A Collective Performance-based Contract for Point-Nonpoint Source Pollution Trading

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Summary Abstract: *Collective performance-based trading can be achieved by pairing a team contract with an auction to determine team membership. The auction effectively overcomes adverse selection, and the team contract reduces the incentive to "free-ride" associated with moral hazard in teams.*

Keywords: Nonpoint Source Pollution, Water Quality Trading, Collective Performance, Asymmetric Information, Team Contract, Auction

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Nonpoint sources are currently the leading cause of water pollution in most areas of the United States (Davies and Mazurek, 1997). Yet, they have avoided intense regulatory scrutiny until fairly recently, due perhaps to the long-standing claim that regulation is impractical because it is inherently difficult to identify individual contributions to nonpoint source pollution loads. The result is that nonpoint sources, such as agriculture, have traditionally been addressed through voluntary subsidy programs that compensate for the adoption of best management practices (BMPs). This tradition has continued in the development of water quality trading (WQT) markets, where nonpoint source participation is voluntary. As a result, WQT markets differ from traditional pollution permit markets, in that point sources are always buyers, nonpoint sources are always sellers. In this sense, WQT markets are similar to a public procurement or contracting programs, with the point source seeking to contract with multiple nonpoint sources to jointly produce a desired level of pollution abatement.

Collective performance-based WQT contracts are complicated by the existence of both adverse selection and moral hazard. However, this is not a problem unique to WQT trading. For example, any government that wishes to contract private firms for major public works projects (i.e., construction of highways or dams) must confront similar informational asymmetries. In practice, governments have designed various contracting mechanisms that address both adverse selection (the government does not know the expected cost of any firm) and moral hazard (the government cannot observe the selected firm's effort to keep its realized production costs low).

What sets the WQT market problem apart is the need to contract jointly with multiple nonpoint sources, coupled with the inability to observe individual productivity. The term "moral hazard in teams" was coined by Holmstrom (1982) to describe this problem. Moral hazard in teams is more pervasive than moral hazard in the single-agent case, as it can occur even when there is no uncertainty in output. Since shirking in effort is only detected through the common final product, the effect of individual shirking is spread across all agents in the group, and cannot be attributed to the responsible party. In this sense, moral hazard in teams is a type of "free-rider" problem prevalent in the provision of public goods.

Even though the actions of the agents are not observable, and so cannot be used as the basis of the contract, the result of the individual actions is verifiable as collective abatement at the end of the period. Therefore, to overcome the moral hazard in teams problem, the collective abatement outcome must be included in the contract that stipulates payment to the agents. A successful contract must pay more when the observable collective performance is a good signal that the individual abatement choices were the required ones. The contract offered by the principal must make each agent feel responsible for the whole of the final product, in order to provide the appropriate incentive for overcoming the free-rider problem.

This paper focuses on the contract design issues associated with the asymmetric information problems inherent in nonpoint source pollution abatement. When a point source offers a contract for nonpoint source pollution abatement several informational problems pose obstacles to success. Nonpoint sources have different abilities (i.e., abatement types) in terms of the cost of reducing emissions. The point source cannot observe the expected abatement costs of particular nonpoint sources, and therefore, does not know which firms are the most efficient trading partners. In addition, each nonpoint source is better informed regarding its own unique abatement production process, and therefore holds private information regarding its actual contribution to observed levels of aggregate loadings.

3.1 Existing Literature on Collective Monitoring and Enforcement

Economists have addressed the issue of moral hazard in teams through a wide array of collective monitoring and enforcement mechanisms. Issues of joint production in the labor literature (Holmstrom, 1982; Rasmussen, 1987; McAfee and McMillan, 1991) have been extended to address the joint production problems in nonpoint source pollution control (Meran and Schwalbe, 1987; Segerson, 1988; Xepapadeas, 1991; Cabe and Herriges, 1992; Bystrom and Bromley, 1998, Pushkarskya, 2003). The primary goal of all of these mechanisms is to provide appropriate production incentives to the individual agents by making each of them liable for the whole team output.

Segerson (1988) applies Holmstrom's (1982) analysis of moral hazard in teams to the problem of nonpoint source pollution, by proposing an ambient tax/subsidy mechanism based on collective monitoring and enforcement. This mechanism pays each individual a firm specific subsidy, or charges each individual a firm-specific tax, based on the difference between observed levels of aggregate pollution and the collective standard. The team contract that I propose is a variation of the contracts proposed by Segerson (1988) and Holmstrom (1982), modified to allow for utilization in a voluntary trading setting. A more unique contribution is the use of a team-entry auction to overcome some of the more onerous information requirements of the principal.

While collective performance-based instruments are appealing in terms of their theoretical efficiency properties, their adoption as practical policy tools has not occurred. A criticism of collective-performance mechanisms is that they require the principal to possess too much information for efficient implementation in practice. In particular, these mechanisms require the principal, traditionally thought to be a regulatory agency, to have perfect information regarding nonpoint source abatement production and cost functions. It is also expected that nonpoint sources know their own abatement production and cost functions, as well as their impact on aggregate loadings.

Assuming that the required contracting information is privately known by the nonpoint sources, practical implementation of collective performance-based mechanisms requires dealing with an adverse selection problem. Pushkarskya (2003) addresses the role of adverse selection in the design of a nonpoint source pollution abatement subsidy program. The principal (i.e., the regulatory agency) faces both moral hazard in teams and adverse selection. The regulator wishes to target subsidy payments to the farmers that can produce the most abatement at the least-cost with collective performance as the only verifiable contract element. A key assumption in this research is that each farmer has perfect information regarding not only their own abatement cost function, but the abatement cost functions of all other farmers.

Similar to Alchian and Demestz (1972) analysis of economic organization, the shared cost information of the nonpoint sources combined with the potential for economic gains through cooperation creates an incentive for the nonpoint sources to organize into a trading association. The formation of the trading association circumvents the adverse selection problem, as the point source can contract directly with the association based on observable group abatement. This collective payment can then be divided by the association between individual members using the observable cost information to internally set optimal sharing rules. The contract that I propose in this chapter relaxes the information assumption in Pushkarskya (2003). The contract implements a collective performance-based contract where nonpoint sources only know their own abatement cost function with certainty.

3.2 A Model of a Two-stage Team Contract for Water Quality Trading

In this section, a two-stage mechanism that pairs a traditional team contract for the control of moral hazard in teams with an auction to determine team membership prior to contracting is examined. The task at hand is to design a collective performance-based contract that has the potential for actual implementation. The contract must transmit to group members clear and readily comprehensible incentives that are consistent with the group's goals of pollution abatement. This means that both incentive compatibility and simplicity, which can be in conflict, are both valued.

In the first stage, multiple nonpoint sources are offered the opportunity to participate in a team contract to produce an aggregate level of abatement, using a sealed bid auction. Bids consist of the quantity of annual pollution reduction the individual pledges to produce, and the corresponding per unit price. The point source accepts the bids of the individuals that, as a group, offer to produce the desired level of nutrient reductions at the lowest cost. The point source will select the group of bidders that, as a team, can reduce the maximum amount of pollution within the point source's fixed budget constraint. The point source's budget constraint is determined by its own abatement cost function. Simply put, the point source will not spend more than it would cost to directly abate the same amount of pollution. In the second stage, the nonpoint sources will produce abatement. At the end of the second stage, the collective nonpoint source abatement is realized and participating nonpoint sources are compensated based on the conditional payment schedule. The selected team is then paid according to an "all or nothing" contract based on observed levels of aggregate nonpoint source pollution. If the observed level of collective nonpoint source pollution reductions is greater than or equal to the contracted group level, each team member is paid for their bid quantity at some agreed upon per-unit price equal to the lowest price bid offered by a non-team member.[1] However, if the observed level of collective nonpoint source pollution reduction is less than the aggregate quantity, each team member is paid nothing (and suffers a loss equal to the costs of abatement produced).

The use of an auction mechanism to select the contracting team members creates incentives for nonpoint sources to truthfully reveal private abatement cost information. This

[1] The price is dependent upon the auction design chosen. Under a discriminatory price auction the contract price will be the bid price, and under a uniform price auction the contract price will be equal to the lowest of the non-team members' bid prices.

serves two purposes. First, the point source can avoid the adverse selection problem by offering a menu of contracts based on the revealed information. Second, the bid information allows the point source to set optimal sharing rules that ensure that the participation constraints of team members are met. This overcomes the traditional criticism regarding the high informational requirements for efficient team contracts. The role of the team contract is to deliver the appropriate incentives to reduce potential shirking (i.e., abating less than the bid quantity).

This contract allows the point source to purchase a given level of nonpoint source pollution reduction, while leaving nonpoint sources their choice of abatement technology to reduce their pollution discharges. Uncertainty as to the effectiveness of on-site abatement technology is borne by the nonpoint sources, which have better information regarding abatement performance, and are best able to handle it. The competition for team membership effectively limits the range of rent seeking possibilities in nonpoint source bid prices, while endogenously providing the point source with the information needed to set the optimal sharing rules within the contract.

Consider a watershed that consists of a single, risk neutral point source and multiple, *n*, risk neutral nonpoint sources. A subset of the nonpoint sources, $m \le n$, (i.e., the "team") are selected to provide individually unverifiable levels of abatement, $a_i \in [0, a_i^{\max}]$. Each nonpoint source has a finite capacity for abatement, $a_i^{\max}$. The cost of abatement is given by a strictly increasing convex cost function, $C_i(a_i)$. The team's aggregate abatement, $A(a,e)$, depends stochastically on the individual abatement actions of the nonpoint sources and random weather effects. Expected team abatement is denoted as: $E[A(a,e)] = \omega \sum_{j=1}^{m} a_i (1+e) + (1-\omega) \sum_{j=1}^{m} a_i (1-e)$, where ω and $1-\omega$ are the probabilities of good and bad weather respectively $(0 < \omega < 1)$, and $1+e$ and $1-e$ represent the impact of good and bad weather respectively $(0 < e < 1)$. Any increase in individual abatement increases the expected level of team abatement, i.e., $E\left[\frac{\partial A(a,e)}{\partial a_i}\right] > 0$. The principal offers an "all-or-nothing" team contract that makes individual payments contingent on the monitoring of team performance. The team target *Λ* is the sum of the individually contracted quantity of abatement for all team members, $\sum_{j=1}^{m} \lambda_j = \Lambda$. If the observed level of aggregate nonpoint source pollution abatement is greater than or equal to the team target, individual team members receive a positive payment. However, if aggregate nonpoint source pollution abatement is less than the team target, payments are withheld from each team member. Table 1 defines the notation used throughout this chapter.

Table 1 – Model Notation

Variable	***Definition***
ω	*Probability of good weather*
$1-\omega$	*Probability of bad weather*
$e:(0 \le e \le 1)$	*Weather shock*
$1+e$	*Impact of good weather on NPS abatement*
$1-e$	*Impact of bad weather on NPS abatement*
n	*Total number of NPS in watershed*
$m:(m \le n)$	*Total number of NPS in team contract*
λ_i	*Quantity of NPS abatement production bid by agent i*
p_i	*Price per unit of NPS abatement bid by agent i*
$\Lambda = \sum_{i=1}^{m} \lambda_i$	*Total quantity of NPS abatement contracted from team*
a_i	*Quantity of abatement produced by NPS i*
$A(a,e):\begin{cases}(1+e)\sum_{i=1}^{m} a_i \\ (1-e)\sum_{i=1}^{m} a_i\end{cases}$	*Quantity of NPS abatement observed in good weather and bad.*
$C_i(a_i)$	*Agent i's NPS abatement cost function*

3.3 A Budget-breaking Team Contract to Avoid Moral Hazard in Teams

As mentioned previously, the proposed WQT contract must confront the combined effects of adverse selection and moral hazard on WQT contract design. However, I will begin with an analysis of moral hazard in teams, in isolation, before including adverse selection. Within this section, it is assumed that the point source knows the efficiency type of each nonpoint source (i.e., the point source knows the abatement cost functions of all nonpoint sources). This allows the point source to select the optimal combination of low-cost trading partners and the optimal sharing rules, without the auction.

The point source offers individualized contracts of the following type:
$r_i = \begin{cases} p_i \lambda_i & \text{if } \mathrm{A(a,e)} \ge \Lambda \\ 0 & \text{if } \mathrm{A(a,e)} < \Lambda \end{cases}$. The symbols p_i and λ_i represents the price paid per unit of abatement to nonpoint source *i*, and the quantity of abatement contracted from nonpoint source *i*, respectively. The profit for each of the *m* nonpoint sources under contract can also be represented as: $\pi_i = \begin{cases} p_i \lambda_i - C_i(a_i) & \text{if } \mathrm{A(a,e)} \ge \Lambda \\ -C_i(a_i) & \text{if } \mathrm{A(a,e)} < \Lambda \end{cases}$. Therefore, the point source can set p_i and λ_i, such that when the target is achieved each team member earns profit, and when the target is not met each team member suffers a loss. Because nonpoint source market

participation is voluntary, the point source must be concerned with meeting each individual's participation constraint. The point source in this case must set the contract price and quantity in order to ensure that each nonpoint source will be made no worse off by participating optimally within the contract.

The participation constraint requires that the payment to each nonpoint source must be greater than or equal to their actual costs of abatement, i.e., $p_i \lambda_i \geq C_i(a_i^*)$, which can be rewritten as $p_i \geq \frac{C_i(a_i^*)}{\lambda_i}$. The right hand side of this inequality is an "adjusted" average abatement cost. Since the point source does not observe the individual abatement decision of the nonpoint sources, actual abatement, a_i, can be greater than, less than, or equal to the contract quantity, λ_i. Thus, the break-even condition of price greater than average cost must be adjusted to take the potential discrepancy between actual and contracted quantities of abatement. The point source will offer a price that guarantees the nonpoint source will, at a minimum, breakeven when producing the desired level of abatement. Under voluntary participation, the breakeven condition is identical to the participation condition. The concept of adjusted average cost is used throughout the remainder of the chapter for this reason.

In order to explicitly include the effects of weather events on the profit maximizing decision of the nonpoint source, I write the expected profit function:

$$\underset{a_i}{Max} \quad \alpha + \beta$$

where,

$$\alpha \equiv \omega\left[\left(p_i\,\lambda_i\right) I\left(\left(1+e\right)\left(\sum_{j\neq i} a_j + a_i\right) \geq \Lambda\right) - C_i\left(a_i\right)\right]$$

$$\beta \equiv (1-\omega)\left[\left(p_i\,\lambda_i\right) I\left(\left(1-e\right)\left(\sum_{j\neq i} a_j + a_i\right) \geq \Lambda\right) - C_i\left(a_i\right)\right].$$

This represents the expected profit of nonpoint source i, given the choice of abatement level, a_i. The conditional payment structure of the team contract is captured through the use of the indicator function, $I(\cdot)$. When the condition inside the indicator function holds, total observed abatement meets or exceeds the group target, and the value of the indicator function is equal to one. Otherwise, the value of the indicator function is equal to zero. The first portion of the objective function, α, represents the expected profit in good weather conditions. Good weather occurs with probability ω, and increases the level of collective abatement observed downstream by ($1+e$). The second portion of the objective function, β, represents the expected profit in bad weather conditions. Bad weather occurs with probability ($1-\omega$), and decreases the level of collective abatement observed downstream by ($1-e$).

The Nash equilibrium abatement strategy maximizes the expected profit of each nonpoint source. The discrete weather distribution assumption allows for analysis of the nonpoint source abatement decision under three weather/payment contingent scenarios (Table 1).[2]

Table 1: Weather/Payment Contingent Scenarios

	Good Weather	**Bad Weather**
1	*Collective target met* $I(\cdot)=1$	*Collective target met* $I(\cdot)=1$
2	*Collective target met* $I(\cdot)=1$	*Collective target not met* $I(\cdot)=0$
3	*Collective target not met* $I(\cdot)=0$	*Collective target not met* $I(\cdot)=0$

Within the first scenario is one has the nonpoint sources choose the optimal abatement strategy that ensures a payment in both weather states. The second scenario has the nonpoint sources choose the optimal abatement strategy to ensure payment is met only in the event of good weather. The third scenario has the nonpoint sources choose to miss the target and forgo payment in both states of weather. Once the optimal strategies under each scenario are determined the Nash abatement strategy can be determined.

PROPOSITON 1: *Assume the point source sets the optimal sharing rules (p_i , λ_i) such that* $p_i \geq \frac{C_i(a_i^*)}{\lambda_i}$*, ensuring that the individual rationality constraint of each team member is met. The abatement production strategy* $a_i = \frac{\lambda_i}{(1-e)}$ *is the expected profit maximizing strategy that guarantees a profit in both good and bad weather.*

PROOF: Let $a_j = \frac{\lambda_j}{(1-e)}$ be the abatement production strategy for all nonpoint sources j ≠i, who were selected into the team. Nonpoint source *i*'s profit maximizing choice of abatement is determined by maximizing expected utility:

[2] We do not consider the combination where there is a positive payout in bad weather and a zero payment in good weather as this is not feasible using a single abatement strategy.

$$\underset{a_i}{Max} \qquad (\alpha)+(\beta)$$

$$where \quad (\alpha) \equiv \omega\left[\left(p_i\,\lambda_i\right) I\left(\left(1+e\right)\left(\left(\frac{1}{(1-e)}\sum_{j\neq i}\lambda_j\right)+a_i\right)\geq \Lambda\right)-C_i\left(a_i\right)\right] \quad . \quad \text{Eq (3.1)}$$

$$and \quad (\beta) \equiv (1-\omega)\left[\left(p_i\,\lambda_i\right) I\left(\left(1-e\right)\left(\left(\frac{1}{(1-e)}\sum_{j\neq i}\lambda_j\right)+a_i\right)\geq \Lambda\right)-C_i\left(a_i\right)\right]$$

The nonpoint source seeks the abatement strategy that guarantees payment regardless of weather effects, i.e., the collective abatement target is met in both good and bad weather. This is equivalent to choosing the expected profit maximizing level of abatement that guarantees $I(\cdot)=1$ in both *(α)* and *(β)*. I begin by solving the contents of both indicator functions.

Solving the contents of indicator function from part (α) of Eq. (3.1):

$$\left(1+e\right)\left(\left(\frac{1}{(1-e)}\sum_{j\neq i}\lambda_j\right)+a_i\right)\geq \Lambda$$

$$=\left(\frac{(1+e)}{(1-e)}\sum_{j\neq i}\lambda_j\right)+\left(1+e\right)a_i \geq \left(\sum_{j\neq i}\lambda_j\right)+\lambda_i$$

$$=\left(1+e\right)a_i \geq \left(\sum_{j\neq i}\lambda_j\right)+\lambda_i -\left(\frac{(1+e)}{(1-e)}\sum_{j\neq i}\lambda_j\right)$$

$$=a_i \geq \sum_{j\neq i}\lambda_j\left(\frac{1}{(1+e)}-\frac{1}{(1-e)}\right)+\frac{\lambda_i}{(1+e)}$$

Solving the indicator function from part (β) of Eq. (3.1):

$$\left(1-e\right)\left(\left(\frac{1}{(1-e)}\sum_{j\neq i}\lambda_j\right)+a_i\right)\geq \Lambda$$

$$=\left(\frac{(1-e)}{(1-e)}\sum_{j\neq i}\lambda_j\right)+\left(1-e\right)a_i \geq \left(\sum_{j\neq i}\lambda_j\right)+\lambda_i$$

$$=\left(1-e\right)a_i \geq +\lambda_i$$

$$=a_i \geq \frac{\lambda_i}{(1-e)}$$

The abatement strategy that will achieve the target in both weather states is the strategy that produces the larger amount of abatement.

Showing the conditions under which $a_i \geq \frac{\lambda_i}{(1-e)}$ *is the production strategy that produces more abatement (i.e., guarantees that the collective target is met in both weather states).*

$$\frac{\lambda_i}{(1-e)} \geq \sum_{j\neq i}\lambda_j\left(\frac{1}{(1+e)}-\frac{1}{(1-e)}\right)+\frac{\lambda_i}{(1+e)}$$
$$=\frac{\lambda_i}{(1-e)} \geq \frac{\Lambda}{(1+e)}-\frac{\sum_{j\neq i}\lambda_j}{(1-e)}$$
$$=\frac{\Lambda}{(1-e)} \geq \frac{\Lambda}{(1+e)}$$

Therefore, $a_i \geq \frac{\lambda_i}{(1-e)}$ is the preferred strategy abatement strategy. The final step is to show that this expected profit maximizing strategy will hold as equality.

Showing that the abatement strategy holds as equality: $a_i = \frac{\lambda_i}{(1-e)}$.

$$\underset{a_i}{Max} \quad \omega\left(p_i\,\lambda_i\,(1)-C_i(a_i)\right)+(1-\omega)\left(p_i\,\lambda_i\,(1)-C_i(a_i)\right)$$
$$s.t. \quad a_i \geq \frac{\lambda_i}{(1-e)}$$

Construct the Hamiltonian:

$$\underset{a_i}{Max} \quad H = p_i\,\lambda_i - C_i(a_i)+k_1(a_i-\frac{\lambda_i}{(1-e)})$$
$$\frac{\partial H}{\partial a_i} \equiv \frac{\partial C_i(a_i)}{\partial a_i}=k_1$$

$$\begin{cases} k_1 > 0 \\ a_i = \frac{\lambda_i}{(1-e)} \end{cases} \qquad \begin{cases} k_1 = 0 \\ a_i > \frac{\lambda_i}{(1-e)} \end{cases}$$

Since $\frac{\partial C_i(a_i)}{\partial a_i} > 0$, then $k_1 > 0$ and $a_i^* = \frac{\lambda_i}{(1-e)}$ holds with equality. Any additional abatement will increase costs but will not change the expected revenue.
QED

This same process needs to be repeated to determine the optimal abatement strategies for the two remaining weather/payment contingent scenarios.

PROPOSITION 2: *Assume the point source sets the optimal sharing rules (* p_i, λ_i *) such that* $p_i \geq \frac{C_i(a_i^*)}{\lambda_i}$*, ensuring that the individual rationality constraint of each team member is* *met. The abatement production strategy* $a_i = \dfrac{\lambda_i}{(1+e)}$ *is the expected profit maximizing strategy when the collective target is achieved in good weather but not in bad weather.*

PROOF: The proof is identical to that of PROPOSITION 1 and is omitted for the sake of brevity.

PROPOSITION 3: *Assume the point source sets the optimal sharing rules (* p_i, λ_i *) such that* $p_i \geq \dfrac{C_i(a_i^*)}{\lambda_i}$*, ensuring that the individual rationality constraint of each team member is met. The abatement production strategy* $a_i = 0$ *is the expected profit maximizing strategy when the collective target is achieved in good weather but not in bad weather.*

PROOF: The proof is identical to that of PROPOSITION 1 and is omitted for the sake of brevity.

These abatement strategies can be labeled as *self-insuring,* $a_i(1-e) = \lambda_i$, *shirking,* $a_i(1+e) = \lambda_i$, and *non-participating,* $a_i = 0$, strategies. They represent the profit maximizing abatement strategies contingent on the weather/payment scenario. The expected profit maximizing strategy among these choices is determined by the distribution of weather, the size of the weather shock, and the contract price and quantities.

The self-insuring strategy has each nonpoint source producing more than their bid quantity so that the target is achieved regardless of weather. The amount of overproduction equals the expected abatement shortfall that occurs under bad weather. Expected profit under the self-insuring strategy is:

$$E[\pi_i]_{SI} = \omega\left(p_i a_i(1-e) - C_i(a_i)\right) + (1-\omega)\left(p_i a_i(1-e) - C_i(a_i)\right) = p_i a_i(1-e) - C_i(a_i)$$

The shirking strategy has each nonpoint source producing less than their bid quantity so that the aggregate abatement target is reached only in the event of good weather. The amount of underproduction equals the expected level of the abatement windfall under good weather. Thus, shirking is constrained by the weather effect. To avoid a loss the nonpoint source must produce enough to guarantee a payment in good weather. Expected profit under the shirking strategy is:

$$E[\pi_i]_S = \omega\left(p_i a_i(1+e) - C_i(a_i)\right) + (1-\omega)\left(-C_i(a_i)\right) = \omega\left(p_i a_i(1+e)\right) - C_i(a_i).$$

The non-participation strategy is the optimal abatement strategy when the target will not be achieved regardless of the weather. In this situation, the expected revenue is equal to zero. Thus, the optimal response is to not produce any abatement, and thus not incur any costs. The expected profit under the non-participating strategy is:

$$E[\pi_i]_{NP} = \omega\left(-C_i(0)\right) + (1-\omega)\left(-C_i(0)\right) = 0.$$

PROPOSITON 4: *Assume the point source sets the optimal sharing rules (* p_i, λ_i *) such that* $p_i \geq \frac{C_i\left(a_i^*\right)}{\lambda_i}$*, ensuring that the individual rationality constraint of each team member is satisfied. The Nash equilibrium production strategy will be a self-insuring strategy,* $a_i(1-e) = \lambda_i$ *, when* $(1-e) > \omega(1+e)$*, and will be a shirking strategy,* $a_i(1+e) = \lambda_i$ *, when* $(1-e) < \omega(1+e)$.

PROOF: It is clear that the non-participating strategy cannot be the optimal strategy, when the participation constraint is met, since both the self-insuring and shirking strategy return positive levels of expected profit. Therefore, the Nash equilibrium abatement strategy will be either self-insuring or shirking determined by the difference in expected profit:

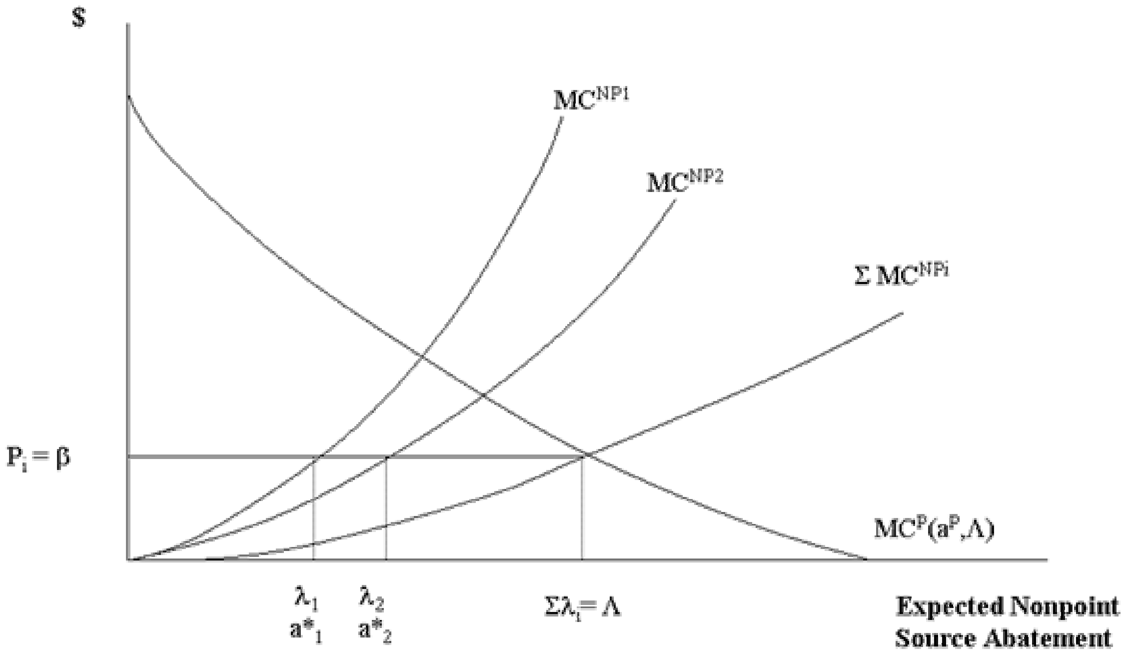
$$E_S[\pi_i] > E_{SI}[\pi_i]$$
$$p_i a_i(1-e) - C_i(a_i) > \omega\left(p_i a_i(1+e)\right) - C_i(a_i)$$
$$(1-e) > \omega(1+e)$$

When this condition holds, the self-insuring strategy returns higher expected profits than the shirking strategy, and vice versa.
QED

These probabilities are common knowledge to the point source and all the nonpoint sources, and thus the Nash abatement strategy will be known as well. This allows the point source to assign each team member's contract price and quantity in order to maximize its own expected abatement cost savings. Ideally the point source would like to set the contract prices and quantities as in Figure 1. The contract price is set equal to the point source's own marginal cost of abatement at the aggregate level of nonpoint source abatement being purchased. This point is denoted as β in Figure 1. In addition, the point source would choose to set the contract quantities of each team member equal to their economically efficient production levels, $\lambda_i = a_i^*$.

However, from the previous analysis it is clear that the team contract will not produce this result. If the Nash abatement strategy is shirking, the nonpoint source will under-produce abatement, and if the Nash abatement strategy is self-insuring the nonpoint source will overproduce abatement. The point source must deviate from the first-best contract price in order to guarantee the contracted level of individual abatement is produced by each nonpoint source.

Figure 1: First-Best Allocation of Contract Price and Quantity



PROPOSITON 5: *If* $(1-e) > \omega(1+e)$, *the point source will set the contract quantity at the first-best efficiency level* $\lambda_i = a_i^* |_\beta$ *and* $p_i = \frac{\beta}{(1-e)}$ *to ensure that the nonpoint source produces abatement* $a_i^* = \lambda_i$.

PROOF: The nonpoint source will choose the self-insuring abatement strategy $a_i(1-e) = \lambda_i$, solving the expected profit maximization problem:

$$\begin{aligned} &\underset{a_i}{Max} \quad p_i\lambda_i - C_i(a_i) \\ &s.t. \quad a_i(1-e) = \lambda_i \end{aligned} \quad \forall i$$

The first order conditions are:

$$p_i(1-e) = \frac{\partial C_i(a_i)}{\partial a_i} \quad \forall i$$

Setting $p_i = \frac{\beta}{(1-e)}$ results in $\beta = \frac{\partial C_i(a_i^*)}{\partial a_i^*}$ which has the nonpoint source producing the desired level of abatement $a_i^* = \lambda_i$.

QED

PROPOSITON 6: *If* $(1-e) < \omega(1+e)$, *the point source will set the contract quantity at the first-best efficiency level* $\lambda_i = a_i^* |_\beta$ *and* $p_i = \dfrac{\beta}{\omega(1+e)}$ *to ensure that the nonpoint source produces abatement* $a_i^* = \lambda_i$.

PROOF: The nonpoint source will choose the shirking abatement strategy $a_i(1+e) = \lambda_i$, solving the expected profit maximization problem:

$$\begin{array}{l} \underset{a_i}{Max} \quad \omega p_i \lambda_i - C_i(a_i) \\ s.t. \quad a_i(1+e) = \lambda_i \end{array} \quad \forall i$$

The first order conditions are:

$$\omega p_i(1+e) = \frac{\partial C_i(a_i)}{\partial a_i} \quad \forall i$$

Setting $p_i = \dfrac{\beta}{\omega(1+e)}$ results in $\beta = \dfrac{\partial C_i(a_i^*)}{\partial a_i^*}$ which has the nonpoint source producing the desired level of abatement $a_i^* = \lambda_i$.

QED

The point source is able to set the contract price such that the desired level of individual nonpoint source abatement is provided from each team member. Figures 2 and 3 illustrate this for the self-insuring and shirking abatement strategies respectively. In both cases, some level of informational rent is extracted by the nonpoint source due to the presence of asymmetric information, and the Nash abatement strategy is the one that provides the largest information rent to the nonpoint sources.

These results, not surprisingly, are similar to those of the mechanisms proposed by Holmstrom (1982) and Segerson (1988). This is because the team contract used in this chapter is a “special case” of the Holmstrom contract, which in turn is what the Segerson instrument is based upon. Theorem 3 in Holmstrom (1988) proposes the contract:

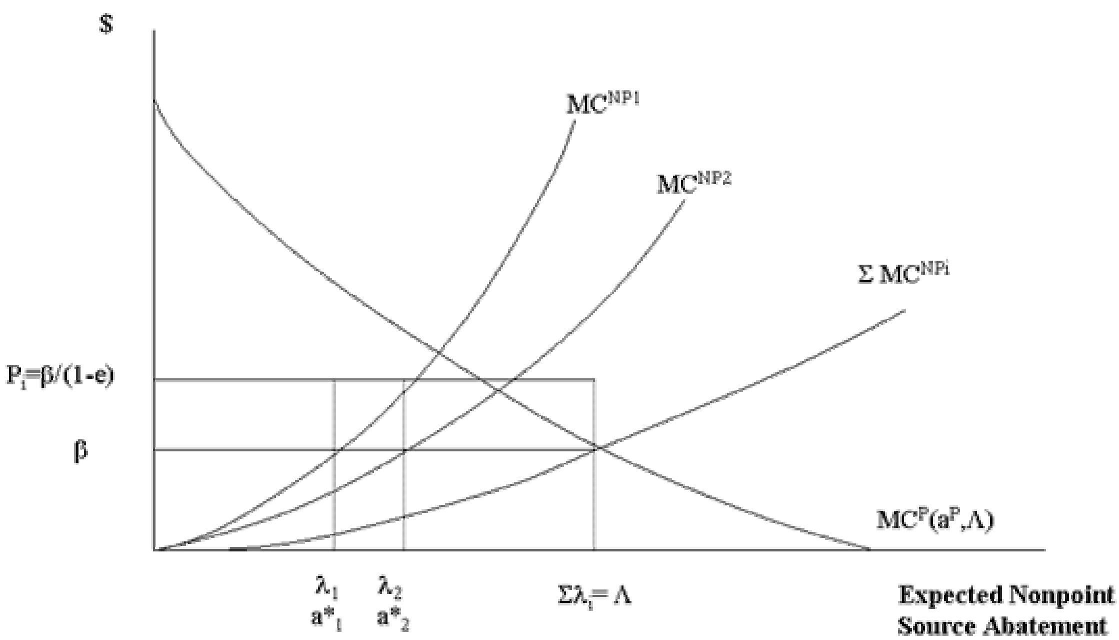
$$s_i(x) = \begin{cases} s_i x & x \geq \bar{x} \\ s_i x - k_i & x < \bar{x} \end{cases}$$

where, s_i is the share of the collective output value (x) attributed to team member *i*, with $\sum_i s_i = 1$, and $k_i > 0$ is a fine for failing to achieve the contract level $(\bar{x})$. The WQT contract presented in this chapter can be rewritten to correspond with this Holmstrom contract as follows:

$$s_i(x) = \begin{cases} s_i \bar{x} & x \geq \bar{x} \\ s_i \bar{x} - k_i & x < \bar{x} \end{cases}$$

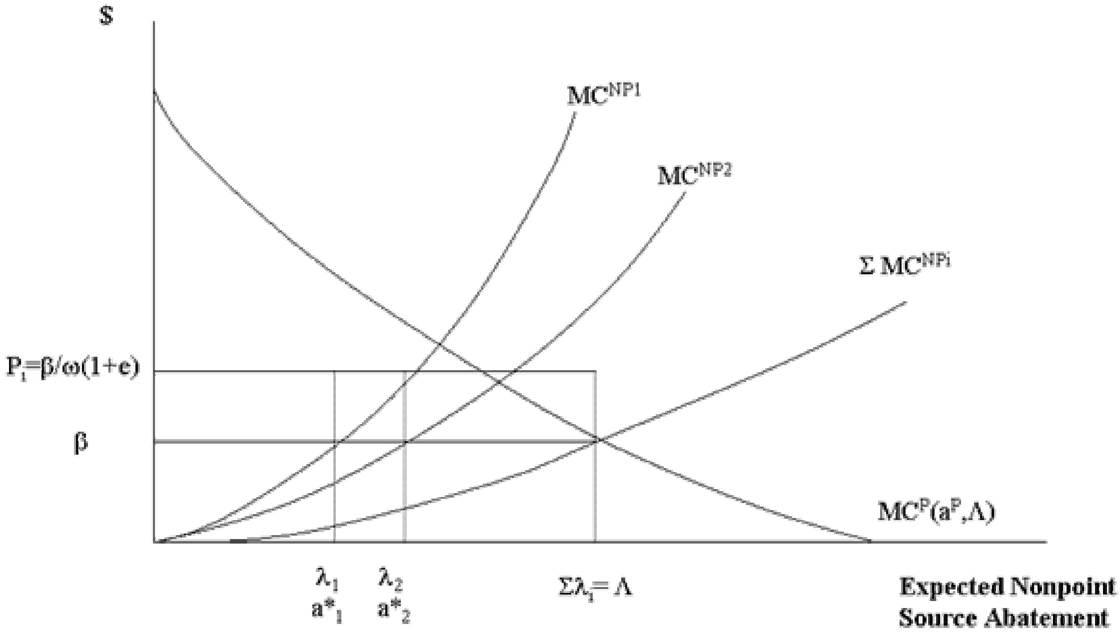
where, $s_i = \dfrac{\lambda_i}{\Lambda}$ and $\bar{x} = p\Lambda$. The differences between the two contracts are in terms of $\bar{x}$ and k_i. In this contract the output value is fixed at the contracted level $\bar{x}$. In addition, the fine for under-compliance, k_i, is always set equal to the individual's share of the fixed output value ($k_i = s_i \bar{x}$). With these contract modifications, the principal seeking full compliance in the face of production uncertainty, will not seek to adjust the fine, as in Holmstrom and Segerson, but instead will adjust the optimal value for output, p_i.[3]

Figure 2: Second-Best Allocation of Contract Quantity and Price (Self-insuring Abatement Strategy and No Adverse Selection)



[3] Changing the output value does affect the size of the fine, as it is the fine is equivalent to the loss of the individual share of total output value under non-compliance. However, this is a direct result of the change in contract price.

Figure 3: Second-Best Allocation of Contract Quantity and Price (Shirking Abatement Strategy and No Adverse Selection)



A common problem often discussed in association with both the Holmstrom and Segerson instruments are the effects of endowment constraints. Endowment constraints restrict the credibility of many collective performance instruments. Under certain conditions, the size of fines required for full compliance may be so large as to eclipse the wealth of the individual agents. In such settings, the mechanism loses its practical enforcement credibility (Karp, 2002). The same is true in the WQT setting, where the per unit price required to secure individual contract quantities may be prohibitively high, especially when weather impacts are large or when the difference in marginal abatement costs between point and nonpoint sources is small. The budget constraint of the point source provides a default to nonpoint source trading. The point source can always opt to produce its own abatement at cost. When the cost of contracting with nonpoint sources is too high, the budget constraint will exceeded and the proposed contract will not permit trading. Unlike the Segerson and Holmstrom mechanisms, endowment constraints do not weaken the credibility of the contract incentives, rather they preclude trade from occurring at all.

3.4 An Auction Mechanism to Determine Team Entry and Sharing Rules

When the assumption regarding the knowledge of individual nonpoint source abatement cost functions is relaxed, the point source no longer possesses the information needed to select efficient team members and set optimal sharing rules. Introducing adverse selection requires the use of a mechanism that can induce the nonpoint sources to voluntarily reveal this private information. Auctions are commonly used for this purpose, and among the wide array of auction designs, two types have generally received the most attention: uniform price and discriminating price, sealed-bid auctions (Harris and Raviv, 1981). In a uniform price auction, a single market price equal to the lowest rejected bid is paid to all accepted bidders. In a discriminating auction all winning bidders are paid their bid price, rather than a common price.

The WQT setting presents some unique challenges regarding the appropriate choice of the auction mechanism. Research on multi-unit auctions has shown that the efficiency conditions proven in the single-unit case are not guaranteed to hold when individual bidders offer multiple-units. In particular, bid-shading in both uniform price and discriminating price auctions leads to inefficient allocation when bidders are allowed to bid for multiple units at differing prices, or when any bidder(s) can exert market power (Ausubel and Cramton, 2002). In the uniform case, the ability to bid for multiple quantities at differing prices can lead to a bidder's own bid being "pivotal" in setting the price, and thus, truth revealing bids are no longer a dominant strategy. Market power allows the dominant bidder to influence the auction price, in the discriminating price auction.

I assume that each nonpoint source has the same maximum capacity for abatement: $a_i^{\max} = a_j^{\max} = a^{\max}$, and thus will have a maximum, strategy contingent, bid quantity, $\lambda_i^{\max} = \lambda_j^{\max} = \lambda^{\max}$. This assumption removes the potential for market domination by any single bidder. In addition, I restrict bidders to a single bid price over all bid quantities. This prevents any bidder's bid from being pivotal in determining its own price in the uniform auction. Under these assumptions, the inefficiencies of multi-unit auctions are avoided (Ausubel and Cramton, 2002).

In the team entry auction, a single risk-neutral point source desires to purchase Λ amount of nonpoint source abatement, subject to a budget constraint. The budget constraint is determined by the point sources own abatement cost function (i.e., the point source will not pay more than its own cost for abatement). Multiple risk neutral nonpoint sources, *n*, bid to join the abatement team. The $m \le n$ nonpoint sources that collectively produce Λ level of abatement at the lowest-cost are chosen for team entry. Bids consist of a per unit price, $p_i(\lambda_i)$, for a quantity of abatement, λ_i. Ties are broken through random selection.

Following Wilson (1979) and Ausubel and Cramton (2002), I represent the multi-unit auction in terms of shares, by normalizing the collective abatement target Λ=1, with individual quantity bids $\lambda_i \in (0, \lambda^{\max})$, and $\lambda^{\max} \in (0,1)$. This simplifies the construction of order statistics needed for an analytical solution for optimal bidding strategies.

Order statistics are useful tools in the analysis of auctions. The point source and all rival nonpoint sources assume that the reservation prices of all bidders $(\theta_1, ..., \theta_n)$ are identical independently drawn random variables from a cumulative density function $G(\cdot)$ with probability density function, $g(\cdot)$. The distribution of reservation prices is known by all, but the individual realization θ_i is only known to bidder *i*.

By arranging the *n* i.i.d. random reservation prices in ascending order of magnitude $(\theta_{(1)} \le \theta_{(2)} \le ... \le \theta_{(n)})$, we can denote the m^{th} order statistic of all bidders other than *i*

as $\theta_{(m)}^{-i}$. Now we can denote $F_{(m)}^{-i}$ as the cumulative density function and $f_{(m)}^{-i}$ the probability density function of the m^{th} order statistic. Now the probability of being accepted into the team can be written as a function of the distribution of the m^{th} order statistic,
$\Pr\left[p_i(\lambda_i) \ \ accepted\right] = \Pr\left[p_i(\lambda_i) < \theta_{(m)}^{-i}\right] = 1 - F_{(m)}^{-i}$.

In the following sections, the same method is used to determine the optimal bid price and quantities for both possible Nash equilibrium abatement strategies. To avoid repetition I will only report the details for the self-insuring strategy within the text. The derivation of the optimal bid price and quantity under the shirking abatement strategy is identical to that presented.[4]

3.5 Uniform Price Team Entry Auction

In a uniform price auction the bidder faces uncertainty in regard to both team entry and the contract price. The m lowest-priced bidders, that collectively bid to produce the team target ($\sum_i^m \lambda_i = \Lambda$), are each contracted to produce their bid quantity at a per unit price equal to the lowest rejected bid. The bid price of the lowest excluded bidder (*m+1*) becomes the contract price, referred to as the "stop-out" price, for all team members. The "stop-out price" ($\overline{p}_{m+1}$) is an expected price, over the distribution of the order statistic distribution, $1 - F_{(m)}^{-i}$. As will be shown, it can also be interpreted as the expected average cost of the *m+1* bidder, $\frac{C_{m+1}(a_{m+1})}{\lambda_{m+1}}$.

Each nonpoint source will bid its true reservation price in the uniform price auction. Truth revelation implies that the bid will reflect the actual costs of abatement for the nonpoint source: $p_i(a_i^*)a_i^* = C_i(a_i^*)$. Therefore, the nonpoint source bid price holds the following relationship to the reservation price: $p_i(a_i^*) = \frac{C_i(a_i^*)}{a_i^*} = \theta_i$. The uniform price auction ensures that the individual rationality constraints of all accepted team members are met, as the contract price is always greater than the bid price of the team members.

PROPOSITION 6: *The competitive team entry auction is a revelation mechanism, which induces the nonpoint source to bid a price that equals its average abatement cost:*
$p_i(a_i^*) = \frac{C_i(a_i^*)}{a_i^*} = \theta_i$.

[4] The only difference between the self-insuring and shirking abatement strategies is in terms of the determination of optimal bid price and quantity is in the weather shock term. Under the shirking abatement strategy $\omega(1+e)$ is used in place of (1-e).

PROOF: To prove this proposition, it must be shown that deviating from the truth revealing bidding strategy does not improve the expected outcome for any bidder. I will do this by showing that neither reducing the bid price below the reservation price, nor increasing the bid price above the reservation price, will improve the auction outcome for any nonpoint source bidder.

When a bidder sets the bid price $p_i(\lambda_i)$ lower than the reservation price θ_i, three possible scenarios exist:

$$(a)\quad p_i(\lambda_i) < \theta_i < \overline{p}_{m+1}$$
$$(b)\quad \overline{p}_{m+1} < p_i(\lambda_i) < \theta_i \quad or$$
$$(c)\quad p_i(\lambda_i) \leq \overline{p}_{m+1} < \theta_i.$$

When the nonpoint source's reservation price, θ_i, is less than the expected competitive auction price, $\overline{p}_{m+1}$, as in scenario *(a)*, decreasing the bid price $p_i(\lambda_i)$ has no effect. The nonpoint source stays in the team and receives the same competitive price. When ϕ_i is greater than $\overline{p}_{m+1}$, reducing the bid price can only make the nonpoint source worse off. Reducing $p_i(\lambda_i)$ to any point greater than $\overline{p}_{m+1}$, as in scenario *(b)*, does not gain the nonpoint source entry into the team, and its auction outcome is unchanged. Setting $p_i(\lambda_i)$ equal to or less than $\overline{p}_{m+1}$, as in scenario *(c)*, worsens the auction outcome of the nonpoint source. When $p_i(\lambda_i) = \overline{p}_{m+1}$, the nonpoint source has a random chance of being selected into the team. If the nonpoint source does not gain entry into the team his status remains unchanged, and if selected the nonpoint source is guaranteed a loss because the auction price will be less than the average cost of abatement. Reducing $p_i(\lambda_i)$ below $\overline{p}_{m+1}$ exacerbates this loss.

When a bidder sets the bid price higher than the reservation price, three possible scenarios exist:

$$(c)\quad \overline{p}_{m+1} < \theta_i < p_i(\lambda_i)$$
$$(d)\quad \theta_i < p_i(\lambda_i) < \overline{p}_{m+1} \quad or$$
$$(e)\quad \theta_i < \overline{p}_{m+1} \leq p_i(\lambda_i).$$

When the reservation price is greater than the stop-out price, as in scenario (*c)*, increasing the bid price does not affect the auction outcome as the nonpoint source will continue to remain outside of the team. When the reservation price is less than the stop-out price, the truth revealing bidding strategy ensures the nonpoint source entrance to the team. Increasing the bid price to any point less than the stop-out price, as in scenario *(d)*, has no effect on the auction outcome. The nonpoint source remains in the team and will receive per unit stop-out price. Raising the bid price equal to or greater than stop-out price, as in situation *(e)* puts the nonpoint source in danger of suffering a loss. Bidding the stop-price results in the nonpoint source having a random chance of being selected into the team. If the nonpoint source is selected into the team the auction outcome remains the same, (i.e., he is paid the stop-price). However, if not selected the nonpoint source suffers the loss of expected profit he would have made had he remained in the team. Obviously, the same loss occurs for any bid price set above the stop-price. It is a dominant strategy for the nonpoint source to bid the reservation price associated with the chosen abatement strategy.
QED

The optimal bid price line is the average abatement cost curve. Thus, the optimal bid price is simply the average cost of abatement at the optimal quantity level.

PROPOSTION 7: *In a uniform price auction, the nonpoint source will always bid the feasible quantity of abatement that maximizes expected profits, given the Nash abatement strategy.*

PROOF: The utility maximizing quantity of abatement under the self-insuring abatement strategy is determined by solving the following expected profit maximization problem:

$$\begin{aligned}
&\underset{a_i,\lambda_i}{Max} \quad \bar{p}_{m+1}\lambda_i - C_i(a_i) \\
&s.t. \qquad \lambda_i = a_i(1-e) \\
&\qquad\qquad \lambda^{\max} = a^{\max}(1-e) \\
&\qquad\qquad \lambda_i \le \lambda^{,\max}
\end{aligned}$$

This maximization problem can be simplified as:

$$\begin{aligned}
&\underset{a_i}{Max} \quad \bar{p}_{m+1}a_i(1-e) - C_i(a_i) \\
&s.t. \qquad a_i = a^{\max}(1-e)
\end{aligned}$$

$$H = \bar{p}_{m+1}a_i(1-e) - C_i(a_i) + k_1(a^{\max}(1-e) - a_i)$$

Show first order conditions with slack constraints:

$$\frac{\partial H}{\partial \lambda_i} \equiv \bar{p}_{m+1} - \frac{\partial C_i(a_i)}{\partial a_i}\frac{1}{(1-e)} - k_1 = 0$$

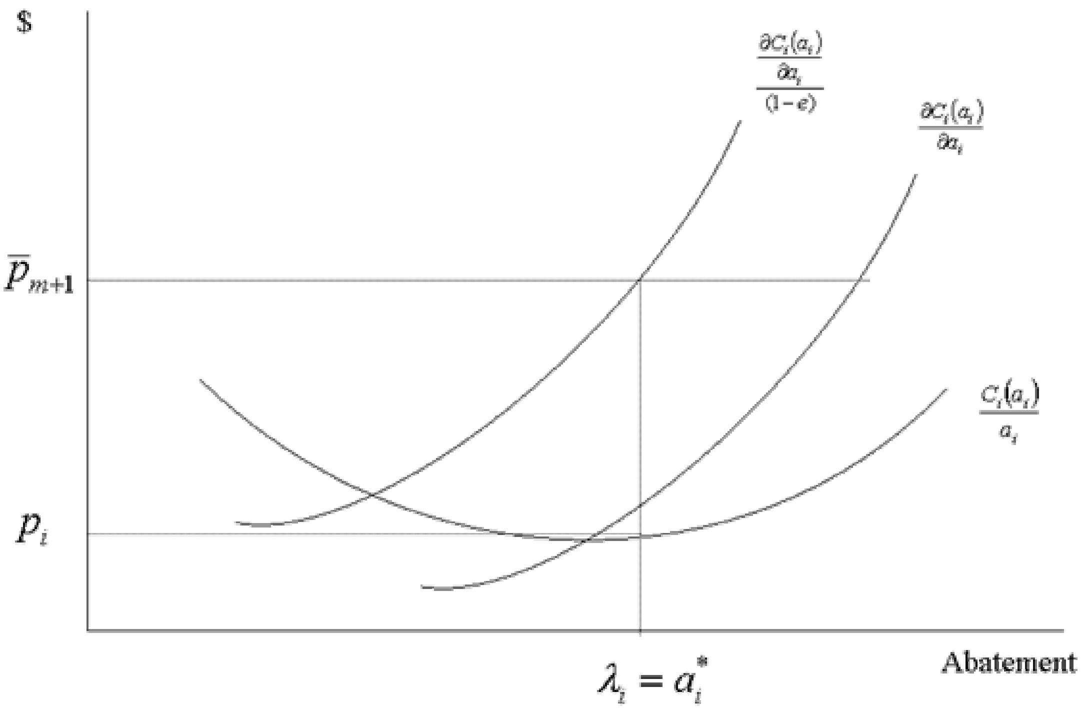
$$\begin{cases} k_1 > 0 \\ _i = a^{\max} \end{cases} \qquad or \qquad \begin{cases} k_1 = 0 \\ a_i < a^{\max} \end{cases}$$

If the expected contract price is greater than the marginal cost of abatement, which is adjusted to account for the Nash abatement strategy, at the maximum allowable bid quantity ($a^{\max}$), the nonpoint maximizes expected profit by bidding this amount. Otherwise, the nonpoint source will bid the quantity(a_i^*) where the "stop-out" price equals the adjusted marginal cost of abatement. The optimal bid quantity is the expected profit maximizing level: $\lambda_i^* \min\left[a^{\max}, a_i^*\right]$

QED

The uniform price auction serves as a truth revelation mechanism, as the optimal bid price is equal to the average cost of abatement at the optimal bid quantity. The optimal bid quantity is less than the first-best profit maximizing level as a result of informational rents from asymmetric information. The nonpoint source accounts for its abatement strategy of over-production in its selection of its bid quantity. However, the contract does ensure that each team member will produce individual abatement levels equal to their bid quantities. The optimal bidding strategy is depicted graphically in Figure 4.

Figure 4: Nonpoint Source Optimal Bid Price and Quantity (Uniform Price Auction and Self-insuring Abatement Strategy)



3.6 Discriminating Price Team Entry Auction

In the discriminating auction, the bidder faces uncertainty about acceptance, but not about price. The *m* lowest-priced bidders, that collectively bid to produce the team target ($\sum_i^m \lambda_i = \Lambda$), are each contracted to produce their bid quantity at their bid price. Thus, all bidders have an incentive to increase their bid price above the reservation price.

PROPOSITION 8: *In a discriminating price auction, the nonpoint source following a self-insuring Nash abatement strategy will bid* $p_i = \frac{C_i(\lambda_i)}{\lambda_i} + \frac{1 - F_{(m)}^{-1}}{f_{(m)}^{-i}}$ *and* $\lambda_i = \min\left[a^{\max}, a_i^*\right]$.

PROOF: The nonpoint source maximizes expected profit, where the expectation is now based on the uncertainty associated with being selected into the team[5], represented by the distribution of the m^{th} order statistic:

$$\begin{aligned}
&\underset{p_i, a_i, \lambda_i}{Max}\left(1-F_{(m)}^{-i}\right)\left(p_i\lambda_i - C_i(a_i)\right)+F_{(m)}^{-i}(0)\\
&s.t. \qquad \lambda_i \le \lambda^{\max}\\
&\qquad\qquad a^{\max}(1-e)=\lambda^{\max}
\end{aligned}$$

The maximization problem can be simplified as:

$$\begin{aligned}
&\underset{p_i, a_i}{Max}\left(1-F_{(m)}^{-i}\right)\left(p_i\lambda_i - C_i\left(\frac{\lambda_i}{(1-e)}\right)\right)\\
&s.t. \qquad a_i \le a^{\max}(1-e)
\end{aligned}$$

Solve nonpoint source profit maximization problem to determine optimal bidding strategy.

$$H=(1-F_{(m)}^{-i})\left(p_i a_i(1-e)-C_i(a_i)\right)+k_1(a^{\max}-a_i)$$

Show first order conditions with slack constraints:

$$\frac{\partial H}{\partial p_i}\equiv -f_{(m)}^{-i}\left[p_i a_i(1-e)-C_i(a_i)\right]+(1-F_{(m)}^{-i})a_i(1-e)=0$$

$$\frac{\partial H}{\partial a_i}\equiv (1-F_{(m)}^{-i})\left[p_i(1-e)-\frac{\partial C_i(a_i)}{\partial a_i}\right]-k_1=0$$

$$\begin{cases} k_1>0 \\ a_i=a^{,\max}\end{cases} \qquad or \qquad \begin{cases} k_1=0 \\ a_i<a^{\max}\end{cases}$$

Rewriting the first order condition taken with respect to p_i condition shows the optimal price bidding strategy for the self-insuring abatement strategy under the discriminating price auction: $p_i=\frac{C_i(a_i^*)}{a_i^*}\frac{1}{(1-e)}+\frac{(1-F_{(m)}^{-i})}{f_{(m)}^{-i}}$. Each bidder will inflate their bid above the reservation price extracting informational rent. The term $\frac{(1-F_{(m)}^{-i})}{f_{(m)}^{-i}}$ is the typical hazard function commonly found in problems of adverse selection. The numerator is the probability of being selected into the team conditional on the bidder's reservation price, and the numerator is the change in the probability of being selected into the team corresponding to a unit increase in bid price above the reservation price. The greater the impact an increase in bid price has on the probability of

[5] Weather uncertainty is incorporated into the choice of abatement strategy.

team entry, the smaller the overall informational rent. Therefore, the nonpoint sources at the low-cost end of the distribution will extract greater informational rents than nonpoint sources at the high-cost end of the distribution. The optimal bid price line is always greater than the average abatement cost ensuring that the individual rationality constraint is always met given the Nash abatement strategy.

The remaining first order condition provides the optimal quantity bidding strategy. I rewrite the first order condition with respect to a_i:

$$\frac{\partial H}{\partial a_i} \equiv (1-F_{(m)}^{-i})\left[p_i - \left(\frac{\partial C_i(a_i)}{\partial a_i}\frac{1}{(1-e)}\right)\right] - \frac{k_1}{(1-e)} = 0$$

By substituting the optimal bid price line for p_i into the equation, the optimal bid quantity can be represented in terms of the relationship between the optimal bid price line and the marginal cost of actual abatement.

$$\frac{\partial H}{\partial a_i} \equiv (1-F_{(m)}^{-i})\left[\left(\frac{C_i(a_i)}{a_i}\frac{1}{(1-e)} + \frac{(1-F_{(m)}^{-i})}{f_{(m)}^{-i}}\right) - \left(\frac{\partial C_i(a_i)}{\partial a_i}\frac{1}{(1-e)}\right)\right] - k_1 = 0$$

$$\begin{cases} k_1 > 0 \\ a_i = a^{\max} \end{cases} \quad or \quad \begin{cases} k_1 = 0 \\ a_i < a^{\max} \end{cases}$$

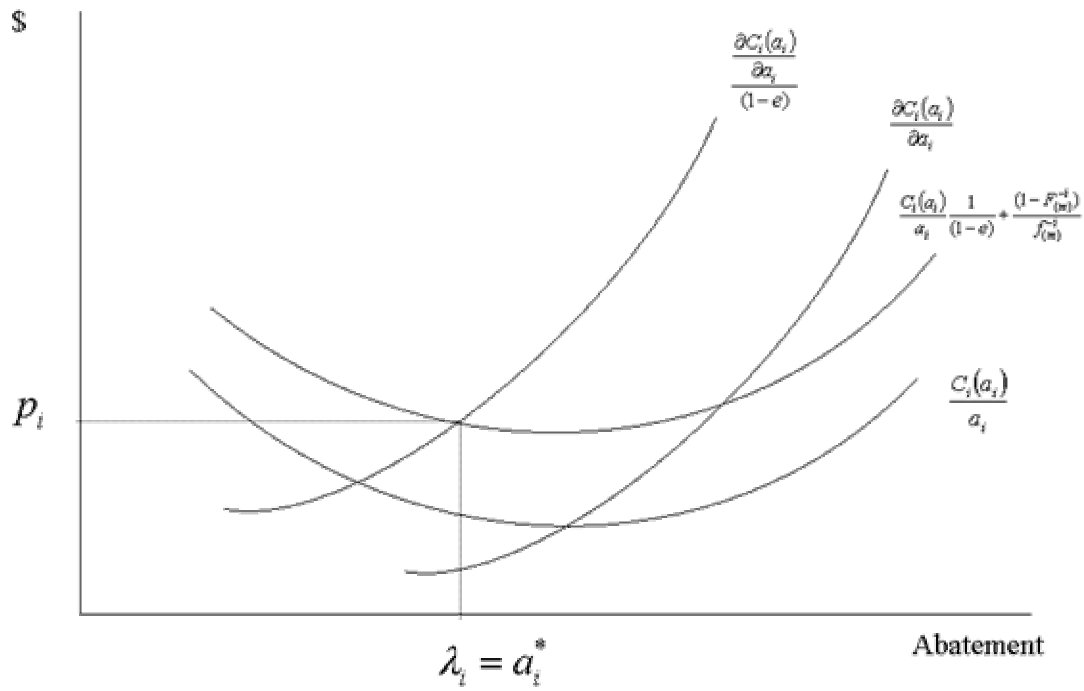
When the optimal bid price line is greater than the marginal cost of abatement at the maximum bid quantity, the nonpoint source bids the maximum. Otherwise, the nonpoint source will bid the expected profit maximizing quantity, where the optimal bid price line intersects the marginal cost of abatement curve (Figure 5).
QED

Vickrey's expected revenue equivalency of the uniform and discriminating price auction, under risk neutrality assumptions, have been well documented (Harris and Raviv, 1981). Traditionally, this has made the seller's choice of auction design unimportant in terms of efficiency. However, in the case of the team entry auction, market efficiency can be greatly affected by the choice of auction design. Only the discriminating price auction can guarantee that the contract prices of all team members are consistent with the incentives necessary for Nash abatement production strategy.

The stability of the Nash equilibrium abatement strategy is dependent on the provision of the optimal contract price for each team member. In the uniform price auction the optimal bid quantity is based on an expected contract price, which may not be the same as the realized contract price. The only guarantee is that it will be greater than the winning bid prices. However, any contract price that differs from the expected price will result in each team member producing abatement at some quantity other than their bid quantity..

This problem does not arise in the discriminating price auction, where bid prices and quantities equal the contracted price and quantities for all winning bidders. When actual draws from the distribution of the m^{th} order statistic differ from expectations, the affect is felt in the selection of team members. Bidders who thought they would be included in the team can be left out, or those expecting to be left out of the team can be selected into the team. In either case, there is no residual effect on the optimal provision of abatement from team members, since the bid price and quantity remain the contract bid and quantity for all nonpoint sources selected into the team, and it remains optimal for each to produce abatement equal to the bid level quantity.

Figure 5: Nonpoint Source Optimal Bid Price and Quantity (Discriminating Price Auction and Self-insuring Abatement Strategy)



3.7 Conclusions

The asymmetric information problems inherent in contracting for nonpoint source pollution abatement can be overcome using a collective performance contract. A two-stage contract, which pairs a team entry auction with a budget breaking team contract can results in a stable abatement production equilibrium. The point source must concede informational rents in order to achieve stability. The amount of informational rent is dependent upon the distribution of weather impacts on abatement in the watershed.

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