자원·환경경제연구 제 9 권 제 5 호
Environmental and Resource Economics Review
Volume 9, Number 5, December 2000: pp. 877~901

Noncooperative Behavior of the Offended in Provision of Self-Protective Measures

Youn-Sang Choi*

〈Contents〉

Ⅰ. Introduction

Most of works about environmental pollution have concentrated on pollution abatement measures taken by polluters. But some recent studies have showed that pollution abatement measures can be taken by both polluters and victims. Shibata and Winrich (1983) classify pollution

* Korea Rural Economic Institute.

abatement measures into two major categories - preventive and (self-) protective measures.[1] They define preventive methods as all methods under the control (private ownership) of polluters who aim to reduce pollutants in the environment of the victims located in a given area. The preventive methods are widely adopted to control the pollution either voluntarily or compulsorily by the authorities in a real world. For instance, any factory emitting pollutants into air is required to have some types of abatement devices installed to reduce the emission of pollutants at least to the standard set by the law. They also define the self-protective methods as those methods under the control of victims who wish to reduce the quantity of pollutants entering into their utility (or cost) functions below the level that would have otherwise occurred.

It has been argued that employment of self-protective activities is a realistic way of dealing with environmental externalities (Shibata and Winrich; Shogren and Crocker, 1991). In fact, once pollution yields harmful effects on some parties, one of the actions, which they could take to diminish its adverse effects, is to adopt their own abatement methods.

If rational individuals, who got damaged by detrimental pollution, find that the cost of employing self-protective measures is relatively smaller compared to its gain, they will surely engage in some type of self-protective activity, individually or collectively. Private provision is made either by a group of the victims from pollution who wish to maximize interests or utilities of their own group members or by an individual to attempt to maximize only his/her own utility. In contrast

1) Its another term is a defensive measure.

with the public provision which would be financed by tax revenues and/or charges on use of public goods, the private provision just relies on the group members' contributions.

For instance, suppose that residents in some residential area, where lack of proper traffic signs causes frequent traffic accidents, decide to put some traffic signs in order to prevent the traffic accidents. They should share the cost of placing the signs because every resident in that area gets benefits from that action in terms of the safer living environment. But the residents can not inhibit any other pedestrians, who do not live in that area and do not contribute for setting the signs, from benefiting from the safety measure. Besides, the benefits which one residence gets from the signs do not reduce the benefit which everyone else gets. Hence, even though the traffic signs are set by the private contribution in order to increase own interest of a private group, they have the characteristics of public goods.

Baumol and Oates divide the externalities into two types, which are a transferable externality and a filterable externality. The transferable externality is one to be able to be transferred to another agent, for example, building high chimneys for emissions. Whether an externality is transferable depends on not only the shifting activity of the original victim but also the resisting activity of his neighbors and their conjectures about each other's activities. The filterable externality is one to be able to be filtered or diluted, for example, discharging contaminated water, which can be cleaned by purification facilities. Bird (1987) points out that aversion by transferring the pollution is an externality generating activity and should be penalized by the same way as the original pollution-generating activity should be.

Shogren and Crocker examine a private self-protection method for undesirable environmental externalities by comparing cooperative and noncooperative behaviors. They demonstrate that noncooperative behaviors would lead to an over-protection under the self-protection that transfers externality and an under-protection under the self-protection that filters externality. It is also showed that the overprotection under the transferable externality would get worse if an agent with more relative power is allowed to take a first-mover advantage or if a damage function is elastic and transferability is uncertain. Homann[2] argues that it is essential to study the cause for the externality as well. He recommends studying the rise of the externality by production or by consumption, a partial abatement and a partial transfer of the externality by the causing agent (or group of agents), and the transfer of the externality among the potential sufferers in one model.

This paper examines how the employment of preventive and self-protective measures against detrimental environmental pollution affects economic behaviors of polluters and victims. It is also observed what types of government interventions can lead the economy to the Pareto optimal state. In part 1, using a simple model only with provision of self-protective measures under no uncertainty, it is shown that the self-protective measures generates an over-provision problem and that the Pigouvian prescription on both sides can achieve the social optimum. In part 2, uncertainty on how far the preventive method filters the pollution is introduced into the model with provision of both preventive and self-protective measures under transferable externality. Then, its

2) In the comments for the article "Environmental Conflicts and Strategic Commitment" by Shogren, Baik, and Crocker.

profit functions for the polluter and the victim i, $i = A, B$, are written as

$$\Pi_e = p_e Y^e(l_e) - C^e(l_e) \tag{2.1}$$

$$\Pi_i = p_v Y^i[l_i, E^i(l_e, q_i, q_j; \beta)] - C^i(l_i, q_i), \quad i = A, B \tag{2.2}$$

where, β is a degree of transferability for the abatement devices whose value is between 0 and 1. Assuming both victims get same degree of transferability. The victims' provision of an abatement device can be characterized by the value of β. If β is zero, no transfer occurs. If β is one, the self-protective measure makes a complete transfer.

The function $E^i(\cdot)$ can be characterized by

$$\frac{\partial E^i}{\partial l_e} > 0, \quad \frac{\partial E^i}{\partial q_i} < 0 \quad \text{and} \quad \frac{\partial E^i}{\partial q_j} > 0$$

The production functions, $Y^e(\cdot)$ and $Y^i(\cdot)$, $i = A, B$, are twice differentiable and strictly concave for an aggregated input and pollutant. The cost functions, $C^e(\cdot)$ and $C^i(\cdot)$, $i = A, B$, are twice differentiable and strictly convex for an aggregated input and own contribution.

2. Optimizations

1) Individual Firm's Problem

The problem for a polluter is

shifts the contaminated water to the other laundry firm.

The additional assumptions made for the model are as follows. First, the well-behaved production and cost functions are assumed. Second, a fixed cost in the production of both a polluter and victims is assumed to be zero in order to exclude the occurrence of the externality owing to the existence of the fixed cost. Third, no negotiation is assumed to be made between a polluter and victims, and thus the Coasian solution is ruled out in the model. Fourth, all victims produce a homogeneous product and thus get a single price for their product in the market.

1. Basic Model

The model presented in this section describes provision of self-protective measures by the offended under no uncertainty which transfers pollution to each other. While the provision of the protective measure reduces the quantity of pollutant which its provider would otherwise get, it also brings a cost to its provider. As described earlier, the model includes one polluter and two victims, and only victims provide abatement measures. The variables are defined in the <Table 1>. The

〈Table 1〉 Definition of Variables ($i = A, B$)

name	definition	name	definition
l_e	aggregated input used by polluter	Y^e	polluter's output
l_i	aggregated input used by victim i	Y^i	victim i's output
q_i	defensive input provided by victim i	p_e	price for polluter's product
E_i	quantity of pollutant entering into the production function of victim i	p_v	price for victims' product

profit functions for the polluter and the victim i, $i = A, B$, are written as

$$\Pi_e = p_e Y^e(l_e) - C^e(l_e) \tag{2.1}$$

$$\Pi_i = p_v Y^i[l_i, E^i(l_e, q_i, q_j; \beta)] - C^i(l_i, q_i), \quad i = A, B \tag{2.2}$$

where, β is a degree of transferability for the abatement devices whose value is between 0 and 1. Assuming both victims get same degree of transferability. The victims' provision of an abatement device can be characterized by the value of β. If β is zero, no transfer occurs. If β is one, the self-protective measure makes a complete transfer.

The function $E^i(\cdot)$ can be characterized by

$$\frac{\partial E^i}{\partial l_e} > 0, \quad \frac{\partial E^i}{\partial q_i} < 0 \quad \text{and} \quad \frac{\partial E^i}{\partial q_j} > 0$$

The production functions, $Y^e(\cdot)$ and $Y^i(\cdot)$, $i = A, B$, are twice differentiable and strictly concave for an aggregated input and pollutant. The cost functions, $C^e(\cdot)$ and $C^i(\cdot)$, $i = A, B$, are twice differentiable and strictly convex for an aggregated input and own contribution.

2. Optimizations

1) Individual Firm's Problem

The problem for a polluter is

$$\text{Max} \quad \Pi_e = p_e Y^e(l_e) - C^e(l_e) \tag{2.3}$$

The equilibrium input demand for an aggregated input of polluter, $l_e^N(p_e)$, is characterized by the following equality.

$$p_e Y_l^e(l_e^N) = C_l^e(l_e^N) \tag{2.4}$$

That is, the marginal value product of the aggregated input is equal to the marginal cost of the aggregated input at the equilibrium.

The problem for victim i, $i = A, B$, is

$$\text{Max} \quad \Pi_i = p_v Y^i[l_i, E^i(l_e, q_i, q_j; \beta)] - C^i(l_i, q_i) \tag{2.5}$$

The equilibrium input demands for an aggregated input and contribution of an abatement input, $l_i^N(p_v, l_e, q_j; \beta)$ and $q_i^N(p_v, l_e, q_j; \beta)$, $i = A, B$, respectively, can be obtained from solving the following first order condition.

$$\text{MRTS}_{ql}^i = \frac{\dfrac{\partial Y^i}{\partial E^i} \dfrac{\partial E^i}{\partial q_i}}{\dfrac{\partial Y^i}{\partial l_i}} = \frac{C_q^i(l_i, q_i)}{C_l^i(l_i, q_i)} \tag{2.6}$$

The condition (2.6) states that the marginal rate of technical substitution of self-protective inputs for the aggregated input must be equal to the ratio of marginal costs of the own contribution and the aggregated input. The marginal rate of technical substitution consists of the impacts of the pollutant on the aggregated input demand of victim i

and the changes in the quantity of pollutant attributable to the changes of his own provision level of the abatement measure.

2) Social Planner's Problem

The social optimizing problem is

$$\begin{aligned} \text{Max} \quad \Pi_i = {} & p_e Y^e(l_e) - C^e(l_e) \\ & + \sum_{i=A,B} \{ p_v Y^i[l_i, E^i(\cdot)] - C^i(l_i, q_i) \} \end{aligned} \tag{2.7}$$

Let $l_e^*(\gamma)$, $l_i^*(\gamma)$ and $q_i^*(\gamma)$, $i=A,B$, where $\gamma = (p_e, p_v; \beta)$, be the optimal solutions to solve the following conditions

$$p_e Y_l^e(l_e) = C_l^e(l_e) - \sum_{i=A,B} p_v \frac{\partial Y^i}{\partial E^i} \frac{\partial E^i}{\partial l_e} \tag{2.8}$$

$$\begin{aligned} \text{MRTS}_{ql}^i = {} & \frac{\partial C^i / \partial q_i}{\partial C^i / \partial l_i} - \frac{p_v \left(\frac{\partial Y^j}{\partial E^j} \frac{\partial E^j}{\partial q_i} \right)}{\partial C^i / \partial l_i} \\ & i, j = A, B, \qquad i \neq j \end{aligned} \tag{2.9}$$

The condition (2.8) states that the polluter's marginal value product of the aggregated input is equal to his marginal cost of the aggregated input minus the sum of the marginal social damage of the pollution to each victim. The marginal social damage to each victim is a change (or a reduction) in his revenue with respect to a change in the quantity of pollutants, which is caused by a change in polluter's aggregated input use. The condition (2.9) states that the sum of the marginal rates of technical substitution between the abatement input and the aggregated input of victim i must be equal to the ratio between the marginal costs of own contribution and the aggregated input demand plus the ratio between the marginal value product of his contribution for the other victim and marginal cost of the aggregated input demand. The second term in the right-hand-side of (2.9) is negative because of the positive relationship between provision level of his protective measure and the quantity of pollutants getting to the other victim as well as the negative relationship between the other victim's production and the quantity of pollutants.

The optimal conditions imply that each victim disregards the impact of his employment of a protective measure on the other victim so that he provides it above its socially optimal level. That is, the victims' noncooperative behavior causes a problem of an over-protection. Therefore, there are two market failures existing in this model: (1) the externality owing to the pollution and (2) the over-provision of the abatement device owing to the noncooperative behavior of the offended.

Proposition 1 A polluter creates an externality by emission of pollutants as a by-product of his production, and an adoption of a self-protective measure by the offended, which transfers the pollution to someone else, generates another externality attributable to its over-provision which results from their noncooperative behavior.

3. Pigouvian Prescriptions

Here, we will examine what types of government policies should be applied to achieve the social optimum. Pollutants emitted cause harmful effects on victims in terms of a decrease in their output production. As Shibata and Winrich state, a Pigouvian tax imposed on each unit of pollutants emitted into the environment forces a rational polluter to reduce the quantity of pollutants emitted. And, Bird refers that the transfer of pollution to someone else using an abatement measure by the offended should be regarded same as an pollution-generating activity. Thus, the offended, who provides an abatement measure to transfer pollution to some else, should also be taxed on each unit of his abatement measure provided. Then, the tax would lower the level of each victim's provision of the abatement measure to its socially optimum level.

The Pigouvian tax rate τ_e, which should be set for the polluter to equate the social cost of pollution to its social benefit, should be equal to the marginal social damage of pollution to the victims. Hence, the condition (2.8) gives

$$\tau_e \equiv - \sum_{i=A,B} p_v \frac{\partial Y^i}{\partial E^i} \frac{\partial E^i}{\partial l_e} \tag{2.10}$$

The best policy to accomplish the Pareto optimum for each victim's contribution of the self-protective measure is a discriminatory tax on each unit of the abatement measure provided. By comparing the equilibrium conditions (2.4) and (2.9), we can derive the marginal damage to the other victim resulting from the self-protective activity of victim i. The optimal tax rate for victim i, denoted by τ^i, i = A, B, should be equal to the marginal damage to the other victim by the self-protective activity of victim i. Thus,

$$\tau^i \equiv -\frac{p_v\left(\frac{\partial Y^j}{\partial E^j}\frac{\partial E^j}{\partial q_i}\right)}{\partial C^i/\partial l_i}, \quad i,j=A,B, \quad i\neq j \qquad (2.11)$$

Proposition 2 A Pigouvian tax should be imposed on each unit of a self-protective measure provided by the offended as well as on each unit of pollutant emitted into the environment by a polluter to accomplish the social optimum, and the tax rates which set for the polluter and the victims are, respectively,

$$\tau_e \equiv -\sum_{i=A,B} p_v\frac{\partial Y^i}{\partial E^i}\frac{\partial E^i}{\partial l_e}$$

and

$$\tau^i \equiv -\frac{p_v\left(\frac{\partial Y^j}{\partial E^j}\frac{\partial E^j}{\partial q_i}\right)}{\partial C^i/\partial l_i}, \quad i,j=A,B, \quad i\neq j$$

Ⅲ. Abatement Activities under Uncertainty

1. Framework

For this section, the model includes an additional assumption that the polluter adopts a preventive measure, which is denoted by q_e. Thus, the quantity of pollution entering into victims' production function depends on the preventive measure provided and the aggregated input employed by the polluter as well as the self-protective measures provided by both victims. A total cost of production for the polluter is thus determined by the amount of the aggregated input and the preventive measure input employed, and is specified as $C^e = C^e(l_e, q_e)$.

Because the victims adopt the self-protective measures which transfer a portion or all of pollution to each other, the quantity of pollutants entering into production function of the victims can be expressed as

$$\begin{aligned} E^i &= \widetilde{E^i}[E^T(l_e), \alpha q_e, q_i, q_j; \beta] \\ &= E^i(l_e, \alpha q_e, q_i, q_j; \beta), \quad i = A, B, \ i \neq j \end{aligned}$$

in which, $E^T(l_e)$ is a total amount of pollutants emitted into the environment before it is filtered by a preventive measure, and α is a degree of filterability of a preventive measure such that $0 \leq \alpha \leq 1$. When $\alpha = 0$, the preventive measure does not filter the pollution at all. When $\alpha = 1$, the preventive measure does a complete filter of the pollution. The function, $E(\cdot)$, can be characterized in the following fashion.

$$\frac{\partial E^i}{\partial l_e} > 0, \quad \frac{\partial E^i}{\partial q_e} < 0, \quad \frac{\partial E^i}{\partial q_i} < 0 \quad \text{and} \quad \frac{\partial E^i}{\partial q_j} > 0$$

The assumption about how much information the victims have about the abatement measures provided by themselves and the polluter are added. First, the victims have a knowledge about the level of both the self-protective measure and the preventive measure. Second, each victim knows the extent to which the externality can be transferred by his and the other victim's self-protective measures. Then, the profit functions for the polluter and the victims can be written as

$$\Pi_e = p_e Y^e(l_e, q_e) - C^e(l_e, q_e)$$

$$\Pi_i = p_v Y^i[l_i, E^i(l_e, \alpha q_e, q_i, q_j)] - C^i(l_i, q_i), \quad i = A, B$$

2. Optimization under Uncertainty

Shogren and Crocker explore the uncertainty about a degree of transferability using their nonstochastic model, which explains how a self-protective activity transfers negative effects of pollution to other victims. Then, they derive impacts of a change in a degree of riskiness on self provision of the self-protective measure. However, our model deals with a transferable externality under an existence of both preventive and protective measures. By assuming both victims employ same type of a protective measure and have a full knowledge of how far their self-protective measures affect the quantity of pollutants entering into a production function of the other, the uncertainty is eliminated from the self-protective activities.

Suppose the victims are given the information about the level of the preventive input provided through a signal from the polluter. Even if the information about how much the preventive measure is provided is available to the victims, an uncertainty about a degree of filterability of the preventive measure still exists because the amount of pollutants getting to the victims also depends on some other factors such as climate, rain, etc., which are not under control of either the polluter or the victims. This means that the geographical distance between the polluter and the victims would be one of the main factors determining the amount of pollutants getting to the victims.

1) Non-cooperative Problem

The problem for the polluter is

$$\text{Max} \quad \Pi_e = p_e Y^e(l_e, q_e) - C^e(l_e, q_e) \tag{3.1}$$

The demands for the aggregated input and the preventive measure of the polluter at equilibrium, denoted by $l_e^N(p_e)$ and $q_e^N(p_e)$, respectively, are characterized by the following equality,

$$\text{MRTS}^e_{ql} = \frac{\partial C^e(l_e^N, q_e^N)/\partial q_e}{\partial C^e(l_e^N, q_e^N)/\partial l_e} \tag{3.2}$$

The condition (3.2) states that the polluter's marginal rate of technical substitution of the preventive measure for the aggregated input must be equal to the ratio of his marginal cost of the preventive input and the aggregated input.

The problem for the victim is

$$\text{Max} \quad \Pi_i = \int_a^b p_v Y^i[l_i, E^i(l_e, \alpha q_e, q_i, q_j)]dF(\alpha;\theta) \tag{3.3}$$

$$- C^i(l_i, q_i) \qquad i, j = A, B \text{ and } i \neq j$$

where, θ is an index of riskiness. The equilibrium input demand of the aggregated input and contribution of victim i, denoted respectively by $l_e^N(p_v, l_e, q_e, q_j; \alpha, \theta)$ and $q_i^N(p_v, l_e, q_e, q_j; \alpha, \theta)$, $i, j = A, B$ and $i \neq j$, can be derived from the following first order conditions,

$$\text{EMVP}^{\,i}_{\,l_i} = \int_a^b p_v \frac{\partial Y^i}{\partial l_i} dF(\alpha;\theta) = \frac{\partial C^i}{\partial l_i} \tag{3.4}$$

$$\text{EMVP}^{\,i}_{\,q_i} = \int_a^b p_v \frac{\partial Y^i}{\partial E^i} \frac{\partial E^i}{\partial q_i} dF(\alpha;\theta) = \frac{\partial C^i}{\partial q_i} \tag{3.5}$$

in which, $\text{EMVP}^{\,i}_{\,l_i}$ and $\text{EMVP}^{\,i}_{\,q_i}$ are the expected marginal value product for the aggregated input and the self-protective measure of victim i, respectively. The conditions (3.4) and (3.5) state that the expected marginal value product of the aggregated input and the self-protective input must be equal to their corresponding marginal cost.

2) Cooperative Problem

The social optimizing problem is

$$\begin{aligned} \text{Max E } \Pi = {} & p_e Y^e(l_e, q_e) - C^e(l_e, q_e) \\ & + \sum_{i=A,B} \left\{ \int_a^b p_v Y^i[l_i, E^i(l_e, \alpha q_e, q_i, q_j)] dF(\alpha;\theta) \right. \\ & \left. - C^i(l_i, q_i) \right\} \end{aligned} \tag{3.6}$$

Let $l_e^*(\delta)$, $q_e^*(\delta)$, $l_i^*(\delta)$ and $q_i^*(\delta)$, $i = A, B$, where $\delta = (p_e, p_v; \alpha, \theta)$, be the optimal solutions to solve the following optimal conditions, i, j = A, B,

$$p_e \frac{\partial Y^e}{\partial l_e} = \frac{\partial C^e}{\partial l_e} - \sum_{i=A,B} \int_a^b p_v \frac{\partial Y^i}{\partial E^i} \frac{\partial E^i}{\partial l_e} dF(\alpha;\theta) \quad (3.7)$$

$$p_e \frac{\partial Y^e}{\partial q_e} = \frac{\partial C^e}{\partial q_e} - \sum_{i=A,B} \int_a^b p_v \frac{\partial Y^i}{\partial E^i} \frac{\partial E^i}{\partial q_e} dF(\alpha;\theta) \quad (3.8)$$

$$\text{EMVP}^i_{l_i} = \frac{\partial C^i}{\partial l_i} \quad (3.9)$$

$$\text{EMVP}^i_{q_i} = \frac{\partial C^i}{\partial q_i} - \int_a^b p_v \frac{\partial Y^j}{\partial E^j} \frac{\partial E^j}{\partial q_i} dF(\alpha;\theta) \quad (3.10)$$

The condition (3.7) states that the marginal value product of the aggregated input for the polluter must be equal to his marginal cost of the aggregated input minus a sum of the expected marginal damages to the victims caused by his emitting the pollutants. The condition (3.8) states that the marginal value product of the preventive measure must be equal to its marginal cost plus a sum of the expected marginal benefit to the victims, attributable to his provision of the preventive measure. The expected social marginal damage to each victim is a change (or a reduction) in his expected revenue occurred by the pollutants. And the expected marginal benefit of the preventive measure to the victim appears to be a change (or an increase) of his expected revenue. The condition (3.9) is identical with (3.4). The condition (3.10) states that one victim's marginal value product with respect to his self-protective measure must be equal to its marginal cost plus its effect on the other victim. A self-protective measure provided by one victim changes the other victim's total revenue by influencing the quantity of the pollutant getting to him.

Comparing the first order conditions, it is obvious that the polluter should be penalized for his activity of generating the pollution and be encouraged for his activity of providing the preventive measure to restrict the production of pollutants. Since the polluter ignores indirect effects of his preventive measure on the victims' production, it is under-provided and the government should induce the polluter to increase the level of his provision to the socially optimal level through a policy measure like a subsidy. The victims create a problem of an over-provision of the protective measure owing to their noncooperative behavior, as seen in previous section. Thus, both victims should be taxed on each unit of their protective measure provided.

Proposition 3 A polluter provides a preventive measure below its socially optimal level since he disregards its positive effects on the production of the offended, and the subsidy on each unit of the preventive measure provided can encourage him to provide it to the socially optimum level.

3. Comparative Equilibrium and Comparative Statics Analyses

1) Comparative Statics under Certainty

How an adoption of a preventive measure by a polluter affects victims' decision about provision of self-protective measures under certainty is examined using the comparative statics.[3] From the first-order conditions of an individual victim i's optimization problem, we can derive, for i =

3) Because the polluter's decision about the preventive measure is independent of the quantity of abatement inputs provided, this analysis concerns only the polluter's problem.

A, *B*,

$$\frac{\partial q_i}{\partial q_e} = \frac{\Pi^i_{q_i l_i} \Pi^i_{l_i q_e} - \Pi^i_{l_i l_i} \Pi^i_{q_i q_e}}{D} \qquad (3.11)^{4)}$$

where, $D = \Pi^i_{l_i l_i} \Pi^i_{q_i q_i} - (\Pi^i_{q_i l_i})^2 > 0$, from the second order condition.

As a convexity of a damage function is assumed, we can have that $\frac{\partial^2 Y^i}{\partial (E^i)^2} > 0$. And, assuming that an increase in contamination raises the victims' demand for the aggregated input, we can have that $\frac{\partial^2 Y^i}{\partial E^i \partial l_i} < 0$. Then, based on these two assumptions, we can claim that

$$\frac{\partial q_i}{\partial q_e} \begin{cases} > 0 & \text{if } \frac{\partial^2 E^i}{\partial q_e \partial q_i} \leq 0 \\ ?\ 0 & \text{otherwise} \end{cases} \qquad (3.12)$$

This implies that the preventive method of the polluter encourages victim's provision of the self-protective measure only if the preventive measure lowers the marginal transferability of the victim's self-protective method, and that the effect of the preventive method on the self-protective method is ambiguous otherwise.

2) Comparative Equilibrium Analysis

Here, we compare the level of the self-protective input when the

---

4) $\Pi'_{ab} = \frac{\partial}{\partial b}\left(\frac{\partial \Pi}{\partial a}\right)$.

victims have no information about the degree of filterability of the preventive measure with the one when they have the information. Under certainty, victim's profit function can be written as, $i = A, B$,

$$\Pi_i = p_v Y^i[l_i, E^i(l_e, \bar{a} q_e, q_i, q_j)] - C^i(l_i, q_i) \qquad (3.13)$$

where $\bar{a}$ is an expected value of a. Let q^c denote the solution which is determined by

$$\text{MVP}^i_{q_i}(\bar{a}) = p_v \frac{\partial Y^i}{\partial E^i} \frac{\partial E^i}{\partial q_i} = \frac{\partial C^i}{\partial q_i} \qquad (3.14)$$

Under uncertainty, the profit function is specified as (3.3) and the optimal condition for the self-protective measure from which the solution, q_i^N, is derived is (3.5). Using the comparative equilibrium analysis, q_i^c is compared with q_i^N. The Jensen's inequality implies

$$\text{EMVP}^i_{q_i}(a) \gtrless \text{MVP}^i_{q_i}(\bar{a}) \qquad (3.15)$$

according as whether $\text{EMVP}^i_{q_i}$ is convex or concave with respect to q_e. In consequent, we can claim that

$$q_i^c \gtrless q_i^N \quad \text{if} \quad \frac{\partial^2 \text{MVP}^i_{q_i}}{\partial q_e^2} \gtrless 0 \qquad (3.16)$$

Proposition 4 How the uncertainty affects victim's provision of a self-protective input depends on the curvature of its marginal value product with respect to a polluter's preventive measure. That is, the level of the self-protective input is higher under uncertainty than under certainty if its marginal value product is concave in the preventive measure, and lower if it is convex. This holds for both victims.

3) Comparative Statics Analysis

Here, assuming each victim's cost function is separable such as $C^i(l_i, q_i) = C^{il}(l_i) + C^{iq}(q_i)$, and the functions, $C^{il}(l_i)$ and $C^{iq}(q_i)$, are convex and twice-differentiable. The impact of an increase in risk on the provision of a self-protective measure, which is derived from the victim's optimization problem, (3.3), is

$$\frac{\partial q_i}{\partial \theta} = \frac{\mathrm{E}\,\Pi^{i}_{q_i l_i}\,\mathrm{E}\,\Pi^{i}_{l_i \theta} - \mathrm{E}\,\Pi^{i}_{l_i l_i}\,\mathrm{E}\,\Pi^{i}_{q_i \theta}}{D} \tag{3.17}$$

where, $D = \mathrm{E}\,\Pi^{i}_{l_i l_i}\,\mathrm{E}\,\Pi^{i}_{q_i q_i} - (\,\mathrm{E}\,\Pi^{i}_{q_i l_i})^2 > 0$, from the second order condition.

For the higher level of pollution, victims would use a more aggregated input to compensate the loss in production, attributable to increased pollution. Under a well-behaved production function, an increase of an input use will lower the marginal productivity of the corresponding input. Hence, $\mathrm{E}\,\Pi^{i}_{q_i l_i}$ should be positive. We can rewrite $\mathrm{E}\,\Pi^{i}_{l,\theta}$ and $\mathrm{E}\,\Pi^{i}_{q_i\theta}$ as following;[5)]

---

5) $Y^i_{abc} = \frac{\partial}{\partial c}\left[\frac{\partial}{\partial b}\left(\frac{\partial Y^i}{\partial a}\right)\right]$, in the following equations.

$$\begin{aligned}
&\mathrm{E}\,\Pi^{i}_{l_i\theta} \\
&= \int_a^b p_v \frac{\partial Y^i}{\partial l_i}\, dF_\theta(\alpha;\theta) \\
&= \int_a^b p_v Y^i_{l_i q_i}\, dF_\theta(\alpha;\theta)\, d\alpha \\
&= p_v \left\{ - Y^i_{l_i q_i} \int_a^b F_\theta(\alpha;\theta)\, d\alpha + \int_a^b \left[\int_a^b F_\theta(\gamma;\theta)\, d\gamma \right] Y^i_{l_i q_i q_i}\, d\alpha \right\}
\end{aligned}$$

$$\begin{aligned}
&\mathrm{E}\,\Pi^{i}_{q_i\theta} \\
&= \int_a^b p_v \frac{\partial Y^i}{\partial E^i} \frac{\partial E^i}{\partial q_i}\, dF_\theta(\alpha;\theta) \\
&= \int_a^b p_v Y^i_{q_i q_i}\, dF_\theta(\alpha;\theta)\, d\alpha \\
&= p_v \left\{ - Y^i_{q_i q_i} \int_a^b F_\theta(\alpha;\theta)\, d\alpha + \int_a^b \left[\int_a^b F_\theta(\gamma;\theta)\, d\gamma \right] Y^i_{q_i q_i q_i}\, d\alpha \right\}
\end{aligned}$$

Obviously, the relationship between the contribution and the risk is ambiguous. As an additional assumption that the aggregated input and the contribution are separable in the victim's production function[6] is incorporated into the model, it gives

$$\frac{\partial q_i}{\partial \theta} = - \frac{\mathrm{E}\,\Pi^{i}_{l_i l_i}\, \mathrm{E}\,\Pi^{i}_{q_i\theta}}{D^*} \tag{3.18}$$

where, $D^* = \mathrm{E}\,\Pi^{i}_{l_i l_i}\, \mathrm{E}\,\Pi^{i}_{q_i q_i} > 0$, from the second order conditions. Let $R^i(q_i) = -\left(Y^i_{q_i q_i} / Y^i_{q_i}\right)$ and be called as the absolute self-protection provision. If $[\partial R^i(q_i)/\partial q_i] \le 0$, then we have $Y^i_{q_i q_i q_i} > 0$ and

6) It implies that $\frac{\partial^2 Y^i}{\partial q_i \partial l_i} = \frac{\partial^2 Y^i}{\partial l_i \partial q_i} = 0$.

$E\Pi^{i}_{q_i\theta} > 0$. We then have a positive relationship between the contribution and the risk. If $[\partial R^{i}(q_i)/\partial q_i] > 0$, then the relationship between the contribution and the risk becomes ambiguous.

Proposition 5 If each victim's cost function is separable,

(i) contribution of self-protective measure and the risk have a positive relationship, if an aggregated input and contribution are separable in victim's production function and the absolute self-protection provision is non-positive.

(ii) the relationship between the contribution and the risk is ambiguous, otherwise.

Ⅳ. Conclusions

This paper shows how an abatement measure is provided by a private sector for self-protection from an undesirable environmental pollution generated by another sector. It is found that victims' provision of a protective measure results in an additional market failure due to over-protection resulting from their noncooperative behavior. As a solution to the problem, the Pigouvian tax on the protective measure can force its total provision to reach its socially optimum level. As well, the optimal Pigouvian tax on the polluter is required to achieve socially optimal level of pollution.

As both a polluter and victims employ pollution abatement measures under a transferable externality, the polluter should be taxed for their activity generating pollution and subsidized for the activity providing the preventive measures. Besides, the victims should also be taxed for the activity of transferring externality to other victims. If the higher level of the preventive measure lowers the marginal transferability of the self-protective measure, the self-protective measure has a positive relationship with a preventive measure.

Uncertainty on the degree of filterability of the preventive method leads to an increase (a decrease) in the level of self-protective measure if the marginal value product of the self-protective measure is concave (convex) for the preventive measure. Furthermore, the contribution of the protective measure and the risk have a positive relationship, if the aggregated input and the contribution are separable in the victim's production function and the absolute self-protection provision is non-positive.

◎ *References* ◎

1. Baumol, W. and W. Oates, *The Theory of Environmental Policy*, New York, NY: Cambridge University Press, 1988.
2. Bird, P., "The Transferability and Depletability of Externalities," *Journal of Environmental Economics and Management*, Vol. 14, 1987, pp. 54～57.
3. Bradley, M. and D. Lehman, "Comparative Equilibrium versus Comparative Statics," *Canadian Journal of Economics*, Vol. 3, 1986, pp. 526～538.
4. Cornes, R. and T. Sandler, *The Theory of Externalities, Public Goods, and Club Goods*, New York, NY: Cambridge University Press, 1989.
5. Dardanoni, V., Optimal Choices Under Uncertainty: "The Case of Two-Argument Utility Functions," *The Economic Journal*, Vol. 98, 1988, pp. 429～450.

6. Rothschild, M. and J. Stiglitz, "Increasing Risk II: Its Economic Consequences," *Journal of Economic Theory*, Vol. 3, 1971, pp. 66~84.

7. Shaw, Daigee and Shaw, Rong-Dean, "The Resistibility and Shiftability of Depletable Externalities," *Journal of Environmental Economics and Management*, Vol. 20, 1991, pp. 224~233.

8. Shibata, H. and J. Winrich, "Control of Pollution When the Offended Defend Themselves," *Economica*, Vol. 50, 1983, pp. 425~437.

9 Shogren, J., "Endogenous Risk and Protection Premiums," *Theory and Decision*, Vol. 31, 1991, pp. 241~256.

10. Shogren, J. and T. Crocker, "Cooperative and Noncooperative Protection from Transferable and Filterable Externalities," *Environmental and Resource Economics*, Vol. 1, 1991, pp. 195~214.

11. ________, "Environmental Conflicts and Strategic Commitment Protection From," *Environmental and Resource Economics*, Vol. 1, 1991, pp. 195~214.

ABSTRACT

자기보호조치 제공에 있어서 피해자들의 비협조적인 행동

최 윤 상

이전 가능한 환경오염으로부터의 피해자가 오염으로 인해 발생하는 피해를 줄이기 위한 방안으로 자기보호조치(self-protective measure)를 제공할 수 있다. 이 때 피해자들이 서로 비협조적으로 행동할 경우, 피해자들의 자기보호조치 제공은 환경오염으로 인해 발생하는 시장실패 이외에 피해자들이 자기보호조치를 적정량 이상으로 제공함으로써 추가적인 시장실패를 발생시키게 된다. 이러한 경우에 사회최적상태에 도달할 수 있도록 하는 최선의 정책은 환경오염을 발생시킨 측과 자기보호조치를 과다하게 제공하는 피해자 모두에게 피구비안(Pigouvian) 세금을 부과하는 것이다.

만약 오염자가 방출되는 오염물의 양을 줄이기 위해 예방조치(preventive measure)를 취함에 있어서 그 조치가 피해자에게 주는 실질 효력이 불확실할 때 피해자의 반응은 자기보호조치의 예방조치에 대한 한계생산곡선의 모양에 좌우된다. 또한 자기보호조치의 제공과 예방조치의 효력에 대한 위험성간의 관계는 피해자의 생산함수 형태에 좌우된다.