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Industrial Garbage Tax and Environmental Policy Game under a Two-Region Model

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This study is intended to examine an efficient industrial garbage disposal system and an optimal policy to establish it. Industrial waste created in processes of all production is increasing every year. That increase is exacerbated by the shortage of disposal space, engendering frequent cases of illegal abandonment. We analyze environmental policies to restrain illegal abandonment and to establish a social optimum under the two-region model that incorporates transboundary movements of industrial garbage. Although a subsidy policy is an optimal policy in the one-region model, it is not optimal policy in the two-region model because of a subsidy-reducing game.

KEYWORDS: industrial garbage tax, monitoring, interregional movement of garbage, subsidy-reducing game

1. Introduction

In Japan recently, the lack of garbage incinerators owned by local governments has been feared because of the expected increase of garbage. New surface-treatment locations, which are considered as the final place to treat the garbage in Tokyo Bay, will overflow after 30 years if the current pace of increasing garbage is maintained. The amount of generated industrial garbage is eight times the garbage discharged by households; it amounts to 415 million tons per year. Although treatment services of household garbage are supplied by all local governments, industrial garbage must be treated not by the local government, but by firms specializing in its disposal because of the complicated treatment processes involved, which engender spreading of chemical substances and various changes of manufacturing technique. Methods to treat them require expert knowledge about them. Local governments have become unable to manage such disposal. Because the market for industrial garbage disposal has grown in recent years, the market has become competitive. Some garbage haulers have an incentive to reduce treatment costs to become more competitive. For that reason, some haulers do not perform proper disposal, which requires high technology and treatment costs. Instead, they do illegal abandonment, which is dumping the garbage into rivers or secluded places among mountains, to save the treatment cost. The number of cases of illegal abandonment is about 1,200 in 1998—it was 46 times higher than that in 1993. Moreover, the amount of abandoned garbage illegally amounted to about 450,000 ton in 1998. The Industrial Garbage-treatment Act was devised in 2000; it prescribes strict punishment for garbage haulers that treat or dispose of industrial garbage illegally.

On the other hand, after going into the effect of the decentralization of power authority Act on Apr. 2000, it is possible for local governments to introduce a specific-purpose tax into the local governments' system of taxation. Because local governments can enforce such taxation, numerous local governments are planning to introduce similar taxes. Above all, some local governments have examined the introduction of taxes imposed on industrial garbage because the impact of industrial garbage on the environment is very serious. Regulation of a tax to industrial garbage was passed in the Mie prefectural assembly in June 2001. The Ministry of General Affairs has enforced it since April 2002 after agreeing to it. Moreover, Aomori, Iwate, and Akita prefecture put this taxation into effect jointly. The introduction of this taxation is under consideration in Okayama prefecture and Fukuoka prefecture (see Table 1).

Generally, two methods exist for imposing an environmental tax on industrial garbage. One is taxation of the discharger producing garbage, the other is taxation of the firm treating the garbage: the hauler. Our consideration of the garbage tax is taxation not to the hauler, but to the discharger. The industrial garbage tax is introduced for the purpose of dealing with the increasing cost of reclamation by the lack of reclaimed land, inhibition of inflow of industrial garbage from other regions, and the promotion of its recycling. This tax revenue allays the cost of operation for any environmental policy or monitoring. Although the introduction of industrial garbage tax cannot prevent the moving of garbage from the region in which the local government imposes this tax, to a region in which the government does not do so, it can inhibit the inflow of industrial garbage from other regions. Presuming that the local government in any region reinforces the monitoring of illegal disposed garbage in his own region, it is possible for the hauler to move the

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Table 1. Introduction of environmental tax by the government.

Pref. (city)	Mie pref.	Akita pref.	Aomori pref.
Date	2004.4	2004.1	2004.1
Pref. (city)	City of Kitakyushu	Iwate pref.	Okayama pref.
Date	2003.1	2004.1	2003.4

garbage into other region illegally.[1]

Numerous studies have specifically addressed topics related to garbage disposal. Fullerton and Kinnaman (1995) and Fullerton and Wu (1998) analyze a general equilibrium model that includes the cycle of goods from consumption to abandonment. Dinan (1993) and Walls and Palmer (2001) specifically addresses this cycle model including disposal and recycle model of consumption goods from the point of view of producer accounts. These studies analyzed the disposal process of garbage in detail by taking account of the material balance of the disposal and recycling of garbage. Notwithstanding, these studies do not investigate a model that includes illegal abandonment of garbage. On the other hand, Choe and Fraser (1999) consider the possibility of illegal abandonment as a way to treat a waste disposal problem. Households, however, yield the garbage in their model and do not discuss the recycling and treatment of garbage yielded in the production sector. As we have explained, most garbage is discharged from industry. Moreover, illegal abandonment or the difficult and complicated disposal of industrial garbage has become an object of public concern.

We consider two policies for firms that treat garbage to construct an efficient disposal system of industrial garbage. One policy is an optimal monitoring policy to restrain illegal abandonment by haulers using low technology. The government imposes an industrial garbage tax on dischargers and uses this tax revenue to pay for costs of monitoring. The other policy is a subsidy policy by which the government gives a subsidy to haulers who treat industrial garbage legally. In this case, the government uses tax revenue to provide this subsidy. We consider a two-region model to analyze the optimal tax rate, recycling rate, and policy choice by governments for these monitoring and subsidy policies. Moreover, regarding the optimal industrial garbage tax rate and environment policy, we try to compare cases for whether there is interregional movement of garbage or not.[2] The remainder of this paper is organized as follows. The next section presents the basic model and explains the behavior of each player. Section 3 deals with the socially optimal equilibrium and the equilibrium under each policy. Section 4 gives a two region model and shows policy competition between governments in both regions. The final section concludes this paper.

2. The Model

The economy in our model comprises dischargers, haulers, landfill operators, and government. First, we consider each behavior under a one-region model.

2.1 Dischargers

There are m homogeneous dischargers that produce industrial garbage in one region. They discharge the amount of industrial garbage W by their economic activities.[3] Therefore, the total amount of garbage discharged by the dischargers is given as mW. Now we assume that W is constant and positive. The dischargers must do recycling of the garbage by a certain fixed ratio or commission; the haulers process the garbage according to the "Expansion producer responsibility Law". Let r represent the recycling ratio that exists from zero to one. The amount of garbage recycled by each discharger is given as rW. The amount of garbage that the discharger commissions the haulers to treat is given as $(1-r)W$. When the dischargers recycle the garbage produced by themselves by the recycling ratio r, they must pay the recycling expense. We define this cost as $C(rW) = a(rW)^2/2$, where the parameter a represents that the marginal recycling cost is positive. On the other hand, the dischargers commission the haulers with the garbage, which is not recycled by themselves. The haulers are obliged to treat it by receiving the disposal price p. Here, the government enforces the industrial garbage tax of τ per unit of garbage on the dischargers. Consequently, the dischargers are obliged to pay $p + \tau$ as a consignment of the treatment per unit of garbage. Therefore, each discharger faces the following cost minimization problem.

$$\min_{r} C(rW) + (1-r)W(p+\tau) \tag{1}$$

The discharger determines the optimal recycling ratio of garbage r^*, where the marginal cost of recycling it is equal to

[1] See Yamaya (2002) for a detailed explanation of proper and illegal disposal of industrial garbage.

[2] No models address interregional movement of garbage, to our knowledge. As an exception, Copeland (1991) is the only study dealing with trading garbage internationally. Highfill, McAsey and Weinstein (1994) discuss the location problem of a garbage recycling center in terms of the transportation cost, but they do not account for interregional movement as we do here.

[3] Because we focus on the stream of garbage disposal system, we do not argue about the aspect of production or consumption of goods.

the marginal commission cost of garbage; that is,

$$r^* = \frac{p + \tau}{aW}. \tag{2}$$

Moreover, introducing the optimal recycling ratio r^* into $(1 - r)W$, we can derive the optimal amount of non-recycled garbage as follows.

$$(1 - r^*)W = W - \frac{p + \tau}{a} \tag{3}$$

2.2 Haulers and landfill operators

After the dischargers' commission, haulers select whether they treat industrial garbage properly or illegally. Illegal disposal is defined as illegal abandonment of garbage by a hauler. We consider a case in which the haulers treat the garbage commissioned by dischargers properly. Its disposal costs firms α per unit of garbage. However, each hauler has different costs of treating it. We assume that the cost is from zero to $\bar{\alpha}$ and that $\alpha \in (0, \bar{\alpha}]$ where this distribution of α is uniform with density one. As a result, we can denote the number of haulers by $\bar{\alpha}$. Moreover, we assume that each hauler can treat only one unit of garbage and $mW < \bar{\alpha}$ is about the amount of garbage. This assumption implies that the total amount of garbage produced in a region mW is not larger than the amount of garbage that all haulers can treat.[4]

Moreover, all economic agents know that the distribution of α though the treatment cost of garbage is each hauler's private information. Each hauler who treats one unit of garbage properly commissions the landfill operators to reclaim it at its final disposal place by paying q. The landfill operators receive the garbage treated by haulers and reclaim it at its final disposal place. Let d represent the marginal cost of reclaiming the garbage treated by haulers properly: it is constant and positive. We assume that the reclamation market has perfect competition and that there are numerous landfill operators. Consequently, we can produce a profit function of landfill operators, π_r, as

$$\pi_r = (q - d)X, \tag{4}$$

where X is the total amount of the garbage dealt with in the reclamation market. Because we assume that this market has perfect competition, we can derive the reclamation price q, which is equal to the marginal cost of reclamation d. The hauler receives the garbage from the dischargers with p, treats it properly, and commissions the landfill operators to reclaim it at final disposal place by paying $q = d$. When the hauler treats it properly, the profit function of haulers is as follows.

$$\pi_t = p - (\alpha + d) \tag{5}$$

Next we consider the case in which some haulers have an incentive to abandon the garbage illegally. Any hauler who has a relatively high treatment cost has an incentive not to treat the garbage properly, but to abandon it illegally. Let v $(0 < v < 1)$ and F represent the probability that illegal abandonment will be revealed by reports of residents and the penalty for illegal abandonment, respectively.[5] The expected profit of the hauler abandoning garbage is

$$(1 - v)p + v(p - F) = p - vF. \tag{6}$$

A hauler with cost α selects a method of treating garbage that yields a higher profit after comparing $p - (\alpha + d)$ with $p - vF$.[6] As shown in Figure 1, the treatment method selected by haulers depends on the treatment cost α and the probability that illegal abandonment will be discovered, the price of reclamation service, and the penalty for illegal abandonment. In other words, even though the increase of v or F engenders the decrease of illegal abandonment, it decreases as the price of reclamation service increases. We describe the behavior of haulers with cost α in Figure 1. As shown in Figure 1, if α is $0 < \alpha \leq vF - d$, the hauler has an incentive to treat his garbage properly. On the other hand,

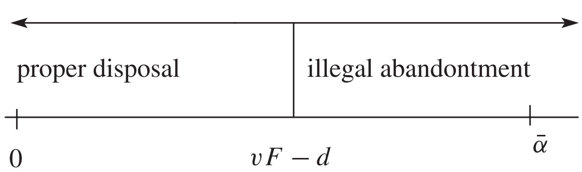

Fig. 1. Hauler behavior.

[4] The treatment cost parameter α differs among the haulers. As we assumed before, α satisfies $\alpha \in (0, \bar{\alpha}]$. This setting regarding the cost parameter implies that a technical gap exists among haulers because of the recent rapid growth of the industrial garbage treatment service market.

[5] This F is an upper limit. Regarding this setting, our model depends on Becker (1968). He maintains in that study that a person who disobeys the law should be punished with a maximum penalty.

[6] When $p - (\alpha + d)$ is equal to $p - vF$, we assume that the hauler selects proper disposal.

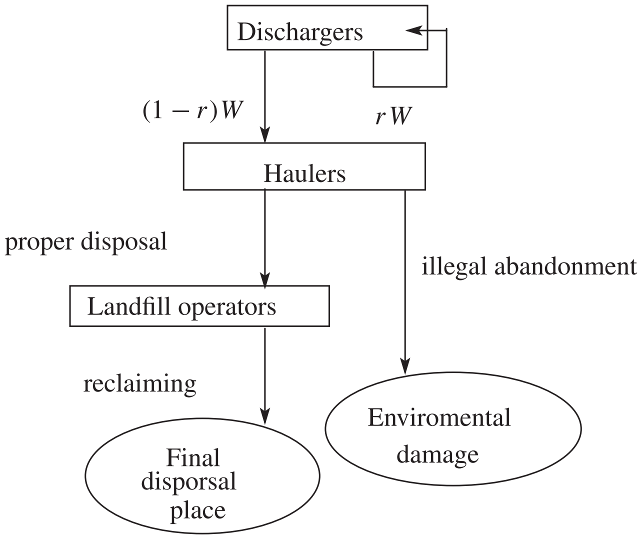

Fig. 2. The industrial garbage flow.

if it is $vF - d < \alpha \leq \bar{\alpha}$, the hauler has an incentive to abandon it illegally.

Finally, because we have examined the behavior of dischargers, haulers, and landfill operators, we present a chart of industrial garbage flow in Figure 2.

2.3 Tax expenditure

We have described the behavior of dischargers, haulers, and landfill operators. Next we discuss tax expenditures by the local government. The local government imposes an industrial garbage tax on dischargers who commission haulers on the disposal of their non-recycled garbage. On the other hand, no hauler has an incentive to treat garbage properly, but to abandon garbage illegally in the mountains or rivers if p is low and q $(= d)$ is high. If any hauler abandons garbage illegally, it may cause serious damage in that region. Consequently, the local government uses the tax revenue to prevent illegal abandonment. The government might use the tax revenue for performing either a strict monitoring policy or a subsidy policy. A strict monitoring policy entails strong government surveillance of illegal abandonment: the government seeks to prevent illegal abandonment. In contrast, by a subsidy policy, the government gives haulers a subsidy for proper disposal; it thereby provides an incentive for proper disposal by haulers. We analyze the effects of those environmental policies on social welfare in subsequent sections.

Local government determines the tax ratio and the environmental policy to use the tax revenue to minimize the social cost, which is defined by the sum of costs for disposal and reclamation of garbage and the value of environmental damage.

3. Optimal Tax Rate in the One-Region Model

We consider a model including one region and compare the situation under each policy with the social optimum. Because we consider a one-region model here, there is no movement of garbage between regions. Comparing the situation under each policy with the social optimum, we analyze the optimal tax rate under each policy.

3.1 Social optimum

First, we consider the socially optimal recycling rate and the number of haulers as a benchmark. We set the following assumption before analyzing them. The cost for environmental damage created by illegal abandonment is larger than the sum of costs for proper disposal and reclamation by the most inefficient hauler; that is, $D > \bar{\alpha}$ where D and α, are the damage to the environment and the treatment cost of the hauler, respectively. That assumption means that the proper disposal costs with the most inefficient haulers are smaller than the social cost incurred as a result of haulers with α carrying out illegal abandonment. In such a case, it is desirable for society not to abandon the garbage illegally, but to treat it properly. It is desirable for society to treat all garbage properly and reclaim it rather than abandoning it illegally. Figure 3 shows this assumption graphically. Therefore, the socially optimal solution is derived by minimizing the social cost incurred by the recycling cost, treatment cost, the reclamation cost of garbage, where the marginal social cost to proper disposal is equal to the marginal recycling cost, as in Figure 4. Consequently, this minimization problem is as follows.

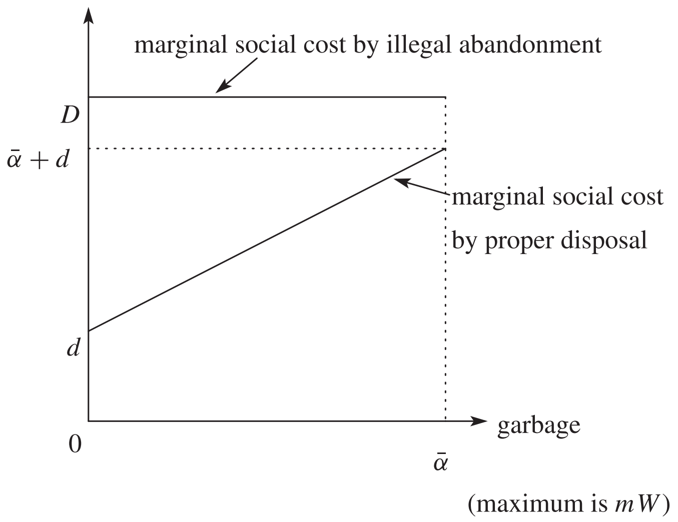

Fig. 3. Proper disposal and illegal abandonment.

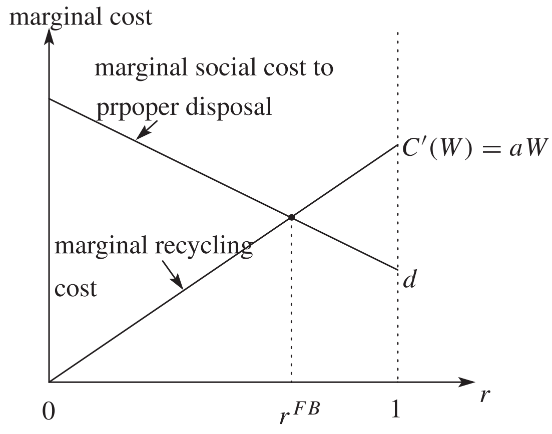

Fig. 4. First-best solution.

$$
\begin{aligned}
\min_r SC &\equiv mC(rW) + \int_0^{m(1-r)W} (\alpha + d)d\alpha \\
&= m\frac{a}{2}(rW)^2 + \frac{1}{2}(m(1-r)W)^2 + m(1-r)Wd \\
&s.t. \quad 0 \leq r \leq 1
\end{aligned}
\tag{7}
$$

For simplification, we normalize the number of dischargers m. Solving the minimization problem without constraint, we can derive the optimal recycling rate as follows.

$$
r^{FB} = \frac{d + W}{aW + W} \tag{8}
$$

Here, we assume that the other is $d < C'(W) = aW$. This assumption dictates that the marginal recycling cost of garbage W is higher than the sum of the costs of proper treatment and garbage reclamation. In other words, it is desirable for society to commission haulers to treat a part of the garbage rather than to recycle all garbage by a discharger. Setting this assumption, we can consider only an interior solution of a recycling rate in terms of a social optimum. This is an interior solution because this solution is satisfied with Assumption 3 ($0 < r^{FB} < 1$). We do not consider a solution in which the recycling rate is derived as an corner solution, that is $r = 1$. Supposing that r is one, no garbage exists in the market. Therefore, we exclude a case like this. The optimal amount of treated garbage X^{FB} is as follows.

$$
X^{FB} = (1 - r^{FB})W = \frac{aW - d}{a + 1} \tag{9}
$$

We know that the hauler with α in $(0, \frac{aW-d}{a+1})$ treats garbage properly in society. We derive these optimal solutions. Next, we use these solutions when we compare it with equilibria achieved in other situations.

3.2 Equilibrium with no policy

We consider the recycling rate and the amount of treated garbage in equilibrium when the trade of garbage between dischargers and haulers is carried out in the garbage market. First, we discuss the case without garbage taxation by the local government and assume that this garbage market is in perfect competition here. Dischargers determine the recycling rate r^* to minimize the sum of the recycling cost and commission cost under any given disposal price p. This r^* is derived from (1) and $\tau = 0$; that is,

$$
r^* = \frac{p}{aW}. \tag{10}
$$

The amount of garbage $S(p)$ that the discharger commissions the haulers to treat is given as

$$
S(p) = (1 - r^*)W = W - \frac{p}{a}. \tag{11}
$$

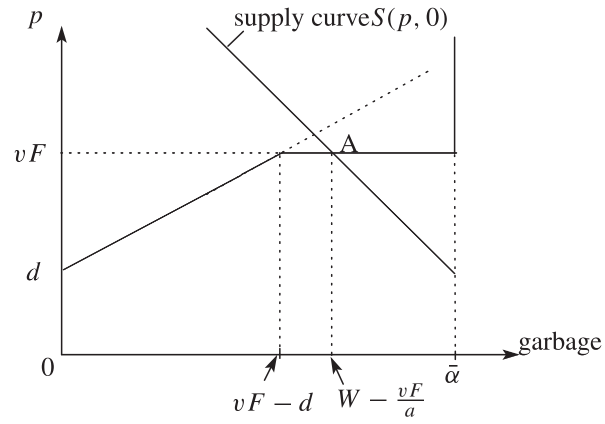

Fig. 5. the equilibrium under no policy.

If the garbage disposal price p is positive, each hauler purchases one unit of garbage in the garbage market. The hauler's profit with treatment cost α is as follows.

- if the hauler treats it properly, the profit is

$$p - (\alpha + d).$$

- if the hauler treats it illegally, the profit is

$$p - vF.$$

This hauler does one unit demand of garbage, if any is positive within the gain of these cases. The hauler with α decides whether the hauler treats garbage properly or not under the change of garbage disposal price as given. Point A in Figure 5 is the price and the amount of traded garbage in equilibrium at the garbage market where the supply is equal to demand in the garbage market. Haulers with cost $\alpha \in (0, vF - d)$ treat garbage properly in equilibrium. On the other hand, a hauler with cost $\alpha \in (vF - d, W - \frac{vF}{a})$ abandons garbage illegally in equilibrium. If the equilibrium disposal price is given as $p = vF$, the recycling rate in equilibrium is

$$r^* = \frac{vF}{aW}. \tag{12}$$

Consequently, we can derive the following proposition.

Proposition 1. *The equilibrium under the case in which the local government does not impose a tax on firms is characterized as follows:*

- *Haulers with cost $\alpha \in (vF - d, W - \frac{vF}{a})$ dump garbage illegally in equilibrium.*
- *The equilibrium recycling rate is lower than the optimal recycling rate,*

$$r^* < r^{FB}.$$

As a result, if the expected penalty for illegal abandonment vF is sufficiently low under the situation without any environmental policy by the local government, the haulers have an incentive to abandon garbage illegally.[7] Next we consider the case in which the local government uses tax revenue to monitor the haulers' behavior.

3.3 Strict monitoring policy

The local government can select either a strict monitoring policy or a subsidy policy as an environmental policy to prohibit illegal abandonment. Here, strict monitoring means monitoring with higher discovery probability strengthened by revenue from the industrial garbage tax. After selecting the policy, the local government uses revenue from taxation imposed on the dischargers. Haulers pay this tax to the government after receiving both p and τ from dischargers. If the government carries out monitoring of illegal abandonment, the cost is covered using revenue from the industrial garbage tax. Let T and $\beta(T)$ represent the total tax revenue and the probability of discovering the illegal abandonment, respectively. $\beta(T)$ is an increasing function with respect to T; that is, $d\beta/dT > 0$. This fact means that the government can monitor illegal abandonment more strictly because the expenditure for it is large. Needless to say, we cannot deny the possibility of discovering illegal abandonment of garbage from reports by residents. Therefore, we assume that the

[7] We assume vF to satisfy that $vF < \frac{a(W+d)}{a+1}$. No hauler deals with garbage under no policy when the assumption in footnote 7 does not held. That is, there is no α holding $\alpha \in [vF - d, W - \frac{vF}{a}]$. We consider the case in which it is possible to have haulers with an incentive to dump garbage illegally under the situation without any policy; we name a parameter to satisfy this assumption. Furthermore, we discuss the deterrent effect of a strict monitoring policy on illegal abandonment using industrial garbage tax revenue.

probability of discovering illegal dumping of garbage is denoted by $\beta(0) = \upsilon$ when the government does not carry out monitoring. If the government discovers illegal abandonment, it punishes illegal firms with a penalty, F. If we assume that the hauler can perform illegal abandonment without cost, we can write their expected profit as

$$\beta(T)(p - F) + (1 - \beta(T))p = p - \beta(T)F, \tag{13}$$

where $\beta(T)F$ means an expected penalty that the haulers face when they abandon garbage illegally. Here we define $\beta(T)F$ as $M(T)$. However, if tax revenue is zero, we assume that their expected penalty is υ, where $\beta(0)F = \upsilon F = M(0)$. So we can describe the following expected profit when they carry out the illegal dumping of garbage.

$$p - M(T) \tag{14}$$

Haulers compare their profit under proper disposal to the expected profit under illegal abandonment and choice their behavior where they can get higher profit. When total tax revenue T of some industrial garbage tax is given, we describe the processing cost of the hauler where the profit under proper disposal is indifferent to the expected profit under illegal abandonment.

$$\begin{cases} \alpha \leq \alpha^* = M(T) - d \Rightarrow \text{proper disposal.} \\ \alpha > \alpha^* = M(T) - d \Rightarrow \text{illegal dumping.} \end{cases}$$

Because α^* is the function of total tax revenue T, we can set the level of α^* by choosing T. Total tax revenue T depends both on the total amount of garbage commissioned by dischargers and the tax rate per unit of garbage τ. We can derive total tax revenue T as a function with respect to τ.

$$T(\tau) = \tau(1 - r^*)W = \tau\left(W - \frac{p + \tau}{a}\right) \tag{15}$$

We consider how the change of industrial garbage tax affects the haulers' behavior. Taking account of the expected penalty, $M(T)$ that is the increasing function with respect to total tax revenue T, we can show the relation between the expected penalty and the rate of tax per unit of industrial garbage in Figure 6. If the rate of industrial garbage tax is low relatively, the effect of raising this rate on the total tax revenue increase is superior to the effect of raising recycling rate by increasing the tax on the total tax revenue decrease. The increase of τ raises the expected penalty by the increase of total tax revenue. On the other hand, if the rate of industrial garbage tax is high relatively, the effect of raising τ on the total tax revenue increase is not superior to the effect of decreasing tax revenue. In this case, the increase of τ decreases the total tax revenue and the expected penalty.[8] We consider the optimal rate of industrial garbage tax based on the above-mentioned arguments.

We consider the case in which the local government chooses a strict monitoring policy. The cost for policy performance is covered by the industrial garbage tax revenue. The probability of discovering illegal dumping is proportional to the amount of money for monitoring. Therefore, the expected penalty is an increasing function with respect to this amount of money. This section presents analysis of the effect of adopting a strict monitoring policy on the behavior of dischargers and haulers and the equilibrium in the garbage market.

As discussed above, the discharger determines the recycling rate to minimize the sum of the recycling cost and the commission cost of garbage under the commission price p and industrial garbage tax τ, as given. Therefore, we can derive the supply function of garbage in the market as follows.

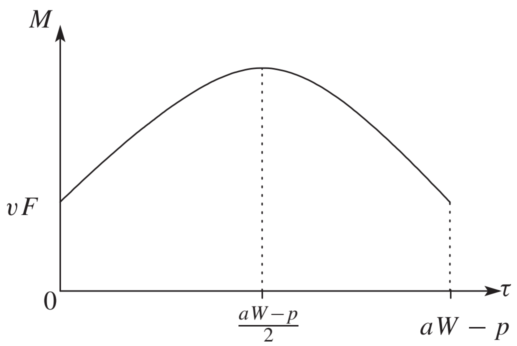

Fig. 6. Expected penalty function.

[8] If the elasticity of garbage disposal function $W - \frac{p+\tau}{a}$ with respect to τ is larger than one, the expected penalty M is the decreasing function with respect to τ. Otherwise, if that elasticity is smaller than one, the increase of τ raises the expected penalty.

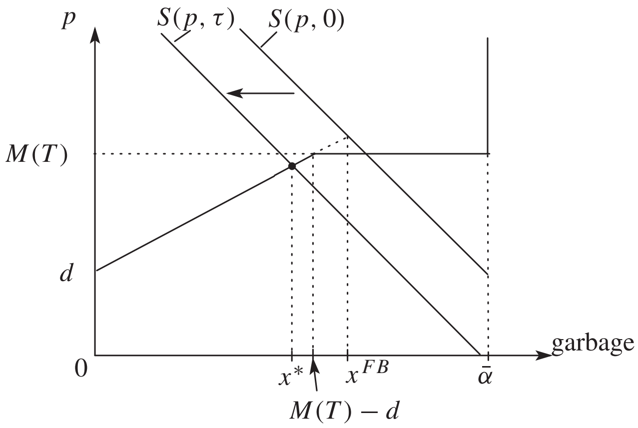

Fig. 7. Strict monitoring policy.

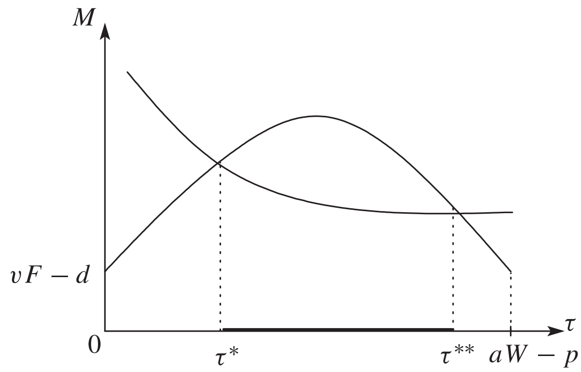

Fig. 8. Tax rate to deter illegal abandonment.

$$S(p, \tau) = W - \frac{p + \tau}{a}$$

The hauler determines his own behavior under p and τ as given. Recall his behavior is either proper disposal or illegal abandonment of garbage. Therefore, we can write the profit of hauler that selects either proper disposal or illegal abandonment by (3) or (4). The hauler's behavior is described in Figure 7. The supply function of garbage $S(p, \tau)$ is a decreasing function with respect to p. If the industrial garbage tax rate τ goes up, this supply function shifts down. On the other hand, the demand function of garbage forms a refracting function. If τ is relatively low, the increase of τ make this demand function shift upward. This upward shift implies that the number of haulers that treat garbage properly goes up because of the increase of τ. If τ is relatively high, the increase of τ makes the function shift downward, meaning that the number of haulers that treat garbage properly goes down because of the increase of τ. We infer that the industrial garbage tax rate τ to inhibit the haulers to abandon it illegally. This is the case in which the total number of proper hauler is larger than the supply at $M(T(\tau))$ and τ is satisfied with the following condition.

$$M(T(\tau)) - d \geq W - \frac{M(T(\tau)) + \tau}{a}, \tag{16}$$

where τ satisfying this condition exists within $[\tau^*, \tau^{**}]$ in the following Figure 8. the recycling rate and traded garbage in equilibrium under the industrial garbage tax τ to restrain illegal abandonment by haulers are as follows.

$$r^m = \frac{d + W + \tau}{aW + W} \tag{17}$$

$$x^m = \frac{aW - d - \tau}{a + 1} \tag{18}$$

Comparing this equilibrium solutions with the socially optimal solutions r^{FB}, x^{FB}, the relation between them is $r^m > r^{FB}, x^m < x^{FB}$. In other words, the equilibrium recycling rate under the strict monitoring policy is larger than the socially optimal recycling rate. Moreover, the amount of treated garbage in equilibrium is smaller than the socially optimal amount. The difference in the rate and amount of treated garbage between the equilibrium solution and socially optimal solution are $\frac{\tau}{aW+W}$ and $\frac{\tau}{a+1}$, respectively. Therefore, the industrial garbage tax rate τ under the restrict monitoring policy should be as small as possible in order to agree with both solutions. So we can derive the following proposition because the tax rate τ exists within $[\tau^*, \tau^{**}]$ in Figure 8.[9]

Proposition 2. *If the local government uses the revenue from industrial garbage tax to reinforce more strict monitoring,*

- *The industrial garbage tax to deter illegal dumping by haulers is within* $[\tau^*, \tau^{**}]$ *where the optimal industrial garbage rate is described by* τ^*
- *The equilibrium recycling rate is larger than the socially optimal recycling rate, that is,*

$$r^m > r^{FB}$$

[9] Because Figure 8 describes inequality (16), Proposition 2 is held only in the case in which the point of intersection in Figure 8 exists. As the reviewer pointing out, it is not necessary to exist the point of intersection in Figure 8 in the arbitrary extent. Supposed that there is no point of intersection in Figure 8, that is, inequality (16) is not satisfied, the illegal abandonment is always happened under every tax rate. Thus, Proposition 2 is held in the only case in which the shape of expected penalty function M has the point of intersection in Figure 8.

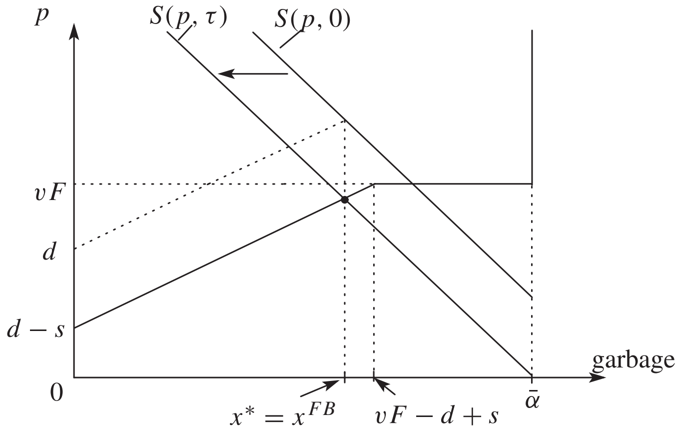

Fig. 9. Subsidy policy.

3.4 Subsidy policy

We next address the case in which the local government uses revenue from industrial garbage tax to give a subsidy to haulers who treat their garbage properly. This subsidy gives haulers an incentive to treat their garbage properly. For that reason, this subsidy policy has a similar effect to the strict monitoring policy. In other words, the subsidy policy recommends haulers to treat their garbage properly though the strict monitoring policy prohibits them to abandon those garbage illegally. In this section, we consider the effect of subsidy policy on the behavior of haulers and discuss whether this policy establishes the social optimality or not. The method to provide haulers with subsidy is as follows. To begin with, landfill operators pay the amount to the haulers that is deducted from subsidy. Moreover, landfill operators receive the total amount of subsidy from the local government by declaring the amount of taking charge of garbage.[10] The behavior of dischargers under the subsidy policy is similar to that under the strict monitoring policy. Therefore, we write the amount of garbage that dischargers supply in the garbage market as $S(p, \tau)$. Haulers can receive subsidy s from the local government if they treat their garbage properly. The profit of a hauler with cost α is

$$p - (\alpha + d) + s.$$

Because the tax revenue from the industrial garbage tax is used for this subsidy, the level of monitoring is not strengthened. For that reason, the expected profit that the the haulers earn is $M(0) = vF$. We can write the expected profit of haulers if they abandon their garbage illegally.

$$p - vF$$

In Figure 9, the increase of industrial garbage tax τ shifts the demand curve downward. On the other hand, the increase of subsidy s shifts it upward. As shown in Figure 9, the combination of industrial waste tax and subsidy to deter illegal abandonment of waste (τ, s) is as follows.[11]

$$vF - d + s \geq W - \frac{vF + \tau}{a} \tag{19}$$

Dischargers must determine the recycling rate of their garbage under the government's environmental policy as given. Consequently, the recycling rate under the subsidy policy is

$$r^S = \frac{d + W + \tau - s}{aW + W},$$

which depends on the tax rate τ and subsidy s. Because the socially optimal recycling rate r^{FB} must be equal to the equilibrium recycling rate r^s under the subsidy policy, the following equation is satisfied:

$$r^{FB} = \frac{d + W}{aW + W} = r^S = \frac{d + W + \tau - s}{aW + W}. \tag{20}$$

The industrial waste tax and subsidy to establish the socially optimal recycling rate are satisfied at

$$\tau = s. \tag{21}$$

[10] Because the government pays out subsidy to the landfill operators, they can not recognize which haulers treat garbage properly. We assume that landfill operators do not falsify reports about the garbage.

[11] Here, the total number of haulers that treat garbage properly is larger than the total amount of garbage supplied at price $p = vF$.

The socially optimal amount of treated garbage is equal to the equilibrium amount of treated garbage under the subsidy policy. No illegal dumping exists in equilibrium and the tax revenue for industrial garbage tax is equal to the total amount of subsidy in this situation ($\tau = s$). For those reasons, the budget constraint of local government is satisfied with the balance of tax revenue and tax expenditure. Therefore we can derive the following proposition.

Proposition 3. *When the local government uses tax revenue from industrial garbage tax as a subsidy for haulers that treat garbage properly and* τ *and* s *is satisfied by the following equation, the subsidy policy can establish a socially optimal recycling rate* r^{FB}.

$$\tau = s \geq \frac{a(W + d) - vF(a + 1)}{a + 1}$$

Comparing the subsidy policy to a strict monitoring policy, we can derive the following corollary.

Corollary 1. *Rather than a strict monitoring policy, it is desirable to use tax revenue from an industrial garbage tax for the subsidy policy.*

4. Optimal Tax Rate in the Two-Region Model

4.1 Extension to the two-region model

In this section, we extend the former one-region model to a two-region model. The flows of garbage in both regions are depicted in Figure 10. The most different point from the one-region model is that the number of executable actions by haulers increases from two to four. Although the haulers in the one-region model must select their actions out of the proper disposal or illegal abandonment in their own region, they can also select where to treat their garbage between two regions adding a choice of the way to treat their garbage. We consider a case that allows transboundary movements of industrial garbage between two regions. Extending from the one-region model to the two-region model creates policy competition between the regions. Therefore, the consequence derived in the two-region model differs from that in the one-region model.

Damage caused by the transboundary pollution between regions is determined as an externality and depends on the spillover rate of transboundary pollution. Thus, local governments in respective regions can not determine the level of that damage. However, the damage caused by transboundary movement of garbage depends on the behavior of haulers in both regions. For that reason, each local government in the two regions can control that damage through their own policies like the subsidy for proper disposal or strict monitoring of illegal disposal.[12] We consider that the economy

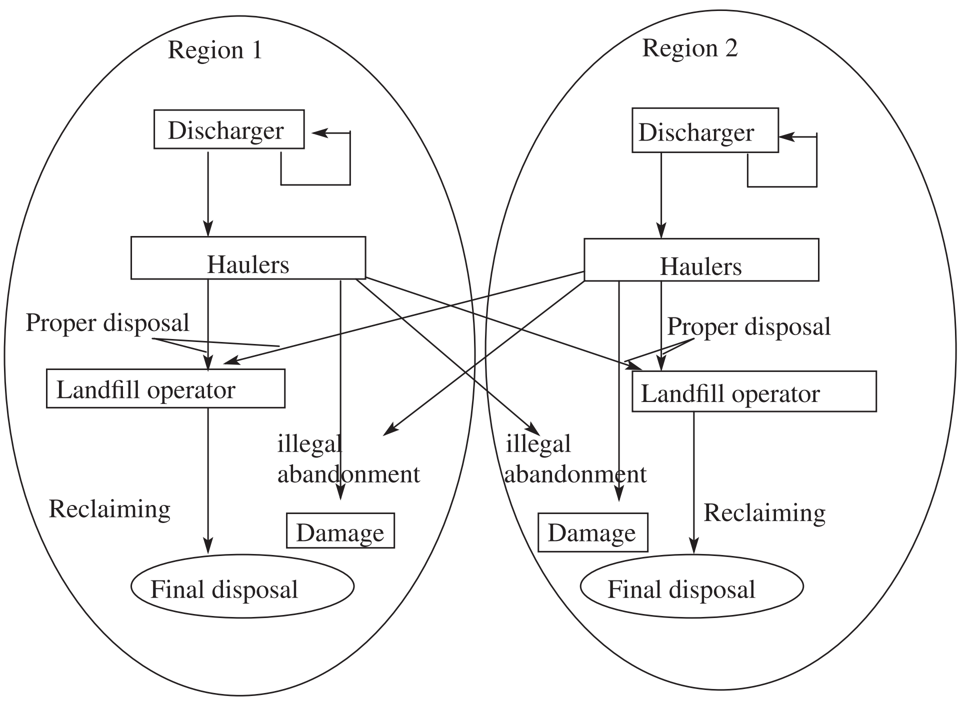

Fig. 10. Two-region model.

[12] Regarding policy competition of export and transboundary pollution, see Brander and Spencer (1985) and Ulph (2000), respectively.

comprises some regions with lower reclamation costs and some with higher costs. Next we assume that the reclamation cost in region 1 is relatively lower than that in region 2 ($d_1 < d_2$).

4.2 Socially optimal solution under the two-region model

First, we derive the socially optimal solution similar to the analysis in region 1. Because the reclamation cost in region 1 is lower than that in region 2, a socially optimal situation is established by reclamation of the proper treated garbage of both regions in region 1 and by determination the recycling rate of dischargers in both regions, r_1^{FB} and r_2^{FB}, which both minimize the garbage disposal cost.[13] Taking account of this social optimum, garbage produced in respective regions is recycled and treated properly in each region; furthermore, it is reclaimed in region 1. Therefore, the socially optimal solutions of r_1^{FB}, r_2^{FB} are as follows.

$$r^{FB} = r_1^{FB} = r_2^{FB} = \frac{d_1 + W}{aW + W} \tag{22}$$

4.3 Strategies of local governments

Each government determines an industrial garbage tax to minimize the social cost in its own region. That cost comprises the proper disposal and recycling cost. Each government also determines how to use the revenue from the industrial garbage tax. Dischargers in each region determine the recycling rate of garbage under the local government policy as given. Behavior of dischargers depends on the industrial garbage tax rate determined by their own government as given, and the commission price of the garbage. On the other hand, haulers depend on both the industrial garbage tax rate and the environmental policy because the haulers can select either proper disposal or illegal abandonment not only in their own region, but also in the other region. If governments in both regions select identical environmental policies, the proper treatment cost in region 1 for the region 2 haulers, $\alpha + d_1$, is lower than that in region 2, $\alpha + d_2$. Thus, the region 2 haulers commission the landfill operators in region 1 to reclaim the treated garbage properly. In this case, it is desirable for both economies to reclaim the properly treated garbage in terms of its disposal over a wide area. Recall that it is more desirable for the local government to choose a subsidy policy for proper disposal under the one-region model. If the region 1 government chooses this policy under the two-region model, the region 1 government must pay the haulers a subsidy to process the garbage and cover it with an industrial garbage tax imposed on dischargers in region 1. As a result, the region 1 government must retain tax revenue and raise the tax rate on industrial garbage because government must also pay the region 2 haulers a subsidy. The recycling rate of garbage by dischargers in region 1 is, therefore, not inefficient.

- The region 1 government adopts an environmental policy to prevent region 2 haulers from moving their treated garbage. That is, government determines the industrial garbage tax rate and how to use the revenue from that taxation.
- On the other hand, the region 2 government adopts an environmental policy to recommend that haulers within its region reclaim their properly treated garbage in region 1 because the reclamation cost in region 2 d_2 is higher than d_1.

As shown above, policies selected by the respective governments differ from one another. Each government selects its environmental policy while taking account of the behaviors of dischargers and haulers in both regions and the policy adopted by the other government. Therefore, the timing of the environmental policy game is as follows.

(1) Governments in regions i ($i = 1, 2$) determine the industrial garbage tax and the purpose of tax revenue, for the strict monitoring policy or for the subsidy for proper disposal, whereas government expects the environmental policy adopted by the other government in the region j ($j = 1, 2,\ i \neq j$).
(2) Dischargers in each region determine the recycling rate.
(3) Haulers in each region determine their own behavior of either illegal abandonment or proper disposal in their region, and illegal abandonment otherwise.

4.4 Optimal strategies of local governments under the environmental policy game

The subsidy policy for proper disposal is more desirable than a strict monitoring policy in the one-region model. Moreover, the subsidy policy can establish the first best solution in Section 2. The subsidy policy for proper disposal can control the behaviors of haulers. Therefore, if the local government adopting this policy sets a lower tax rate than that of the other region, the government can recommend to haulers in its region to move garbage to the other region. Next we examine whether a subsidy policy for proper disposal is desirable under the two-region model. Behaviors of dischargers in both regions are unaffected by the model change; the amount of garbage consigned by dischargers is given as (2). Haulers can choose either proper disposal of the garbage or illegal abandonment of it. Moreover, they can determine where such proper disposal of the garbage or its illegal abandonment is carried out. When the industrial garbage tax and subsidy for proper disposal are τ_i ($i = 1, 2$) and s_i ($i = 1, 2$), respectively, the behaviors and profit of

[13] Actually, the Ministry of Health, Labor and Welfare takes no notice of the movement of industrial garbage between regions and recommends its treatment over a wide area, including multiple regions, if waste is thereby treated properly.

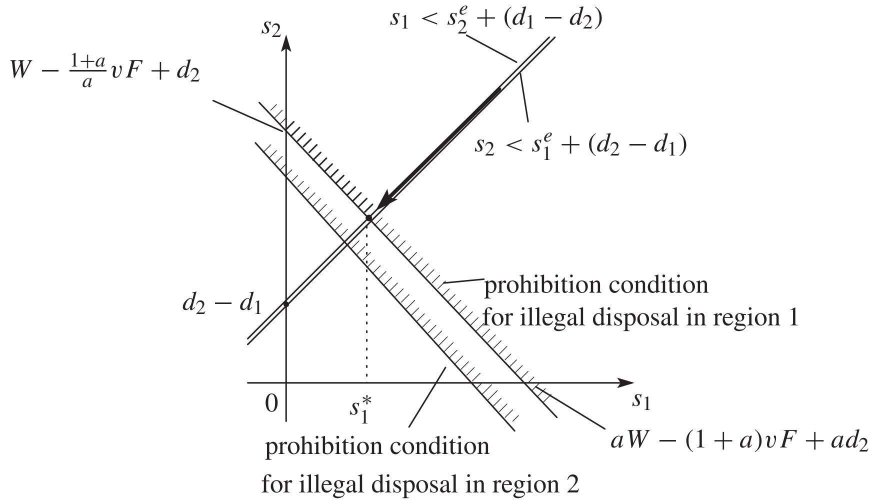

Fig. 11. Subsidy reduction competition.

the haulers in region i are as follows.

$$\begin{cases} \text{proper disposal and reclamation in region } i\text{:} & p_i - (\alpha + d_i - s_i) \\ \text{illegal abandoning in region } i\text{:} & p_i - vF \\ \text{proper disposal and reclamation in region } j\text{:} & p_i - (\alpha + d_j - s_j) \quad (i \neq j) \\ \text{illegal abandonment in region } j\text{:} & p_i - vF \quad (i \neq j) \end{cases}$$

Presuming that the haulers abandon the garbage illegally, their expected profit is the same in all regions. We assume that the haulers abandon the garbage in their region if their expected profit from the illegal abandonment is identical with respect to region. Thus, three haulers' behaviors exist: proper disposal and reclamation in their own region, illegal abandonment in their own region, and proper disposal or reclamation in another region. The hauler's action depends on the environmental policies selected by each government, particularly on the subsidy for proper disposal s_i, s_j. As a result, the government in region i ($i = 1, 2$) expects the environmental policy chosen in the other region and determines the industrial garbage tax and the subsidy as its own environmental policy after taking account of the haulers' behaviors in both regions and the dischargers in his region. This subsidy reduction competition is described in Figure 11. Initially, the region 1 government sets the subsidy to prevent region 2 haulers from moving their garbage into region 1.The region 1 government expects the subsidy s_2^e determined by the region 2 government and determines its subsidy s_1.

$$s_1 < s_2^e + (d_1 - d_2) \tag{23}$$

Presuming that the above condition is satisfied, the net reclamation cost of haulers in region 1 is higher than that in region 2. Therefore, the region 2 haulers do not carry their garbage into region 1 and commission the reclamation firms in region 2 to reclaim their garbage into land in region 2. The region 1 government determines the industrial garbage tax and the subsidy for proper disposal taking account of (19), (21), and (23). Moreover, because of the higher social costs, it is desirable for the region 2 government to recommend that haulers in its region carry the garbage, produced by dischargers in region 2, to region 1 rather than to reclaim their garbage in region 2. As a result, the region 2 government sets the subsidy for proper disposal s_2 to compel the haulers in its region to carry their garbage into region 1. In this case, presuming that the region 2 government anticipates the subsidy set by the region 1 government s_1^e, subsidy s_2 must be satisfied with the following condition.

$$s_2 < s_1^e + (d_2 - d_1) \tag{24}$$

Thus, the region 2 government determines the industrial garbage tax τ_2 and subsidy for proper disposal s_2 taking into account three conditions (19), (21), and (24). Now we denote the equilibrium subsidies of both regions by s_1^* and s_2^*, respectively. As understood from (23) and (24), the reduced competition of subsidies by governments in both regions is performed in order to recommend to their own haulers to carry their garbage to the other region. Each government lowers its subsidy to less than that in the other region to incite the haulers in its own region to carry their garbage to the other region. This competition of subsidy reduction will continue until s_1^*, which is subject to prohibiting the haulers from illegal abandonment. If the region 1 government lowers the subsidy to less than s_1^*, it is possible to cause illegal abandonment in region 1. Thereby, the region 2 government will win this reduction competition game of subsidy between regions. Consequently, the garbage produced in region 2 will be carried to region 1. In this case, the equilibrium recycling rate of garbage by the discharger in region 2 is

$$r^{FB} = r_2^* = \frac{d_1 + W}{aW + W}, \tag{25}$$

which is equal to the socially optimal solution. However, the region 1 government must pay a s_1^* subsidy to the haulers who properly treat garbage that is produced in region 2 and carried from region 2 to region 1. From (21), the region 1 government must set $\tau_1 = s_1$ to establish the socially optimal recycling rate in equilibrium. Moreover, these subsidies are covered by the tax revenue imposed on dischargers in region 1. Consequently, the budget constraint of the region 1 government is as follows.

$$\tau_1^*(1 - r_1^*)W = s_1^*(1 - r_1^*)W + s_1^*(1 - r_2^{FB})W \tag{26}$$

$$\tau_1^* > s_1^* \tag{27}$$

Because the region 1 government must pay haulers in both regions a subsidy in equilibrium, the government needs more tax revenues than are socially optimal; it can not establish the most efficient recycling rate of garbage:

$$r^{FB} < r_1^*. \tag{28}$$

The socially optimal recycling rate r^{FB} can be achieved by setting $\tau_1 = s_1$ from (21). However, the region 1 government must tax the haulers in both regions for the subsidy and needs to increase the industrial garbage tax to the dischargers in region 1. Because $\tau_1^* > s_1^*$ is satisfied from (26) to balance the budget, social efficiency can not be achieved. The inefficiency of subsidy policy is larger, whereas the difference between τ_1^* and s_1^*. We next concentrate on the penalty to haulers that abandon garbage illegally and examine the inefficiency of selecting a subsidy policy for proper disposal. If the penalty for illegal abandonment, F, is sufficiently small, the prohibition condition for illegal abandonment shifts that curve in the opposite direction from the origin. As the penalty, F, becomes larger, the subsidy in region 1 increases. Next we consider the effect of the subsidy on the equilibrium tax rate. Using the implicit function theorem to (26), we can confirm the relation between s_1 and τ_1 as follows.

$$\frac{d\tau_1}{ds_1} = -\frac{-(\tau_1 - s_1)W(dr_1/ds_1) - (1 - r_1)W - (1 - r_2)W}{(1 - r_1)W - (\tau_1 - s_1)W(dr_1/d\tau_1)} \tag{29}$$

However, we can not determine the sign of $d\tau_1/ds_1$.[14] Now we assume that $d\tau_1/ds_1$ is positive. Presuming that the effect of s_1 on the increase of tax revenue is sufficiently large, the industrial garbage tax decrease as the subsidy for proper disposal increases. Moreover, the decrease of penalty F increases the subsidy s_1^* and decreases the industrial garbage tax τ_1^*. These imply that the difference between τ_1^* and s_1^* becomes smaller along with the degree of inefficiency for region 1. On the other hand, when the penalty for illegal abandonment F is sufficiently large, the curves to prohibit illegal abandonment in both regions shift to the direction of origin and the increase of penalty F decreases s_1^* and increases τ_1^*. However, this occurrence spreads the degree of inefficiency for region 1. This property of penalty F is paradoxical to the argument that the penalty for any violation should be the severest punishment, as argued by Becker (1968). In other words, although the recycling rate in region 1 is inefficient by carrying the garbage from region 2 to region 1, the smaller penalty F engenders the improvement of the recycling rate and the social welfare. On the other hand, setting a higher penalty F can not achieve the social optimum.

Proposition 4. *Under the two-region model,*

- *The transboundary movement of garbage from region 2 to region 1 is caused and the socially optimal recycling rate is achieved only in region 2* $r^{FB} = r_2^*$.
- *The inefficient recycling rate* $r_1^* > r^{FB}$ *is achieved by carrying garbage to region 1.*
- *The severest penalty* F *is not necessarily the maximum penalty.*

5. Concluding Remarks

We constructed a model that explicitly describes the disposal stream of industrial garbage. We analyzed the ratio of industrial garbage tax and the use of revenue from it to construct an efficient industrial garbage disposal system. When the local government uses tax revenue for a strict monitoring policy, it must impose a larger tax on dischargers to deter illegal abandonment by haulers and cover the cost of carrying out this policy. Therefore, a strict monitoring policy can not engender a socially optimal recycling rate (**Proposition 2**). On the other hand, when the local government adopts a subsidy policy, imposing the tax is income transfer from the dischargers to the haulers. Because this subsidy policy does not distort the garbage market, the subsidy policy can lead to a socially optimal recycling rate (**Proposition 3**). Next we extended the one-region model to the two-region model including the possibility of movement of garbage between regions. If local governments in both regions adopt the use of tax revenue for the subsidy policy, it is possible for haulers in the other region to carry the garbage into their own region. Thus, each local government should do the

[14] The increase of subsidy s_1 is caused not only by the direct increase of subsidy to the haulers, but also by the increase of consignment garbage by dischargers. These effects increase the industrial garbage tax.

subsidy reduction competition and apply an excessive tax rate and recycling rate in the region with a lower reclamation cost (**Proposition 4**).

We have left the analysis of some points in this paper. We assume that the local government imposes an industrial garbage tax on dischargers. However, the local government imposes the tax on haulers to deter movement of garbage from the other region. Consequently, it is very important to analyze the effects of taxation on their behavior. Next, although only haulers are punished in the discovery of the illegal abandonment, dischargers should reconfirm whether the haulers have treated the commissioned garbage properly in the process. Consequently, we must take account of the responsibility of illegal abandonment. It is also important to include this factor into our model. Finally, future studies must address cases in which either the dischargers or the landfill operator can abandon the garbage illegally. Moreover, it might be interesting to construct a model that includes the consumption and production of goods within this framework. Furthermore, although we consider a disposal system comprising dischargers, haulers, landfill operators, and government in our model, it is interesting to consider a system in which landfill operators treat garbage and put garbage in landfills. Comparison of such a system with the system posited in this study might yield interesting results. These problems will be confronted in future research efforts.

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REFERENCES

[1] Becker, G., "Crime and punishment: An economic approach," *J. Polit. Econ.*, **76**: 169–217 (1968).
[2] Brander, J., and Spencer, B., "Export subsidies and market share rivalry," *J. Int. Econ.*, **18**: 83–100 (1985).
[3] Choe, C., and Fraser, I., "An economic analysis of household waste management," *J. Environ. Econ. Manage.*, **38**: 234–246 (1999).
[4] Copeland, R. B., "International trade in waste products in the presence of illegal disposal," *J. Environ. Econ. Manage.*, **20**: 143–162 (1991) .
[5] Dinan, T. M., "Economic efficiency effects of alternate policies for reducing waste disposal," *J. Environ. Econ. Manage.*, **25**: 242–256 (1993).
[6] Fullerton, D., and Kinnaman, T. C., "Garbage, recycling, and illicit burning or dumping," *J. Environ. Econ. Manage.*, **29**: 78–91 (1995).
[7] Fullerton, D. and Wu, W., "Policies for green design," *J. Environ. Econ. Manage.*, **36**: 131–148 (1998).
[8] Highfill, J., McAsey, M., and Weinstein, R., "Optimality of recycling and the location of a recycling center," *J. Reg. Sci.*, **34**: 583–597 (1994).
[9] Livernois, J., and McKenna, C. J., "Truth or consequences: Enforcing pollution standards with self-reporting," *J. Public Econ.*, **71**: 415–440 (1999).
[10] Ministry of the Environment Japan, "The report of the round-table conference about the administration of industrial garbage," `http://www.env.go.jp/recycle/waste/sanpai-kon/index.html` (in Japanese) (2002).
[11] Ministry of the Environment Japan, "The report of the situation surrounding illegal dumping industrial garbage in 2001," `http://www.env.go.jp/press/press.php3?serial=3848` (in Japanese) (2002).
[12] Ulph, A., "Harmonization and optimal environmental policy in a federal system with asymmetric information," *J. Environ. Econ. Manage.*, **39**: 224–241 (2000).
[13] Walls, M. and Palmer, K., "Upstream pollution, downstream waste disposal, and the design of comprehensive environmental policies," *J. Environ. Econ. Manage.*, **41**: 94–108 (2001).
[14] Yamaya, S., Ed., The Public Policy of the Circulatory Society (in Japanese), Chuokeizai-sha, Tokyo (2001).