Double Waste Reduction under Standards

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Abstract

This paper proposes a general equilibrium model with "double waste reduction" under standards of waste finally disposed of, and shows that some types of tax and/or subsidy must be required in addition to the standards to internalize externalities due to the waste disposal. Households and firms can reduce their waste independently using inputs or time. Two types of waste are distinguished, one of which is called "potential waste" from the households, and the other is called "actual waste" from the firms.

The combinations of tax-and-subsidy policies under standards can be classified by the existence or inexistence of waste reduction by each agent. For all the cases, a degree of marginal disutility due to waste disposal relative to a shadow price of actual waste under the standards is particularly important since it determines whether a tax or a subsidy is required. We also examine a special case where the standards are not binding as a result of zero or very low price of potential waste.

Key Words ; waste reduction, waste disposal, externality, standards, tax-and-subsidy

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1. Introduction

This paper proposes a general equilibrium model with "double waste reduction" under standards of waste finally disposed of, and shows that some types of tax and/or subsidy must be required in addition to the standards to internalize externalities due to the waste disposal. The *double* waste reduction means, in this paper, that households and firms can reduce their waste independently using inputs or time. We distinguish two types of waste, one of which is called "potential waste" from the households, and the other is called "actual waste" from the firms.

In recent years, Japan has set several targets for reducing municipal or industrial waste emission and recycling or recovering used resources in many industrial sectors. The Basic Plan for Establishing a Recycling-Based Society announced in March 2003 provides waste reduction targets, including a reduction of the amount of waste discharged from households and businesses by 20% per capita per day for the next ten years, and a reduction of the amount of industrial waste landfilled by 75% for the same years[1].

Following this legislation, in October 2003, the Basic Plan for the Improvement and Construction of Waste Treatment Facilities sets three goals; increasing a recycling rate of municipal waste by five points for the next five years, increasing its effective treatment rate by two points for the same years, and keeping residual years of landfill sites for municipal waste at the level of 2002. As the second method, power generation and thermal recycling of solid waste should be encouraged as thoroughly as possible if it has to be incinerated[2].

The enforcement of these numerical goals works as standards of waste finally

1 This plan has been based on the Basic Law for Establishing a Recycling-Based Society [*Junkangata Shakai Keisei Suishin Kihon Ho*] promulgated in June 2000 and completely enforced in January 2001.

2 These targets are made to meet a legal requirement spelled out in the Waste Management and Public Cleansing Law [*Haikibutsu Shori Ho* in short] often amended in recent years. The plan mentioned here is called *Haikibutsu Shori Shisetsu Seibi Keikaku* in Japanese.

disposed of, although they have not been imposed directly on the individual[3]. Since activities for waste reduction or recycling determine the amount of disposal waste, higher reduction efforts lead to lower disposal rates. In environmental economics, we have had many theoretical models of recycling, discussing the necessity of policy combinations such as taxes and subsidies applied to transactions in a decentralized economy[4]. However, there have been few papers regarding standards and such combinations at the same time with waste reduction or recycling activities.

The exception is Palmer and Walls (1997). Their analysis shows optimal but complicated tax rates to internalize externalities coupled with standards or requirements to attain the ratio of recycled materials to total virgin plus recycled ones[5]. We apply quite simpler standards than theirs, set upon waste finally disposed of or actual waste[6].

On the other hand, without standards, Choe and Fraser (2001) examine a simple equilibrium model which contains both *source reduction* by firms at production of goods and *waste reduction* by households after consumption. They conclude that a continuum of optimal policies is obtained if the household does not reduce waste,

3 On the other hand, individual targets of the recycling rate have been determined by commodity and businesses in the Guidelines for Waste Treatment and Recycling (drew up by the Industrial Structure Council in the Ministry of Economic, Trade and Industry, revised in 2001).

4 See an excellent survey of Kinnaman and Fullerton (2000), and the previous important papers edited by Kinnaman (2003).

5 They are named "minimum recycled content standards" in the analysis. This policy cannot achieve optimal allocation by itself, because the optimal combination of the two inputs does not necessarily yield the optimal output and waste at the same time. The essential implication that additional policies must be combined with such standards is unchanged even in Walls and Palmer (2001) in which they introduce two types of emission standards in more comprehensive modeling.

6 Koide (2004 a) shows that minimum recycling rate standards (different from ones by Palmer and Walls (1997) and Walls and Palmer (2001)) are imperfect substitutes for taxing residues after recycling in the context of the Home Appliance Recycling Law [*Kaden Recycle Ho* in short] enforced in Japan since 2001. Maintaining a charge system built in the Law, Koide (2004 b) introduces a simpler model which demonstrates how the existence or inexistence of the system affects the property of the policy combination. The model includes the possibility of illegal disposal by households in a very simple way.

and that the policy combination must be unique otherwise[7]. Our double waste reduction model also produces fruitful results in a different way from theirs.

The resulting "tax-and-subsidy policies" under standards in this paper can be classified by the existence or inexistence of waste reduction by each agent, whose cases are "[Case-N] no reduction," "[Case-H] only household reduction," "[Case-M] only firm reduction," and "[Case-D] double reduction," respectively. For all the cases, a degree of marginal disutility due to waste disposal relative to a shadow price of actual waste under the standards is particularly important since it determines whether a tax or a subsidy is required. On the other hand, we examine a special case where the standards are not binding as a result of zero or very low price of potential waste.

The implications derived from this analysis are summarized in advance. First, if neither the household nor the firm reduces waste ([Case-N]), only one type of tax or subsidy is needed depending on the sign of the marginal disutility relative to the shadow price of actual waste. It should be set upon any of three taxable goods, that is, potential waste, products, and labor for supplying them.

Second, if the household reduces his/her waste while the firm does not ([Case-H]), a policy on potential waste is necessary and sufficient, which is the same result as in [Case-N]. If it cannot be enforced, a policy on waste reduction by the household is required besides the one on either products or labor. In this case, each combination of policies includes a set of tax-and-subsidy which is determined by the sign of the marginal disutility relative to the shadow price of actual waste.

Third, when the firm reduces his/her waste while the household does not ([Case-M]), we also need combinations of tax-and-subsidy as in [Case-H]. However, contrary to that case, a policy on waste reduction by the firm is always necessary

7 Choe and Fraser (1999) build a more developed model incorporating the possibility of illegal dumping by households as well as waste reduction efforts by firms and the households. They point out that, as the second-best optimal policy set, it is necessary to achieve the optimal probability of catching dumping in addition to the optimal taxation on waste discharged by the firm and illegal disposal by the household.

irrespective of whether a policy on potential waste is adopted or not.

Finally, when both agents reduce their waste ([Case-D]), the results can be demonstrated by combining the ones in [Case-H] and [Case-M]. Policies on each waste reduction must be enforced independently although their tax rates seem to be alike.

The rest of this paper is organized as follows. First of all, in section 2, we propose a theoretical model with double waste reduction. Then, in section 3, Pareto optimum conditions of the model are derived. On the other hand, in section 4, we obtain competitive equilibrium conditions in a decentralized economy under standards of actual waste. Subsequently, optimal tax-and-subsidy policies besides the standards are examined by dividing into four cases in section 5. Finally, the analysis concludes with some remarks in section 6.

2. Model

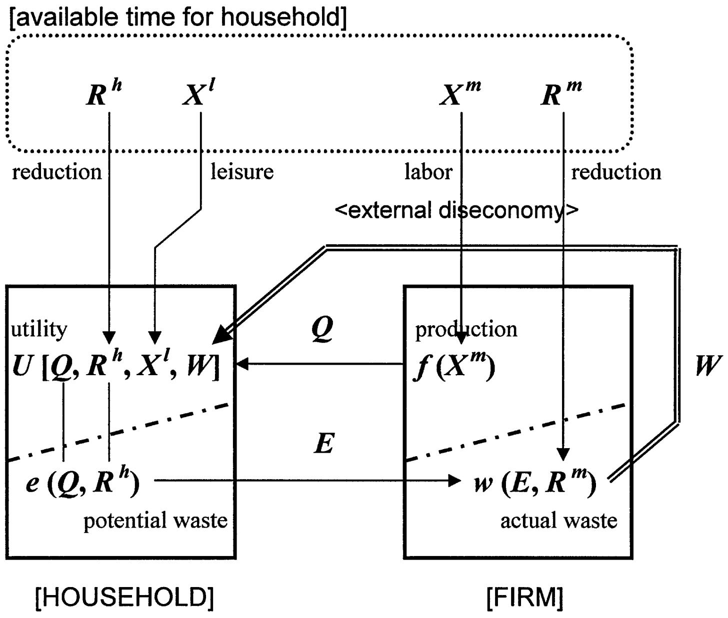
In this section, we present a simple general equilibrium model with double waste reduction. We first assume that there are two types of representative economic agent in this model ; a household with endowment of time, and a firm selling products. The essence of the model remains unchanged even if there were more but homogeneous agents.

Figure 1 illustrates a material flow of the model. A set of available time for the household is the only resource of this economy. He/she provides some of the time for supplying products and reducing (potential) waste to the firm as labor, while he/she uses the rest of the time to enjoy his/her leisure or reduce waste after using the products.

We introduce some mathematical assumptions of the model in the following paragraphs. First, the amount of products, Q, is defined as

$$Q \equiv f\left(X^m\right), \tag{2-1}$$

Figure 1. Material Flow of Model.



where X^m is the amount of labor for the production. The marginal product of the products with respect to labor is assumed to be positive and concave, $f' > 0$ and $f'' < 0$ [8].

Next, two types of waste are assumed. The amount of waste after using products, E, is defined as

$$E \equiv e(Q, R^h). \tag{2-2}$$

We call this "potential waste" emitted by the household.

In Equation (2-2), R^h is the amount of waste reduced which is, for simplicity, equal to the time devoted to the reduction by the household[9]. We assume that use of products increases potential waste while self reduction efforts decrease it, that is, $e_Q > 0$ and $e_R < 0$[10]. We further assume that this function is convex and that the

8 Single or double primes on a function denote its first or second derivatives hereafter.

cross partial derivative is zero, $e_{QQ} > 0$, $e_{RR} > 0$ and $e_{QR} = 0$.

The firm receives potential waste from the household at some positive price, and can reduce it using time as the latter does. The amount of waste finally disposed of, W, is defined as

$$W \equiv w(E, R^m), \tag{2-3}$$

We call this "actual waste" from the firm.

In Equation above, R^m is the amount of waste reduced that is also equal to the time devoted by the firm. We assume that potential waste increases actual waste while reduction efforts decrease it, namely $w_E > 0$ and $w_R < 0$. In addition, suppose that actual waste cannot be produced if there is no potential waste the firm receives, $w(0, R^m) = 0$. Further, we assume that the function of actual waste is convex and that the cross partial derivative is equal to zero, $w_{EE} > 0$, $w_{RR} > 0$ and $w_{ER} = 0$.

Moreover, a utility function of the household, U, is assumed to be

$$\begin{aligned} U &\equiv U[Q, R^h, X^l, W] \\ &= U[Q, R^h, X^l, w(e(Q, R^h), R^m)], \end{aligned} \tag{2-4}$$

where

9 Choe and Fraser (1999, 2001) argue that this activity is not observable and verifiable for a regulator while waste reduction efforts by firms are easier to monitor. Hence, their model excludes any policy on waste reduction by households. Our model leaves this possibility although it is not necessary if other policies are available and properly applied.

10 Single or double subscripts on a function denote its first or second partial derivatives hereafter.

$$U_Q > 0, \quad U_R < 0, \quad U_X > 0, \quad U_W < 0,$$

$$U_{QQ} < 0, \quad U_{RR} < 0, \quad U_{XX} < 0, \quad U_{WW} < 0, \quad \text{and} \tag{2-5}$$

$$U_{QR} = U_{QX} = U_{QW} = U_{RX} = U_{RW} = U_{XW} = 0.$$

X^l is the amount of leisure the household consumes. The first line of Equation (2-5) states that more use of products and leisure increase his/her utility while more self efforts to waste reduction and more actual waste decrease it. The second line gives the concavity to the utility function, and the third excludes the entire cross partial derivatives.

Finally, a resource constraint is represented by

$$\overline{X} = X^l + R^h + X^m + R^m, \tag{2-6}$$

where $\overline{X}$ is the total amount of time available for this economy. This equation is used for closing the general equilibrium model.

3. Pareto Optimum

In this section, we derive Pareto optimum conditions to attain efficient allocation in the economy. A social planner solves an optimization problem that is to maximize

$$U\left[Q, R^h, X^l, W\right], \tag{3-1}$$

subject to

$$W = w\left(E, R^m\right), \quad E = e\left(Q, R^h\right), \quad Q = f\left(X^m\right) \quad \text{and}$$
$$\overline{X} = X^l + R^h + X^m + R^m. \tag{3-2}$$

The corresponding Lagrangean is assumed to be

$$\Lambda \equiv U\left[Q, R^h, X^l, w\left(e\left(Q, R^h\right), R^m\right)\right]$$
$$+ \lambda\left[f\left(X^m\right) - Q\right] + \sigma\left[\overline{X} - X^l - R^h - X^m - R^m\right], \tag{3-3}$$

where λ and σ are Lagrangean multipliers associated with production and resource constraints, respectively.

The first-order conditions for attaining Pareto optimum allocation of the problem can be arranged as follows.

$$U_Q + U_W w_E e_Q - \lambda = 0, \tag{3-4}$$

$$U_R + U_W w_E e_R - \sigma \le 0, \quad R^h \ge 0, \quad \left(U_R + U_W w_E e_R - \sigma\right) R^h = 0, \tag{3-5}$$

$$U_X - \sigma = 0, \tag{3-6}$$

$$U_W w_R - \sigma \le 0, \quad R^m \ge 0, \quad \left(U_W w_R - \sigma\right) R^m = 0, \quad \text{and} \tag{3-7}$$

$$\lambda f' - \sigma = 0. \tag{3-8}$$

The interior solutions of optimal Q, X^l and X^m are assumed throughout this analysis. Also, the second-order conditions are assumed to be satisfied for all equations[11].

Combining equations (3-4), (3-7) with $R^m > 0$ and (3-8), we obtain a marginal rate of (technical) substitution of effort reducing actual waste for potential waste at the Pareto optimum as

$$\left.\frac{dR^m}{dE}\right|_{\overline{W}} = -\frac{w_E}{w_R} = \frac{1}{e_Q}\left(\frac{U_Q}{\sigma} - \frac{1}{f'}\right) > 0. \tag{3-9}$$

11 In particular, the second partial derivatives of Equation (3-4), (3-5) and (3-6) are expressed as $U_{QQ} + \left(U_{WW} w_E + U_W w_{EE}\right) e_Q^2 + U_W w_E e_{QQ} < 0$, $U_{RR} + \left(U_{WW} w_E + U_W w_{EE}\right) e_R^2 + U_W w_E e_{RR} < 0$, and $U_{WW} w_R^2 + U_W w_{RR} < 0$, respectively.

W with an upper bar means that the amount of actual waste holds constant on the same locus $W = w\,(E,\ R^m)$. This rate has a positive slope because more efforts will be needed to keep actual waste unchanged for an increase in potential waste. Alternatively, the different expression of the marginal rate can be obtained by using Equation (3-5) with $R^h > 0$ instead of (3-4), that is

$$\left.\frac{dR^m}{dE}\right|_{\overline{W}} = \frac{1}{e_R}\frac{U_R - \sigma}{\sigma} > 0. \tag{3-10}$$

Moreover, we obtain the marginal rate of substitution of effort reducing potential waste for products after use at the Pareto optimum, by equating (3-10) with (3-9),

$$\left.\frac{dR^h}{dQ}\right|_{\overline{E}} = -\frac{e_Q}{e_R} = \frac{U_Q - \sigma/f'}{\sigma - U_R} > 0. \tag{3-11}$$

E with an upper bar means that the amount of potential waste holds constant on the same locus $E = e\,(Q,\ R^h)$. Similar to the function mentioned above, its slope is positive because more self efforts will be needed to keep potential waste constant for an increase in products.

4. Competitive Equilibrium

In the following, we derive competitive equilibrium conditions in the decentralized economy under standards of actual waste. At the same time, we introduce possible tax rates on each variable as candidates for attaining optimality even if some of them would be unnecessary.

First, a representative household is assumed to maximize his/her utility,

$$U \equiv U\left[Q, R^h, X^l, \overline{W}\right], \tag{4-1}$$

subject to the condition on potential waste represented by Equation (2-2), and a

budget constraint,

$$P^X\left(\overline{X} - X^l\right) = \left(P^Q + T^Q\right)Q + \left(P^X + T^{Rh}\right)R^h + \left(P^E + T^E\right)E. \tag{4-2}$$

W with an upper bar in Equation (4-1) denotes the amount of actual waste that he/she cannot determine by himself/herself although it affects his/her utility. Therefore, we suppose that he/she has to take it as given.

In Equation (4-2), P^X and P^Q are the prices of labor (or equivalently leisure) and products, respectively. The potential waste will be delivered to the firm at the price P^E. In addition, T^Q, T^{Rh} and T^E are the tax rates per unit of product, self effort to waste reduction, and waste itself, respectively.

The Lagrangean associated with this problem is set to be

$$\begin{aligned}\Lambda^c \equiv\ & U\left[Q, R^h, X^l, \overline{W}\right] \\ & + \sigma^c\left[P^X\left(\overline{X} - X^l\right) - \left(P^Q + T^Q\right)Q - \left(P^X + T^{Rh}\right)R^h - \left(P^E + T^E\right)e\left(Q, R^h\right)\right],\end{aligned} \tag{4-3}$$

where the superscript c means that all the markets in the economy are perfectly competitive, and E is replaced by the one in Equation (2-2). The first-order conditions of this utility-maximizing problem are obtained as follows.

$$U_Q - \sigma^c\left[\left(P^Q + T^Q\right) + \left(P^E + T^E\right)e_Q\right] = 0, \tag{4-4}$$

$$\begin{aligned}& U_R - \sigma^c\left[\left(P^X + T^{Rh}\right) + \left(P^E + T^E\right)e_R\right] \le 0, \quad R^h \ge 0, \\ & \left[U_R - \sigma^c\left[\left(P^X + T^{Rh}\right) + \left(P^E + T^E\right)e_R\right]\right]R^h = 0, \quad \text{and}\end{aligned} \tag{4-5}$$

$$U_X - \sigma^c P^X = 0. \tag{4-6}$$

Second, a representative firm supplying products maximizes his/her profits under the production constraint and the standards of actual waste, that is,

$$\Pi^c \equiv P^Q Q - \left(P^X + T^{Xm}\right)X^m - \left(P^X + T^{Rm}\right)R^m + P^E E$$
$$+ \lambda^c\left[f\left(X^m\right) - Q\right] + \eta\left[\hat{W} - w\left(E, R^m\right)\right] \tag{4-7}$$

$\hat{W}$ denotes the upper bound of actual waste which can be disposed of. The second multiplier, η, does not have a superscript since there is no corresponding constraint in the previous optimization problem. T^{Xm} and T^{Rm} are the tax rates per unit of labor for serving products and effort reducing actual waste, respectively. The following first-order conditions are derived by solving this profit-maximizing problem.

$$P^Q - \lambda^c = 0, \tag{4-8}$$

$$-\left(P^X + T^{Xm}\right) + \lambda^c f' = 0, \tag{4-9}$$

$$-\left(P^X + T^{Rm}\right) - \eta w_R \le 0, \quad R^m \ge 0,$$
$$\left[-\left(P^X + T^{Rm}\right) - \eta w_R\right]R^m = 0, \quad \text{and} \tag{4-10}$$

$$P^E - \eta w_E = 0. \tag{4-11}$$

Since we have both competitive equilibrium and Pareto optimum conditions, we are ready to derive several equations for optimal tax-and-subsidy policies under the standards of actual waste by comparing each other. The equations described below will be useful to all of the cases examined in the next section.

First of all, it is easy to find that, by equating (4-6) to (3-6),

$$\sigma^c = \frac{\sigma}{P^X}. \tag{4-12}$$

This equation states that the marginal (private) utility of income must be equal to the marginal (social) one of time divided by its market price at the Pareto optimum[12].

Next, by equating (4-9) to (3-8) and using (4-12), we have

$$\lambda^c = \lambda\left(\frac{1}{\sigma^c} + \frac{T^{Xm}}{\sigma}\right). \tag{4-13}$$

This implies that a policy on labor to supply products may be useful in some situation.

Notice that the price of potential waste can be represented by

$$P^E = \eta w_E, \tag{4-14}$$

from Equation (4-11) alone. It is positive since the shadow price of waste standards and the marginal product of waste are both positive. On the other hand, when P^E is equal to *zero*, the shadow price must be zero for any positive marginal product.

Furthermore, we obtain an important equation associated with products by using (3-4), (4-4) and (4-8) as well as (4-12) to (4-14), which is

$$\left(\eta w_E + T^E\right)e_Q + T^Q + \frac{1}{f'}T^{Xm} = -\frac{U_W w_E e_Q}{\sigma^c} > 0. \tag{4-15}$$

Therefore, we are sure that one of the three tax rates is necessary and sufficient to hold this equality while the others are set to zero.

5. Tax-and-Subsidy Policies under Standards: Four Cases

In this section, we classify tax-and-subsidy policies according to whether the household and/or the firm engage in waste reduction or not at the competitive equilibrium. Since each agent has two choices, the possible cases can be divided into “[Case-N] no reduction,” “[Case-H] only household reduction,” “[Case-M] only

12 In addition, both values of the marginal utility must be equal if the price of time is normalized to one, as many researchers do. Notice that applying this method from the beginning may miss the linkage of the variables via the normalized price in comparing the conditions.

firm reduction," and "[Case-D] double reduction." In the following, we examine optimal policies consistent with the equilibrium in each case, using (4-12) to (4-15) as the common equations for all the cases.

5.1. Case-N: No Reduction

This is a case where $R^h = R^m = 0$. Hence, the associated first-order conditions may not be held with equality, which implies that we should derive optimal policies only using the equations (4-12) to (4-15).

The objective of the policies is to internalize a marginal disutility due to waste disposal (in monetary terms) or externalities involved which originally relate to the use of products, represented by RHS of Equation (4-15). However, the candidates may be too many, as shown in its LHS. It is quite reasonable that fewer policies are better in a view point of easier enforcement, so that any of them will be necessary and sufficient if properly valued.

We consider a policy on potential waste at the beginning. If we set $T^Q = T^{Xm} = 0$ in Equation (4-15),

$$T^E = w_E\left(-\frac{U_W}{\sigma^c} - \eta\right) = w_E\Gamma, \tag{5-1}$$

where

$$\Gamma \equiv -\frac{U_W}{\sigma^c} - \eta \gtrless 0, \tag{5-2}$$

which is the difference between the marginal disutility due to waste disposal and the shadow price of actual waste ($\eta > 0$). Γ is positive if the former dominates the latter, concluding that taxation on potential waste is required. Conversely, the subsidy per unit of waste should be sent to the household if Γ is negative[13].

Table 1. Tax-and-Subsidy in Case-N : no reduction.

	on E		not on E		tax rate
	$\Gamma > 0$	$\Gamma < 0$	$\Gamma > 0$	$\Gamma < 0$	
potential waste E	+	−	0		$w_E\Gamma$
product Q or labor X^m	0		+	−	$w_E e_Q \Gamma$ or $w_E e_Q f'\Gamma$
number of policies	1		1		

We can internalize the externalities even if such policy cannot be enforced for some reason, however. In a situation where we set $T^E = 0$ instead, the alternative policy can be obtained as

$$T^Q = w_E e_Q \Gamma \gtrless 0 \quad \text{for} \quad \Gamma \gtrless 0, \tag{5-3}$$

or

$$T^{Xm} = w_E e_Q f'\Gamma \gtrless 0 \quad \text{for} \quad \Gamma \gtrless 0. \tag{5-4}$$

Similar to the policy on potential waste, we should set a tax for positive Γ and a subsidy otherwise. Therefore, in any case, we need only one policy to internalize the externalities when neither the household nor the firm reduces waste.

Table 1 shows the results in this case[14]. Clearly, the ambiguity of the signs is brought by the shadow price associated with standards. Remark that we need no policy except the standards to internalize the externalities if Γ is *accidentally zero*, not written in the tables below.

13 Notice that there is no direct relation between the marginal disutility and the shadow price.
14 In all tables, the standards are not counted in the number of policies.

5.2. Case-H: Only Household Reduction

This is a case where $R^h > 0$ and $R^m = 0$. Now we can use one more equation which is, from equations (3-5), (4-5) and (4-8) as well as (4-12) and (4-14),

$$\left(\eta w_E + T^E\right)e_R + T^{Rh} = -\frac{U_W w_E e_R}{\sigma^c} < 0. \tag{5-5}$$

As in Equation (4-15), LHS of this equation also includes the tax rate per unit of potential waste, T^E. If we set $T^{Rh} = 0$,

$$T^E = w_E \Gamma, \tag{5-6}$$

which is the same as Equation (5-1). Therefore, the policy on potential waste is only needed.

We have a different result from [Case-N] if $T^E = 0$, since

$$T^{Rh} = w_E e_R \Gamma \lesseqgtr 0 \qquad \text{for} \quad \Gamma \gtreqless 0 \tag{5-7}$$

must be set upon waste reduction by the household *in addition to* the policy, either (5-3) or (5-4).

Hence, as shown in Table 2, two policies must be combined in the absence of the policy on potential waste, one of which is a tax and the other is a subsidy. Therefore, this case needs one more policy than in [Case-N]. Needless to say, the standards are also necessary in this case unless Γ is zero.

5.3. Case-M: Only Firm Reduction

This is a case where $R^h = 0$ and $R^m > 0$. The conditions associated with waste reduction by the firm are available and arranged to, from equations (3-7) and (4-10),

$$P^X + T^{Rm} = -\frac{\sigma\eta}{U_W} > 0. \tag{5-8}$$

Thus, using Equation (4-12) as well, we have

Table 2. Tax-and-Subsidy in Case-H : only household reduction.

	on E		not on E		tax rate
	$\Gamma > 0$	$\Gamma < 0$	$\Gamma > 0$	$\Gamma < 0$	
potential waste E	+	−	0		$w_E\Gamma$
product Q or labor X^m	0		+	−	$w_E e_Q \Gamma$ or $w_E e_Q f'\Gamma$
house reduction R^h	0		−	+	$w_E e_R \Gamma$
number of policies	1		2		

$$T^{Rm} = w_R \Gamma \lesseqgtr 0 \qquad \text{for} \quad \Gamma \gtreqless 0. \tag{5-9}$$

The other policies are almost the same as in [Case-N].

Similar to the results described in [Case-H], there are policy combinations which include a set of tax-and-subsidy, as we see in Table 3. The difference is that, in this case, the policy (5-9) is always necessary irrespective of whether the policy on potential waste is adopted or not. This means that one policy beside standards is not sufficient to internalize the externalities when the firm engages in waste reduction. In addition, if we cannot set any policy on the waste reduction, the internalization of the externalities fails for nonzero Γ.

5.4. Case-D: Double Reduction

This is a case where $R^h > 0$ and $R^m > 0$. We do not need to investigate the optimal policies further, because we can easily obtain the results by combining the ones in [Case-H] and [Case-M].

Table 4 is a composite of the policies demonstrated previously. The most

Table 3. Tax-and-Subsidy in Case-M : only firm reduction.

	on E		not on E		tax rate
	$\Gamma > 0$	$\Gamma < 0$	$\Gamma > 0$	$\Gamma < 0$	
potential waste E	+	−	0		$w_E \Gamma$
product Q or labor X^m	0		+	−	$w_E e_Q \Gamma$ or $w_E e_Q f' \Gamma$
firm reduction R^m	−	+	−	+	$w_R \Gamma$
number of policies	2		2		

Table 4. Tax-and-Subsidy in Case-D : double reduction.

	on E		not on E		tax rate
	$\Gamma > 0$	$\Gamma < 0$	$\Gamma > 0$	$\Gamma < 0$	
potential waste E	+	−	0		$w_E \Gamma$
product Q or labor X^m	0		+	−	$w_E e_Q \Gamma$ or $w_E e_Q f' \Gamma$
house reduction R^h	0		−	+	$w_E e_R \Gamma$
firm reduction R^m	−	+	−	+	$w_R \Gamma$
number of policies	2		3		

Table 5. Policies for Zero or Very Low Price of Waste.

	on E	not on E	tax rate
potential waste E	+	0	$-U_W w_E / \sigma^c$
product Q or labor X^m	0	+	$-U_W w_E e_Q / \sigma^c$ or $-U_W w_E e_Q f' / \sigma^c$
house reduction R^h	0	−	$-U_W w_E e_R / \sigma^c$
firm reduction R^m	unnecessary since R^m is zero		$(-P^X)$
number of policies	1	2	

complicated combination is the one without a policy on potential waste, which includes a tax on products or labor employed and subsidies to two types of waste reduction if Γ is positive. Notice that we need policies on each waste reduction independently although their tax rates seem to be alike.

Here we discuss how these policy combinations could be modified (or simplified indeed) in a special case where the price of potential waste is zero or very low at the competitive equilibrium. From Equation (4-11), $0 - \eta w_E < 0$ and the amount of potential waste the firm receives, E, must be zero due to the Kuhn-Tucker condition. Moreover, this induces $W = w\,(0,\, R^m) = 0$ by the assumption, and thus η must be zero for any positive level of $\hat{W}$. Finally, the amount of waste reduction by the firm becomes zero since $-(P^X + T^{Rm}) < 0$ in Equation (4-10).

As shown in Table 5, the policies in this case are all unambiguous since the shadow price of actual waste is equal to zero. Since the standards on waste are not binding, the results can be clarified and similar to the ones obtained by my former analyses (2000, 2002) which include other externalities due to recycling of used materials as well as waste disposal.

6. Concluding Remarks

This paper has analyzed a general equilibrium model with double waste reduction under standards of waste finally disposed of, and derived the tax-and-subsidy policies needed for attaining optimality in the presence of the standards. The policies have been classified according to whether the household and/or the firm engage in waste reduction or not at the equilibrium.

The implications of the analysis can be simplified as follows. If both agents do not engage in waste reduction, one type of tax or subsidy is sufficient. If the household only reduces his/her waste, one more policy on the reduction is necessary than in no reduction case when a policy on potential waste cannot be enforced.

Conversely, if the firm only reduces waste, a policy on the reduction must be needed irrespective of whether a policy on potential waste is adopted or not. Finally, policies can be obtained by combining the ones in each case when both agents reduce waste. Throughout the analysis, the key factor that determines whether policy is required at each point is a relative degree of marginal disutility due to waste disposal to a shadow price of waste under the standards.

As the most importance, we have found that, when some type of waste reduction activity is permitted in the model, setting standards for disposing waste is theoretically insufficient to achieve optimality without any complementary taxation or subsidization. In a real world, there are many examples of severe standards to be set on particular emissions or materials although their effectiveness would not be assured. One possibility for making such policies more effective is to apply (or change to) other types of standards that need fewer complementary policies. It is very useful to pursue this topic for further analysis.

In addition, it is also important to sophisticate pricing on (potential) waste allowing for the possibility of negative prices. In our model, as most of the models in this field apply, any market price of waste is implicitly assumed to be positive (or nonnegative), and is given to the associated agents as for other economic goods. However, they could be negative if more constraints that affect the pricing of waste exist (in addition to Equation (4-14), for example). Equilibrium in the waste market will be changed with this extension, and the optimal policies might have to take this phenomenon into account besides the existing externalities.

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