A Theoretical Analysis of Polluter-Pays Principle with 'Allocated Costs' between Economic Agents*

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Abstract

The aim of this paper is to clarify both original and extended definitions of "Polluter-Pays Principle," point out the shortcomings of the theoretical analysis frequently used in environmental economics, and then build a simple general equilibrium model showing several ways of internalizing social costs emerged by pollution from production of goods, with an introduction of so called "allocated costs" between economic agents concerned. This is an economic attempt to determine whether the Polluter-Pays Principle could be held or modified depending on informational certainty about abatement costs.

As a result of obtaining efficiency under the externalities, we will show four cases. A "Complete Polluter-Pays Principle" is required only if the social

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costs due to pollution are internalized by setting allocated and abatement costs properly and the latter are known to both the polluter and the pollutee exactly. On the other hand, when the pollutee does not know the abatement costs while the polluter does, they should bear the external costs fifty-fifty as the allocated ones, which can be interpreted as an "Equally-Pays Principle." Moreover, it is interesting to note that a "Pays-and-Receives Principle" should be applied to the cost internalization when the pollutee overestimates the abatement costs. Finally, it is almost impossible to internalize the social costs without the allocated ones.

Key Words : Polluter-Pays Principle, allocated cost, cost internalization, cost allocation

JEL Classification Numbers : D62, H21, K32

1. Introduction

The aim of this paper is to clarify both original and extended definitions of "Polluter-Pays Principle," point out two shortcomings of the theoretical analysis frequently used in environmental economics, and then build a simple general equilibrium model showing several ways of internalizing social costs emerged by pollution from production of goods, with an introduction of so called "allocated costs" between economic agents concerned. This is an economic approach to determine whether the Polluter-Pays Principle could be held or modified depending on informational certainty about abatement costs which the polluter should bear[1].

In recent years, the meanings of the Polluter-Pays Principle have varied

1 In this paper, two verbs, to "pay" some costs and to "bear" the ones will be used in the same meaning. Thus, they would appear interchangeably in the text. The reason is that, as a basic analysis, it concerns only *efficiency*, not *equity*. Therefore, the actual incidence of the costs remains to be solved on another occasion. Recently, Rahman and Edwards (2004) develop mathematical supply-demand models to explore optimal liability schemes in terms of efficiency, equity and ethics in a world of favor seeking politics.

considerably between objectives of environmental laws or policies and countries enforcing them, although the original one proposed by OECD more than thirty years ago was quite simple. This paper does not follow up the history of the Principle steadily, since Nash (2000) carries out the thorough survey[2].

An economic interpretation of the Polluter-Pays Principle by Pezzey (1988) is very useful for classifying many types of Principles adopted into a "Standard PPP" and an "Extended PPP." Further, Turner *et al*. (1994) refer to it effectively in their elementary explanation. In discussing a nature of the Polluter-Pays Principle, environmental economists frequently use a diagrammatic model for minimization of the social costs, defined as the sum of abatement and external costs, showing that the social optimality is obtained at the point where the marginal abatement costs are equal to the marginal external ones.

Additionally, Stevens (1994) points out that the Polluter-Pays Principle has two essential functions, which are a "Cost Internalization" and a "Cost Allocation." However, the existing analyses have mostly discussed the *former* within a *partial* equilibrium framework, that is, how much should be paid for internalizing externalities due to some pollution emerging activities.

The model presented in this paper investigates the *latter* as well, that is, who should pay the costs associated with such damaging activities, or what proportion of the costs should be paid by each agent, namely, a polluter and a pollutee. We can say nothing about the cost allocation using the conventional model containing the polluter only. However, the concept is much important in the real world where it is quite common to bear the social costs among multiple agents connected with market transactions. This is a reason why the allocated costs must be set upon to internalize the externalities among the agents concerned within a *general* equilibrium framework.

We can say that, as a result of obtaining efficiency under the externalities, a

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2 See also Otsuka (2002) for the cases of Japanese environmental laws.

"Complete Polluter-Pays Principle" or the Extended PPP defined by Pezzey is required only if the social costs due to pollution are internalized by setting allocated and abatement costs properly and the latter are known to both the polluter and the pollutee.

In contrast, when the pollutee does not know the abatement costs while the polluter does, they should bear the external costs fifty-fifty in the form of the allocated ones while the polluter bears the abatement ones as well. This situation can be expressed as an "Equally-Pays Principle" combined with the Standard PPP in Pezzey's terms.

Furthermore, a "Pays-and-Receives Principle" should be adopted when the abatement costs are overestimated by the pollutee, which requires that the polluter pays more than the overall allocated costs and the pollutee receives the excess. Finally, it is almost impossible to internalize the social costs without the allocated ones, even if both agents know the abatement costs exactly.

The paper proceeds in the following way. We begin by showing the definitions of the original and the extended Polluter-Pays Principles and the related useful terminology in Section 2. The conventional diagrammatic model is also presented in that section with pointing out the analytical weaknesses. Next, in Section 3, we introduce a simple general equilibrium model with externalities and derive the Pareto optimum conditions. Additionally, in Section 4, we examine whether such optimality can be obtained using the allocated and/or the abatement costs in order to internalize the social ones, dividing the possibilities into some cases according to informational certainty about the abatement costs. Finally, we conclude this analysis with some remarks in Section 5.

2. Discussions on the Polluter-Pays Principle

In this section, we first show the definitions of the original and the extended Polluter-Pays Principles and some useful terminology in our analysis. Remember that we do not follow the long history of these Principles in detail but focus on the theoretical ways of sorting them out to clarify the points at issue. Then, we present the well-known diagrammatic model of explaining the Principles briefly, and point out its analytical weaknesses which could be overcome by the modeling shown in the next section.

The Polluter-Pays Principle was originally proposed by OECD in 1972. The following paragraph is cited from Annex I to "Recommendation of the Council on Guiding Principles Concerning International Economic Aspects of Environmental Policies" (underlined by the author)[3].

> The principle to be used for allocating costs of pollution prevention and control measures to encourage rational use of scarce environmental resources and to avoid distortions in international trade and investment is the so-called "Polluter-Pays Principle". This principle means that the polluter should bear the expenses of carrying out the above-mentioned measures decided by public authorities to ensure that the environment is in an acceptable state. In other words, the cost of these measures should be reflected in the cost of goods and services which cause pollution in production and/or consumption. Such measures should not be accompanied by subsidies that would create significant distortions in international trade and investment.

As we can see, the original Principle is quite simple in that it requires the allocation or burden of the costs for pollution prevention and control, and the imposition of the burden of these costs on the polluter. It can be understood that, from the passage above, the polluter's responsibility is limited and some

3 Paragraph 4 of Annex I to "Recommendation of the Council on Guiding Principles Concerning International Economic Aspects of Environmental Policies," C(72)128, OECD, 26 May 1972.

compensation for his/her polluting activity to the pollutee is *not* necessary. Also notice that, to avoid needless confusion, this Principle calls for realizing or improving cost *efficiency* by nature, not some distributional *equity* between the economic agents involved. The latter is, in fact, another problem.

Since this Recommendation was made, the notion of the Polluter-Pays Principle has been gradually developed in thirty years, especially in industrialized countries coping with their serious environmental problems including air, water and soil pollution[4]. At the same time, it has caused many different interpretations or abuses of the Principle[5].

To get rid of the confusion and make its essence clearer, Pezzey (1988) classifies many Principles into two types, such as a "Standard PPP" and an "Extended PPP." The former requires that, in net terms, the polluter should pay the costs of optimal effluent control, but *not* for the pollution damage done by the remaining optimal effluent or residual pollution. In contrast, the latter requires that, also in net terms, the polluter should pay the costs of optimal effluent control *and* for the pollution damage done by the remaining optimal effluent[6]. In terms of environmental economics, it can be said that the Standard PPP corresponds to paying "Abatement Costs (AC)" while the Extended PPP to the sum of these costs and "External Costs (EC)."

Needless to say, the original Polluter-Pays Principle by OECD matches the first definition by Pezzey, that is, the payment of AC only. Rather, the second one or the payment of EC as well as AC has been mainly applied, in various contexts, to the practices of cost bearing and compensation for the damage caused by pollution

4 The short report distributed by OECD in 1992 gives an outline of developments of the Polluter-Pays Principle after twenty years from adopting the original one ("The Polluter-Pays Principle : OECD Analyses and Recommendations," OCDE/GD(92)81, OECD, Paris).

5 For the detailed history of the Polluter-Pays Principle, see Nash (2000). The recent report prepared by Henri Smets (Association pour le développement de l'économie et du droit de l'énvironnement, Paris) is also useful ("The Polluter-Pays Principle as it Relates to International Trade," COM/ENV/TD(2001)44/FINAL, OECD, 23 Dec 2002).

6 Pezzey (1988), pp.208‐209.

activities. Economic analyses have tried to clarify how the external costs can be "internalized" to the individual economic decisions of the polluter or other agents since A. C. Pigou[7]. Here it is important to point out that there may be the case where the abatement costs cannot be fully internalized because the informational asymmetry exists between the agents. In this situation, the Principles mentioned above may be insufficient to realize the efficiency even if the externalities can be internalized.

One more useful point of view is proposed by Stevens (1994). He argues three interpretations of the existing Polluter-Pays Principles, such as (i) a "Cost Allocation" for domestic environments, (ii) a "Cost Internalization" for them, and (iii) a Cost Internalization for shared (or global) environments[8]. The Cost Allocation asks *who* should pay, while the Cost Internalization matters *how much* should be paid.

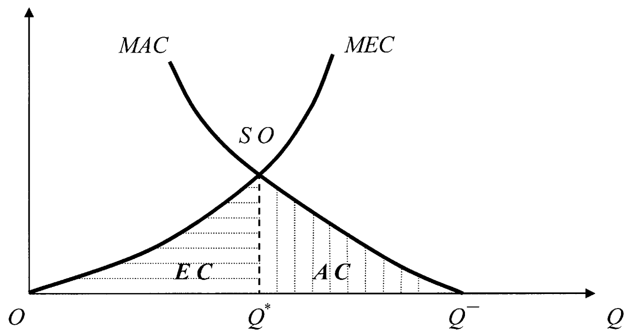
It seems that the conventional analyses of the externalities have been devoted mostly to examine the latter (for example, deriving optimal values of a tax or subsidy rate and a price of a tradable permit that the polluter pays or receives), but giving little attention to the former. One of the reasons is that the costs are unable to be allocated since the conventional models assume no agent except the polluter. Moreover, it is important to consider whether the abatement costs could be internalized besides the external ones, as mentioned previously.

The representative model frequently used to explain the Polluter-Pays Principle can be described as follows. Assume that a producer of goods is also a polluter because one unit of production Q yields the same unit of pollution. The abatement costs are assumed to be expressed by the function $c(\overline{Q}-Q)$, where $\overline{Q}$ is the maximum pollution in the absence of abatement. The remaining pollution, not abated by the polluter, imposes external costs on society which are represented by the function $e(Q)$. Assume that these costs are increasing and convex in each

7 The recent version of his famous "Economics of Welfare" is available as Pigou (2002).

8 Stevens (1994), pp.579-589.

Figure 1. The Optimum of the Partial Equilibrium Model.



variable, namely, $c' > 0$, $c'' > 0$, $e' > 0$, and $e'' > 0$. As a rule, the social costs are defined as the sum of the abatement and the external costs.

Using these assumptions, we obtain the optimum of this model by minimizing the social costs. Figure 1 shows only the result, where *MAC* and *MEC* represent the marginal abatement costs and the marginal external costs curves, respectively. The intersecting point *SO* expresses the social optimum where the social costs are minimized, and the optimal amount of production or pollution Q^* is derived by the first-order condition $c'(Q^*) = e'(Q^*)$. The corresponding abatement and external costs are represented by the areas of *AC* and *EC*, respectively. According to the definitions by Pezzey, the polluter should pay only *AC* as the Standard PPP, while paying both *AC* and *EC* as the Extended PPP. Notice that, in this model, the abatement costs are certainly internalized by the polluter since he/she knows it exactly.

Here we point out two analytical weaknesses of this model.

First, there is no way of cost allocation since it is a partial equilibrium model containing only a polluter. Hence, we cannot give any theoretical answer to the issue about allocating the costs mentioned by Stevens. More assumptions are needed to examine this theme.

Second, pollution abatement should be distinguished from a reduction in production in order to allow other effective activities, such as reuse, recycling, and recovery of used goods. The assumption placed on the abatement of pollution is so simple that it may exclude possibilities to prevent or control the pollution which are *independent* of the production of goods. It seems natural that, in order to reduce pollution, the polluter would prefer to use some cost effective means rather than decrease the amount of production itself if he/she has some alternatives. This also reflects the realities of advancing numerous technologies of pollution control or recycling in many countries.

Regarding these points, we present a general equilibrium model which involves both cost internalization and its allocation in the next section. Before doing this, we introduce two more important factors.

The one is called "Allocated Costs (LC)." These are in the form of *internalized* external and/or abatement costs, distributed to the two economic agents concerned. The agents assumed in the model are a polluter who is also a producer, and a pollutee who is also a consumer. The notion of the allocated costs will allow us to find the appropriate cost allocations.

Another factor is informational certainty about the abatement costs. The previous model implicitly assumes perfect information, while we investigate several uncertain cost cases to see whether the uncertainty of information affects the results of cost internalization and its allocation. To be seen, it will be found that it does.

3. Theoretical Model

In this section, we propose a general equilibrium model in the presence of externalities due to pollution emitted by a producer, and derive the Pareto optimum conditions in assuming only interior solutions.

As previously mentioned, we assume two representative economic agents, which are a "polluter" who is also a "producer," and a "pollutee" who is also a "consumer." The former produces consumption goods, emits pollution accompanied by the production, and reduce or abate the pollution. Both production and abatement must use labor provided by the latter that consumes the goods and suffers damage from the pollution in the form of an increase in his/her disutility.

In the following paragraphs, we introduce mathematical assumptions of this model. First, the consumer’s utility function is assumed to be

$$U \equiv u[Q, L, E], \tag{1}$$

where Q, L and E are the amounts of consumption goods, leisure and “net” pollution, respectively. The term “net” is added since the “gross” pollution from production can be reduced by using labor, as described below. Suppose that either increases in the first two variables or a decrease in the other marginally increase the utility, that is, $u_Q > 0$, $u_L > 0$ and $u_E < 0$[9]. Assume also that this function is concave in each variable and that all the cross partial derivatives are zero for simplicity, such as $u_{QQ} < 0$, $u_{LL} < 0$, $u_{EE} < 0$ and $u_{QL} = u_{QE} = u_{LE} = 0$.

Second, we give assumptions on the side of the producer. The production function of the consumption goods is simply defined as

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

where X^Q is the amount of labor used for the production[10]. In addition, it is assumed to be an increasing function with concavity, that is, $f' > 0$ and $f'' < 0$[11]. On the other hand, the producer also engages in pollution abatement whose activity function is assumed to be linear, such as

$$A \equiv \beta X^A, \tag{3}$$

9 Single or double subscripts on each function denote its first or second partial derivatives hereafter.

10 Some material could be introduced as an input combined with labor to make the model more realistic (like Koide (2002), for example), but it has no effect on the main implications of this analysis.

11 Single or double primes on the production function denote its first or second order derivatives hereafter.

where A and X^A are the amounts of abatement and labor used, respectively. β is some positive coefficient and called the "marginal abatement of labor."

Third, the external costs function is defined as

$$EC \equiv E \equiv e(Q, A). \tag{4}$$

For simplicity, we assume that one unit of net pollution corresponds to one unit of the external cost exactly, so that Equation (4) can be also seen as a net pollution function. We assume that the costs are increased by either an increase in the amount of production or a decrease in abatement, $e_Q > 0$ and $e_A < 0$. It means that the production of goods causes external costs while the abatement of pollution yields external *benefits* to the contrary. Assume also that this function is concave in each variable and that the cross partial derivative is positive, or $e_{QQ} < 0$, $e_{AA} < 0$ and $e_{QA} > 0$[12].

Finally, the resource constraint closing this model is set to be an equation

$$\overline{X} = X^Q + X^A + L, \tag{5}$$

where $\overline{X}$ is the total time given to the consumer.

Now we are ready to examine a Pareto optimization problem which is characterized by the maximization of the representative consumer's utility subject to the constraints shown above. Set the Lagrangean for this optimization,

$$\begin{aligned} L &\equiv u[Q, L, E] + \lambda[f(X^Q) - Q] \\ &= u\left[Q, \overline{X} - X^Q - \frac{A}{\beta}, e(Q, A)\right] + \lambda[f(X^Q) - Q], \end{aligned} \tag{6}$$

where λ is the Lagrangean multiplier for the production constraint. Note that the resource constraint and the pollution abatement function have been already

12 The last assumption means that the marginal pollution of production, e_Q, increases as the amount of abatement increases since the pollution underlain is less than before. There may be the opposite case in some types of pollution. However, this change of the sign would affect almost no modification of the results.

substituted for leisure in the utility function, and also the net pollution has been replaced by the external costs function.

Consider only the possibility of interior solutions. The Pareto optimum conditions of this problem are therefore derived as follows.

$$u_Q + u_E e_Q = \lambda, \tag{7}$$

$$u_L = \lambda f', \tag{8}$$

$$u_L = u_E e_A \beta, \quad \text{and} \tag{9}$$

$$f - Q = 0. \tag{10}$$

The LHS of Equation (7) must be positive at the optimum, although its second term is negative due to the marginal disutility of pollution. In Equation (9), multiplying the disutility by the marginal pollution reduction due to abatement makes the RHS positive, which must be equal to the marginal utility of leisure, as appeared in Equation (8). The last equation repeats the constraint on the production of goods, Equation (2).

Combining equations (7) to (9), we obtain the familiar condition in general equilibrium theory that the marginal rate of substitution is equal to that of technical substitution at the optimum,

$$\frac{u_Q + u_E e_Q}{u_L} = \frac{u_Q + u_E e_Q}{u_E e_A \beta} = \frac{1}{f'}. \tag{11}$$

It is not our purpose to clarify the properties of the equilibrium further, but to find ways of efficient cost internalization and its allocation in decentralized decision makings by the economic agents.

Before doing this, however, it may be informative to show whether the pollution abatement is promoted by increasing its productivity β. As shown in Lemma 1 and its proof below, this expectation is right in some range, but the production and hence the emission of the gross pollution will be also promoted at the same time! As a result, the *net* amount of pollution does not necessarily increase in these cases.

[*Lemma 1*] If the marginal abatement of labor β is increased in assuming that $\Omega \equiv f' W + u_{LL}/\beta$ is either positive or negative but small in absolute values, (i) the amount of production *increases*, (ii) the amount of abatement increases, and finally, (iii) the net amount of pollution increases or decreases. Conversely, for sufficiently negative Ω, all the directions of these changes are uncertain.
proof. See Appendix.

4. Internalization of Social Costs : Four Cases

In this section, assuming perfectly competitive markets in this modeled economy, we try to examine whether the Pareto optimality previously mentioned can be obtained using so called allocated costs (LC) and/or abatement costs (AC) to internalize the social costs (SC) in several situations.

First of all, we examine a basic model. We assume that profits of the producer or the polluter are written by

$$\begin{aligned}\Pi &\equiv P^Q Q - P^X X^Q - P^X \frac{A}{\beta} + \lambda^x \left[f\left(X^Q\right) - Q\right] - \theta c(Q, A) \\ &= P^Q Q - P^X X^Q - AC + \lambda^x \left[f\left(X^Q\right) - Q\right] - \theta LC,\end{aligned} \tag{12}$$

where λ^x is the multiplier for the production constraint, $0 \leq \theta \leq 1$ is the "allocation rate" between the polluter (θ) and the pollutee($1-\theta$), $c(Q, A)$ and is the LC function. In addition, we assume a linearity of this function for simplicity, such as

$$LC \equiv c(Q, A) \equiv C^Q Q + C^A A. \tag{13}$$

As shown in Equation (12), the AC function in this model is expressed as linear in A,

$$AC \equiv P^X X^A = \frac{P^X A}{\beta}. \tag{14}$$

Maximization of the profits (12) gives the first-order conditions as follows.

$$P^Q = \lambda^\chi + \theta C^Q, \tag{15}$$

$$P^X = \lambda^\chi f', \tag{16}$$

$$\frac{P^X}{\beta} = -\theta C^A, \quad \text{and} \tag{17}$$

$$f - Q = 0. \tag{18}$$

Now we turn to a problem solved by the consumer or the pollutee. Set the Lagrangean for his/her utility maximization to be

$$L^\chi \equiv u\left[Q, \overline{X} - X^Q - \frac{A}{\beta}, \overline{E}\right] + \sigma\left[P^X X^Q + \alpha P^X \frac{A}{\beta} + I - P^Q Q - (1-\theta)c(Q, A)\right], \tag{19}$$

where $\overline{E}$ is the level of net pollution unable to be controlled by him/her, σ is the multiplier for the budget constraint which contains the portion $(1-\theta)$ of LC as his/her costs, $0 \leq \alpha \leq 1$ is the simple parameter that indicates whether the pollutee knows or expects the true AC accurately, and I is the (fixed) payment fulfilling the remaining portion of income for engaging in the pollution abatement[13].

Suppose that α equals to one if he/she knows AC exactly while zero if he/she does nothing at all. Unusually, it could exceed one in a case where the overestimation is made, which interestingly induces paying-and-receiving situations

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13 We adopt the last treatment not to decrease the actual payment to the consumer for any value of α. I thank Yasunori Fujita (Keio University) to have pointed out this "weakness" at the meeting of the Japanese Economic Association.

described later. Notice also that, besides the value of α, AC is a benefit for the pollutee since it is received as a payment for providing labor to the pollution abatement[14].

The first-order conditions for this maximization are,

$$\sigma P^Q = u_Q - \sigma(1-\theta)C^Q, \tag{20}$$

$$\sigma P^X = u_L, \tag{21}$$

$$\frac{\sigma\alpha}{\beta}P^X = \frac{u_L}{\beta} + \sigma(1-\theta)C^A, \quad \text{and} \tag{22}$$

$$P^X X^Q + \alpha P^X \frac{A}{\beta} + I - P^Q Q - (1-\theta)c = 0. \tag{23}$$

To realize the Pareto optimality under the decentralized decisions made by both agents, we require the following conditions. First, by equations (16) and (21), the marginal utility of labor is equal to $\sigma\lambda^x f'$, which yields

$$\lambda^x = \frac{\lambda}{\sigma}. \tag{24}$$

Second, comparing equations (15) and (20), we have $u_Q - \sigma C^Q = \sigma\lambda^x$. Hence,

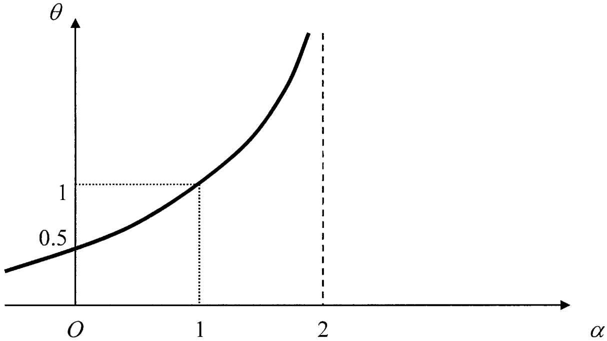
$$C^Q = \frac{-u_E}{\sigma}e_Q > 0. \tag{25}$$

This is the optimal marginal allocated costs in increasing production or pollution.

Third, we find that, combined with equations (17), (21) and (22), the (optimal)

14 It may be appropriate to define AC generally as the function of α and $P^X A/\beta$ (serapately) in order to obtain more fruitful results, however. Using the product of them as in the text is the simplest approach.

Figure 2. Inverse Proportion between Parameters.



allocation rate can be expressed as a simple function of α, or

$$\theta = \frac{-1}{\alpha - 2}. \tag{26}$$

Figure 2 shows the allocation rate θ that is monotonously increasing in α until it approaches to two from below.

Finally, Equation (26) induces another optimal parameter

$$C^A = (\alpha - 2)\frac{u_E}{\sigma} e_A < 0. \tag{27}$$

This represents the optimal marginal allocated *benefits* in increasing pollution abatement since it is negative by the assumptions.

In the rest of this section, we investigate four possible cases according to informational certainty about abatement costs, where (i) both economic agents know them, (ii) only the polluter knows them, (iii) the pollutee overestimates them, and (iv) no allocated cost is available in any situation. The implication in the last case is valid whether the pollutee knows the abatement costs or not.

4-Ⅰ. Both agents know AC

If the polluter and the pollutee know abatement costs or AC, the parameter on the pollutee side α must be one, resulting

$$\theta_{\alpha=1} = 1 \tag{28}$$

from Equation (26)[15]. And the marginal allocated benefits are shown as

$$C^{A}_{\alpha=1} = \frac{-u_E}{\sigma} e_A < 0. \tag{29}$$

Therefore, LC is *not* allocated in effect and is imposed on the polluter *entirely*. In addition, he/she must also bear AC regardless of the value of α. Considering the circumstances mentioned above, we derive the following proposition and lemmas by the equations (28), (25) and (29).

[*Proposition 1*] The polluter should bear the social costs alone at the Pareto optimum when both allocated and abatement costs are available and both agents know the latter exactly.

[*Lemma 2*] The marginal costs in increasing pollution with production borne by the polluter should be equal to the marginal disutility in monetary terms at the optimum.

[*Lemma 3*] The marginal *benefits* in increasing pollution abatement received by the polluter should be equal to the marginal utility in monetary terms at the optimum.

In this case, the cost allocation supported by Proposition 1 can be interpreted as a "Complete Polluter-Pays Principle," or the Extended PPP according to Pezzey's definition. This analysis proves that these Principles have the theoretical validity in

15 Hereafter this type of subscript notes the specific value of α applied to the associated parameters or variables.

order to internalize SC efficiently. The following two Lemmas show the way of cost internalization in the form of the optimal marginal costs and benefits.

Substituting equations (25) and (29) into (13), we derive the optimal allocated costs as[16],

$$LC_{\alpha=1} = \frac{-u_E}{\sigma}\left(e_Q Q + e_A A\right). \qquad (30)$$

For example, it is equal to $-u_E E/\sigma > 0$ simply if the net pollution function is assumed to exhibit constant returns to scale[17].

4−Ⅱ. Only the polluter knows AC

In contrast to the previous case, if the pollutee knows nothing about the abatement costs (despite the fact that he/she receives some payment from engaging in abatement activities), the parameter α must be zero. It yields

$$\theta_{\alpha=0} = 1/2. \qquad (31)$$

Hence, LC should be divided between the polluter and the pollutee *equally*, while AC is borne by the former, as is the previous case. The way of this cost allocation can be expressed as an "Equally-Pays Principle," combined with the Standard PPP by Pezzey's definition.

As for cost internalization, the marginal costs in increasing pollution are the same as Equation (25), while the marginal benefits in increasing pollution abatement are represented by

$$C^A_{\alpha=0} = -2\frac{u_E}{\sigma}e_A < 0. \qquad (32)$$

16 The general expression of the costs allocated between two agents is $(-u_E/\sigma)(e_Q Q + \theta^{-1} e_A A)$, by using equations (13), (25), (26) and (27).

17 Kohn (1998) investigates several types of the pollution-related functions applied in environmental economics, including the pollution prevention, the recycling of pollutive output, the end-of-pipe abatement, and so on.

Since it is negatively twice as much as Equation (29) in the previous case, the subsidy rate to the pollution abatement is doubled for both agents.

[*Proposition 2*] The polluter and the pollutee should bear the external costs fifty-fifty at the Pareto optimum when allocated and abatement costs are available and only the polluter knows the latter and so bears it.

The optimal allocated costs in this case can be written by

$$LC_{\alpha=0} = LC_{\alpha=1} - \frac{u_E}{\sigma} e_A A < LC_{\alpha=1}. \tag{33}$$

It is easily shown that, for the polluter, the burden in this case, (1/2) $LC_{\alpha=0}$, is smaller than the one in the previous case, $LC_{\alpha=1}$. The equal allocation of the costs to both agents also contributes to this reduction of the financial burden on the polluter.

4-Ⅲ. The pollutee overestimates AC

In this model, we can observe a curious case that some part of the payment from the polluter should be sent to the pollutee. It occurs when the latter overestimates the abatement costs, that is, α exceeds one.

It requires that θ is also greater than unity, which means that the costs are imposed on the polluter "too much." Although we have constrained the range of θ between zero and one at the beginning of this section, there emerges little theoretical difficulty even if the parameter goes over this range, as shown in Figure 2.

On the other hand, in this situation, the pollutee does not bear any cost. Rather, he/she can get some *subsidies* from the polluter because $1-\theta$ is negative. Therefore, the rule of the cost "allocation" seems to be violated, but the cost internalization is still realized. The scheme described above can be called a "Pays-and-Receives Principle," coupled with the Standard PPP proposed by Pezzey[18].

[*Proposition 3*] The polluter must bear the social costs overly and pay the excess to the pollutee when the latter overestimates the allocated costs.

Using the same optimal values as in equations (25) to (27), we have the optimal allocated costs as follows.

$$LC_{\alpha>0} = LC_{\alpha=1} + (\alpha - 1)\frac{u_E}{\sigma} e_A A > LC_{\alpha=1}. \tag{34}$$

Hence, in this Pays-and-Receives Principle, the polluter experiences the heaviest burden among the three cases. Contrary to this, the pollutee benefits the most with this Principle. As we have discussed, the degree of the informational asymmetry between them is the most important factor to determine each financial burden in order to internalize the social costs optimally.

4-Ⅳ. Only AC cannot internalize SC

There is one more case to be worth examining. When LC is not available for some practical reasons, the internalization of SC with the remained instrument AC will be much difficult. There are two reasons for this difficulty. Here we investigate only a case where both agents know AC accurately, because the other uncertainty cases do not satisfy one simple condition mentioned later.

The first-order conditions for profit maximization of the producer are modified as

$$P^Q = \lambda^\chi, \tag{15'}$$

$$P^X = \lambda^\chi f', \tag{16'}$$

18 Notice that this subsidy is not a compensation for polluting and damaging other economic agents *ex post*, since this model concerns only *ex ante* economic efficiency. See Chapter 6 of Tsuru (1999) which explains one of the famous Japanese compensation schemes for the victims damaged by "kōgai" ("disamenities inflicted on the public" in his meaning (p.23)), Pollution-Related Health Damage Compensation Law enacted in 1974.

$$\frac{P^X}{\beta} = 0, \quad \text{and} \tag{17)'}$$

$$f - Q = 0. \tag{18)'}$$

Equation (17)' requires the marginal abatement of labor, β, to be infinite for any positive price of labor, which is the first difficulty.

Similarly, the first-order conditions for utility maximization of the consumer are rewritten by

$$\sigma P^Q = u_Q, \tag{20)'}$$

$$\sigma P^X = u_L, \tag{21)'}$$

$$\frac{\sigma\alpha}{\beta} P^X = \frac{u_L}{\beta}, \quad \text{and} \tag{22)'}$$

$$P^X X^Q + \alpha P^X \frac{A}{\beta} - P^Q Q = 0. \tag{23)'}$$

Obviously, equations (21)' and (22)' will be the same if α is equal to one. Otherwise, the difference contradicts this equation system. This is the reason why other informational asymmetric cases need not to be examined in detail.

These conditions will match the Pareto optimum ones if

$$\lambda^\chi = \frac{\lambda}{\sigma}, \quad \text{and} \tag{24)'}$$

$$u_E e_Q = 0. \tag{35}$$

The former condition has no theoretical problem. As for the latter, $u_E = 0$ means

Table 1. Four Cases of Cost Internalization and its Allocation.

To internalize SC with	Type of AC	Cost Internalization	Cost Allocation	Burden	
				Polluter	Pollutee
LC and AC	**I.** [$\alpha = 1$] **Both know**	Possible	[$\theta = 1$] **Complete Polluter-Pays** (= Extended PPP)	LC + AC	0
	II. [$\alpha = 0$] **Polluter knows**	Possible	[$\theta = ½$] **Equally-Pays** with Standard PPP	½LC +AC	½LC
	III. [$\alpha > 1$] **Over-estimated**	Possible	[$\theta > 1$] **Pays-and-Receives** with Standard PPP	θLC + AC	(1−θ)LC < 0
AC only	**IV.** **Both know** (etc.)	Almost impossible			

that the externality does not exist because of *no pollution* due to perfect abatement (a case where the amount of production is equal to that of abatement, for example), while $e_Q=0$ indicates *no production*. Needless to say, both possibilities are extreme[19]. Therefore, there seems to be no effective way of cost internalization, and it is appropriate to conclude that

[*Proposition 4*] The internalization of the social costs will fail without applying allocated costs to the agents concerned.

Before finishing this section, we put all the results of this analysis in order using Table 1. For the first three cases (Ⅰ. to Ⅲ.), the ways of cost allocation are different one another, while all applying the Standard PPP as an essential component[20]. Hence, AC is always borne by the polluter in these cases. The last case (Ⅳ.) has almost no possibility to internalize the social costs successfully,

19 The perfect abatement or recycling of pollution is physically inconsistent with the Second Law of Thermodynamics, which is famous by the name of the "law of entropy" (Daly and Farley (2003)).

20 Note that the Extended PPP includes this narrower definition, as mentioned in Section 2.

implying that there is nothing to be mentioned further.

5. Concluding Remarks

This paper has clarified both original and extended definitions of the Polluter-Pays Principle, pointed out the shortcomings of the theoretical analysis frequently cited in environmental economics, and built the simple general equilibrium model showing several ways of internalizing social costs emerged by pollution from production of goods, with the introduction of costs allocated between economic agents concerned.

Although the meanings of the Polluter-Pays Principle have varied considerably between objectives of environmental laws or policies and countries, the economic interpretation of the Principles by Pezzey is quite useful which classifies them into the Standard PPP and the Extended PPP. Moreover, Stevens points out the Cost Internalization and the Cost Allocation as the essential principles (in Section 2). The analysis developed in this paper has used these terms as possible to evaluate the economic efficiency of the principles, although some unfamiliar terms have been introduced to derive new results within the general equilibrium framework (in Section 3 and 4).

Here we repeat the four propositions derived in Section 4. First, the Complete Polluter-Pays Principle or the Extended PPP by Pezzey's definition is required if the social costs due to pollution are internalized by setting the proper allocated and abatement costs and the latter are known to both agents. Second, when the pollutee does not know the abatement costs while the polluter does, the Equally-Pays Principle combined with the Standard PPP should be enforced. Third, the Pays-and-Receives Principle is appropriate to cost internalization when the abatement costs are overestimated by the pollutee. Finally, it is almost impossible to internalize the social costs without the allocated ones since some theoretical difficulties cannot be avoided.

To finalize this paper, we have three remarks for the development of this research. First, the form of allocated costs and the ways of the allocation should be examined further. This analysis has shown that, with a simple modeling, allocated costs are the most important tools to internalize social costs, coupled with abatement ones. Such situations must be more complicated if we take more agents and transactions into account. Recently, OECD (2001) defines the practical meanings of the Extended Producer Responsibility as it includes physical and/or financial responsibilities, as well as full or partial[21]. Hence, how the costs should be allocated among the agents involved must be highly important in the area of policy making, which depends crucially on the form of the costs.

Second, the formal analysis of imperfect information should be applied to this problem. We have seen that the types of information on abatement costs affect both cost internalization and its allocation on the quite rough assumption that it is solely determined by the pollutee's expectation. In the text of the Extended Producer Responsibility, the informational factor built in the products by the producer or the potential polluter will be also important[22]. The theoretical sophistication must be needed for further examination.

Third and finally, we should clarify any incentives for the agents to *avoid* bearing the costs. In Section 4, we have examined the four cases separately. By comparing the results, it is found that disclosing precise information to the pollutee could be unfavorable to the polluter, since it can shift the financial burden to himself/herself! This work also requires much investigation, as mentioned in the second remark.

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21 OECD (2001), p.18. The research papers in this area are collected in OECD (2004a, 2004b). In their theoretical papers, Runkel (2003) and Walls (2006) individually compare the effectiveness of several Extended Producer Responsibility policies based on each equilibrium model.

22 In a different context, Koide (2006) introduces uncertainty of information about a detailed destination of waste after its discharge the police want to clarify in the illegal disposal and concealment problem.

Appendix : Proof of Lemma 1

Total differentiation of the equation system from (7) to (10) yields

$$\begin{bmatrix} V & 0 & W & -1 \\ 0 & Y & u_{LL}/\beta & f' \\ W & u_{LL}/\beta & Z & 0 \\ -1 & f' & 0 & 0 \end{bmatrix} \begin{bmatrix} dQ \\ dX^{Q} \\ dA \\ d\lambda \end{bmatrix} = \begin{bmatrix} 0 \\ u_{LL}A/\beta^{2} \\ (u_{LL}A-\beta u_{L})/\beta^{3} \\ 0 \end{bmatrix} d\beta, \tag{A1}$$

where

$$V \equiv u_{QQ} + u_{EE}e_{Q}^{2} + u_{E}e_{QQ} < 0, \quad W \equiv u_{EE}e_{Q}e_{A} + u_{E}e_{QA},$$

$$Y \equiv u_{LL} + \lambda f'' < 0, \quad \text{and} \quad Z \equiv \frac{1}{\beta^{2}}u_{LL} + u_{EE}e_{A}^{2} + u_{E}e_{AA} < 0. \tag{A2}$$

The determinant of the matrix (A1), Δ, must be negative for this maximization that can be expressed as

$$\Delta = -Z\left(f'^{2}V + Y\right) + 2\frac{f'}{\beta}u_{LL}W + \frac{1}{\beta^{2}}u_{LL}^{2} + f'^{2}W^{2}. \tag{A3}$$

Note that the first term of this equation is negative, the second is uncertain because of the sign of W, and the others are positive, respectively.

Applying the comparative statics concludes that

$$\frac{\partial Q}{\partial \beta} = \frac{1}{\Delta}\frac{f'}{\beta^{3}}\left[-\beta Z u_{LL}A + \left(u_{LL}A - \beta u_{L}\right)\Omega\right], \tag{A4}$$

$$\frac{\partial X^{Q}}{\partial \beta} = \frac{1}{f'}\frac{\partial Q}{\partial \beta}, \quad \text{and} \tag{A5}$$

$$\frac{\partial A}{\partial \beta} = \frac{-1}{\Delta}\frac{1}{\beta^{3}}\left[\left(u_{LL}A - \beta u_{L}\right)\left(f'^{2}V + Y\right) - \beta u_{LL}A\Omega\right], \tag{A6}$$

where

$$\Omega \equiv f'W + \frac{u_{LL}}{\beta}. \tag{A7}$$

Because the first term of Equation (A7) has either sign while the second one is negative, Ω may be positive or negative.

As the first equation (A4) shows, with an increase in the marginal abatement of labor, the amount of production or gross pollution is *increased* if Ω is positive, or negative but small in absolute values. Likewise, Equation (A5) states that the amount of labor for the production changes in the same direction as this.

In contrast, as we can see in Equation (A6), the amount of abatement is also increased with this marginal change if Ω is positive.

Finally, the net amount of pollution could change in either direction since

$$\begin{aligned}\frac{\partial E}{\partial \beta} &= e_Q \frac{\partial Q}{\partial \beta} + e_A \frac{\partial A}{\partial \beta} \\ &= \frac{1}{\Delta}\frac{1}{\beta^3}\left[-\beta u_{LL} A\left(f'Ze_Q - \Omega e_A\right) + \left(u_{LL}A - \beta u_L\right)\left(\Omega f'e_Q - \left(f'^2 V + Y\right)e_A\right)\right]\end{aligned} \tag{A8}$$

Q.E.D.

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