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Waste Recycling under Take-back and Tax/Subsidy Mechanisms

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***Abstract*—In the implementation of extended producer responsibility (EPR) principle on waste management, some countries use a take-back mandate mechanism in which manufacturers bear responsibility to recycle their products till they reach a mandated recycling rate level. Other countries follow a tax/subsidy mechanism in which manufacturers pay an advance disposal fees; the government intervenes in transferring the payment received from manufacturers to subsidize the recycling sector. The purpose of this paper is to compare the relative performance of these two EPR mechanisms on the waste recycling rate. We found that when the recycling technology is relatively efficient, the recycling rate is higher under the tax/subsidy mechanism than the take back mandate mechanism. This result is reversed when the recycling technology becomes less efficient.**

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I. INTRODUCTION

In the recent decade, waste management has gone beyond imposing duties on households only, and has moved toward placing more responsibility on manufacturers. This emerging policy direction has been labeled as the extended producer responsibility (EPR) mechanism (OECD, 1996). Many countries have implemented their waste recycling policies based on EPR. Some countries such as Germany, United Kingdom and Korea prefer a take-back mechanism in which the government sets up a recycling rate target and ask manufacturers to take direct responsibility for recycling in order to achieve the target. Some other countries such as Taiwan, follow a tax/subsidy mechanism where manufacturers bear only financial responsibility by paying waste recycling fees and the government intervenes by transferring the fees to subsidize the recycling sector. This paper intends to compare the relative performance of these two EPR mechanisms on the waste recycling rate.

The focus of this paper is to compare the performance of these two EPR mechanisms. In particular, we are interested in exploring which mechanism can reach a higher recycling rate in the pursuit of maximum social welfare. To do so, we shall construct two models to represent the two EPR mechanisms. Both mechanisms are under the same production and recycling markets conditions. The only difference is on their institutional setting in recycling responsibility born by manufacturers. Through our theoretical analysis, we intend to explore more policy insights in the choice of EPR mechanisms.

II. THE SETTING OF THE MODELS

We consider an economy with one manufacturer and many recyclers. The manufacturer is a monopolist in the output market and produces output Q with no production costs.[1] Assume that there are many recyclers in the recycling sector; the recycling market is prefect competitive. The manufacturer in our model is a monopsonist in the recycling service market as well as a monopolist in the output market.[2]

Under the principle of EPR, the manufacturer needs to bear recycling responsibility. Assume that one unit of output generates one unit of waste.[3] The manufacturer does not recycle its waste; it delegates the job to the recycling sector. Denote X as the amount of recycling and defines $C(X)$ as the total recycling cost with $C' > 0$ and $C'' > 0$. The recycling rate is defined as the amount of recycled divided by total output, i.e. $\frac{X}{Q}$. The economy in the end has (Q-X)

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[1] The focus of this paper is on waste recycling, we thus simplify the model by assuming zero production costs.

[2] This assumption is to emphasize the fact that manufacturers under the take-back mandate often form a ‘producer responsibility organization,” to handle recycling jobs. Such organization is a monopsonist in the recycling service market.

[3] This assumption is to satisfy the material balance requirement described in Walls and Palmer (2001). As an example, one can think of the PVC bottle market. One PVC bottle generates one bottle of waste if it is not recycled.

amount of waste that is not being recycled. We further assume each unit of discharged waste will cause e units of environmental damage with $e>0$.

The difference between the two EPR mechanisms is characterized by the manufacturer's responsibility on waste recycling and the associated policy instrument set up by the government. Under the take-back mandate mechanism, the government determines an endogenous recycling rate as its policy instrument. To fulfill the government's recycling mandate, the manufacturer needs to pay to the recycling sector to accomplish the endogenous recycling target.

The government's policy instrument is different under the tax/subsidy mechanism. As in this regime, the government directly intervenes in recycling services by subsiding, the manufacturer bears only financial responsibility. More specifically, the government determines a social optimal output tax rate and a recycling subsidy rate to be imposed on the manufacturer and the recycling sector respectively. Given the tax and the subsidy rates, the manufacturer determines its output and the recycling sector chooses the amount of recycling. The manufacturer does not interact with the recycling sector directly.

In order to better explain our findings, we assume that (i) the recycling costs is a convex function with $C(X)=kX^2/2$ where $k>0$ represents the recycling efficiency and a higher k implies a lower recycling efficiency and (ii) the inverse demand function is $P(Q)=1-Q$. To ensure that the recycling rate is between zero and one, we further assume that the relationship between recycling efficiency and the marginal environmental damage must satisfy: $k \geq \frac{e}{1-e}$. Moreover, to ensure a positive output tax rate, we further assume $e > 1/2$ holds. With these settings we build two models to represent each EPR mechanism and further to compare their equilibrium recycling rates to gain more policy insights.

III. The Take-back Mandate Mechanism

There are two stages in the take-back mandate mechanism model. At the first stage, the government determines a recycling rate to mandate on the manufacturer. At the second stage, the manufacturer decides an optimal output based on the government's recycling mandate. Delegated by the manufacturer, the recycling sector also determines its optimal amount of recycled materials at the second stage. We solve this game in a backward fashion.

The recycling sector's profit function π^R is represented as the following[4]:

$$\underset{X}{Max} \quad \pi^R = vX - C(X) \tag{1}$$

[4] As we assume that the recycling sector is perfectly competitive. Each firm in the sector earns only 1/n of the profits as specified in equation (1) where n is the number of firms in the sector.

where v is the recycling fee paid (and determined) by the manufacturer to the recycling sector for each unit of waste recycled. Overall, the recycling sector receives vX from the manufacturer. The recycling costs are $C(X)$. The first-order condition for profit maximization of (1) is:

$$v - C'(X) = 0 \tag{2}$$

By assumption, the second-order condition $-C'' < 0$ is satisfied. Thus, the optimal amount of recycled X is determined at the level where the unit recycling fee v equals to the marginal recycling cost. From (2) it is straightforward to show that the recycling sector's optimal amount of recycling X is positively related to v. If the manufacturer wants to recycle more X, it needs to pay a higher v to the recycling sector. We can therefore write the recycling sector's inverse supply function as $v = v(X)$ with $v' > 0$.

On the other hand, the manufacturer's profit function π^M can be expressed as next:

$$\underset{Q}{Max} \quad \pi^M = P(Q)Q - v(X)X \qquad s.t. \quad X = \alpha Q \tag{3}$$

where $P(Q)$ is the inverse demand function for output Q and α is the mandated recycling rate set by the government. Plugging $X=\alpha Q$ into equation (3), we can rewrite the manufacturer's profit function as follows:

$$\underset{Q}{Max} \quad \pi^M = P(Q)Q - v(\alpha Q)\cdot \alpha Q$$

The optimal output is determined by the following first-order condition:

$$P(Q) + P'(Q)Q - \alpha[v(\alpha Q) + v'(\alpha Q)\alpha Q] = 0 \tag{4}$$

Assume the second-order condition is satisfied. The optimal output Q is determined at the level where the marginal revenue of output equals to the marginal cost of recycling. Applying the recycling cost and output demand functions $C(X)=kX^2/2$ and $P(Q)=1-Q$ into the model, we can calculate the manufacturer's optimal output Q, the optimal amount of recycling X and the recycling fee v as:

$$Q = \frac{1}{2(1+\alpha^2 k)}, \; X = \frac{\alpha}{2(1+\alpha^2 k)} \text{ and } v = \frac{\alpha k}{2(1+\alpha^2 k)} \tag{5}$$

Let us solve the government's social welfare maximization problem next. The social welfare function is characterized as the following:

$$\underset{\alpha}{Max} \; W = \int_{s=0}^{Q(\alpha)} P(s)ds - C(X(\alpha)) - e\cdot[Q(\alpha) - X(\alpha)]$$

where the first two terms capture the consumer surplus and producer surplus, and the third term represents the pollution damage. Denote the social optimal recycling rate as α^*. The first-order condition for the welfare maximization is:

$$W_\alpha = [P(Q) - e]Q_\alpha - [C'(X) - e]X_\alpha = 0$$

Using the specified recycling cost and output functions, we can calculate the equilibrium recycling rate under the take-back mandate mechanism as follows:

$$\alpha^* = A + (A^2 + \frac{1}{k})^{\frac{1}{2}} \quad \text{where } A = 1 - \frac{3}{4e} \tag{6}$$

Under the take-back mandate mechanism, the equilibrium recycling rate is affected by the size of marginal environmental damage and recycling efficiency.

IV. THE TAX/SUBSIDY MECHANISM

Under the tax/subsidy mechanism, the manufacturer is asked to pay a waste disposal output tax to the government. The government then uses this tax revenue to subsidize the recycling sector. There are two stages in this model. At the first stage, the government determines the optimal tax rate and the subsidy rate. At the second stage, the manufacturer determines its optimal output level and the recycling sector determines its optimal amount of recycling.

We start by solving the manufacturer and the recycling sector's problems. The recycling sector's profit function $\hat{\pi}^R$ and the manufacturer's profit function $\hat{\pi}^M$ can be written as:

$$\underset{X}{Max} \quad \hat{\pi}^R = sX - C(X) \tag{7}$$

$$\underset{Q}{Max} \quad \hat{\pi}^M = [P(Q) - t]Q \tag{8}$$

where s and t represent the subsidy rate and the tax rate respectively. The first-order conditions for the profit maximization are:

$$s - C'(X) = 0 \tag{9}$$

$$P(Q) + P'(Q)Q - t = 0 \tag{10}$$

From equation (9) we find that the recycling sector's optimal amount of recycling X depends solely on the level of subsidy rate s, i.e. $X = X(s)$. As the subsidy rate increases, the recycling sector's optimal amount of recycling also increases. The manufacturer's optimal output, on the other hand, is determined solely on the tax rate t, i.e. $Q = Q(t)$. A higher tax rate will decrease the manufacturer's optimal output. Moreover, applying the specific recycling cost and output demand functions into the model, we can calculate the optimal output and the amount of recycling as follows:

$$Q = \frac{1-t}{2} \text{ and } X = \frac{s}{k} \tag{11}$$

Next, we move to the first stage to solve the government's problem. The government's objective function is similarly defined as:

$$\underset{s,t}{Max} \quad G = \int_{z=0}^{Q(t)} P(z)dz - C(X(s)) - e[Q(t) - X(s)] \tag{12}$$

The first-order conditions for the welfare maximization are:

$$G_s = [e - C'(X)]X_s = 0 \tag{13}$$

$$G_t = [P(Q) - e]Q_t = 0 \tag{14}$$

Utilizing the two specified functions, we can further calculate the equilibrium tax rate and subsidy rate, denoted as $\hat{t}$ and $\hat{s}$ respectively, as follows:

$$\hat{t} = 2e - 1$$
$$\hat{s} = e$$

As $e > 1/2$ by assumption in section 2, the equilibrium tax rate must be positive.[5]

V. THE COMPARISON

This section compares the performance of the two EPR mechanisms on the recycling rate. Recall that the equilibrium recycling rate under the take-back mandate mechanism is $\alpha^* = A + (A^2 + \frac{1}{k})^{\frac{1}{2}}$ where $A = 1 - \frac{3a}{4e}$ and the equilibrium recycling rate under the tax/subsidy mechanism is $\hat{\alpha} = \frac{e}{k(a-e)}$. Comparing the relative magnitudes of the two recycling rates, we find that $\hat{\alpha} \geq \alpha^*$ if $k \leq \frac{e}{1-e} \cdot \frac{2e}{2e-1}$. Recall that for an interior solution to exist, we have assumed $k \geq \frac{e}{1-e}$. We thus can conclude the following proposition:

Proposition: If the recycling is efficient (i.e. $k \leq \frac{e}{1-e} \cdot \frac{2e}{2e-1}$*), then the recycling rate is higher under the tax/subsidy mechanism than the take-back mandate mechanism. Contrarily, if recycling is inefficient (i.e.* $k > \frac{e}{1-e} \cdot \frac{2e}{2e-1}$*), then this result is reversed.*

This proposition shows that the relative magnitude of the recycling rates under the two mechanisms depend on the recycling efficiency. Other things being equal, if the recycling cost is high, the performance of the take-back mandate mechanism (in terms of recycling rates) is superior to the tax/subsidy mechanism. This result is reversed if the recycling cost is low. The intuition of this result is as follows. Under the tax/subsidy mechanism, the government can use two policy instruments (tax and subsidy) to correct the entire distortions. As a result, the recycling rate and the

[5] The reason that we assume that the social optimal tax rate is positive is to match with the real situation in Taiwan. Theoretically, the optimal tax rate can be negative and this happens when environmental damage e is small.

associated output and the amount of recycling in the tax/subsidy mechanism are always the first-best. In contrast, under the take-back mandate mechanism, the government only has one policy instrument which is the mandated recycling rate to rectify the two distortions in the economy. Consequently, the recycling rate and the associated output and the amount of recycling under the take-back mandate are away from the first-best solutions.

VI. Policy Implications and Conclusion

In this paper, we have compared the waste recycling rates under the take-back mandate and the tax/subsidy mechanisms. Through our discussions, we have had an interesting finding which might be helpful to a government when selecting an EPR mechanism in waste recycling management. Based on our analysis, the performance of the two EPR mechanisms depends on recycling efficiency. If the recycling is efficient, the tax/subsidy EPR mechanism can reach a higher recycling rate. This result is independent on the magnitude of the environmental damage.

We can use our finding to comment on the Taiwan's recycling institutional reform in 1998 which switched from the take-back mandate to the tax/subsidy EPR mechanism. Before 1998, the manufacturers in Taiwan were required to have their recyclables collected and disposed appropriately by the EPA. The manufacturers thus sponsored several nonprofit organizations to achieve the EPA's mandatory recovery and recycling rate. However, due to the lack of incentives and corruption, the take-back mandate EPR failed in Taiwan. To improve the recycling performance, the EPA thus decided to adopt the tax/subsidy mechanism by establishing the Resource Recycling Management Fund. Although the switch of the institution was mainly due to a failure of governance, we can still support the institutional reform for two reasons. First, the tax/subsidy mechanism can achieve a higher recycling rate if the recycling efficiency is high. Second, by adopting the tax/subsidy mechanism, the policy-makers do not have to worry over market distortions and environmental externalities as all distortions can be rectified by proper tax and subsidy rates under the tax/subsidy EPR mechanism. For these reasons, we support the switch of the mechanism.

Our finding also provides a theoretical explanation for why German's recycling rate is higher than Taiwan's for some but not all of the recycled materials. The statistics show that the German's recycling rates on paper and glass were both 83% in 2004. In contrast, Taiwan's waste recycling rates on paper and glass were 50% and 42% respectively in 2001 according to a research done by Hsiao (2004). Based on our analysis, the low recycling rates in Taiwan may be due to low recycling efficiency. As recycling is less efficient in Taiwan, the German's take-back mandate recycling rate thus is higher than the tax/subsidy mechanism.

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