$$