The Curse of Low-valued Recycling*

Hiroaki Ino[†] and Norimichi Matsueda[‡]

Abstract

This paper discusses how to deal with low-valued recyclable residual wastes whose reprocessing itself does not pay financially. While such a recycling activity can potentially improve social welfare if the social costs associated with their disposal are sufficiently significant, governmental policies to promote recycling may lead to illegal disposal. Explicitly considering the government's monitoring cost in preventing firms from disposing of collected wastes illicitly, we show that the second-best policy for a low-valued recyclable is either one of the two following schemes: a deposit-refund scheme (DRS) that gives birth to a recycling market or an advanced-disposal fee (ADF) that does not create a recycling market. However, in order to select the optimal policy scheme and implement it appropriately, recycling market information is needed. Thus, the structure of the second-best policy itself indicates that a policy-maker has to face critical information issues in implementing it, which is in stark contrast to a DRS for a non-low-valued recyclable.

*The authors thank useful comments by Jiro Akita, Alain Ayong le Kama, Paul Calcott, Etienne Farvaque, Ida Ferrara, Lionel Ragot, Hiroaki Sakamoto, Akihisa Shibata, Takayoshi Shinkuma, the participants of workshops at the Victoria University of Wellington and Kwansei Gakuin University, the 15th Annual Meeting of the Association for Public Economic Theory at the University of Washington (Seattle), the 21st Annual Conference of the European Association of Environmental and Resource Economists at the University of Helsinki, the 15th Journées Louis-André Gérald-Varet (International Conference in Public Economics) in Aix-en-Provence, and the 26th Annual Conference of the Canadian Resource and Environmental Economists in Banff, Alberta. The usual disclaimer applies. This work was supported by JSPS KAKENHI (23730260 and 25285087).

†Corresponding author. School of Economics, Kwansei Gakuin University, 1-1-155 Uegahara, Nishinomiya, Hyogo 662-8501, Japan. E-mail: hiroakiino@04.alumni.u-tokyo.ac.jp. Tel:+81-0798-54-4657. Fax:+81-0798-54-4657.

‡School of Economics, Kwansei Gakuin University, 1-1-155 Uegahara, Nishinomiya, Hyogo 662-8501, Japan. E-mail: nmatsued@kwansei.ac.jp

Keywords: advanced disposal fee; deposit-refund; illegal waste disposal; monitoring; recycling
JEL Classification: H21; Q21; Q28

1 Introduction

In the presence of a household's incentive to illegally dispose of its waste, a so-called "two-part instrument (2PI)" or "deposit-refund scheme (DRS)" is considered to be a more effective policy tool over others.[1] To the best of our knowledge, most of the previous studies have not paid close attention to the possibility that commercially-transacted recyclable residual wastes are illegally disposed by firms and do not actually get recycled.[2] However, illegal disposal by firms can be a real problem since it may be the most profitable option for firms when the government provides a subsidy for simply obtaining wastes in a recycling market.

Ino (2011) examines the implications of such illicit behaviors by firms in determining the optimal policy levels, and finds that a DRS is still reasonably effective as long as the net private benefit of recycling is positive, at least, up to a certain extent. Unfortunately, this condition does not always hold in reality. While the recycling of containers and packaging, in general, have recently seen increasing governmental involvement in the forms of taxes and subsidies in some developed countries, recycled materials from used PET bottles and glass containers currently have very small economic values, as opposed to, say, aluminum cans. Low-valued recyclables may get recycled solely due to the presence of these policies, and the mere fact of private firms' participating in residual waste trades does not imply that the recycling is socially desirable. Indeed, by carefully estimating the net social benefit of recycling household solid wastes, Kinnaman, Shinkuma, and Yamamoto (2014) report that the welfare-maximizing recycling rates would be well below the observed and mandated recycling rates for Japan and perhaps for other developed nations as well. In this paper, we describe the optimal policy for low-valued recyclables and also discuss how such an "over-encouragement" of recycling can be easily induced in the process of implementing such a policy due to the informational difficulties that are inherent in the structure of the optimal policy set.

When the recycled materials have very low economic values, this potential "over-encouragement"of recycling can lead to firms' illegal disposal of wastes that are initially intended for recycling. In Japan, for instance, numerous midnight dumping cases of cleansed and properly-sorted PET bottles in large chunks have been reported in the news

[1]Fullerton and Kinnaman (1995) and Palmer and Walls (1997) are seminal works in this literature. Fullerton and Wolverton (2005) show its effectiveness in a more general context.

[2]On the other hand, illegal disposal by households has been carefully examined by Fullerton and Kinnaman (1995) and Choe and Frazer (1999), for instance.

media since the implementation of the Law for the Promotion of Sorted Collection and Recycling of Containers and Packaging (or, the Container and Packaging Recycling Law, in short) in 1997. Given typically enormous volumes of those wastes, it is obvious that they were discarded by firms and not by households. In principle, the law is intended to make the manufacturers of packaging and the retailers of packaged products financially responsible for the disposal of the packaging wastes and also to encourage the recycling of those wastes by providing extra monetary incentives for recyclers. It is suspected, however, that some recyclers have taken advantage of the law and received illegitimate financial benefits for the recycling activities they have not conducted properly. Whereas the law's administrator, the Japan Containers and Packaging Recycling Association, claims that "recycling fees are paid to recyclers after it has been confirmed that the recycled materials have been sold to the users of these goods" on its own website,[3] several news media reported cases where the products made of the supposedly "recycled" materials proved to contain very little or effectively no recycled content when they were tested in laboratories.[4]

On the other hand, it is not necessarily the case that such "low-valued recycling" is inefficient from a society's perspective, especially when the disposal cost of the waste is large. Recycling can be justified on the social welfare ground even if a recycled material *per se* has a fairly low market value. For instance, incineration of scrap tires can pose a serious environmental problem as they result in thick smoke which can contain pollutants harmful to human health throughout the surrounding area. Disposing of tires in landfills can also create potentially significant environmental issues as those tires tend to rise to the surface, and they have also been proven to be serious breeding grounds for mosquitoes and can leach toxic chemicals into groundwater.[5] In order to raise funds to address the current stockpile issue and to prevent future problems by increasing recycling and proper disposal of scrap tires, many states in the U.S. now collect the deposits on tire purchases and they are used to subsidize scrap tire processors or sales of products made from scrap tires (Walls, 2013).

This paper discusses how to deal with low-valued recyclable residual wastes whose

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[3]`http://www.jcpra.or.jp/tabid/603/index.php` (accessed February 9, 2015).

[4]In one show, a plastic hunger that the then Minister of the Environment brought to the TV studio and claimed as an example of a successful plastic recycling program later turned out to be made almost entirely of virgin materials (broadcast on the NTV channel on Dec. 23, 2008).

[5]The environmental impacts of these disposal options would be even greater in the case of illegal dumping.

reprocessing itself does not pay financially by constructing a model that includes disposal and recycling activities and, furthermore, by explicitly considering the government's monitoring cost in preventing firms from disposing of collected wastes illicitly. We show that the second-best policy for a low-valued recyclable is either one of the two following schemes: a deposit-refund scheme (DRS) that gives birth to a recycling market or an advanced-disposal fee (ADF) that does not create a recycling market.[6]

Scrutinizing the structure of the induced second-best policies itself, however, reveals that information of recycling market is necessary to select the optimal policy scheme and implement it appropriately. Thus, the structure of the second-best policy itself indicates thata policy-maker has to face critical information issues in its implemention. This is in stark contrast to a DRS for a non-low-valued recyclable as is shown in Ino (2011). This informational challenge associated with a low-valued recyclable could result in the creation of a socially inefficient recycling market by the government and also in the illegal waste disposal by a firm.

The paper is organized as follows. The next section describes our economic model and in Section 3, we derive the second-best policy set under the condition that the recycled material has such a small market value that makes the net private benefit of recycling negative for a recycler. Then, in Section 4, we discuss why it would be quite difficult to actually implement the second-best deposit-refund policy for a low-valued recyclable product without over-encouraging recycling activities The final section concludes the paper.

2 The Model

In this study, we adopt a modified version of the partial equilibrium model in Ino (2011), which includes both the product and recyclable residual waste markets. For simplicity, we consider only one representative household, and one representative firm which plays the roles of both a recycler and a producer.[7] The household and the firm are supposed

[6]In general, an ADF is considered to be a socially inferior policy tool compared to a DRS because an ADF provides an insufficient incentive for recycling. In contrast, our result indicates that, when a monitoring cost on a firm is taken into account, it can be quite plausible that an ADF should be favored over a DRS by the government. If this "downstream" cost is neglected, it could induce the over-encouragement of recycling. Acuff and Kaffine (2013) also find a result that an ADF should supported over a DRS in the presence of "upstream" externalities, such as greenhouse gas emissions.

[7]All the results and implications of this paper can be readily extended to an economy with $m \geq 1$ firms and $n \geq 1$ households and also to the case where recyclers and output producers are separate

to be price-takers.

We assume that one unit of the product generates one unit of recyclable waste after consumption. The authorities provide the legal waste collection service for the household, and the unit charge for this service equals $\tau \in \mathbb{R}_+$. Potentially, the household can dispose of its residual wastes illegally to avoid this unit charge. To mitigate such an incentive, the authorities can monitor illegal disposal activities by the household. By choosing the stringency of their monitoring activities, the authorities essentially control the expected unit penalty on the household's illegal disposal, $\tau_h \in \mathbb{R}_+$. We suppose that it costs the authorities $\Gamma_h(\tau_h) : \mathbb{R}_+ \mapsto \mathbb{R}_+$ to monitor the household's disposal activities, where Γ_h is a convex and strictly increasing function.

Regarding the policies for the household, we restrict our focus to the cases where the authorities set $\tau_h = \tau$ in order to prevent the household from sending its wastes into the illegal disposal stream.[8] Under the suppositions that legal and illegal disposal activities of the household respectively generate constant marginal social costs of $d \in \mathbb{R}_{++}$ and $d_h \in \mathbb{R}_{++}$,[9] and that $d < d_h$ holds since the marginal social cost of illegal disposal would typically be greater than that of legal disposal options, such as controlled landfills and proper incineration,[10] this restriction is not harmful in implementing the optimal policy (see Caveat 1 below). Hereafter, we use only one variable τ_h in referring to the unit charge on legally disposed wastes and also to the expected unit penalty for illegally-discarded wastes by the household.

Caveat 1 Indeed, under these settings regarding the monitoring cost and the social costs, we can show that the authorities should always set $\tau = \tau_h$. This is because, when $\tau < \tau_h$, the authorities can save the monitoring cost by reducing τ_h and resetting $\tau_h = \tau$, with other things being constant; and, when $\tau > \tau_h$, all the illegal wastes from the household are turned into legal ones by reducing τ and resetting $\tau = \tau_h$, with other things being constant.

Thus, with a sufficiently high level of the expected unit fine, the household will not

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entities.

[8]We assume that the household chooses to dispose of its wastes legally if its private costs of two disposal options are equivalent, i.e., $\tau = \tau_h$.

[9]d includes not just the cost associated with the waste processing services but also certain environmental damage costs while d_h consists of environmental damage costs of illegally-discarded wastes and, possibly, the clean-up costs if such activities are conducted.

[10]This assumption is also adopted by Choe and Frazer (1999).

resort to illicit disposal options even when there is some positive unit charge on legal disposal. Then, the following simple material balance condition applies: $z = x^d - r^s$, where z is the amount of wastes legally disposed by the household, x^d the household's demand for the product, and r^s the household's supply of the recyclable wastes to the firm. We consider the case where $x^d > 0$ and $r^s \geq 0$ (hence, the boundary case of zero recycling by the household is allowed). Moreover, in order to focus on a realistic case where, with currently available recycling technologies, it is not socially optimal to attain zero waste disposal, we assume $r^s < x^d$; that is, we exclude the case where z is zero.

With the use of a quasi-linear utility function, we assume that the representative household's behavior is summarized by the following constrained utility maximization problem with respect to x^d, r^s, and a numeraire, y:

$$\max_{x^d, r^s, y} U(x^d) + y, \tag{1}$$

$$\text{s.t. } P_x x^d + y + \tau_h (x^d - r^s) + C_r(r^s) \leq I + P_r r^s, \tag{2}$$

where I is the household's income, $P_x \in \mathbb{R}_{++}$ the price of the product, and $P_r \in \mathbb{R}$ the price of the recyclable wastes.[11] Also, $U : \mathbb{R}_+ \mapsto \mathbb{R}$ signifies the sub-utility function of the household, which is strictly increasing and strictly concave, and $C_r(r^s) : \mathbb{R}_+ \mapsto \mathbb{R}_+$ is a strictly increasing and strictly convex cost function associated with the household's separation and other activities that are necessary for subsequent proper recycling by the firm.[12]

Then, the following first-order conditions give us the household's inverse demand function for the product and its inverse supply function of the recyclable residual wastes, respectively:

$$P_x(x^d; \tau_h) = U'(x^d) - \tau_h, \tag{3}$$

$$P_r(r^s; \tau_h) = C_r'(r^s) - \tau_h, \tag{4}$$

for all $x^d > 0$ and $r^s \geq 0$. Here, we define $P_r(0; \tau_h) \equiv \lim_{r^s \to 0} P_r(r^s; \tau_h) = C_r'(0) - \tau_h$.

[11] When $P_r > 0$ ($P_r < 0$), the firm (household) pays in the recyclable residual market. Note that P_r can be negative because the household may still be willing to pay for the recycling services in order to avoid the charge for the waste disposal.

[12] $C_r(\cdot)$ can account for the presence of intermediate traders that provide collection and sorting activities. If all the markets in which these intermediate traders participate are perfectly competitive, the entire cost in these processes is passed on to the household.

The firm produces a recyclable product with some technology that is represented by a strictly increasing and strictly convex cost function, $C_x(x^s) : \mathbb{R}_+ \mapsto \mathbb{R}_+$, where x^s is the firm's supply of the product. The firm also demands the recyclable household wastes by the amount of r^d. After the firm obtains the residual wastes, it could illegally dispose of the wastes, instead of recycling them properly. We denote the amount of the firm's illegal waste disposal by z^f, and r^c is the quantity of residual wastes that are completely reprocessed by the firm. Again, we suppose a simple material balance condition for the firm as well: $z^f = r^d - r^c$.

The firm's net benefit of proper recycling is given by a strictly concave function, $B(r^c) : \mathbb{R}_+ \mapsto \mathbb{R}$. Note that we allow the value of $B(r^c)$ to be negative since it includes the cost of reprocessing the residual wastes.[13] Indeed, in order to focus on the issues arising when the recycled material has relatively low economic value, we assume below that $B'(0) \leq 0$.[14] Furthermore, we suppose that $\lim_{r\to\infty} B'(r) = -\infty$.

As practical policy tools to affect the firm's behaviors, we consider two policy instruments which could be called a "deposit-refund scheme (DRS)" in combination: the unit tax $t \in \mathbb{R}$ (deposit) on x^s and the unit subsidy $s \in \mathbb{R}$ (refund) on r^d. We suppose that the tax and subsidy bases, that is, x^s in the product market and r^d in the recyclable residual waste market, are verifiable for the policy maker without any cost since they are the information readily available in the market.

As an important assumption, we suppose that it is costly to know the amount of residual wastes completely reprocessed by the firm, i.e., r^c, because this constitutes the firm's private information. Alternatively, the authorities could somehow observe the firm's illegal disposal z^f, and subtract it from the verifiable level of r^d in order to know the actual amount of proper recycling r^c, but this can be very costly (see Caveat 2 below). In sum, the total amount of the transacted residual wastes, r^d, which is observable in

[13]In our model, the net benefit of proper recycling, $B(r^c)$, is given exogenously, and $B(r^c)$ can be interpreted in several different ways. For example, by letting $\alpha \in (0, 1]$ be an exogenously-given recycling content ratio (thus, r^c/α is the amount of recycled products), $B(r^c)$ can be defined as

$$B(r^c) = pr^c/\alpha - C(r^c/\alpha),$$

where p is an exogenously given price of the recycled product and $C(\cdot)$ is the cost of producing the recycled product including the reprocessing of the residual wastes. If the firm sells its recycled product in some market, p is simply the market price of the product or, a (hedonically) perfectly substitutable product made of virgin materials. If the firm uses the recycled material as an input for its own production, p is the price of a (hedonically) perfectly substitutable virgin input, v, provided that the production function of the good x is of the form $x = f(r^c + v)$. In this case, $\alpha = 1$ in the above expression.

[14]The case where $B'(0) > 0$ is analyzed in Ino (2011).

the recycling market, is separated into two unobservable variables, illegally disposed wastes, z^f, and properly reprocessed ones, r^c, according to the material balance equation, $r^d = z^f + r^c$.[15] The authorities control the expected unit penalty on the firm's illegal disposal, $\tau_f \in \mathbb{R}_+$ by spending the cost $\Gamma_f(\tau_f) : \mathbb{R}_+ \mapsto \mathbb{R}_+$ to monitor the firm's disposal activities, where Γ_f is convex and strictly increasing. If the level of monitoring is not sufficiently high, the firm might surreptitiously get rid of its obtained residual wastes and pretend to have reprocessed the wastes properly.

Caveat 2 As measures to detect r^c (or z^f), we consider two principal ways. One is to monitor illegal disposal activities of the firm (e.g., by patrolling), and verify how much of the transacted residuals are disposed of illegally. The other is to directly monitor proper recycling activities of a firm (e.g., by on-site inspection of the reprocessing process or by testing the final products for recycled contents in a laboratory). The important assumption for the second-best case below is that the monitoring cost is increasing in these efforts, which leads to $\Gamma'_f(\tau_f) > 0$.[16]

Finally, the waste disposal activities of the firm z^f generates constant marginal social costs of $d_f \in \mathbb{R}_{++}$, including the costs associated with certain environmental damages. Since illegal disposal, such as midnight dumping and illicit burning, would typically be socially more costly than legal disposal options, we assume $d < d_f$. Then, the social

[15] In the terms typically found in the environmental economics literature, r^d and r^c respectively correspond to the reported and actual levels of emission abatement while z^f is the level of the fabricated abatement by the firm. Thus, our setting of the monitoring problem readily conforms to one widely used in the conventional literatures. See Harford (1978) and Lee (1984) among others.

[16] If it is easy to trace the whole recycling processes and the monitoring cost is negligible, that is, if Γ_f is infinitesimally small, our model becomes close to the first-best situation (see Footnote 27).

welfare, W, can be expressed as[17]

$$W = [U(x^d) - C_x(x^s) - dz] + [B(r^c) - C_r(r^s) - d_f z^f] - \Gamma_h(\tau_h) - \Gamma_f(\tau_f). \tag{8}$$

3 The Optimal Policy Set

We solve the optimal policy-choice problem in steps. First, given the policy variables, $(t, s; \tau_f, \tau_h)$, we derive the market equilibrium. Then, we find the monitoring level that achieves zero illegal disposal by the firm. In particular, we call such a monitoring level as the "optimal monitoring rule." In deriving the optimal policy set, we focus our attention on the equilibrium quantities and prices that are induced under the optimal monitoring rule. As we will see below in Lemma 1, this is admissible due to the assumption that the illegal waste disposal by the firm is always socially more costly than the legal waste disposal by the household. Finally, we obtain the second-best policy set that maximizes the social welfare.

3.1 Behavior of the Firm and the Market Equilibrium

The profit maximization problem of the firm is given by

$$\begin{aligned} &\max_{x^s, r^c, r^d, z^f} [(P_x - t)x^s - C_x(x^s)] + [B(r^c) - \tau_f z^f - (P_r - s)r^d] \\ &\text{s.t. } r^d = z^f + r^c. \end{aligned} \tag{9}$$

[17] Originally, the social welfare function, W, is given by

$$\begin{aligned} W \equiv &[U(x^d) - P_x x^d] + [P_r r^s - C_r(r^s)] - \tau_h z & (5)\\ &+ [(P_x - t)x^s - C_x(x^s)] + [B(r^c) - (P_r - s)r^d] - \tau_f z^f & (6)\\ &+ \tau_h z + \tau_f z^f + t x^s - s r^d - \Gamma_h(\tau_h) - \Gamma_f(\tau_f) - dz - d_f z^f. & (7) \end{aligned}$$

Here, (5) and (6) are the consumer surpluses and the producer surpluses, respectively. Note that the second brackets of (5) and (6) are the surpluses related to the reprocessing/recycling activities, and the third terms of the respective lines are the (expected) payments associated with waste disposal. Finally, (7) signifies the sum of the authorities' tax and fine revenues, subsidy and monitoring costs, and the social costs associated with waste disposal. With the two market clearing conditions, i.e., $x^d = x^s$ and $r^d = r^s$, we can reduce W into the form (8). Note that the terms related to the tax and subsidy are canceled in W since they are simply monetary transfers.

Then, the first-order conditions for the profit maximization are

$$P_x = C_x{}'(x^s) + t, \tag{10}$$

$$B'(r^c) \leq \mu \quad \text{with equality if} \quad r^c > 0, \tag{11}$$

$$\mu \leq P_r - s \quad \text{with equality if} \quad r^d > 0, \tag{12}$$

$$-\tau_f \leq \mu \quad \text{with equality if} \quad z^f > 0, \tag{13}$$

where μ is the Lagrangian multiplier associated with the constraint. Presuming $x^s > 0$, (10) gives the inverse supply function of the product. Thus, the equilibrium amount of the product, represented by $x^*(t; \tau_h)$, is given by (3) and (10):

$$P_x(x^*(t; \tau_h); \tau_h) = C_x{}'(x^*(t; \tau_h)) + t. \tag{14}$$

Caveat 3 Although the subsidy for recycling activities is provided for the purchase of the original residual wastes in the above formalization (9), our analytical model can readily be reinterpreted to represent a different case where the subsidy is provided on the transaction of a final recycled product.[18] Suppose that $\alpha \in (0, 1]$ is the actual recycling content ratio that is exogenously determined by the firm's recycling technology and let $\alpha^r \in (0, 1]$ be the reported ratio by the firm. Typically, an exact value of α is the firm's private information since it is a parameter of the firm's private technology. In the absence of monitoring, therefore, the firm can intentionally inflate $\alpha^r (> \alpha)$ even to the extent that the actually traded amount of final recycled products exactly equals the amount under which no transacted waste would have been illegally disposed of, that is, $r^c/\alpha = r^d/\alpha^r$. Rearranging the last equation with the material-balance condition, we obtain $z_f = (\alpha^r/\alpha - 1)r^c$. Thus, selecting r^c and α^r is essentially the same as selecting r^c and z^f for the firm. Moreover, the authorities provide subsidy $\alpha^r s$, that is, based on the claimed recycled content, for the recycled products of the amount $r^c/\alpha (= r^d/\alpha^r)$. Then, the total subsidy amount is $\alpha^r s(r^c/\alpha) = sr^d$, which is the same under a situation where the unit subsidy of s is provided for the firm at the point of the waste transaction for the amount of r^d.

[18] See also Caveat 2 for a related discussion and Footnote 13 for the specification of the benefit function B that is consistent to this interpretation.

If we suppose for the time being that $z^f = 0$ ($r^d = r^c$), (11) and (12) give the inverse demand function for the recyclable waste, $P_r = B'(r^d) + s$ when $r^d > 0$, where the right-hand side is the net marginal benefit of proper recycling to the firm. Thus, the equilibrium amount of the recyclable waste, represented by $r^*(s; \tau_h)$, is given by (4) and (11)–(12):

$$P_r(r^*(s;\tau_h);\tau_h) = B'(r^*(s;\tau_h)) + s, \tag{15}$$

if $P_r(0;\tau_h) < B'(0) + s$, and $r^*(s;\tau) = 0$ if $P_r(0;\tau_h) \geq B'(0) + s$. The equilibrium point defined by the market clearing condition under proper recycling (15) is shown by the point E' in Figure 1. We denote the equilibrium price of the residual wastes defined here by $P_r^*(s, \tau_h) \equiv P_r(r^*(s;\tau_h);\tau_h)$.

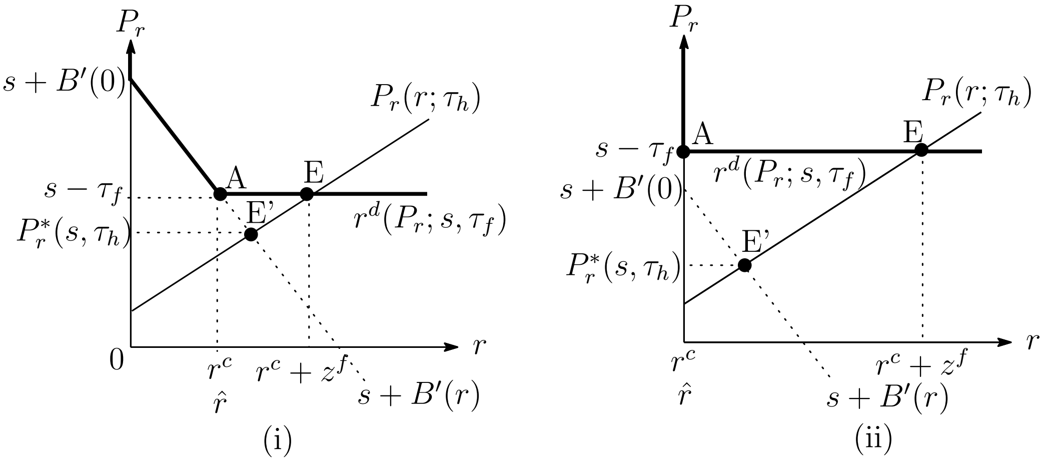

Figure 1: (i)$B'(0) > -\tau_f$, (ii)$-\tau_f \geq B'(0)$

However, the firm potentially disposes of recyclable wastes ($z^f > 0$). Taking this into consideration, from (11) – (13) and the constraint, the demand for the recyclable waste can be illustrated by the bold lines in Figure 1 for the two cases: (i) $B'(0) > -\tau_f$ and (ii) $-\tau_f \geq B'(0)$, respectively.[19] Since $s + B'(r)$ is the net marginal benefit of proper

[19] Formally, the demand correspondence is described as follows. When (i) $B'(0) > -\tau_f$, it is

$$r^d(P_r; s, \tau_f) = \begin{cases} 0 & \text{if} \quad P_r \geq B'(0) + s, \\ B'^{-1}(P_r - s) & \text{if} \quad B'(0) + s \geq P_r \geq s - \tau_f, \\ [\hat{r}(\tau_f), \infty) & \text{if} \quad P_r = s - \tau_f, \end{cases} \tag{16}$$

where $\hat{r}(\tau_f) = B'^{-1}(-\tau_f)$. Thus, $\hat{r}(\tau_f)$ is the residual waste amount where $s + B'$ equals $s - \tau_f$. When (ii) $-\tau_f \geq B'(0)$, on the other hand, the demand correspondence is

$$r^d(P_r; s, \tau_f) = \begin{cases} 0 & \text{if} \quad P_r \geq s - \tau_f, \\ [\hat{r}(\tau_f), \infty) & \text{if} \quad P_r = s - \tau_f, \end{cases} \tag{17}$$

recycling, which can be derived from (11) and (12), and $s - \tau_f$ is the net marginal benefit of illegal disposal, which can be derived from (12) and (13), the wastes that are obtained by the firm are properly recycled when $s + B'(r) \geq s - \tau_f$, whereas the firm illicitly disposes of its wastes when $s + B'(r) \leq s - \tau_f$.

The equilibrium outcome in the residual waste market is determined by the intersection of the demand and supply curves, i.e., the point E in Figure 1. Thus, the illegally disposed amount is given by the segment to the right of the kinked point A until it hits the supply curve at the point E. In case (ii), especially, all the transacted wastes eventually end up being disposed illegally by the firm.

3.2 The Optimal Monitoring Rule

Let $z_f^*(t, s; \tau_f, \tau_h)$ be the equilibrium level of the firm's illegal disposal under a policy set $(t, s; \tau_f, \tau_h)$, which is represented by the segment A-E in Figure 1, then we can obtain the following result:

Lemma 1. *When $z_f^*(t, s; \tau_f, \tau_h) > 0$ for a given policy set, there exists an alternative policy set that improves social welfare.*

The mathematical proofs of all the lemmas and propositions in this paper can be found in the Appendix. Thanks to this lemma, in deriving the optimal set of policies, we can exclude the cases where the firm illegally disposes of the residual wastes it has obtained, and focus on the monitoring level that achieves $z_f^* = 0$. In order to prevent any illegal disposal, the authorities basically need to maintain the monitoring level sufficiently high. In addition, they should select the lowest among such sufficient monitoring levels to save on the monitoring cost. Specifically, the authorities should maintain the monitoring efforts at a level that is high enough to satisfy *the optimal monitoring rule* $\hat{\tau}_f(s; \tau_h)$ defined by

$$\hat{\tau}_f(s; \tau_h) = \begin{cases} s - P_r^*(s, \tau_h) & \text{if} \quad s > P_r^*(s; \tau_h), \\ 0 & \text{if} \quad s \leq P_r^*(s; \tau_h), \end{cases} \tag{18}$$

where $P_r^*(s, \tau_h)$ is the equilibrium price of the residual wastes that is induced under the condition that illegal disposal from the firm is zero (defined just after (15)).

When $s > P_r^*$ as in the first line of (18), the subsidy for transacted residual wastes is

where $\hat{r}(\tau_f) = 0$. For the respective cases, the demand curves are drawn in bold lines in Figure 1.

higher than the price if the firm is properly engaged in recycling. Hence, the firm might have an incentive to purchase the residual wastes further and dispose of them illegally after pocketing the subsidy surreptitiously. To remove this incentive, the expected penalty on illegal disposal should completely offset the subsidy-price margin, $s - P_r^*$, as is stated in the optimal monitoring rule. When $s \leq P_r^*$ as in the second line of (18), since the subsidy-price margin is negative, the firm does not have an incentive to purchase the residual wastes solely for the sake of illegal disposal and thus, the optimal monitoring level is zero.[20] As a result, when $\tau_f = \hat{\tau}_f(s;\tau_h)$, the firm's illegal disposal z_f^* is zero and thus the equilibrium amount of the recycled wastes is $r^*(s;\tau_h)$ defined in (15). It then follows that, under the optimal monitoring rule, the equilibrium amount of legally disposed household's wastes is $z^*(t,s;\tau_h) = x^*(t;\tau_h) - r^*(s;\tau_h)$.

Now, we can identify the following two key threshold levels of the subsidy, $\bar{s}$ and $\hat{s}$. The threshold $\bar{s}$ is the smallest amount of the subsidy that could induce the firm to recycle the wastes properly, provided that its incentive to dispose of the wastes illicitly is sufficiently curtailed. The threshold $\hat{s}$ is the largest subsidy level under which no monitoring cost incurs.

Lemma 2. *(i)* $r^*(s;\tau_h) = 0$ *if and only if* $s \leq \bar{s} \equiv P_r(0;\tau_h) - B'(0) = C_r'(0) - \tau_h - B'(0)$.
(ii) $\hat{\tau}_f(s;\tau_h) = 0$ *if and only if* $s \leq \hat{s} \equiv P_r(0;\tau_h) = C_r'(0) - \tau_h$.

Because we suppose $B'(0) \leq 0$, $\hat{s} \leq \bar{s}$ always holds (with strict inequality if $B'(0) < 0$). This relation implies that since the reprocessing is always unprofitable, proper recycling activities by the firm never start without the authorities' monitoring on the firm's illegal disposal.[21] Graphically in Figure 2, when $s = \bar{s}$, the demand for the residual wastes is represented by the downward-sloping bold line, which is the marginal benefit of proper recycling $B'(r)+\bar{s}$, as long as the sufficient level of monitoring is conducted, and it exactly touches the supply curve of the residual wastes $P_r(r,\tau_h)$ at $r = 0$.[22] The other threshold level of subsidy is $\hat{s}$, which gives a horizontal line in the figure and also touches the supply

[20]Under the optimal monitoring rule, point A in Figure 1 is exactly on the supply curve of the residual wastes at $P_r^*(s;\tau_h)$ when $\hat{\tau}_f > 0$ and below the supply curve when $\hat{\tau}_f = 0$. Thus, when $\tau_f \neq \hat{\tau}_f$, the authorities can improve the welfare by eliminating the firm's illegal disposal (when $\tau_f < \hat{\tau}_f$) or by saving on the monitoring cost (when $\tau_f > \hat{\tau}_f$). It is important to note that the optimal monitoring rule works as well even if $r^* = 0$ ($P_r(0;\tau_h) \geq B'(0) + s$) since $P_r^*(s;\tau_h) = P_r(0;\tau_h) = C_r'(0) - \tau_h$.

[21]Notice that if some level of subsidy induces proper recycling activities without monitoring to the contrary, the subsidy level must be within $(\bar{s}, \hat{s}]$.

[22]However, if $\tau_f = 0$, the dotted horizontal line at $\bar{s}$ will be the actual demand curve.

curve of the residual wastes $P_r(r, \tau_h)$ at $r = 0$. Therefore, when $\hat{s} < s \leq \bar{s}$, as is seen in the case where $s = s'$ in Figure 2, both $r^*(s; \tau_h) = 0$ and $\hat{\tau}_f(s; \tau_h) > 0$ are satisfied. In such a situation,[23] even though the residual waste market does not exist, the authority must conduct some monitoring on the firm because, without monitoring ($\tau_f = 0$), the waste market emerges and all the wastes obtained by the firm (i.e., all the traded residual wastes of the amount A in Figure 2) are illegally discarded.

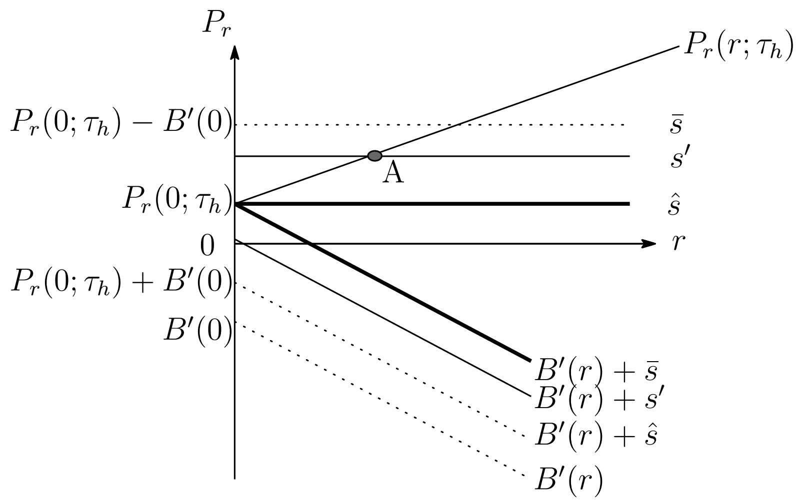

Figure 2: Thresholds in the subsidy levels

3.3 Welfare maximization

Given the optimal monitoring rule and the resulting equilibrium outcomes, we now proceed to the final step, where we determine the optimal policy set $(t^*, s^*; \tau_h^*, \tau_f^*)$ so as to maximize the social welfare under the condition $\tau_f^* = \hat{\tau}_f(s^*; \tau_h^*)$. The welfare maximization problem is formally described as:

$$\max_{t,s;\tau_h} W^*(t, s; \tau_h) \equiv [U(x^*(t; \tau_h)) - C_x(x^*(t; \tau_h))] + [B(r^*(s; \tau_h)) - C_r(r^*(s; \tau_h))] - d[x^*(t; \tau_h) - r^*(s; \tau_h)] - \Gamma_h(\tau_h) - \Gamma_f(\hat{\tau}_f(s; \tau_h)). \quad (19)$$

The solution to this problem gives us the second-best policy set.[24]

[23]In the figure, the marginal benefit of illegal disposal s' intersects the supply curve of the residual wastes $P_r(r, \tau_h)$, but the marginal benefit of proper recycling $B'(r) + s'$ does not.

[24]We assume that the appropriate second-order conditions with respect to (t, s) are globally met when $x^* > 0$ and $r^* > 0$.

First, we can derive that the authorities should not charge the household for the waste disposal service.

Proposition 1. *Under the optimal policy set, the authorities always set* $\tau_h^* = 0$.

Therefore, for obtaining the optimal policy set, we can focus on the case where $\tau_h = 0$. Henceforth, we omit τ_h from the arguments unless it is necessary.

Second, we can show that the optimal product tax (or, the deposit on a unit of the product) is equal to the marginal social cost of the legally disposed wastes by the household.

Proposition 2. *Under the optimal policy set, the authorities always set* $t^* = d$.

Now, the next step is to derive the optimal subsidy level with $\tau_h = 0$ and $t = d$. To solve the problem (19) with respect to s, we divide the situation into the following two cases depending on whether the residual waste market emerges or not (note that $P_r(0; 0) = C_r'(0)$). We can obtain the following proposition:

Proposition 3. *(i) If* $r^*(s^*; 0) > 0$ *under the optimal policy set, the subsidy level is given by* $s^* = s^M$*, which satisfies* $s^M = d - A(s^M)$*, where*[25]

$$A(s^M) \equiv -B''(r^*(s^M; 0))\Gamma_f'(s^M - P_r^*(s^M; 0)) > 0.$$

(ii) If $r^*(s^*; 0) = 0$ *under the optimal policy set, the optimal subsidy is any* s *that satisfies* $s \le C_r'(0)$.

Finally, we can derive the condition under which the emergence of the recycling market is socially desirable. Along with the definition of the optimal monitoring rule in the previous subsection and the optimal subsidy levels described in the proposition just above,

[25] Note that, in finding the actual level of s^M, we need to know $A(s^M)$, which includes the information that is available only in the residual waste market because we have the relation:

$$B''\Gamma_f' = \frac{dP_r}{dr^d}\Gamma_f' = \frac{P_r\Gamma_f'}{r}\left(\frac{dP_r/P_r}{dr^d/r}\right) = \frac{P_r\Gamma_f'}{r\eta_r^d},$$

where η_r^d represents the elasticity of the demand for the residual wastes.

this condition gives us the threshold level of d that distinguishes different patterns of monitoring the firm as a part of optimal policy set.

Proposition 4. *There exists $\bar{d} \geq \bar{s} + A(\bar{s})$ (with equality if and only if $B'(0) = 0$)*[26] *such that $r^*(s^*; 0) > 0$ under the optimal policy if and only if $d > \bar{d}$. Thus, the optimal expected penalty on the firm is $\tau_f^* = s^M - P_r^*(s^M; 0) > 0$ if $d > \bar{d}$; and $\tau_f^* = 0$ if $d \leq \bar{d}$.*

Propositions 1-4 give us the second-best policy structure. For convenience, Table 1 summarizes the results of these propositions, and Figure 3 depicts the pattern of the optimal tax and subsidy for the case where $B'(0) < 0$ and the case where $B'(0) = 0$, respectively.

The optimal policy set in the case where $d > \bar{d}$ (the second column of Table 1 and the right-hand region of each panel in Figure 3 that is denoted by "monitoring-with") is the system of imposing a tax on the product, i.e., a deposit ($t^* = d$), for the full social cost of the legal disposal, a somewhat reduced subsidy to the commercially transacted residual wastes, i.e., a refund ($s^* = d - A$), and free disposal service for legally disposed household waste ($\tau_h^* = 0$) to avoid conducting any monitoring on the household. This is a deposit-refund scheme (DRS) modified by taking into account the monitoring cost.[27] Since the environmental damage d is sufficiently large in this case, the authorities should encourage the firm to undertake recycling by providing the appropriate amount of the subsidy ($s^* > \hat{s}$: the optimal subsidy level is given by the bold line of Figure 3) and implementing the necessary monitoring on the firm ($\tau_f^* > 0$). The subsidy level needs to be reduced by $A(s^M)$ since it necessitates the monitoring efforts by the authorities while encouraging the recycling activities.

In the case where $d \leq \bar{d}$ (the third column of Table 1 and the left-hand region of each panel in Figure 3 that is denoted by "monitoring-without"), however, the environmental damage d is small enough that the authorities should avoid incurring any monitoring cost ($\tau_f^* = 0$) by simply abandoning the idea of creating a recycling market through policy interventions. Thus, the authorities must keep the subsidy at a lower level than the one

[26] As is in the proof, in order to induce $\bar{d}$, we must compare two locally maximized welfare levels, $W^*(d, s^M)$ and $W^*(d, C_r'(0))$. Thus, $\bar{d}$ consists of the market information that is only available in the residual waste market.

[27] When the monitoring cost for the firm is infinitesimally small, i.e., Γ_f' is almost zero everywhere, $A(s^M)$ is also close to zero according to the composition of $A = -B''\Gamma_f'$. In such a case, therefore, our second-best DRS approximates the first-best DRS (i.e., $t = s = d$).

cases	$d > \bar{d}$	otherwise
tax t	$t^* = d$	$t^* = d$
subsidy s	$s^* = d - A(s^M) > C_r'(0)$	$s^* \leq C_r'(0)$
monitor τ_f	$\tau_f^* = s^M - P_r^*(s^M) > 0$	$\tau_f^* = 0$
fee τ_h	$\tau_h^* = 0$	$\tau_h^* = 0$
recycling r	$r^*(s^*; \tau_h^*) > 0$	$r^*(s^*; \tau_h^*) = 0$

Table 1: Optimal policy set and recycling

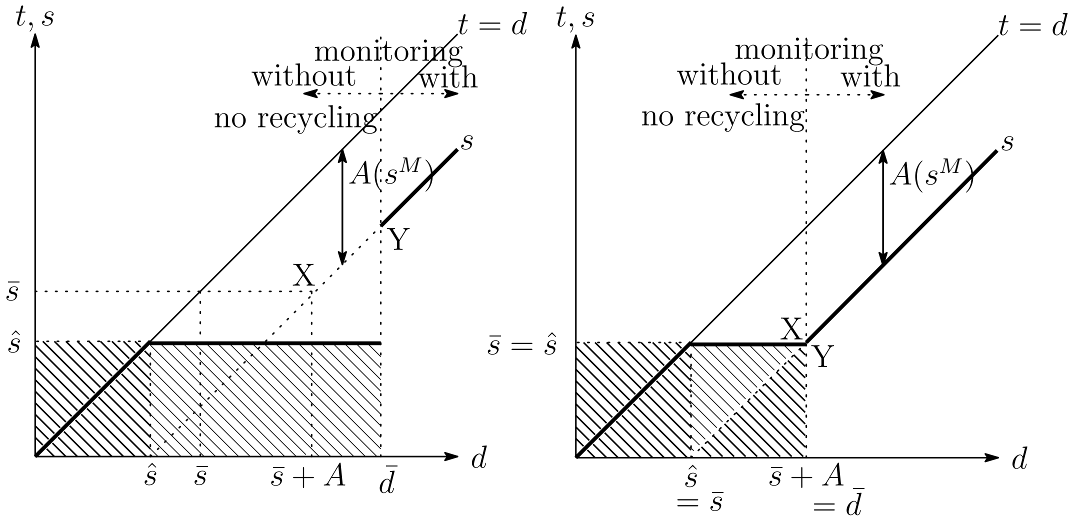

Figure 3: Pattern of the optimal policy: The left panel depicts the case where $B'(0) < 0$ and the right panel the case where $B'(0) = 0$

that requires the monitoring ($s^* \leq \hat{s}$: the optimal subsidy level is given by the shaded area of Figure 3). Since the optimal quantity of recycling is zero along with no monitoring at all, only a tax on the product is actually implemented; that is, the optimal policy set consists solely of an advanced disposal fee (ADF) in this case ($t^* = d$ and $\tau_h^* = 0$).

3.4 An Illustrative Example

In order to demonstrate the plausibility of our analysis, we provide a simple illustrative example with the following functional forms: $B(r) = -ar - (b/2)r^2$, $C_r(r) = (c/2)r^2$, and $\Gamma_f(\tau_f) = \gamma\tau_f$, where $a \geq 0$ and $b, c, \gamma > 0$. Under these specifications, we have $B'(0) = -a \leq 0$ and $C_r'(0) = 0$.

Let us consider the case where the government intends to create the recycling market by implementing the second-best DRS, i.e., $t = d$ and $s = s^M = d - A(s^M)$, along with the optimal level of monitoring that enforces the firm to recycle appropriately i.e., $\tau_f = \hat{\tau}_f(s^M) = s^M - P_r^*(s^M)$ and the free disposal service for legally disposed household waste, i.e., $\tau_h = 0$. Under the current specifications, we have $A(s^M) = -B''\Gamma_f' = b\gamma$, which leads to $s^M = d - b\gamma$. The equilibrium amount of the recyclable residual r^* is given by $C_r'(r^*) = B'(r^*) + s^M$, following (15), and thus we obtain $r^* = (-a + s^M)/(b + c)$. Since the price of residuals is $P_r^*(s^M) = cr^*$, the monitoring level is given by $\tau_f = (ac + bs^M)/(b + c)$. Under this policy set, all the illegal disposal is prevented because of the optimal monitoring, i.e., $z^f = 0$, and as a result, the household legally disposes of the residuals that are not recycled, i.e., $z = x^* - r^*$. Then, the equilibrium welfare value is

$$\begin{aligned} W^*(d, s^M) &= [U(x^*) - C_x(x^*)] + [B(r^*) - C_r(r^*)] - d(x^* - r^*) - \Gamma_f(\hat{\tau}_f(s^M)) \\ &= [U(x^*) - C_x(x^*) - dx^*] + \left[\frac{\{d - (a + b\gamma)\}^2}{2(b + c)} - a\gamma \right], \end{aligned}$$

where the equilibrium product amount x^* is given by $U'(x^*) = C_x'(x^*) + d$, based on (14).

On the other hand, when the government gives up on creating the recycling market by providing a sufficiently small subsidy amount, typically $s = 0$ (no subsidy), and simply implements the optimal ADF, i.e., $t = d$, along with $\tau_h = 0$ (free disposal). Since all the wastes are disposed legally (but not recycled) by the household under this policy, i.e., $z = x^*$, no monitoring for illegal disposal whatsoever is needed. In this case, the equilibrium welfare is

$$W^*(d, 0) = U(x^*) - C_x(x^*) - dx^*,$$

where x^* is also given by $U'(x^*) = C'_x(x^*) + d$, based on (14).

It is better to create the recycling market if the welfare under the optimal DRS, i.e., $W^*(d, s^M)$above, is larger than the welfare under the optimal ADF, i.e., $W^*(d, 0)$ above. Notice that x^* is given by exactly the same conditions and, therefore, the amount of x^* is common for both cases. Thus, the only difference in social welfare is the terms inside the last square brackets of $W^*(d, s^M)$. First, $d > \bar{s} + A$, or equivalently, $d > a + b\gamma$ must hold to have the optimal DRS because the subsidy $s^M = d - A$ has to exceed $\bar{s} = a$ in order to create a proper recycling market, i.e., $r^* > 0$ (positive recycling). Hence, in this domain, the first term inside the brackets is increasing in d and thus, we can find the threshold marginal social cost of the legal disposal, $\bar{d}$, above which $W^*(d, s^M) > W^*(d, 0)$ obtains. Under the current specifications, $\bar{d}$ can be calculated as $\bar{d} = a + b\gamma + 2\sqrt{a(b + c)\gamma}$. This threshold curve, $\bar{d}$, is shown as the function of $B'(0) = -a$ in Figure 4.

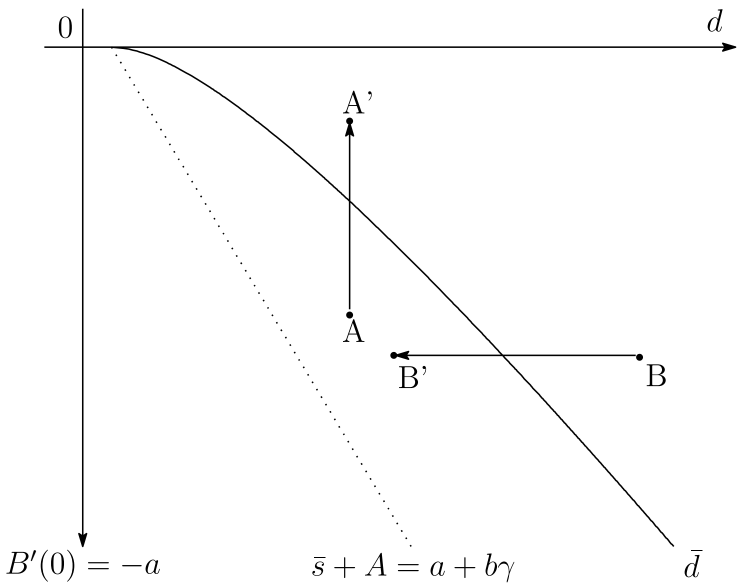

Figure 4: The threshold marginal social cost of legal disposal

Above the threshold curve, $\bar{d}$, the DRS is preferred to the ADF policy on the social welfare ground. We can find that as an improvement in recycling technologies raises the net benefit of recycling, the second-best policy can switch from the ADF (point A) to the DRS (point A') for a fixed level of d as shown in Figure 4. On the other hand, a decrease in the social cost of legal disposal, due to the establishment of a more efficient incineration plant, for instance, leads to the opposite policy switch (point B to point B') for a given $B'(0)$. On the contrary, an increase in the social cost of legal disposal, which can be induced by a stronger environmental preference, calls for the policy switch from the ADF to the DRS (point B' to point B).

As we elaborate in the next section, however, the implementation of the DRS can present a fundamental informational difficulty for a policy maker in creating the recycling market.

4 Discussion

In the previous section, we find the second best policy combination for a low-valued recyclable product and show that there are the two distinct types of optimal policy sets depending on the level of environmental damage d: the DRS with monitoring that gives birth to the waste market, and the ADF without monitoring that does not create the recycling market. In this section, we further elaborate on this result and argue that, due to the structure of the optimal policy set, these policies are by nature difficult to implement appropriately. One potential consequence is that it becomes quite plausible that the government mistakenly creates the waste market when it should not. As a likely scenario we focus on the case where the social cost of the legally disposed household wastes, i.e., d, gradually increases for certain reasons, such as increasing shortage of waste disposal sites and a gradual rise in the society's environmental awareness, and discuss the difficulties that are involved in implementing the optimal policies we have proposed above.

If the monitoring on the firm is costless (hence, there is no monitoring issue concerning the firm), it is true that the waste market should not emerge if and only if it does not emerge with the first-best DRS, $t = s = d$.[28] Thus, in this ideal case, just by implementing this two-part policy instrument, the waste market emerges when d reaches the level at which it should emerge. In other words, once the authorities are engaged in the appropriate DRS, the market forces automatically lead to the social optimum as regards the creation of a recycling market. Hence, they do not need to worry about exactly when the waste market should be created.

In contrast, when there is a monitoring issue concerning the firm, the optimal emergence of recycling market is not guaranteed. This is because the structure of the second-best policy implies the following:

Corollary 1. *Suppose that the authorities engage in the optimal DRS. If $B'(0) < 0$, the*

[28] See footnote 27. Then, illegal disposal by the firm can be prevented without any cost, and zero monitoring activity for the household is a part of this first-best policy set, i.e., $\tau_h = 0$.

residual waste market emerges with the second-best level of refund $s = d - A(s^M)$ if but not only if it should emerge.

When $d \leq \bar{d}$, the waste market should not emerge in the second-best situation. However, if the subsidy is provided at the level of $d - A(s^M)$,[29] there is a situation where $d \leq \bar{d}$ and a socially inefficient recycling market emerges because $s = d - A(s^M)$ exceeds the smallest subsidy level for the proper recycling $\bar{s}$ (shown in Figure 3 by the segment XY). In this case, the monitoring cost to the firm's illegal activities is too higher than the social cost saved by the proper recycling. Thus, it is not enough for the authorities just to engage in the appropriate DRS and they need to examine the desirability of the recycling market according to some other criteria.

Hence, as the magnitude of d increases, we have to make the policy shift from the ADF to the DRS, according to the second-best policy set criteria identified in the previous section. In order to implement such a policy shift appropriately, the authorities need to know (i) the level of subsidy $s^M = d - A(s^M)$ that should be included in the DRS and (ii) the threshold level in the marginal social cost of the legal disposal, $\bar{d} \geq \bar{s} + A(\bar{s})$, above which level a change in the policy structure needs to be undertaken. However, these two critical values contain the information that can be obtained only in the recycling market.[30] In a sense, the authorities face a dilemma in implementing the second-best policy: they need to give birth to the recycling market in order to obtain the information that is necessary to know whether they should create the recycling market and how they should create it. Indeed, the following particular feature of the second-best subsidy is the key property that makes this dilemma quite troublesome.

Corollary 2. *When $B'(0) < 0$, the second-best subsidy level s^* is discontinuous at $d = \bar{d}$.*

If $B'(0) = 0$, the dilemma may not be so serious as in the case where $B'(0) < 0$. In this case, s^M approximates the threshold subsidy level which leads to the creation of the desirable recycling market, i.e., $\bar{s} = d - A(\bar{s})$, when d barely exceeds $\bar{d}$, and thus, the second-best subsidy level is continuous at $d = \bar{d}$, as is seen in the right panel of Figure 3. This implies that the recyclable waste market first emerges in the minimal

[29] Since the following is true even if the refund is provided in this reduced level, all the more if the first-best refund level $s = d$ is provided.

[30] See footnotes 25 and 26. In order to know the exact level of $\bar{d}$, further market information is needed to estimate the welfare.

scale possible with the implementation of the second-best policy. In this case, therefore, it is possible for the authorities to induce a small recycling market experimentally and gather the necessary information to find the value of $A(\bar{s})$ without a serious welfare loss.[31] Moreover, the threshold for the policy shift is exactly at $\bar{d} = \bar{s} + A(\bar{s})$ (Proposition 4). Hence, when $A(\bar{s})$ is estimated, $\bar{d}$ can be identified by the same market information.

However, when the recycled material is sufficiently "low-valued" in the sense that $B'(0) < 0$, the second-best subsidy level discontinuously jumps up at $d = \bar{d}$ as is seen in the left panel of Figure 3. This implies that the waste market should suddenly reach a substantial scale as soon as it is launched. Thus, an experimental policy shift could carry a high risk of substantial welfare loss. Furthermore, the threshold social cost for the policy switch is given by $\bar{d} > \bar{s} + A(\bar{s})$ when $B'(0) < 0$ (see Proposition 4). The market information that is necessary to find $\bar{d}$ no longer coincides with the information that is necessary to find s^M. This structure of the optimal policy itself renders the authorities quite clueless over whether the creation of the waste market is desirable or not. We might as well call this "the curse of low-valued recycling."

Remark 1 Let us explain the rationale behind the Corollaries. A key result is $\hat{s} < \bar{s}$ for $B'(0) < 0$ (Lemma 2). As is seen in in the paragraph following Lemma 2, the authorities must monitor the firm when s exceeds $\hat{s}$ even before s reaches $\bar{s}$. Otherwise, the subsidy induces the firm to participate in the recycling market simply to get the subsidy and dispose of the obtained recyclable wastes illegally. Lest such an undesirable recyclable waste market should emerge, the authorities are suddenly burdened with substantial monitoring costs once the market is about to be created. In the presence of the monitoring costs, this potential loss from the undesirable recycling market should be taken into account. This induce the gap XY in Figure 3 stated in Corollaries above.

Remark 2 Even when there is a monitoring issue concerning the firm's behavior, as long as the recycled material has a positive net economic value, at least, for a certain amount of initial units, i.e., $B'(0) > 0$, Ino (2011) finds it true that zero recycling activity is socially desirable if and only if recycling activities does not arise with the level of

[31] Since $\bar{s} = P_r(0)$ is the market price when the recycling is minimal, the required market information $A(\bar{s})$ can be obtained once the smallest recycling market emerges and demand elasticity is estimated around this price.

subsidy given by $s = d$.[32] Hence, there is no concern of creating a socially inefficient waste market by over-encouraging the recycling activities through this simple subsidy scheme. Thus, the above problem is a challenge inherent only for low-valued recyclable products.[33]

Remark 3 Given the condition $d > \bar{d}$ for the optimality of the DRS, the issues involved in shifting from the ADF to the DRS seem to be irrelevant to the classes of products whose social costs of disposal are fairly small. However, it should be noted that, in the conditions described above, the recycling technology $B(\cdot)$, and thus, the critical value $\bar{d}$ is not common across the classes of products which have various technologies. Figure 3 shows that the DRS with an appropriate level of monitoring may be desirable not just when the marginal cost of legal disposal is quite high (this would represent the case of scrap tires) but also when the marginal cost is not so significant as long as the net benefit of recycling is not sufficiently negative (this would correspond with the cases of PET bottles and glass).

5 Concluding Remarks

In this paper, we have identified the second-best deposit-refund policy when there is a possibility that a firm dumps acquired recyclable wastes illegally, especially focusing on the case of low-valued recyclable wastes whose reprocessing is always unprofitable *per se*. As a main result, we found that the structure of the second-best policy is qualitatively different from the one obtained for a case where the recycled material commands a positive net value as is investigated in Ino (2011).

When the social costs associated with its disposal are sufficiently significant, even a fairly low-valued recycling activity can potentially improve the social welfare, which calls

[32]See Proposition 2 in Ino (2011). This is because the smallest subsidy level that induces the proper recycling $\bar{s}$ is strictly smaller than the largest subsidy level that does not require the monitoring $\hat{s}$ when $B'(0) > 0$. Thus, before d reaches $\hat{s}$, the subsidy of $s = d$ creates a proper recycling market without monitoring.

[33]When $B'(0) > 0$, the "curse" is completely avoidable. As explained here, the policy-maker does not need to consider the monitoring problem alongside with the desirability of recycling market in this case. Thus, when the monitoring issue arises, the proper recycling market that gives us necessary information has already been there. Indeed, in conducting the monitoring, the critical information that is related to the policy shift is $\hat{s}$, which can be obtained by a simple market-based criteria: When $B'(0) > 0$, the subsidy level s exceeds the price for the recycling market if and only if $s > \hat{s}$. See Ino (2011) for the details.

for the creation of a recyclable waste market through some policy measures. However, the mere creation of the market via the subsidy scheme can give birth to the undesirable recyclable waste market that leads to inefficient illicit disposal by the firm which is supposed to be engaged in reprocessing, due to the negative financial incentive of such an activity. As a result, substantial monitoring efforts by the authorities may become necessary to deter illegal dumping by the firm as the illicitly-dumped wastes are typically more socially-costly than the municipal processing of legally-disposed wastes by the household. Thus, the desirability of the existence of the recycling market critically hinges on the relative magnitudes of the monitoring cost expended by the authorities and the social cost of legally-disposed wastes by the household.

Major issue in implementing the second-best deposit-refund policy for a low-valued recyclable product is that the information only available in the waste market is critical in finding; the level of the refund, i.e., the subsidy provided in that market; and the exact level of the marginal social cost of the household above which the subsidy should be provided. Even when the former subsidy level is identified, the authorities do not know the latter critical value. However, the creation of the proper recycling market could require substantial monitoring activities from the first place as was stressed in the previous section. This could stifle an effort to extract such information from the market experimentally. These issues do not occur if the recycled material has a positive net value, which justifies a simple use of a modified deposit-refund scheme as is elaborated in Ino (2011). This informational difficulty can pose a great challenge in encouraging the recycling of low-value recyclables through policy actions even though the recycling itself is potentially desirable from the society's viewpoint.

As the empirical work by Kinnaman et al. (2014) suggests, the over-encouragement of recycling activities are likely to be prevalent phenomena in many developed nations. Such a finding can be related to the information difficulty that the second-best policy structure caused by nature, as we have discussed in this paper. In the case of low-valued recyclables, the government can be quite clueless about critical values in implementing the second-best policy set. Policies chosen by such an ill-informed government can lead to substantial illegal waste disposal by firms or to an exorbitant monitoring cost if the government wishes to create proper recycling markets. This informational issue is unique to low-valued recyclables and can be a big obstacle in achieving the welfare-maximizing outcome.

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Appendix

Proof of Lemma 1

Proof. This proof is applicable to both case (i) and case (ii) above. Let the given policy set $(t, s; \tau_f, \tau_h) = (t', s'; \tau_f', \tau_h')$ and suppose that $z_f^*(t', s'; \tau_f', \tau_h') = z_f' > 0$. We now alter the levels of policy instruments. We depict the starting states in Figure 1. In these states, the following must be satisfied: $P_r(\hat{r}(\tau_f'); \tau_h') < s' - \tau_f'$ and $r^c = \hat{r}(\tau_f')$. Reset $s = s' - \{(s' - \tau_f') - P_r(\hat{r}(\tau_f'); \tau_h')\}$ and, therefore, $s - \tau_f' = P_r(\hat{r}(\tau_f'); \tau_h')$. Then, we have $z_f = 0$ and still, $r^c = \hat{r}(\tau_f')$. Thus, $\Delta r = -z_f'$, where Δ represents the difference between the starting state and the state after the alteration of the policy and r is the equilibrium amount of the wastes transacted at the market. Since s does not affect the supply and demand of the product, $-\Delta r = \Delta z$ since $z = x^d - r^s$. In other words, all the firms' illegally disposed residual wastes are converted into the household's legal waste. Thus, $\Delta W = (d_f - d)z_f' + C_r(z_f' + \hat{r}(\tau_f')) - C_r(\hat{r}(\tau_f')) > 0$. Note that, because the monitoring level on the firm is unchanged, the monitoring cost is unchanged as well. □

Proof of Lemma 2

Proof. (i) It immediately follows from the definition of $r^*(s; \tau)$ that $r^*(s; \tau_h) = 0$ if and only if $P_r(0; \tau_h) \geq B'(0) + s$, or equivalently, $s \leq P_r(0; \tau_h) - B'(0)$. (ii) First, consider the case where $s \leq P_r(0; \tau_h) - B'(0)$. In this case, we have $r^*(s; \tau_h) = 0$. This implies that $P_r^*(s; \tau_h) = P_r(0; \tau_h)$. Thus, $\hat{\tau}_f(s; \tau_h) > 0$ if and only if $s > P_r^*(s; \tau_h) = P_r(0; \tau_h)$ by the definition of (18). Next consider the case where $s > P_r(0; \tau_h) - B'(0)$. In this case, $s > P_r(0; \tau_h)$ is always obtained by $B'(0) \leq 0$. Furthermore, in this case, we have $r^*(s; \tau_h) > 0$. Hence, $P_r^*(s; \tau_h) = B'(r^*(s; \tau_h)) + s$. Since $B'(r^*(s; \tau_h)) < 0$, it follows that $P_r^*(s; \tau_h) < s$ and thus $\hat{\tau}_f(s; \tau_h) > 0$ by the definition of (18). □

Proof of Proposition 1

Proof. Suppose that a set of optimal policies is given by $(t^*, s^*; \tau_h^*) = (t', s'; \tau_h')$ and $\tau_h' > 0$. Note that, under the optimal policy set, we have $\tau_f = \hat{\tau}_f(s'; \tau_h')$, and thus $z_f^* = 0$. Then, the equilibrium outcomes under this policy set are $(x, r, z) = (x^*(t'; \tau_h'), r^*(s'; \tau_h'), x^*(t'; \tau_h') - r^*(s'; \tau_h'))$. Consider the case where the authorities reset the policy $(t, s; \tau_h) = (t' + \tau_h', s' + \tau_h'; 0)$ under the optimal monitoring rule $\tau_f = \hat{\tau}_f(s' + \tau_h'; 0)$. Then, the equilibrium outcomes in this case are exactly the same as those before the alteration; that is, $x^*(t';\tau'_h) = x^*(t'+\tau'_h;0)$ and $r^*(s';\tau'_h) = r^*(s'+\tau'_h;0)$ and, thus, the equilibrium amount of the legal disposal by the household, $z^* = x^* - r^*$, is also unchanged. This is because the supply curves for the product and recycling markets both shift up by τ'_h and simultaneously the demand curves for the product and recycling markets both shift up by τ'_h. Furthermore, we have $P_r^*(s'+\tau'_h;0) - P_r^*(s';\tau'_h) = \tau'_h$. This implies that $\hat{\tau}_f(s';\tau'_h) = \hat{\tau}_f(s'+\tau'_h;0)$ by the definition of the optimal monitoring rule. Since only the monitoring cost for the household is changed and all the other things are constant after the alteration of the policy set, $W^*(t'+\tau'_h, s'+\tau'_h;0) - W^*(t', s';\tau'_h) = \Gamma_h(\tau'_h) - \Gamma_h(0)$. Since $\Gamma_h(\tau'_h) > \Gamma_h(0)$ when $\tau'_h > 0$, this policy change leads to the saving in the monitoring cost on the household. This poses a contradiction to the claim that $(t', s'; \tau'_h)$ are optimal. □

Proof of Proposition 2

Proof. The first-order conditions of the problem (19) with respect to t is

$$\frac{\partial W^*(t,s)}{\partial t} = U'\frac{\partial x^*}{\partial t} - Cx'\frac{\partial x^*}{\partial t} - d\frac{\partial x^*}{\partial t} = 0. \tag{20}$$

Plugging the first-order conditions, (3) and (10), obtained for the product market into (20) and solving the equation with respect to t, we get $t = d$. □

Proof of Proposition 3

Proof. In the first case, we have $r^*(s;0) > 0$, or equivalently, $s > C_r'(0) - B'(0)$, under the optimal policy set. When $s > C_r'(0) - B'(0) \geq C_r'(0)$, $\hat{\tau}_f(s) = s - P_r^*(s;0) > 0$ holds by Lemma 2. Therefore, in the first case, the first-order condition of the problem (19) with respect to s becomes:

$$\frac{\partial W^*(t,s)}{\partial s} = B'\frac{\partial r^*}{\partial s} - C_r'\frac{\partial r^*}{\partial s} + d\frac{\partial r^*}{\partial s} - \Gamma_f'\left[1 - \frac{\partial P_r^*}{\partial s}\right] = 0. \tag{21}$$

Plug the first-order conditions for the residual waste market, (4) and (15), into (21) and solve the equation with respect to s, making use of the following comparative statics results derived from (4) and (15):

$$\frac{\partial P_r^*}{\partial s} = \frac{C_r''(r^*)}{C_r''(r^*) - B''(r^*)} > 0, \tag{22}$$

$$\frac{\partial r^*}{\partial s} = \frac{1}{C_r''(r^*) - B''(r^*)} > 0. \tag{23}$$

and, we eventually obtain $s^* = s^M$ in the proposition. In the second case, we have $r^*(s;0) = 0$, or equivalently, $s \leq C_r'(0) - B'(0)$, under the optimal policy set. When $s \leq C_r'(0) - B'(0)$, $W^*(d,s)$ is decreasing in s if $s > C_r'(0)$ since $r^*(s;0) = 0$ and $\hat{\tau}_f(s) = s - C_r(0) > 0$; $W^*(d,s)$ is constant in s if $s \leq C_r'(0)$ since $r^*(s;0) = 0$ and $\hat{\tau}_f(s) = 0$. Therefore, in the second case, the optimal subsidy level is any s such that satisfies $s \leq C_r'(0)$. □

Proof of Proposition 4

Proof. Choose the value of d that satisfies $s^M = \bar{s} = Cr'(0) - B'(0)$ and $d = \bar{s} + A(\bar{s})$, and denote it by d', where

$$A(\bar{s}) \equiv -B''(r^*(\bar{s}))\Gamma_f'(\bar{s} - P_r^*(\bar{s})) = -B''(0)\Gamma_f'(-B'(0)),$$

since $r^*(\bar{s}) = 0$ and $P_r^*(\bar{s}) = P_r(0) = C_r'(0)$. Consider the case where $d > d'$. Then, $s^M > \bar{s}$ holds. This is because, if $s^M \leq \bar{s}$, $d \leq d'$ must hold since

$$d = s^M + A(s^M) = s^M - B''(0)\Gamma_f'(s^M - C_r'(0)) \leq s^M - B''(0)\Gamma_f'(-B'(0)) \leq d',$$

as $s^M \leq \bar{s}$ and $\Gamma_f'' \geq 0$. In this case, we must compare two locally maximized welfare levels, $W^*(d,s^M)$ and $W^*(d,C_r'(0))$ (see Figure 5). Due to the envelope theorem and the fact that $r^*(s^M) > 0$ as $s^M > \bar{s}$, we have $\partial W^*(d,s^M)/\partial d = r^*(s^M) - x^*(d)$. Also from the envelope theorem and the fact that $r^*(C_r'(0)) = 0$ as $C_r'(0) \leq \bar{s}$, we have $\partial W^*(d,C_r'(0))/\partial d = r^*(C_r'(0)) - x^*(d) = -x^*(d)$. Thus, (i) $W^*(d,s^M) - W^*(d,C_r'(0))$ is strictly increasing in $d > d'$. Now take an arbitrary s such that $s > \bar{s}$. Then, $W^*(d,s^M) \geq W^*(d,s)$ since $s = s^M$ gives the local maximum in this range. Then, $\partial(W^*(d,s) - W^*(d,C_r'(0)))/\partial d = r^*(s) > 0$, where $r^*(s)$ is constant for any d. Hence, if d is sufficiently large, (ii) there exists $d > d'$ such that $W^*(d,s^M) - W^*(d,C_r'(0)) \geq W^*(d,s) - W^*(d,C_r'(0)) > 0$. Furthermore, (iii) $W^*(d,s^M) - W^*(d,C_r'(0)) \leq 0$ holds if

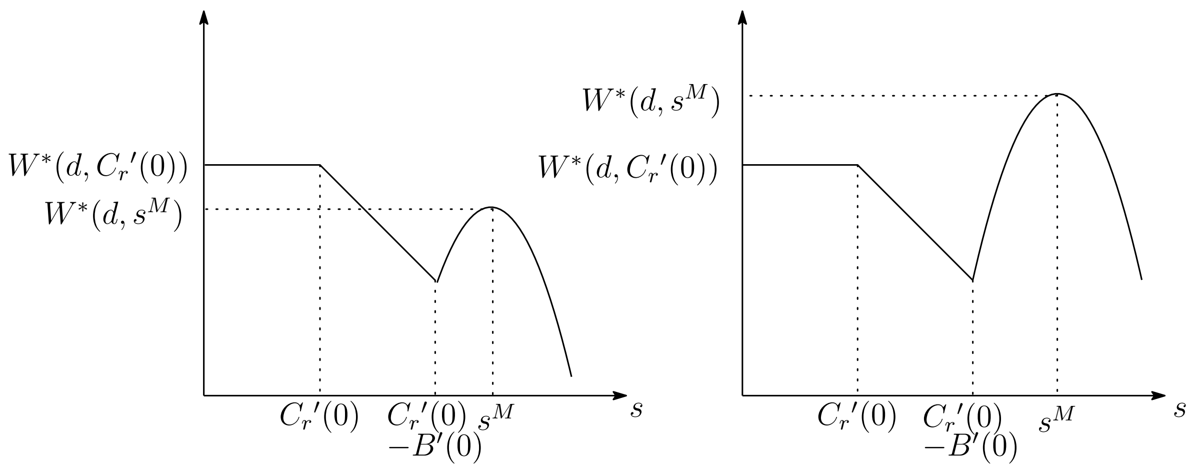

Figure 5: Welfare comparison

$d = d'$ (with equality if and only if $B'(0) = 0$) since $W^*(d, \bar{s}) \leq W^*(d, C_r'(0))$ (note that $W^*(d, s)$ is decreasing in s when $C_r'(0) < s \leq \bar{s}$ as shown in the proof of Proposition 3). From (i)-(iii), there exists a value of $\bar{d} \geq d'$ such that $W^*(d, s^M) - W^*(d, C_r{}'(0)) > 0$ if and only if $d > \bar{d}$, where $\bar{d} = d'$ if and only if $B'(0) = 0$. Consider the case where $d \leq d'$. Then, $W^*(d, s)$ is decreasing in s when $s > \bar{s}$ since $s^M \leq \bar{s}$. Therefore, under the optimal policy, $s^* \leq C_r{}'(0)$ and $r^*(s^*) = 0$. □