DISCUSSION PAPER SERIES

Discussion paper No.56

On Second-best Policing Effort against the Illegal Disposal of Recyclable Waste

Mariko Onoda

Doctoral Course Researcher in the Graduate School of Economics,
Kwansei Gakuin University

May, 2010

MASTERY FOR SERVICE

SCHOOL OF ECONOMICS

KWANSEI GAKUIN UNIVERSITY

1-155 Uegahara Ichiban-cho
Nishinomiya 662-8501, Japan

On Second-best Policing Effort against the Illegal Disposal of Recyclable Waste*

Mariko Onoda†

May 20, 2010

Abstract

In this paper, we construct a partial equilibrium model of a product that can be manufactured by using a recycled material as well as a virgin natural resource. In particular, we consider the possibility that a household may resort to the illicit disposal of its waste, such as midnight dumping, instead of discarding it properly. Our focus is on conducting a comparative static analysis on the second-best level of the government's policing effort to counter illegal disposal. More specifically, we examine how the government should adjust the effort level in response to changes in the environmental damage cost of illegal disposal and exported waste.

Keywords: illegal waste disposal, recycling, second-best policy

JEL classification: Q20

*I would like to express my gratitude to Kenzo Abe, Kenji Fujiwara, Keisaku Higashida, Mitsunori Hirogaki, Hiroaki Ino, Masamichi Kawano, Norimichi Matsueda, Tomomichi Mizuno, Osamu Murata and Tetsuya Shinkai for their helpful comments and suggestions for improving an earlier version of this paper. Of course, all remaining errors are mine.

†Corresponding author: Graduate School of Economics, Kwansei Gakuin University. 1-155 Uegahara Ichiban-cho, Nishinomiya, Hyogo, 662-8501, Japan. Tel: +81-798-54-6204. Fax: +81-798-51-0944. E-mail: bkg49364@kwansei.ac.jp.

1 Introduction

It is frequently reported that the illegal dumping of household waste and exported waste pose increasingly significant problems. A number of economic studies have tackled the issue of reducing unlawful waste disposal and, in particular, recycling wasted materials into productive resources (e.g., Smith, 1972, Dinan, 1993, Fullerton and Kinnaman, 1995, Palmer and Walls, 1997, Shinkuma, 2003). These studies have mainly examined the properties of some combinations of different policy instruments, ranging from a disposal fee-cum-subsidy, a recycling charge-cum-subsidy, a tax on the extraction of the virgin resource, and recycled content standards under a variety of settings.

As for illegal waste disposal, Sullivan (1987) derives the optimal enforcement effort of the budget-constrained authority, along with the optimal subsidy for the legal disposal to counter midnight dumping by waste generating producers. Sullivan (1987) resorts to the assumption of 'a rational criminal' a la Becker (1968) in describing the behavior of these producers.[1] In this article, we follow a similar line of reasoning regarding the causes of illegal waste disposal, which eventually lead to environmental damage. Hence, we suppose that the prevalence of illegal disposal will be influenced by the size of the expected fine, which in turn depends on the severity of the governmental policing effort used to deter the illegal activity. This level of effort should be considerably easier to manipulate relative to other policy instruments and even to changing the level of the fine for illicit waste disposal, owing to the legislative and judicial procedures involved in the implementation of policy alterations. Thus, we consider that the authority adjusts the level of policing activities so that they are more readily altered in accommodating possible changes in circumstances.

In contrast to Sullivan (1987), where attention is mostly paid to the direct effect of reducing illegal disposal, this paper also considers the impact of illegal disposal on recycling activities and the output market. These have not been fully explored in previous work. More specifically, we conduct a simple comparative static analysis and show how, in the absence of other policy instruments, the second-best policing effort level depends

[1] More recent advances in the methods of enforcing environmentally related regulations are surveyed in Cohen (1999) and Heyes (2000). For a more general regulation case, see Polinsky and Shavell (2000).

on various environmental conditions, including the cost arising from damage through illegal disposal and exported waste.

The remainder of the paper is as follows. Section 2 describes the structure of our model. In Section 3, we set up a social welfare function and conduct a comparative static analysis on the second-best policing effort. The final section contains some concluding remarks.

2 The Model

Our model contains a price-taking household and a price-taking producer of a potentially recyclable consumer product. For simplicity, we normalize the number of households and producers to one, respectively.

We suppose that the consumption of x_D units of the product yields x_D units of waste to be disposed of. In disposing of its own waste, the household has two options. The first is legal disposal where the household must hand its waste over to the producer of the consumer product in a specific manner. We assume that legal disposal causes a certain level of inconvenience to the household, as well as the costs involved in temporary storage and the ensuing transportation of waste to a proper collection site at a specified date. The second alternative for the household is to get rid of its waste unlawfully, such as dumping the waste at nondesignated sites at midnight. Disposal of illegal waste in this manner leads to a negative environmental externality. Moreover, in discarding waste illicitly, the household incurs some cost, physically and perhaps psychologically. The household disposes of w units of waste legally, while the remainder, i.e., $x_D - w$ units of household's waste, are disposed of illegally. Accordingly, in this economy, w units of waste are processed legally and eventually handed over to the producer through the government collection.[2]

Further, we assume that the producer has the responsibility to treat the waste, either by recycling to create a resource that can be used for the production of the original output

[2]In Japan, for instance, the national government has recently implemented a new law that requires a producer of consumer products to take back certain types of household waste and make an effort to recycle some pre-specified portion (Kawakami, 2001).

or by exporting and selling the waste to a foreign firm at a fixed price.[3] As a result, the firm can produce the output by using both a recycled resource, r, and a virgin natural resource, v, that can be purchased at a fixed price.

2.1 The Behavior of the Household

Let us start by describing the representative household's behavior. As a critical assumption, we suppose that the household is sufficiently rational or far-sighted so that, when determining how much of the good it purchases, it takes into account the eventual waste disposal following consumption of the product.

We first consider the household's decision making concerning how to discard its waste. In disposing of waste, which amounts to x_D, the household attempts to minimize its expected disposal cost by selecting the level of legal disposal, w ($0 \leq w \leq x_D$), as follows:[4]

$$\underset{w}{Min}\ C^H(x_D, w) = \alpha w + \frac{\beta}{2} w^2 + \left\{ \pi\phi (x_D - w) + \frac{\eta}{2} (x_D - w)^2 \right\}. \tag{1}$$

In (1), α ($\alpha > 0$) is the collection charge per unit of legal disposal, which the household pays to the government. Legal disposal incurs another type of cost for the household in the form of a carrying cost, which is represented in a quadratic fashion by the parameter, β ($\beta > 0$). The terms in curly brackets then signify the expected total cost of illegal disposal. The first term represents the expected penalty for illegal disposal. Here, π ($0 \leq \pi \leq 1$) is the probability of the household being caught for illicit disposal [as shown in the next section, this can be altered by the authority devoting more resources to crackdown activities] and ϕ ($\phi > 0$) is the predetermined fine per unit of illegally disposed waste upon being detected by the authority. In addition, we include in our model the household's cost of resorting to illegal disposal activities, such as cautiously carrying the waste to a remote unpopulated area so as not to be detected. This nonpenalty cost of illicit disposal to the household is assumed to be quadratic with respect to the amount of illegally disposed

[3] In this paper, we assume the producer who does not dispose of waste illegally, fearing for distrust of his/her enterprise. Therefore, our model focuses on only the household's illegal dumping.

[4] We assume $w \leq x_D$, which means that the household cannot dispose of more waste than it consumes. That is, we do not consider the possibility that a household handles its neighbors' waste for any reason.

waste, $x_D - w$, and is represented by the second term in the curly brackets with η ($\eta > 0$) as the parameter.

The first-order condition for cost minimization in (1) yields:[5]

$$\frac{\partial C^H(x_D, w)}{\partial w} = \alpha + \beta w - \pi\phi - \eta(x_D - w) = 0. \tag{2}$$

Solving (2) for w, we obtain:

$$w^* = \frac{\eta}{\beta + \eta} x_D + \frac{\pi\phi - \alpha}{\beta + \eta}, \tag{3}$$

where w^* is the cost minimizing value of w given x_D and we assume that $0 < w^* < x_D$.

Given this result, the household determines its demand for x_D by maximizing the following expected utility function:

$$\underset{x_D,\ z}{Max}\ U(x_D, z) = \theta x_D - \frac{1}{2}(x_D)^2 + z, \tag{4}$$

$$s.t. \quad I = p x_D + z + C^H(x_D, w^*), \tag{5}$$

$$w^* = \frac{\eta}{\beta + \eta} x_D + \frac{\pi\phi - \alpha}{\beta + \eta}, \tag{6}$$

where the utility of the representative household from its consumption activities, $U(x_D, z)$, is assumed to be quasi-linear, with z being the consumption of the composition goods that yield no harmful waste and $\theta - x_D$ is the marginal utility of the recyclable product, x_D. As for the constraints, (5), is simply the household's budget constraint, where I and p, respectively, denote the income of the household and the unit price of x_D. The unit price of z is normalized to 1.

Inserting (6) into (5) and then substituting (5) into (4) to cancel z, we can rewrite the household's utility maximization problem (4) - (6) as follows:

$$\begin{aligned} \underset{x_D}{Max}\ U(x_D) = {} & \theta x_D - \frac{1}{2}(x_D)^2 \\ & + \left\{ I - p x_D - \frac{\beta\eta}{2(\beta + \eta)}(x_D)^2 - \frac{\alpha\eta + \beta\pi\phi}{\beta + \eta} x_D + \frac{(\pi\phi - \alpha)^2}{2(\beta + \eta)} \right\}. \end{aligned} \tag{7}$$

[5] The second-order condition for minimization is always satisfied as $\frac{\partial^2 C^H(x_D, w)}{\partial w^2} = \beta + \eta > 0$.

The first-order condition for maximization is:

$$\frac{\partial U\left(x_D\right)}{\partial x_D} = \theta - x_D - p - \frac{\beta\eta}{\beta+\eta}x_D - \frac{\alpha\eta+\beta\pi\phi}{\beta+\eta} = 0. \tag{8}$$

Furthermore, we can obtain the inverse demand function of the representative household as follows:

$$p^D\left(x_D\right) = -\left(\frac{\beta+\eta+\beta\eta}{\beta+\eta}\right)x_D + \left(\theta - \frac{\alpha\eta+\beta\pi\phi}{\beta+\eta}\right). \tag{9}$$

2.2 The Behavior of the Producer

In the following, we consider the behavior of a firm that produces and sells the output derived from the recycled resource processed from the household waste, r, and a virgin natural resource, v. The producer attempts to minimize its total cost of production and disposal by choosing the level of input, v and r, so the cost minimization problem is as follows:

$$\underset{v,r}{Min}\ C^P\left(v,r\right) = p_v v + p_r r - \gamma(w^* - r), \tag{10}$$

$$s.t.\quad w^* = \frac{\eta}{\beta+\eta}x_S + \frac{\pi\phi-\alpha}{\beta+\eta}, \tag{11}$$

$$x_S = v^\tau r^\rho. \tag{12}$$

We assume that the virgin natural resource can be purchased at a fixed price of p_v ($p_v > 0$) in the input market. In processing the household waste into a productive input, the producer incurs a recycling cost of p_r ($p_r > 0$) per unit of the resource. Alternatively, the producer can sell the remainder of the household waste, $w^* - r$, to a foreign firm at a price of γ ($\gamma > 0$). The constraint (11) represents the total amount of household's legal waste disposal collected by the government, which is distributed to the producer without through the market. In our model, the producer is assumed to recognize that amount and the way of distribution. The constraint (12) expresses the production function, where τ

is a parameter associated with the productivity of the virgin resource input and ρ is that of the recycled resource input $(0<\tau<1,\ 0<\rho<1,\ 0<\tau+\rho<1)$.[6]

By substituting (11) - (12) into (10), we can rewrite the producer's cost minimization problem (10) - (12) as follows:[7]

$$\begin{aligned}\underset{v,r}{Min}\ C^P(v,r) &= p_v v + p_r r - \gamma\left\{\left(\frac{\eta}{\beta+\eta}x_S + \frac{\pi\phi-\alpha}{\beta+\eta}\right) - r\right\} \\ &= p_v v + (p_r+\gamma)\, r - \gamma\left(\frac{\eta}{\beta+\eta}v^{\tau}r^{\rho} + \frac{\pi\phi-\alpha}{\beta+\eta}\right). \end{aligned} \tag{13}$$

Then, the first-order conditions for cost minimization in (13) can be obtained as:[8]

$$\frac{\partial C^P(v,r)}{\partial v} = p_v - \gamma\frac{\eta}{\beta+\eta}\tau v^{\tau-1}r^{\rho} = 0, \tag{14}$$

$$\frac{\partial C^P(v,r)}{\partial r} = (p_r+\gamma) - \gamma\frac{\eta}{\beta+\eta}\rho v^{\tau}r^{\rho-1} = 0. \tag{15}$$

We first solve (14) and (15) with regard to v and r, respectively, and substitute them into (12):

$$v = \left[\left\{\frac{\tau(p_r+\gamma)}{\rho p_v}\right\}^{\rho} x_S\right]^{\frac{1}{\tau+\rho}}, \tag{16}$$

$$r = \left[\left\{\frac{\tau(p_r+\gamma)}{\rho p_v}\right\}^{-\tau} x_S\right]^{\frac{1}{\tau+\rho}}. \tag{17}$$

[6] Thus, output has to fall to zero whenever one of the two inputs is unused, which is the case, for instance, of a standard Cobb–Douglas production. Furthermore, the assumption, $\tau+\rho<1$, means that the production function decribed (12) exhibits decreasing returns-to-scale.

[7] We assume that $w^*>r$, i.e., $\frac{\eta}{\beta+\eta}v^{\tau}r^{\rho}+\frac{\pi\phi-\alpha}{\beta+\eta}>r$, which not only means that the producer cannot recycle more waste than what households carry to the producer but also implies that the waste exported to a foreign country has an inner solution.

[8] The second-order conditions for minimization are always satisfied as
$\frac{\partial^2 C^P}{\partial v^2} = -\gamma\frac{\eta}{\beta+\eta}\tau(\tau-1)v^{\tau-2}r^{\rho}>0,\ \frac{\partial^2 C^P}{\partial r^2} = -\gamma\frac{\eta}{\beta+\eta}\rho(\rho-1)v^{\tau}r^{\rho-2}>0,$
$\begin{vmatrix}\frac{\partial^2 C^P}{\partial v^2} & \frac{\partial^2 C^P}{\partial v\partial r}\\ \frac{\partial^2 C^P}{\partial r\partial v} & \frac{\partial^2 C^P}{\partial r^2}\end{vmatrix} = \begin{vmatrix}-\gamma\frac{\eta}{\beta+\eta}\tau(\tau-1)v^{\tau-2}r^{\rho} & -\gamma\frac{\eta}{\beta+\eta}\tau\rho v^{\tau-1}r^{\rho-1}\\ -\gamma\frac{\eta}{\beta+\eta}\tau\rho v^{\tau-1}r^{\rho-1} & -\gamma\frac{\eta}{\beta+\eta}\rho(\rho-1)v^{\tau}r^{\rho-2}\end{vmatrix}$
$=\left(\gamma\frac{\eta}{\beta+\eta}v^{\tau-1}r^{\rho-1}\right)^2\tau\rho(1-\tau-\rho)>0.\ (\because 0<\tau<1,\ 0<\rho<1,\ 0<\tau+\rho<1.)$

We can rewrite the producer's cost as a function of x_S by using (13) as well as (16) and (17):

$$C^P(x_S) = C^{v,r} \cdot (x_S)^{\frac{1}{\tau+\rho}} - \gamma \left(\frac{\eta}{\beta+\eta} x_S + \frac{\pi\phi - \alpha}{\beta+\eta} \right), \tag{18}$$

$$\textit{where we replace } \left[p_v \left\{ \frac{\tau(p_r+\gamma)}{\rho p_v} \right\}^{\frac{\rho}{\tau+\rho}} + (p_r+\gamma) \left\{ \frac{\tau(p_r+\gamma)}{\rho p_v} \right\}^{-\frac{\tau}{\tau+\rho}} \right] \textit{ as } C^{v,r}.$$

Then, the producer's profit maximization problem is expressed as follows:

$$\underset{x_S}{Max}\ \Pi(x_S) = p x_S - C^P(x_S). \tag{19}$$

The first-order condition for maximization is:

$$\frac{\partial \Pi(x_S)}{\partial x_S} = p - MC^P(x_S) = 0. \tag{20}$$

Furthermore, by using (18) and (20), we can obtain the inverse supply function of the producer as follows:

$$\begin{aligned} p^S(x_S) &= MC^P(x_S) \\ &= \left(\frac{1}{\tau+\rho} \right) C^{v,r} \cdot (x_S)^{\frac{1}{\tau+\rho}-1} - \gamma \frac{\eta}{\beta+\eta}. \end{aligned} \tag{21}$$

Substituting (9) and (21) into the market clearing condition, i.e., $p^* = p^D(x_D) = p^S(x_S)$, the following equation is yielded:

$$\left\{ -\left(\frac{\beta+\eta+\beta\eta}{\beta+\eta} \right) x_D + \left(\theta - \frac{\alpha\eta + \beta\pi\phi}{\beta+\eta} \right) \right\} = \left(\frac{1}{\tau+\rho} \right) C^{v,r} \cdot (x_S)^{\frac{1}{\tau+\rho}-1} - \gamma \frac{\eta}{\beta+\eta}. \tag{22}$$

We express the equilibrium amount of goods that satisfies (22) as $x^* (= x_D^* = x_S^*)$.

In the following, we focus on the probability of the household being caught for illicit disposal, π, which we call the enforcement level, and conduct a comparative static analysis with respect to π.

2.3 Comparative Statics Results

As described above, the market clearing condition is given by (22). By applying the implicit function theorem to (22), we can derive the followings:[9]

$$\frac{dx^*}{d\pi} < 0, \qquad (23)$$
$$\text{where } x^* \left(=x_D^* = x_S^*\right),$$

$$\frac{dp^*}{d\pi} < 0, \qquad (24)$$

$$\frac{dw^*}{d\pi} > 0, \qquad (25)$$

$$\frac{d\left(x^* - w^*\right)}{d\pi} = \frac{dx^*}{d\pi} - \frac{dw^*}{d\pi} < 0, \qquad (26)$$

where the asterisk $*$ of each variable expresses its equilibrium amount. That is, p^*, w^* and $x^* - w^*$, respectively, denote the equilibrium price of goods, the equilibrium amount of legal waste disposal, and that of illegal one.

We can also obtain the following propositions.

Proposition 1. *If the enforcement level increases, the equilibrium amount of recycling decreases.*

Proof. By using (17) and (23), we have:

$$\frac{dr^*}{d\pi} = \frac{dr^*}{dx_S^*} \cdot \frac{dx_S^*}{d\pi} = \left(\frac{1}{\tau+\rho}\right)\left\{\frac{\tau\left(p_r+\gamma\right)}{\rho p_v}\right\}^{-\frac{\tau}{\tau+\rho}} \left(x_S\right)^{\frac{1}{\tau+\rho}-1} \cdot \frac{dx^*}{d\pi} < 0. \qquad (27)$$

Q.E.D.

According to (23), if the enforcement level increases, then the equilibrium amount of goods x_D^* decreases, which leads to a decrease in the equilibrium supply x_S^*. Then, by (17), the decrease in x_S^* also causes a decrease in the equilibrium amount of recycling r^*.

[9] See Appendix I for details of the derivations.

Proposition 2. *If the enforcement level increases, the equilibrium amount of virgin natural resource used by the producer decreases.*

Proof. By using (16) and (23), we have:

$$\frac{dv^*}{d\pi} = \frac{dv^*}{dx_S^*} \cdot \frac{dx_S^*}{d\pi} = \left(\frac{1}{\tau+\rho}\right) \left\{\frac{\tau\left(p_r+\gamma\right)}{\rho p_v}\right\}^{\frac{\rho}{\tau+\rho}} (x_S)^{\frac{1}{\tau+\rho}-1} \cdot \frac{dx^*}{d\pi} < 0. \tag{28}$$

Q.E.D.

Similarly to Proposition 1, if the enforcement level increases, then the equilibrium values of x_D^* and x_S^* decrease. This induces a decrease in v^*, i.e., the equilibrium virgin natural resource used by the producer.

Proposition 3. *If the enforcement level increases, the equilibrium amount of waste exported to a foreign country increases.*

Proof. By using (25) and Proposition 1, we have:

$$\frac{d\left(w^*-r^*\right)}{d\pi} = \frac{dw^*}{d\pi} - \frac{dr^*}{d\pi} > 0. \tag{29}$$

Q.E.D.

According to (25) and Proposition 1, if the enforcement level increases, the equilibrium legal waste disposal w^* increases and the equilibrium amount of recycling r^* decreases. Therefore, the equilibrium waste exported to a foreign firm, w^*-r^*, eventually increases.

These propositions suggest the following. By increasing the enforcement level on household's illegal dumping, the equilibrium amounts of recycling and the virgin natural resource used by the producer decrease, while the equilibrium amount of exported waste increases. That is, control of the enforcement level influences not only the household's behavior directly but also the producer's behavior indirectly, which suggests that the government's policy for the household can affect how much the producer engages in recycling, uses the virgin resource and exports waste to a foreign country.

A higher level of policing the household's illegal dumping leads to not only an increase in the household's legal waste disposal, w^*, but also a decrease in the household's demand for goods, x_D^*. The former effect, i.e., an increase in w^*, may lead to increase the potentially recycled material. On the other hand, in response to the latter effect, i.e., a decrease in x_D^*, the firm lowers his/her production itself, which causes a decrease in the use of inputs, r^* and v^*. In our model, however, since we consider the possibility that the firm can export waste carried from the household to a foreign country, that former ripple effects can not occur, which leads to a decrease in recycling, r^*, as is shown in Proposition 1, and an increase in the amount of exported waste, $w^* - r^*$, as in Proposition 3.

In the next section, we set up a social welfare function and conduct a comparative static analysis on the second-best policing effort.

3 On the Second-best Policing Effort

3.1 A Social Welfare Function

Our social welfare function consists of the consumer surplus, CS, from which the cost incurred by the household is deducted, the producer's surplus (the firm's profit), PS, the government's expected net benefit, GB, which is defined here as the difference between the government revenue from the household (the total collection charge of legal disposal, αw, plus the expected fine revenue, $\pi\phi(x_D - w)$) and its expense spent on the policing effort, $\frac{\mu}{2}\pi^2$, and, lastly, the environmental damage costs, DC. We can write such a welfare function, W, as follows:

$$\begin{aligned} W\left(p, x_D, w, v, r\right) &= CS + PS + GB - DC \\ &= \left\{\theta x_D - \frac{1}{2}\left(x_D\right)^2 + \left(I - p x_D - \alpha w - \frac{\beta}{2}w^2 - \pi\phi\left(x_D - w\right) - \frac{\eta}{2}\left(x_D - w\right)^2\right)\right\} \\ &\quad + \left[p(v^\tau r^\rho) - \left\{p_v v + p_r r - \gamma(w - r)\right\}\right] \\ &\quad + \left\{\alpha w + \pi\phi\left(x_D - w\right) - \frac{\mu}{2}\pi^2\right\} \\ &\quad - \left\{\delta_d(x_D - w) + \delta_e(w - r)\right\}. \end{aligned} \tag{30}$$

$$\begin{aligned} \therefore W\left(x_D, w, x_S, r\right) = &\left\{\theta x_D - \frac{1}{2}\left(x_D\right)^2 + \left(I - \frac{\beta}{2}w^2 - \frac{\eta}{2}\left(x_D - w\right)^2\right)\right\} \\ &- C^P\left(x_S\right) - \frac{\mu}{2}\pi^2 - \left\{\delta_d(x_D - w) + \delta_e(w - r)\right\}. \end{aligned} \tag{31}$$

Note that the household's payment for x_D, px_D, is exactly offset by the producer's revenue, $p(v^{\tau}r^{\rho})$. Similarly, the amount of total penalties paid by the household, $\pi\phi(x_D - w)$, is also offset by the government's fine revenue, and furthermore, the amount of total collection charge, αw, is also offset between the household and the government. We can rewrite the producer's cost, $\{p_v v + p_r r - \gamma(w - r)\}$, as $C^P(x_S)$ by using (18). The expense of the policing effort is assumed to be quadratic and increasing in π, which is the probability of catching a illicit waste disposer, with μ as an exogenous parameter. The terms in the last brackets signify two different types of environment-related costs, where δ_d is the marginal cost of illegally disposed waste and δ_e is the marginal cost of exported waste. For simplicity, we assume that all illegally discarded waste by the household, whether detected or not by the authority, causes environmental damage in a uniform manner. The environmental damage cost of exported waste is associated with the external diseconomies occurred through the recycling processes of developing countries. In these countries, their own governments can not treat or dispose of any imported waste appropriately and recycling workers' life and health are endangered.

As an important assumption in this study, we consider that the government can only control one variable, π, as its policy instrument through determining the level of resources devoted to a crackdown on illegal waste disposal. We consider that the severity of policing activities is significantly easier to change than other policy instruments, including the disposal fees/subsidies and recycling charges/subsidies that are typically the focus of most existing studies. It may even be easier to change than the fine for illicit dumping owing to the legislative and judicial procedures required for implementation of these political alterations.

Then, given the equilibrium amount of x_D, x_S, w and r, the welfare maximization problem can be expressed as follows:

$$\underset{\pi}{Max}\ W(\pi) = \left[\theta x_D^* - \frac{1}{2}(x_D^*)^2 + \left\{I - \frac{\beta}{2}(w^*)^2 - \frac{\eta}{2}(x_D^* - w^*)^2\right\}\right] - C^P(x_S^*) - \frac{\mu}{2}\pi^2 - \{\delta_d(x_D^* - w^*) + \delta_e(w^* - r^*)\}. \tag{32}$$

The first-order conditions for the welfare maximization problem with respect to π can then be expressed in the following fashion:[10]

$$F_W : \left[\left(\frac{\partial W}{\partial x_D^*} + \frac{\partial W}{\partial x_S^*} \right) \frac{dx^*}{d\pi} + \frac{\partial W}{\partial w^*} \cdot \frac{dw^*}{d\pi} + \frac{\partial W}{\partial r^*} \cdot \frac{dr^*}{d\pi} \right] + \frac{\partial W}{\partial \pi} = 0. \tag{33}$$

The crackdown level that satisfies (33) can be considered as its second-best level, and we refer to this as π^*. Applying the partial derivatives of (32), $\frac{\partial W}{\partial x_D^*}$, $\frac{\partial W}{\partial x_S^*}$, $\frac{\partial W}{\partial w^*}$ and $\frac{\partial W}{\partial r^*}$, (33) is eventually expressed as follows:[11]

$$F_W : \left[(\pi\phi - \delta_d) \cdot \frac{dx^*}{d\pi} + \{(\alpha - \pi\phi) + (\delta_d - \delta_e)\} \cdot \frac{dw^*}{d\pi} + \delta_e \cdot \frac{dr^*}{d\pi} \right] - \mu\pi = 0. \tag{34}$$

In the following section, we conduct a comparative static analysis of the second-best level of policing effort, π^*, by using (34).

3.2 Comparative Static Analysis

In this section, we present the results of comparative static analysis. Our comparative static exercise focuses on the second-best enforcement level π^* and, in particular, examines how this equilibrium level depends on the environmental parameters.

If F_W has the equilibrium solution π^*, we can express the implicit function as follows:

$$\pi^* = \pi^*(\delta_d, \delta_e, ...). \tag{35}$$

By applying the implicit function theorem, we obtain the following propositions.

Proposition 4. *If the environmental damage cost associated with the household's illegal waste disposal increases, the second-best enforcement level should also increase.*

Proof. Applying the implicit function theorem and using (26), combined with the results derived in Appendix II, we have:[12]

$$\frac{\partial \pi^*}{\partial \delta_d} = -\frac{\left(\frac{\partial F_W}{\partial \delta_d}\right)}{\left(\frac{\partial F_W}{\partial \pi}\right)} = -\frac{-\left(\frac{dx^*}{d\pi} - \frac{dw^*}{d\pi}\right)}{\left(\frac{dx^*}{d\pi} - \frac{dw^*}{d\pi}\right)\phi - \mu} > 0. \tag{36}$$

[10]The second-order condition of (32) is satisfied, i.e., $\frac{\partial F_W}{\partial \pi} < 0$. See Appendix II.

[11]See Appendix II for the detailed calculations of $\frac{\partial W}{\partial x_D^*}$, $\frac{\partial W}{\partial x_S^*}$, $\frac{\partial W}{\partial w^*}$ and $\frac{\partial W}{\partial r^*}$.

[12]In this case, we fix all of the exogenous variables except δ_d at their original level, and so we use ∂ instead of d and express these as $\frac{\partial \pi^*}{\partial \delta_d}$. We apply the same notation to the following proposition. Furthermore, note that $\frac{\partial F_W}{\partial \pi}$, the denominator of $\frac{\partial \pi^*}{\partial \delta}$, is always negative. This is also obvious because $\frac{\partial F_W}{\partial \pi} < 0$, i.e., the second-order condition of (32) is always satisfied.

Q.E.D.

This result is rather intuitive in that an increase in environmental damage caused by illegal waste disposal can be coped with fairly directly by an increase in the level of policing activities. If the government increases the enforcement level π, then it is sure that the household will decrease the amount of illegal waste disposal, and this leads to a resolution of the illegal dumping problem.

Proposition 5. *If the environmental damage cost of exported waste increases, the second-best enforcement level should decrease.*

Proof. By the implicit function theorem and the results shown in Appendix II, (26) and Proposition 3, we can derive:

$$\frac{\partial \pi^*}{\partial \delta_e} = -\frac{\left(\frac{\partial F_W}{\partial \delta_e}\right)}{\left(\frac{\partial F_W}{\partial \pi}\right)} = -\frac{-\left(\frac{dw^*}{d\pi} - \frac{dr^*}{d\pi}\right)}{\left(\frac{dx^*}{d\pi} - \frac{dw^*}{d\pi}\right)\phi - \mu} = \frac{\frac{d(w^*-r^*)}{d\pi}}{\left(\frac{dx^*}{d\pi} - \frac{dw^*}{d\pi}\right)\phi - \mu} < 0. \tag{37}$$

Q.E.D.

The environmental damage cost of exported waste, δ_e, can increase for several reasons, for instance, more significant environmental damage has occurred through the recycling processes of developing countries, which leads to endanger the life and health of these countries' recycling workers. A decrease in the enforcement level π generates an increase in illegal disposal by household and a decrease in legal waste disposal w. Conversely, a decrease in the enforcement level raises the amount of recycling, r , and therefore the amount of waste exported to a foreign firm, $w - r$, decreases. This leads to resolving the problem of exported waste.

The propositions described suggest that, if the government can control only the enforcement level as a policy instrument for resolving environmental problems, then whether it should increase the level or not depends on which problem is currently the most serious. If the environmental damage cost of exported waste increases, then the government should decrease the crackdown level and regulate more loosely, whereas, if the environmental damage cost of the household's illegal waste disposal increases, then it should carry out more severe regulation by increasing the level of enforcement.

The illegal dumping by the household, $x_D - w$, which is not carried to the producer for recycling, causes the environmental problem. The exported waste by the producer, $w - r$, which has been carried from the household but not reborn as recycled material, also causes an environmental problem. In the social welfare analysis, we explore how the government should control the enforcement level on household's illegal dumping when each of the environmental damage costs, δ_d and δ_e, increases. The propositions above indicate that, in terms of the enforcement level, the opposite direction should be taken to deal with these two problems.

4 Concluding Remarks

In this paper, we have explored how the second-best crackdown level on illegal waste dumping depends on the environmental damage costs. As shown, the overall effects of changing the enforcement effort against illegal waste dumping are not easy to grasp in certain situations, and the authority must carefully take into account the impact of its choices on various aspects of the economy. The comparative static analysis based on our model indicates that, while the government should respond to the increase in the cost of illegal disposal by devoting more resources to the crackdown effort, it should decrease its policing effort as the environmental damage cost of exported waste becomes more significant. The waste the household do not dispose of legally causes the illegal dumping problem, just as the producer who does not recycle relates to the problem through exporting those waste to a foreign country. Both problems lead to environmental damage. In terms of government regulation, however, opposing policy instruments should be applied to these problems. We also suggest that government policy for the household, such as more severe regulation of illegal dumping, can indirectly influence the producer's behavior, such as a decrease in recycling, a decrease in the use of the virgin resource and an increase in exported waste.

We can easily extend our simple model with a recyclable product to more complex situations. One possible extension would be to include international trade in the recyclable product, as well as international natural resource input and output markets. Recently, the transportation of recyclable waste to developing nations has drawn public attention from both environmental and commercial perspectives. At the same time, a new line of economic studies focusing on recycling activities in the context of international trade and the environment is emerging (e.g., Higashida and Jinji, 2006).

Another potential direction would be to include the dynamic aspects of the environment alongside the decision making of concerned economic agents. Some of the environmental damages involved may exhibit the characteristics of stock pollution, which necessitates a dynamic analysis. Alternatively, the consideration of time is especially important when discussing the recycling of durable consumer products, such as household electric and electrical appliances, whose treatment is attracting attention and some controversy in Japan. In this situation, we believe that we can use our simple analytical setup as the basis for more extended analyses in different contexts.

References

[1] Becker, G. S., 1968, Crime and Punishment: An Economic Approach, *Journal of Political Economy*, 76, 169–217.

[2] Cohen, M. A., 1999, Monitoring and Enforcement of Environmental Policy, in H. Folmer and T. Tietenberg, eds, *The International Yearbook of Environmental and Resource Economics 1999/2000*, Edward Elgar, Cheltenham, UK.

[3] Dinan, T. M., 1993, Economic Efficiency Effects of Alternative Policies for Reducing Waste Disposal, *Journal of Environmental Economics and Management*, 25, 242–256.

[4] Fullerton, D. and T. C. Kinnaman, 1995, Garbage, Recycling and Illicit Burning or Dumping, *Journal of Environmental Economics and Management*, 29, 78–91.

[5] Heyes, A., 2000, Implementing Environmental Regulation: Enforcement and Compliance, *Journal of Regulatory Economics*, 17, 107–129.

[6] Higashida, K. and N. Jinji, 2006, Strategic Use of Recycled Content Standards under International Duopoly, *Journal of Environmental Economics and Management*, 51, 242–257

[7] Kawakami, K., 2001, Outline of Law for Recycling Specified Kinds of Home Appliances in Japan, *Environmental Economics and Policy Studies*, 4, 211–218.

[8] Palmer, K. and M. Walls, 1997, Optimal Policies for Solid Waste Disposal Taxes, Subsidies, and Standards, *Journal of Public Economics*, 65, 193–205.

[9] Polinsky, A. M. and S. Shavell, 2000, The Economic Theory of Public Enforcement of Law, *Journal of Economic Literature*, 38, 45–76.

[10] Shinkuma, T., 2003, On the Second-best Policy for Household Waste Recycling, *Environmental and Resource Economics*, 24, 77–95.

[11] Smith, V. L., 1972, Dynamics of Waste Disposal: Disposal Versus Recycling, *Quarterly Journal of Economics*, 86, 600–616.

[12] Sullivan, A., 1987, Policy Options for Toxics Disposal: Laissez-Faire, Subsidization, and Enforcement, *Journal of Environmental Economics and Management*, 14, 58–71.

Appendix I: The Derivations of (23) - (26)

In this appendix, we derive (23) - (26) described in 2.3.

(23) : $\mathbf{\frac{dx^*}{d\pi} < 0}$, **where** $\mathbf{x}^* \, (= \mathbf{x}^*_{\mathbf{D}} = \mathbf{x}^*_{\mathbf{S}})$.

If the enforcement level increases, the equilibrium amount of goods decreases.

Proof. By shifting terms, we can rewrite (22) in 2.2 as follows:

$$F_C : \left\{ -\left(\frac{\beta + \eta + \beta\eta}{\beta + \eta} \right) x_D + \left(\theta - \frac{\alpha\eta + \beta\pi\phi}{\beta + \eta} \right) \right\} - \left(\frac{1}{\tau + \rho} \right) C^{v,r} \cdot (x_S)^{\frac{1}{\tau+\rho} - 1} + \gamma \frac{\eta}{\beta + \eta} = 0. \tag{A1.1}$$

If (A1.1) has the equilibrium solution x^*, we can express the implicit function as follows:

$$x^* = x^*(\alpha, \beta, \pi, \phi, ...). \tag{A1.2}$$

By applying the implicit function theorem and fixing all the exogenous variables except π at their original levels, we obtain (23) as follows:

$$\begin{aligned}\frac{dx^*}{d\pi} &= -\frac{\left(\frac{\partial F_C}{\partial \pi}\right)}{\left(\frac{\partial F_C}{\partial x}\right)} \\ &= -\frac{-\left(\frac{\beta\phi}{\beta+\eta}\right)}{-\left(\frac{\beta+\eta+\beta\eta}{\beta+\eta}\right) - \left(\frac{1}{\tau+\rho}\right)\left(\frac{1}{\tau+\rho} - 1\right) C^{v,r} \cdot (x_S)^{\frac{1}{\tau+\rho}-2}} < 0. \\ &\quad (\because 0 < \tau + \rho < 1.)\end{aligned} \tag{A1.3}$$

Q.E.D.

(24) : $\mathbf{\frac{dp^*}{d\pi}} < \mathbf{0}$.
If the enforcement level increases, the equilibrium price of goods decreases.

Proof. By using (21) and (23), we have:

$$\begin{aligned}\frac{dp^*}{d\pi} &= \frac{\partial p^*}{\partial x_S^*} \cdot \frac{dx^*}{d\pi} \\ &= \left(\frac{1}{\tau+\rho}\right)\left(\frac{1}{\tau+\rho} - 1\right) C^{v,r} \cdot (x_S)^{\frac{1}{\tau+\rho}-2} \cdot \frac{dx^*}{d\pi} < 0. \\ &\quad (\because 0 < \tau + \rho < 1.)\end{aligned} \tag{A1.4}$$

Q.E.D.

(25) : $\mathbf{\frac{dw^*}{d\pi}} > \mathbf{0}$.
If the enforcement level increases, the equilibrium amount of legal waste disposal increases.

Proof. By using (3) and (A1.3), we have:

$$
\begin{aligned}
\frac{dw^*}{d\pi} &= \frac{\partial w^*}{\partial x_D^*} \cdot \frac{dx^*}{d\pi} + \frac{\partial w^*}{\partial \pi} \\
&= \left(\frac{\eta}{\beta+\eta}\right) \cdot \frac{dx^*}{d\pi} + \left(\frac{\phi}{\beta+\eta}\right) > \left(\frac{\eta}{\beta+\eta}\right) \cdot \left(-\frac{\beta\phi}{\beta+\eta+\beta\eta}\right) + \left(\frac{\phi}{\beta+\eta}\right) \\
&> \left(\frac{\eta}{\beta+\eta}\right) \cdot \left(-\frac{\phi}{\eta}\right) + \left(\frac{\phi}{\beta+\eta}\right) = 0. \qquad \text{(A1.5)} \\
&\left(\because -\left(\frac{\phi}{\eta}\right) < -\left(\frac{\beta\phi}{\beta+\eta+\beta\eta}\right) < \frac{dx^*}{d\pi} < 0.\right)
\end{aligned}
$$

Q.E.D.

If the enforcement level increases, the equilibrium legal waste disposal w^* directly increases, while indirectly decreases through the decrease of the equilibrium amount of goods x_D^*. The indirect decrease expressed as $\frac{\partial w^*}{\partial x_D^*} \cdot \frac{dx^*}{d\pi}$ is always smaller than the direct increase, $\frac{\partial w^*}{\partial \pi}$, on the absolute value, so the sign of $\frac{dw^*}{d\pi}$ always becomes positive.

(26) : $\mathbf{\frac{d(x^*-w^*)}{d\pi} < 0}$.

If the enforcement level increases, the equilibrium amount of illegal dumping decreases.

Proof. By using (A1.3) and (A1.5), we have:

$$
\frac{d\left(x^*-w^*\right)}{d\pi} = \frac{dx^*}{d\pi} - \frac{dw^*}{d\pi} < 0. \qquad \text{(A1.6)}
$$

Q.E.D.

The amount of the illegal dumping can be expressed as the difference between the amount of goods and the legal waste disposal, that is, $x_D - w$, so the $\frac{d(x^*-w^*)}{d\pi}$ represents how much the equilibrium illegal dumping decreases when the enforcement level increases.

In summary, we can suggest the following: If the enforcement level increases and the regulation on the household's illegal dumping becomes tighter, then the equilibrium amount of goods, x^*, the equilibrium price of goods, p^*, and the equilibrium amount of illegal dumping, $x^* - w^*$, decreases ($\because$(A1.3), (A1.4) and (A1.6)), while the equilibrium amount of legal disposal, w^*, increases ($\because$(A1.5)).

Appendix II: The Partial Derivatives of the Social Welfare Analysis

In this appendix, we derive the sign of the partial derivatives used in the proposition 4 - 5 in section 3.2.

As described in 3.1, the first-order condition for the welfare maximization problem with respect to π was represented as follows:

$$\begin{aligned} \underset{\pi}{Max}\ W(\pi) = &\left[\theta x_D^* - \frac{1}{2}(x_D^*)^2 + \left\{ I - \frac{\beta}{2}(w^*)^2 - \frac{\eta}{2}(x_D^* - w^*)^2 \right\}\right] \\ &- C^P(x_S^*) - \frac{\mu}{2}\pi^2 - \{\delta_d(x_D^* - w^*) + \delta_e(w^* - r^*)\}. \end{aligned}$$

$$F_W : \left[\left(\frac{\partial W}{\partial x_D^*} + \frac{\partial W}{\partial x_S^*}\right)\frac{dx^*}{d\pi} + \frac{\partial W}{\partial w^*}\cdot\frac{dw^*}{d\pi} + \frac{\partial W}{\partial r^*}\cdot\frac{dr^*}{d\pi}\right] + \frac{\partial W}{\partial \pi} = 0. \tag{A2.1}$$

The partial derivatives of x_D^* and x_S^* can be expressed as follows:[13]

$$\begin{aligned} \frac{\partial W}{\partial x_D^*} + \frac{\partial W}{\partial x_S^*} &= \{\theta - x_D^* - \eta(x_D^* - w^*)\} - \delta_d - MC^P(x_S^*) \\ &= \pi\phi - \delta_d. \end{aligned} \tag{A2.2}$$

$$\because \theta - x_D^* - \eta(x_D^* - w^*) = p^* + \pi\phi. \tag{A2.3}$$

$$\because MC^P(x_S^*) = p^*. \tag{A2.4}$$

Similarly, the partial derivative of w^* can be yielded as follows:[14]

$$\begin{aligned} \frac{\partial W}{\partial w^*} &= \{-\beta w^* + \eta(x_D^* - w^*)\} + (\delta_d - \delta_e) \\ &= (\alpha - \pi\phi) + (\delta_d - \delta_e). \end{aligned} \tag{A2.5}$$

[13] (A2.3) is yielded by combining (2) and (8), and we can obtain (A2.4) by (20).

[14] (A2.6) is yielded by (2).

$$\because -\beta w^* + \eta \left(x_D^* - w^*\right) = \left(\alpha - \pi\phi\right). \tag{A2.6}$$

We can also obtain:

$$\frac{\partial W}{\partial r^*} = \delta_e. \tag{A2.7}$$

Finally, by substituting (A2.2), (A2.5) and (A2.7) into (A2.1), we can rewrite:

$$F_W : \left[(\pi\phi - \delta_d) \cdot \frac{dx^*}{d\pi} + \{(\alpha - \pi\phi) + (\delta_d - \delta_e)\} \cdot \frac{dw^*}{d\pi} + \delta_e \cdot \frac{dr^*}{d\pi}\right] - \mu\pi = 0. \tag{A2.8}$$

As described in 3.2, if (A2.8) has the equilibrium solution π^*, we can express the implicit function as follows:

$$\pi^* = \pi^*(\delta_d, \delta_e, ...). \tag{A2.9}$$

By applying the implicit function theorem and using (26) and (29), we can obtain the following results, which we use in the proposition 4 - 5 in section 3.2.

$$\frac{\partial F_W}{\partial \pi} = \left(\frac{dx^*}{d\pi} - \frac{dw^*}{d\pi}\right)\phi - \mu < 0, \tag{A2.10}$$

$$\frac{\partial F_W}{\partial \delta_d} = -\left(\frac{dx^*}{d\pi} - \frac{dw^*}{d\pi}\right) > 0, \tag{A2.11}$$

$$\frac{\partial F_W}{\partial \delta_e} = -\frac{dw^*}{d\pi} + \frac{dr^*}{d\pi} = -\left(\frac{dw^*}{d\pi} - \frac{dr^*}{d\pi}\right) = -\frac{d\left(w^* - r^*\right)}{d\pi} < 0. \tag{A2.12}$$