Optimal Liability Rule in Water Quality Trading Market under Moral Hazard Problem*

Bong-Ju Kim**, Haesun Park***

This paper aims to find optimal liability rule considering moral hazard issue in the market design for water quality trading and examines how the liability is distributed between buyer and seller depending on their attitude toward risk.

In case where buyer (point source polluter) is risk neutral but seller (nonpoint source polluter) is risk averse, there is no case in which buyer and seller share liability. In this case, the buyer who is risk neutral generally pays the full penalty. In case buyer is risk averse but seller is risk neutral, when non-compliance is detected in water quality trading market, there are the following three optimal cases: (i) seller pays the full penalty, (ii) buyer pays the full penalty, (iii) seller and buyer share the penalty. Finally, when a contract consider an ex post individual rationality condition, buyer pays the full penalty regardless of a degree of seller's risk aversion.

Key Words: Liability, Moral Hazard, Water Quality Trading
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 ** Director, Industry and Resources Team National Assembly Research Service, Tel: 02-788-4590, E-mail: kbongju@gmail.com, The First Author
*** Associate professor, Economic Dept., Konkuk university, Tel: 043-840-3469, Email: hspark@kku.ac.kr, Corresponding Author

Ⅰ. Introduction

Water quality is one of the most important environmental concerns around world today. Sources of water quality impairment can be divided into two categories according to their characteristics: point sources and nonpoint sources. Point sources are like sewage treatment plants and industrial facilities that discharge pollutants into waterbody via a discrete conveyance such as a pipe. Pollution from nonpoint sources, by contrast, is diffuse in nature such as agricultural or urban runoff. The precise origin of pollution from nonpoint sources is difficult to identify because of its characteristics. This makes it hard to regulate for pollutant discharges from these sources (WRI 2009).

The standard approach to water quality regulation has been to regulate discharges using technology-based restrictions (command & control approach) on point source polluters. These regulations have been proved to be successful to control the point source pollution. The application of technology-based requirements through the U.S. Enviromnetal Protection Agency's National Pollutant Discharge Elimination System (NPDES) permit program has achieved substantial success in controlling the point source pollution.

However, these have some weaknesses that make us seek to find the new market-based trading. The technology-based restrictions are a relatively expensive way to achieve the pollution reduction target, and emphasize on the regulation of point source pollution. These regulations are not appropriate to address the nonpoint source problem that is a major source of water quality problem because the nonpoint source runoff is not easy to be monitored by regulatory agent [Vedlitz, et al. (1999)]. In addition, there are demands for looking for cost-effective alternatives to expensive regulation tool to get the water quality goals in the social level and to expensive capital investments in their plants to meet the goals in the point source level.

For the perspective of nonpoint source polluter, market-based trading program gives the incentive to regulate for their own pollutants voluntarily by participating in the market. Because of these reasons, there has been

growing interest in developing watershed-based trading as a regulatory tool to achieve water quality goals recently, and actually many water-quality trading programs have been designed and implemented in the world. Water quality trading is a market-based tool that is gaining popularity as a mechanism to cost-effectively meet water quality goals. According to World Resources Institute, 57 water quality trading programs were identified in 2008. Among these, 26 are active, 21 are under consideration, and 10 are inactive (WRI, 2009).

Trading between regulated point sources and unregulated nonpoint sources such as agriculture is one of the most common form of water quality trading because water quality trading is most commonly applied to nutrients and the majority of nutrient pollution originates from nonpoint sources, mainly agricultural sources. As mentioned in WRI (2009), water quality trading has many formulations. Trades between regulated point source-that is, two sewage treatment plant trading to meet permitted discharge levels-are the most straightforward. Water quality trading program can also allow trading between regulated point sources and unregulated point sources, such as agricultures. Trading between point and nonpoint sources enable point source with high compliance costs to purchase pollution reduction credits from nonpoint sources with lower pollution reduction costs. In most instances, point source facilities are controlled by regulatory discharge permits while nonpoint sources are generally not controlled by regulatory discharge limits. In these types of programs, nonpoint sources are typically sellers of pollution reduction credits and not buyers, since they are under no regulatory obligation to reduce their discharge. Over 70 percent of active water quality trading programs are between point and nonpoint sources. Our paper are focused on trading between regulated point sources and unregulated point sources.

From the problem that discharge from nonpoint sources cannot be easily monitored, asymmetric information problem such as moral hazard may happen in water quality trading between point and nonpoint sources. Nonpoint sources under moral hazard may not exert their best efforts for pollution reduction. The objective of this paper is to find optimal liability sharing rule between seller and buyer in water quality trading market in

order to avoid the moral hazard problem. This paper aims to find optimal liability rule considering moral hazard issue in the water quality trading market design.

In addition, Woodward and Kaiser (2002) categorized market structure into four main types : exchange, bilateral negotiations, clearinghouses, and sole-source offsets. They analyzed four types of market structures in terms of market efficiency and environmental efficacy. They stated that bilateral negotiations type of market structure is most common in water-quality market and especially in case that effluent trading program is trying to include nonpoint source polluters because of the advantage that non-uniform goods can be traded in this market unlike exchange market. Hence we will deal with trading between point and nonpoint sources in market of bilateral negotiations type in our model.

Ⅱ. Liability rules in water quality trading market

"Liability rules are used to guide compensation decisions when polluters are sued for damages in a court of law. Such rules can provide ex ante incentives for the polluters to use more environmentally friendly production practices." [Ribaudo. et al. (1999)]. They discuss two different types of liability rules that are relevant for the polluters: (1) strict liability and (2) negligence. Under strict liability, polluters are absolutely liable for payment of any damages that occurs. Under a negligence rule, polluters are liable only if they failed to act with the "due standard of care". [Ribaudo. et al. (1999)] When there are multiple polluters, damage costs under "joint and several liability" rule can be divided among polluters according to any distribution of the court's decision. However, if a specific distributional rule is set ex ante, damage costs can be distributed according to this rule. Liability rules can be categorized in different manner. The rules can be defined as an allocation rule of responsibility in case a party which has transferred parts of its assigned amount is found in non-compliance [Barion 1999]. Barion (1999) provides a technical assessment about the following main types of liability rules for international greenhouse gas emission

trading : issuer liability (issuer beware), buyer liability (buyer beware) and shared buyer/issuer liability.

Considering these liability rules, we analyze following three options in water quality trading market in this paper: (1) seller liability (in case of non-compliance, seller would pay the penalty or non-compliance fees), (2) buyer liability in case of non-compliance (in case of non-compliance, buyer would pay the penalty), (3) shared liability (in case of non-compliance, each party would pay the his or her share of penalty).

Ⅲ. The model

In water quality trading, the credit seller may not actually exert his effort to reduce the pollution to meet the required reduced amount because his effort cannot be easily monitored. Our study is to find optimal liability rule to prevent moral hazard problem. In the model setting, we use the basic moral hazard model of Laffont and Martimort (2002).

Suppose the principal is a credit buyer (point source polluter) and the agent is a credit seller (nonpoint source polluter). A point source polluter purchase credits from the nonpoint source polluters who are able to gurantee a supply of credits. We consider a seller who can exert a costly effort e. Here we normalize efforts level as a zero effort level ($e = 0$) and a positive effort of one ($e = 1$). Exerting effort e implies a disutility for the agent that is equal to $\Psi(e)$ with $\Psi(0) = 0$ and $\Psi(1) = \Psi$. Seller receives a transfer t (this is nothing but the price of credit) from buyer by selling the credits that he or she created. We assume that his or her utility function is a separable function of money and effort, $U = u(t) - \Psi(e)$, with $u(t)$ increasing and concave in t ($u' > 0$ and $u'' < 0$). In addition, the inverse function $h = u^{-1}$ is increasing and convex in t ($h' > 0$, $h'' > 0$).

We assume the ambient concentration at a given monitoring point is observable, and the ambient concentration at a given monitoring point is stochastic because of the weather, the type of land and so on. These monitoring points can capture the emission level from some nonpoint

sources of local area including the credit seller of this effluent trading.

Seller's effort affects the ambient concentration at a given monitoring point as follows: the stochastic ambient concentration at a given monitoring point $\widetilde{E}$ can only take two values $\{\overline{E}, \underline{E}\}$, and $\overline{E} > E^* > \underline{E}$ where E^* is a critical threshold of the pollutant. If $e = 1$ (the agent exerts the positive effort), then $E = \underline{E}$ (the ambient concentration at a given monitoring point is less than a critical threshold of the pollutant) with probability π_1 and $\overline{E}$ (the ambient concentration at a given monitoring point is greater than a critical threshold of the pollutant) with probability $(1 - \pi_1)$, and when $E = \overline{E}$[1], the penalty P is '0' with probability η_1 and $\overline{P}$ with probability $(1 - \eta_1)$. We assume there is no penalty when non compliance is not detected by regulatory agent.

If $e = 0$, then $E = \underline{E}$ with probability π_0 and $\overline{E}$ with probability $(1 - \pi_0)$, and when $E = \overline{E}$, the penalty P is '0' with probability η_1 and $\overline{P}$ with probability $(1 - \eta_1)$. Here, it should be noted that $\pi_1 > \pi_0$. In this situation, seller's action is not observable by buyer, but the local ambient emission level can be observable by the principal.

Buyer can only offer a contract based on the observable and verifiable local ambient emission level $t(E)$. With two possible outcomes such as $\overline{E}$ and $\underline{E}$, the contract can be defined equivalently by a pair of transfers $\overline{t}$ and $\underline{t}$. The transfer $(\overline{t}, \underline{t})$ is a payment received by seller if the local ambient emission level $\overline{E}$ (or $\underline{E}$) is realized. Moreover, buyer and seller sign the contact in which if a regulator charges the penalty for non-compliance, seller has to pay a proportion of penalty $[(1 - \alpha)]$, where $0 \leq \alpha \leq 1$.

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1) When the ambient concentration at a given monitoring point is greater than a critical threshold of the pollutant, the regulator would start to inspect the emission source, but imposing the fine is also stochastic because of the difficulty of monitoring.

Ⅳ. Main Results

Consider a water quality trading in which there exist a point source polluter and a nonpoint source polluters. The nonpoint sources are sellers of pollution reduction credits assigned by the regulator. In addition, they are under no regulatory obligation to reduce their discharge. The point source polluter is a risk-neutral credit buyer. His or her expected cost saving from the credit trading is written as:

$$V_1 = C_n - \left\{ \pi_1 \underline{t} + (1 - \pi_1)(\overline{t} + (1 - \eta_1)\alpha\overline{P}) \right\} \tag{1}$$

We assume buyer want seller to exert the effort.

That is, $V_1 = C_n - \left\{ \pi_1(\underline{t}) + (1 - \pi_1)(\overline{t} + (1 - \eta_1)\alpha\overline{P}) \right\} \geq V_0 = C_n - \left\{ \pi_0(\underline{t}) + (1 - \pi_0)(\overline{t} + (1 - \eta_1)\alpha\overline{P}) \right\}$, where C_n is the costs saving through purchasing pollution reduction credits from nonpoint sources. Although it depends on pollution reduction technology and so on, for the sake of simplicity, we assume that C_n is constant.

Since buyer does not observe the seller's effort, his or her optimization problem is given by

$$\text{Max } V_1 = C_n - \left\{ \pi_1 \underline{t} + (1 - \pi_1)(\overline{t} + (1 - \eta_1)\alpha\overline{P}) \right\}$$

subject to

$$\pi_1 u(\underline{t}) + (1 - \pi_1)[\eta_1 u(\overline{t}) + (1 - \eta_1)[u(\overline{t} - (1 - \alpha)\overline{P}] - \Psi \geq 0 \tag{2}$$

$$\Delta\pi u(\underline{t}) + \Delta\pi[\eta_1 u(\overline{t}) + (1 - \eta_1)[u(\overline{t} - (1 - \alpha)\overline{P}] - \Psi \geq 0 \tag{3}$$

where $\Delta\pi = \pi_1 - \pi_0$, $o \leq \alpha \leq 1$.

We set Largrangian function L, where μ and λ denote Largrangian multipliers for the inequality (2) and (3) respectively. Eq. (2) is the participation constraint that ensures that if seller exerts effort, it will yield at least his reservation utility, that is, '0'. Eq. (3) is the incentive constraint that imposes upon the seller to prefer to exert a one effort level which means that the seller's expected utility for him or her to exert a one effort level is greater than or equal to that to exert zero effort level.

We have the following necessary conditions for maximization with respect to $\underline{t}$, $\overline{t}$, and α:

$$\partial L / \partial \underline{t} = -\pi_1 + \mu \eta_1 u'(\underline{t}) + \lambda \Delta \pi u'(\underline{t}) = 0 \tag{4}$$

$$\partial L / \partial \overline{t} = -(1 - \pi_1) + \mu(1 - \pi_1)[\eta_1 u'(\overline{t}) + (1 - \eta_1)[u'(\overline{t} - (1 - \alpha)\overline{P})]$$
$$- \lambda \Delta \pi [[\eta_1 u'(\overline{t}) + (1 - \eta_1)[u'(\overline{t} - (1 - \alpha)\overline{P})] = 0 \tag{5}$$

From $\partial L / \partial \alpha \leq 0$, we have

$$-(1 - \pi_1) + \mu(1 - \pi_1) u'(\overline{t} - (1 - \alpha)\overline{P}) - \lambda \Delta \pi u'$$
$$(\overline{t} - (1 - \alpha)\overline{P}) \leq 0 \tag{6}$$

$$\partial L / \partial \lambda = \pi_1 u(\underline{t}) + (1 - \pi_1)[\eta_1 u(\overline{t}) + (1 - \eta_1)$$
$$[u(\overline{t} - (1 - \alpha)\overline{P})] - \Psi \geq 0 \tag{7}$$

$$\partial L / \partial \mu = \Delta \pi u(\underline{t}) - \Delta \pi [\eta_1 u(\overline{t}) + (1 - \eta_1)$$
$$[u(\overline{t} - (1 - \alpha)\overline{P})] - \Psi \geq 0 \tag{8}$$

Remark. Assuming that α has a corner solution, i.e., '0', for maximization, complementary slackness condition, that is, $\alpha(\partial L / \partial \alpha) = 0$, holds.

Proposition 1. Suppose that buyer (point source polluter) is risk neutral but seller (non-point source polluter) is risk averse. In water quality trading market, when non-compliance is detected, there is no case in which buyer and seller share liability.

Proof. We prove it by way of contradiction. Suppose that $0 < \alpha < 1$. Rearranging Eq. (5), we have

$$
\eta_1[-(1-\pi_1)+\mu(1-\pi_1)u'(\bar{t})-\lambda\Delta\pi u'(\bar{t})] + (1-\eta_1)[-(1-\pi_1)
$$
$$
+\mu(1-\pi_1)u'(\bar{t}-(1-\alpha)\overline{P})-\lambda\Delta\pi u'(\bar{t}-(1-\alpha)\overline{P})] = 0 \tag{9}
$$

From Eq. (6), we have

$$
-(1-\pi_1)+\mu(1-\pi_1)u'(\bar{t}-(1-\alpha)\overline{P})-\lambda\Delta\pi u'
$$
$$
(\bar{t}-(1-\alpha)\overline{P}) = 0 \tag{10}
$$

Subtracting Eq. (10) from Eq. (9), we obtain

$$
\eta_1[\mu(1-\pi_1)-\lambda\Delta\pi][u'(\bar{t})-u'(\bar{t}-(1-\alpha)\overline{P})] \geq 0 \tag{11}
$$

Since $0 \leq \alpha < 1$, $\bar{t}-(1-\alpha)\overline{P} < \bar{t}$. Moreover, from $u''(\cdot) < 0$, we have

$$
u'(\bar{t}) < u'(\bar{t}-(1-\alpha)\overline{P}) \tag{12}
$$

From Eqs. (11) and (12), we have

$$
[\mu(1-\pi_1)-\lambda\Delta\pi] \leq 0 \tag{13}
$$

Combined Eq. (4) with Eq. (6), we obtain the following relationships with respect to μ and λ.

$$\mu = \pi_1 / u'(\underline{t}) + (1 - \pi_1) / u'(\overline{t} - (1 - \alpha))\overline{P}) \tag{14}$$

$$\lambda = [\pi_1(1 - \pi_1) / \Delta\pi][1 / u'(\underline{t}) - 1 / u'(\overline{t} - (1 - \alpha)\overline{P})] \tag{15}$$

From Eqs. (14) and (15), the left hand side of Eq. (13) is given

$$[\mu(1 - \mu_1) - \lambda\Delta\pi] = (1 - \pi_1) / u'(\overline{t} - (1 - \alpha)\overline{P}) > 0 \tag{16}$$

From Eqs. (13) and (16), we have a contradiction. It is easy to check that the second condition for maximization is satisfied.

Notice that we have $\alpha = 0$ (seller's liability) or $\alpha = 1$ (buyer's liability) as a candidate for optimal solution. The first case in which seller who is more risk averse than buyer pays the full liability is somewhat counter-intuitive. Since it holds for $[\mu(1 - \pi_1) - \lambda\Delta\pi] \leq 0$, this is the case in which π_1 is high and $\Delta\pi$ is large. This means that if seller's action largely improves the probability of success which means that ambient concentration at a given monitoring point is less than a critical threshold of the pollutant, the seller has a full liability.

Proposition 2. Suppose that buyer is risk averse but seller is risk neutral. In water quality trading market, when non-compliance is detected, there can be following three cases: (ⅰ) seller pays the full penalty, (ⅱ) buyer pays the full penalty, (ⅲ) seller and buyer share the penalty.

Proof. Buyer who wants to induce effort must choose the contract that solves the following problem:

Max
$$V_1 = \pi_1 u(C_n - \underline{t}) + (1 - \pi_1)[\eta_1 u(C_n - \overline{t}) + (1 - \eta_1)u$$
$$(C_n - \overline{t} - \alpha\overline{P})] \tag{17}$$

subject to

$$\pi_1 \underline{t} + (1 - \pi_1)\left\{\overline{t} - (1 - \eta_1)(1 - \alpha)\overline{P}\right\} - \Psi \geq 0 \qquad (18)$$

$$\Delta\pi\underline{t} - \Delta\pi[\overline{t} - (1 - \eta_1)(1 - \alpha)\overline{P}))] - \Psi \geq 0 \qquad (19)$$

Let denote $\tilde{t} := \overline{t} - (1 - \eta_1)(1 - \alpha)\overline{P}$.

When seller is risk neutral, the buyer can choose incentive compatible transfers $\underline{t}$ and $\tilde{t}$, which make the seller's participation constraint (Eq. (18)) binding and leave no rent to the seller. Now we choose the above transfers $\underline{t}$ and $\tilde{t}$ binding for inequalities (18) and (19) as follows:

$\pi_1 \underline{t} + (1 - \pi_1)\tilde{t} - \Psi = 0,$

$\Delta\pi\underline{t} - \Delta\pi\tilde{t} - \Psi = 0.$

So, we have $\underline{t} = \dfrac{(1 - \pi_0)}{\Delta\pi}\Psi$, $\tilde{t} = -\dfrac{\pi_0}{\Delta\pi}\Psi$, and $\overline{t} = (1 - \eta_1)(1 - \alpha)$

$\overline{P} - \dfrac{\pi_0}{\Delta\pi}\Psi$.

At the above solution, since the inequality (18) is binding, seller has no surplus. Therefore, we know that given α, though buyer cannot observe seller's behavior, buyer can extract the seller's full-surplus.

Inserting the above solution into (17), we can simplify the above maximization program as follows:

Max

$$\pi_1 u(C_n - \underline{t}) + (1 - \pi_1)[\eta_1 u(C_n - (1 - \eta_1)(1 - \alpha)\overline{P} + \frac{\pi_0}{\Delta\pi}\Psi) +$$

$$(1 - \eta_1)u(C_n - (1 - \eta_1)(1 - \alpha)\overline{P} + \frac{\pi_0}{\Delta\pi}\Psi - \alpha\overline{P})] \text{ such that } 0 \leq \alpha \leq 1.$$

We set Largrangian function L, where μ and λ denote Largrangian multipliers for the inequality $\alpha \geq 0$ and $1 - \alpha \geq 0$ respectively.

$$\frac{\partial L}{\partial \alpha} = (1 - \pi_1)(1 - \eta_1)[\eta_1 u'(W) - (1 - \eta_1)u'(W - \alpha\overline{P})]\overline{P}$$
$$+ \mu - \lambda = 0 \qquad (20)$$

$\alpha\dfrac{\partial L}{\partial \alpha} = 0,\ \mu\alpha = 0,\ \lambda(1 - \alpha) = 0$ (complementary slackness condition),

where W denote $C_n - (1 - \eta_1)(1 - \alpha)\overline{P} + \dfrac{\pi_0}{\Delta\pi}\Psi$.

From (20), we have

$$(1 - \pi_1)(1 - \eta_1)[\eta_1 u'(W) - (1 - \eta_1)u'(W - \alpha\overline{P})] = (-\mu + \lambda)/\overline{P} \quad (21)$$

Since $W \geq W - \alpha\overline{P}$ and $u''(\cdot) < 0$, we know that $u'(W) < u'(W - \alpha\overline{P})$. Thus we consider the following three optimal cases:

Case 1 (seller's liability): $\eta_1 u'(W) > (1 - \eta_1)u'(W - \alpha\overline{P})$

In this case, the left hand of Eq. (21) is negative. From the above equation, it is clear that $\mu > 0$. Therefore, from complementary slackness we have $\alpha = 0$. This case holds if $(1 - \eta_1) > \eta_1$. This means that the probability for detecting non-compliance $(1 - \eta_1)$ is relatively high, seller pays the full penalty.

Case 2 (buyer's liability): $\eta_1 u'(W) > (1 - \eta_1)u'(W - \alpha\overline{P})$.

In this case, the left hand of Eq. (21) is positive. From the above equation, it is clear that $\lambda > 0$. Therefore, from complementary slackness we have $\alpha = 1$. Similarly to the above case, this case holds if the probability for detecting non-compliance $(1 - \eta_1)$ is relatively low, buyer pays the full penalty.

Case 3 (shared liability): $\eta_1 u'(W) > (1 - \eta_1) u'(W - \alpha \overline{P})$.

In this case, the left hand of Eq. (21) is zero. Thus, we conclude that if the probability for detecting non-compliance $(1 - \eta_1)$ is intermediate higher than 1/2, there exists an optimal solution in which seller and buyer have shared liability for penalty. It is easy to check that the second condition for maximization is satisfied.

We show that when non-compliance is detected, there are the three possible liability cases: seller's liability, buyer's liability, and shared liability between seller and buyer. In this case, shared liability between buyer and seller happens contrary to the case in which buyer is risk neutral but seller is risk averse. The reason is that higher the probability for detecting non-compliance is, a risk averse buyer has the more incentive to share the penalty to be charged with a risk neutral seller.

So far, we assume that seller's individual rationality condition expressed as Eq. (2) for a risk averse seller or expressed as Eq. (18) for a risk-neutral seller holds under interim individual rationality in which expected utility is determined as random events depending on emission level and the detection possibility. This condition is weaker than ex post individual rationality condition for seller in which no individual wishes to walk away from a mechanism after all information has been revealed and the decision and transfers fully specified, regardless of the realization of probabilistic events. For the risk averse seller, ex post individual rationality condition is written below:

$$\text{Max} \quad V_1 = C_n - \left\{ \pi_1 \underline{t} + (1 - \pi_1)(\overline{t} + (1 - \eta_1) \alpha \overline{P}) \right\}$$

subject to

$$\pi_1 u(\underline{t}) + (1 - \pi_1) [\eta_1 u(\overline{t}) + (1 - \eta_1) [u(\overline{t} - (1 - \alpha) \overline{P})]] - \Psi \geq 0 \quad (2)$$

$$\Delta\pi u(\underline{t}) - \Delta\pi[\eta_1 u(\overline{t}) + (1-\eta_1)[u(\overline{t}-(1-\alpha)\overline{P})] - \Psi \geq 0 \quad (3)$$

$$u(\underline{t}) - \Psi \geq 0 \tag{22}$$

$$u(\overline{t}) - \Psi \geq 0 \tag{23}$$

$$u(\overline{t}-(1-\alpha)\overline{P}) - \Psi \geq 0 \tag{24}$$

We observe that ex post individual rationality conditions, i.e., Eqs. (22)~(24) implies interim individual rationality condition, i.e., Eq. (2). The buyer's optimization problem is as follows:

Max $\ V_1 = C_n - \left\{\pi_1\underline{t} + (1-\pi_1)(\overline{t}+(1-\eta_1)\alpha\overline{P})\right\}$

subject to

$$\Delta\pi u(\underline{t}) - \Delta\pi[\eta_1 u(\overline{t}) + (1-\eta_1)[u(\overline{t}-(1-\alpha)\overline{P})] - \Psi \geq 0 \quad (3)$$

$$u(\underline{t}) - \Psi \geq 0 \tag{22}$$

$$u(\overline{t}) - \Psi \geq 0 \tag{23}$$

$$u(\overline{t}-(1-\alpha)\overline{P}) - \Psi \geq 0 \tag{24}$$

From Eqs. (23) and (24), it is easy to show that inequality (24) is binding at an optimal solution.

So we have:

$$\overline{t} = h(\Psi) + (1-\alpha)\overline{P} \tag{25}$$

From combined Eqs. (3) and (22) with the above result, it is easy to show that inequality (3) is binding at an optimal solution. So we obtain:

$$u(\underline{t}) = \Psi/\Delta\pi + \eta_1 h(\Psi) + (1 - \eta_1)\Psi + \eta_1(1 - \alpha)\overline{P} > \Psi \qquad (26)$$

Notice that when the state $\underline{E}$ is realized, a seller obtains a rent. It is easy to prove that this also holds for a risk neutral so that the seller has an positive interim expected rent contrary to the assumption under the interim individual rationality condition in which the seller have no interim expected rent.

From (26), we have:

$$\underline{t} = h[\Psi/\Delta\pi + \eta_1 h(\Psi) + (1 - \eta_1)\Psi + \eta_1(1 - \alpha)\overline{P}] \qquad (27)$$

Inserting Eqs. (26) and (27) into V_1, we have the following optimization problem:

Max

$$C_n - \pi_1 h[\Psi/\Delta\pi + \eta_1 h(\Psi) + (1 - \eta_1)\Psi + \eta_1(1 - \alpha)\overline{P}]$$
$$- (1 - \pi_1)[h(\Psi) + (1 - \alpha)\overline{P} + (1 - \eta_1)\alpha\overline{P}] \text{ such that } 0 \leq \alpha \leq 1.$$

We set Largrangian function L, where μ and λ denote Largrangian multipliers for the inequality $\alpha \geq 0$ and $1 - \alpha \geq 0$ respectively.

$$\frac{\partial L}{\partial \alpha} = [\pi_1\eta_1 h'(W) + (1 - \pi_1)\eta_1]\overline{P} + \mu - \lambda = 0 \qquad (28)$$

$$\alpha\frac{\partial L}{\partial \alpha} = 0, \ \mu\alpha = 0, \ \lambda(1 - \alpha) = 0 \text{ (complementary slackness condition),}$$

where W denote $\Psi / \Delta \pi + \eta_1 h(\Psi) + (1 - \eta_1)\Psi + \eta_1(1 - \alpha)\overline{P}.$

From Eq. (28), we have

$$\pi_1\eta_1 h'(W) + (1 - \pi_1)\eta_1 = (-\mu + \lambda)/\overline{P} \tag{29}$$

Since the left hand side of Eq. (29) is positive, we know that $\lambda > 0$. From complementary slackness condition, we have $\alpha = 1$. Therefore, buyer pays the full penalty.

Similarly to the above case, we can prove that buyer pays the full penalty when is risk neutral but seller is risk averse. It is easy to check that the second condition for maximization is satisfied. The above results can be summarized by Proposition 3.

Proposition 3. Suppose that a contract consider an ex post individual rationality condition for seller in which he or she doesn't have less than a zero rent from a mechanism after all information has been revealed. Regardless of a degree of seller's risk aversion, in water quality trading market, when non-compliance is detected, buyer pays the full penalty (buyer's liability).

Assuming an ex post individual rationality, we have a solution of $\alpha = 1$ (buyer's liability) in two cases. This implies buyer pays the full penalty regardless of their risk attitude when non-compliance is detected. An economic reason for that is buyer has to consider compensation with transfer (t) in order to avoid the seller's default considering seller's ex post individual rationality if both parties share the penalty. When $0 \leq \alpha < 1$, we have $\bar{t} = h(\Psi) + (1 - \alpha)\overline{P} > h(\Psi)$ from Eq. (25). This result ensures that buyer has to pay a positive rent to seller when the ambient concentration at a given monitoring point is more than a critical threshold of the pollutant. In other words, buyer should pay rent to seller if buyer impose a part of liability to seller. However, imposing a part of liability to seller cannot be

a solution because it reduce his or her net benefit compared to the case of buyer's full liability.

Ⅴ. Summary and Discussion

This study considers water quality trading in which a point source polluter is a credit buyer for pollution emissions and a non-point source polluter is a credit seller. We examined how the liability is distributed between buyer and seller depending on their attitude toward risk. At first, consider the case where buyer (point source polluter) is risk neutral but seller (nonpoint source polluter) is risk averse. In water quality trading market, when non-compliance is detected, there is no case in which buyer and seller share liability. In this case, the buyer who is risk neutral generally pays the full penalty. However, if seller's action largely improves the probability of success which means that the ambient concentration at a given monitoring point is less than a critical threshold of the pollutant, the seller has the full liability for the penalty. To prevent a moral hazard of seller, seller's liability can be an answer when the probability for detecting non-compliance $(1 - \eta_1)$ is relatively high.

Second, considering the case buyer is risk averse but seller is risk neutral, when non-compliance is detected in water quality trading market, there are the following three optimal cases: (ⅰ) seller pays the full penalty, (ⅱ) buyer pays the full penalty, (ⅲ) seller and buyer share the penalty. In particular, we show that if buyer is risk averse but seller is risk neutral, there is a case in which buyer and seller share liability. In this case, shared liability between buyer and seller happens contrary to the case in which buyer is risk neutral but seller is risk averse. The reason is that higher the probability for detecting non-compliance is, a risk averse buyer has the more incentive to share the penalty to be charged with a risk neutral seller.

Third, we assume that the contract between buyer and sellers depends on the ambient emission at a given monitoring point. However, we consider the complex contract form which is contingent on not only an ambient emission level but also the detection possibility. Therefore, it is needed to

analysis the optimal contract for this case.

Fourth, our paper is entirely focused on trading between regulated point sources and unregulated nonpoint sources. However, water quality trading has many formulations, for example, trades between regulated point sources or trade between nonpoint sources. Thus, we investigate these cases.

Finally, a contract should consider an ex post individual rationality condition for seller in which he or she has not less than a zero rent from a mechanism after all information has been revealed. Regardless of a degree of seller's risk aversion, in water quality trading market, when non-compliance is detected, buyer pays the full penalty (buyer's liability). The reason is that buyer has to consider compensation with transfer (t) in order to avoid the seller's default considering seller's ex post individual rationality if both parties share the penalty.

Our model showed that if ex post individual rationality constraint to prevent the default of unregulated non-point source seller is considered, the optimal liability rule under moral hazard is buyer's full liability instead of seller's or shared liability. In reality, under the Clean Water Act of the United States, a regulated point source purchasing credits from another regulated point source can transfer regulatory compliance liability to the seller. However, a regulated point source purchasing credits from an unregulated nonpoint source cannot transfer legal liability (WRI 2009). This result implies that prohibiting buyer (point source polluter) from transfer liability to sellers (nonpoint source polluters) by the Clean Water Act of the United States can be an appropriate measure.

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국문초록

수질오염 거래 제도에서 최적 책임 배분규칙에 관한 연구

김봉주
국회입법조사처 경제산업조사실

박혜선
건국대학교 부교수

본 연구는 수질거래를 위한 시장제도를 마련하는데 있어 도덕적 해이 문제를 고려한 최적의 책임 분배규칙을 찾으려는 시도이다. 점오염원인 배출권 구매자가 위험중립적인 경우에는 구매자와 판매자간에 책임을 공유하는 경우는 발생하지 않는다. 이 경우에 위험중립적인 구매자가 과태료의 전액을 지불한다. 구매자가 위험기피적이며 판매자가 위험중립적인 경우에는 위반이 적발되면 다음의 세 가지 최적 상황이 존재한다. 즉, (ⅰ) 판매자가 과태료 전액을 지불하는 경우, (ⅱ) 구매자가 과태료 전액을 지불하는 경우, (ⅲ) 구매자와 판매자가 과태료를 공동 부담하는 경우가 모두 가능하다. 마지막으로 당사자 간의 계약에 있어 사후적 개인 합리성 조건을 고려할 경우, 구매자가 판매자의 위험기피 정도에 무관하게 전액의 과태료를 지불하게 된다.

주제어: 책임, 도덕적 해이, 수질거래