Mechanism Design for Nutrient Trading under Asymmetric Information*

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Abstract

The objective of this paper is to evaluate first- and second-best trading mechanisms for regulating point and nonpoint source phosphorus emissions. The trading mechanisms are differentiated on the degree to which regulators can observe abatement efforts. The deadweight losses attributable to informational asymmetries and those of the second-best mechanisms will provide regulators the shadow value of foregoing first-best measures.

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Introduction

Regulators of agricultural, nonpoint sources pollution have traditionally employed policies designed to encourage agricultural producers to adopt alternative (or "best") management practices (BMPs) to mitigate nutrient or sediment emissions (Heimlich and Claassen, 1998). These are typically cost-share programs (e.g., CRP), which pay farmers directly to adopt pollution abating management practices. Modest successes from these agri-environmental programs (Feather and Hellerstein, 1997; Ribaudo, 1989) illustrate the potential gains to the use of performance-based, market mechanisms such as effluent fees or tradable emissions permits to control agricultural pollution. It is not unrealistic to assume that future water quality regulation will employ various market mechanisms to encourage the adoption of BMPs (USEPA, 2001a).

While some BMPs have been found to be relatively inexpensive to implement (e.g., conservation tillage regimes on corn-bean rotations in the Midwest) there are others that are relatively expensive for a farm to implement (e.g., land retirement). It has been argued that one means to achieve substantial reductions in total emissions is to allow point sources such as wastewater treatment facilities or confined animal feeding operations (CAFOs) to purchase emissions-offsets from surrounding farmers. Motivating this argument is the assumption that it is cheaper for the utility or feedlot to avoid costly abatement investments by paying farmers to adopt nutrient best management practices on agricultural cropland.

The transition to permit trading mechanisms for regulating agricultural pollution has not been quite as rapid as one might have expected given the achievements of trade-based regulatory systems in other sectors (e.g., SO_2 permit trading for electric utilities – Coggins and Swinton,

1996; water trades in California – Howitt, 1998). The performance or appropriateness of trade-based mechanisms for nonpoint source (NPS) pollution has been questioned for a number of reasons (Stavins, 1995; Taff and Senjem, 1996). One persistent criticism of permit markets that include nonpoint sources is informational asymmetries lead to a moral hazard problem; i.e., farmers may misrepresent abatement efforts (Shortle and Dunn, 1986; Smith and Tomasi, 1999; Moledina et al., 2001). Many have examined methods of monitoring and enforcement to address this issue (Russell et al., 1986; Malik, 1993; Garvie and Keeler, 1994; Van Egteren and Weber, 1996; Amacher and Malik, 1996, 1998; Stranlaund and Dhanda, 1999; Harford, 2000; Kaplan et al., 2001). These illustrate that, in much the same way second-best policies may be preferable to first-best policies in the arena of water pricing (Tsur and Dinar, 1997), it may be that due to informational asymmetries, second-best mechanisms for regulating nonpoint pollution can achieve abatement more efficiently than can first-best mechanisms.

The objective of this paper then is to evaluate first- and second-best emissions trading mechanisms in the presence of moral hazard when both point and nonpoint sources are required to invest in and report abatement efforts. The mechanism design for the emissions trading system (ETS) is based on the extent to which the regulator can observe various nonpoint abatement efforts. A first-best trading mechanism (ETS-2) allows nonpoint sources to trade permits based on the full range of abatement efforts available to the source. This is compared to restricted trading mechanisms: one allowing nonpoint sources to base trades on crop choice, tillage, and fertilizer application method choices, but not on fertilizer application rates (ETS-1); and another allowing nonpoint sources to base permit trades only on crop choice and tillage practices (ETS-0).[1] Furthermore, the regulator can combine a trading mechanism an investment in monitoring

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[1] Basing permit trades on the degree to which BMPs are directly observable is similar to recent developments in USEPA-sponsored offset programs (Environomics, 1999).

equipment. Each trading/monitoring mechanism has associated deadweight losses due to asymmetric information and moral hazard. These losses provide regulators a means to compare optimal mechanism and monitoring choices when facing a budget constraint.

This paper is organized as follows. Section 2 defines the model environment and develops the regulator's welfare maximization problem. Section 3 uses regional data from the Minnesota River Valley to illustrate the effect of asymmetric information on the regulator's choice of control and mechanism. Section 4 provides discussion and extensions to the model framework. Section 5 concludes with summary comments.

The Model

There are n sources ($i = 1, ..., n$) that emit phosphorus into a watershed: m point sources ($i = 1, ..., j$) and n-j nonpoint sources ($i = j + 1, ..., n$). The regulator has observed historical emissions by sources for given expected weather patterns and can expect total emissions in the absence of regulation (ex-ante) to be $\overline{E} = \sum_{i=1}^{n} \overline{e}_i$. Total emissions in the presence of regulation (ex-post) are $E = \sum_{i=1}^{n} e_i$. Aggregate abatement is $A = \sum_{i=1}^{n} a_i$, where abatement effort (a_i) for source i is the difference between ex-ante emissions ($\overline{e}_i$) and ex-post emissions (e_i).

The cost to source i to abate quantity $\hat{a}_i$ is given as $C_i(\hat{a}_i)$ for i = 1, …, j, where $C_i(a_i)$ maps the cost-minimizing choice of abatement effort for each source necessary to achieve any desired abatement level. For nonpoint sources, abatement is a function of two parameters: observable abatement effort (*r*) and unobservable abatement efforts (*z*). These efforts can be loosely thought of as abatement effort on the observable extensive margin (e.g., crop choice and tillage practice) and abatement effort on the unobservable intensive margin (e.g., fertilizer

application methods and rates).[2] The nonpoint abatement cost function can then be written

$$C_i(a_i(r_i, z_i)) \ \forall i = j+1, ..., n.[3]$$

These cost functions exhibit the typical properties one might expect from constraining emissions: $C'_{ia}(a_i) > 0$ and $C''_{iaa}(a_i) > 0 \ \forall i = 1, ..., n$. Nonpoint abatement is increasing in abatement effort: $a'_r > 0$, $a'_z > 0$, which implies $C'_{ir}(a_i) > 0$ and $C'_{iz}(a_i) > 0 \ \forall i = j+1, ..., n$.

Regulator Problem

As individual costs are convex in abatement it must be that aggregate abatement costs for the watershed are also convex, $C'(A) > 0$ and $C''(A) > 0$. The function $B(A)$ maps the benefits to society of restricting emissions of phosphorus. Benefits are strictly concave in abatement, $B'(A) > 0$ and $B''(A) < 0$.[4]

With perfect information the regulator's problem, RP^0, is to choose aggregate abatement $\tilde{A}$ to maximize social welfare (SW):

[1] $$RP^0 \equiv \max_A SW(A) = \max_A B(A) - C(A).$$

The first-order condition characterizing a solution to [1] is necessary and sufficient given the assumptions on the benefit and cost functions. This is:

[1a] $$B'(\tilde{A}) = C'(\tilde{A}).[5]$$

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[2] Yiridoe and Weersink (1998) discuss abatement costs on the intensive and extensive margins.
[3] The regulator has observed (via surveys or direct observation) mean levels of *r* and *z* in the past and has mapped emission levels and profits as a function of weather, soil characteristics, *r* and *z* for nonpoint sources using a biophysical soils model. Furthermore, given observable data (i.e., weather and soil characteristics) and reported data (i.e., *r* and *z*) the regulator can accurately estimate emissions from nonpoint sources. As mentioned, the regulator can readily observe actual *r*-abatement efforts. The only parameter that the regulator cannot observe is the farm choice of *z*.
[4] Assume that $B'(0) > C'(0) = 0$ and that for *A* sufficiently large $B'(A) < C'(A)$.
[5] The zero abatement corner solution, whereby it is not optimal for the regulator to induce any level of abatement, is not considered.

Once chosen from [1a], the regulator can achieve $\tilde{A}$ by employing a number of regulatory mechanisms, generally a price (e.g., Pigouvian tax) or quantity (e.g., tradable quota or permit) approach.[6] Mechanisms have different advantages and disadvantages, but under full information they can achieve *Pareto optimality.* In the case of tradable emissions permits, the regulator may distribute endowments of tradable permits, $\overline{\ell}_i$, such that $\sum_{i=1}^{n} \overline{\ell}_i = \overline{E} - \tilde{A}$. Each permit represents the right to emit 1 pound of phosphorus into the river in the year the permit was issued. Under this trading system each source will buy and sell permits ($\tilde{x}_i$) and choose abatement ($\tilde{a}_i$) to solve the source problem (SP):

[2] $SP_i \equiv \min_{a_i, x_i} C_i(a_i) - P_\ell x_i$, where $x_i = \overline{e}_i - \overline{\ell}_i - a_i$ and P_ℓ is the equilibrium permit price.

The corresponding necessary and sufficient, *n+1* first-order conditions are:

[2a] $C_{ia}'(\tilde{a}_i) \geq P_\ell \cap \tilde{a}_i (C_{ia}'(\tilde{a}_i) - P_\ell) = 0 \; \forall i = 1, ..., n$ and $\sum_{i=1}^{n} \tilde{a}_i = \tilde{A}$.

The solution to [1] characterized by the vector of equilibrium abatement levels, $\tilde{\mathbf{a}} = \mathbf{a}(\tilde{\mathbf{r}}, \tilde{\mathbf{z}})$, results in the equalization of marginal abatement costs across sources and is *Pareto optimal.*[7]

Asymmetric Information

Assume now that the regulator has determined $\tilde{A}$ and $\tilde{a}_i$ œ $i = 1, ..., n$, given known costs and benefits, but cannot directly observe the nonpoint choice vector **z**. There now exists the incentive for nonpoint sources to misrepresent abatement efforts; i.e., to cheat. This cheating, if it occurs, will be of the following form. First, there is no possibility of point sources misrepresenting their abatement efforts or of nonpoint sources to misrepresent adoption of **r**,

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[6] See Weitzman (1974) for an exposition on price and quantity instruments to restrict production of an economic parameter.

both of which are freely observed. If nonpoint sources were fully to exploit the unobservable $\mathbf{z}$ (the vector of all possible unobservable abatement choices), they would simply report $\hat{\mathbf{a}} = \mathbf{a}(\mathbf{0}, \hat{\mathbf{z}})$, where $\hat{\mathbf{z}} = \max(\mathbf{z})$, and adopt $\hat{\mathbf{a}}' = \mathbf{a}(\mathbf{0},\mathbf{0}) = \mathbf{0}$. However, because the regulator knows $C_i(a_i(r_i, z_i)) \ \forall i = j+1,...,n$ and because $\mathbf{r}$ is freely observable, the nonpoint sources must report at the least $\hat{\mathbf{a}}(\hat{\mathbf{r}},\hat{\mathbf{z}}) = \tilde{\mathbf{a}}(\tilde{\mathbf{r}},\tilde{\mathbf{z}})$, resulting in the abatement vector $\hat{\mathbf{a}}' = \mathbf{a}(\hat{\mathbf{r}},\mathbf{0}) \le \tilde{\mathbf{a}}$.

Given this behavioral possibility the regulator can do one or more things depending on the extent to which $\hat{\mathbf{a}}' = \mathbf{a}(\hat{\mathbf{r}},\mathbf{0})$ is expected to deviate from $\tilde{\mathbf{a}} = \mathbf{a}(\tilde{\mathbf{r}},\tilde{\mathbf{z}})$. The regulator can simply accept the resulting aggregate abatement, $\tilde{A}' = \sum_{i=1}^{j} \tilde{a}_i + \sum_{i=j+1}^{n} \hat{a}'_i$, resulting from ETS-2. The regulator can eliminate abatement credits for $\mathbf{z}$ abatement choices (i.e., not allow nonpoint sources to base permit trades on expected abatement levels resulting from increasing unobservable abatement efforts) corresponding to ETS-0 and ETS-1. The regulator may also invest in monitoring efforts to reveal nonpoint choices of $\mathbf{z}$ and employ ETS-0, ETS-1, or ETS-2.

Assume that the regulator can purchase monitoring device (d) at cost $CC(d)$. One device (d=1) allows monitoring of nonpoint source application methods. Another device (d=2) allows monitoring of application rates. Both devices can be employed at control cost $CC(3)$.[8] The range of investment choices available to the regulator is then $d \in (0, 1, 2, 3)$, where the following relationship is assumed: $0 < CC(1) < CC(2) < CC(3) < CC(1) + CC(2)$.   The range of trading mechanisms is $m \in (0,1,2)$.   Corresponding to the regulator's choice of mechanism is an abatement level, $A(m) = A^m$, which solves [1] for ETS-0, 1, and 2, respectively. For each A^m the regulator will distribute tradable permits, $\sum_{i=1}^{n} \overline{\ell}_i = \overline{E} - A^m$, and invest in monitoring devices (d)

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[7] Trivially from the First Welfare Theorem (Varian, 1992).

to maximize expected social welfare. Given *d, m*, and cheating, the expected abatement levels, costs and benefits will be $A(d,m) = A^{dm}$, $C(A(d,m)) = C^{dm}(A^{dm})$, and $B(A(d,m)) = B(A^{dm})$.

The corollary to [1] is the unconstrained social welfare problem under asymmetric information [3], where the regulator chooses [*d, m*] to solve (RP^1):

[3] $RP^1 \equiv \max_{d,m} SW(A^{dm}) = \max_{d,m} B(A^{dm}) - C^{dm}(A^{dm}) - CC(d))$.

The first-order conditions for each $m \in (0,1,2)$ characterizing a solution, $\tilde{A}^{dm}$, are:

[3a] $B'_d(\tilde{A}^{dm}) - C'_d(\tilde{A}^{dm}) \geq 0$ n $\tilde{d}[B'_d(\tilde{A}^{dm}) - C'_d(\tilde{A}^{dm})] = 0, \forall m = 0,1,2$.

At $\tilde{A}^{dm}$ the marginal benefits to investing in monitoring devices will equal the marginal costs of the increased abatement level.

If the regulator is given an exogenous budget ($B) to spend on monitoring, the new regulator problem is to choose [*d, m*] to solve (RP^2):

[4] $RP^2 \mid_{\$B} \equiv \max_{d,m} SW(A^{dm}) = \max_{d,m} B(A^{dm}) - C^{dm}(A^{dm})$ subject to $CC(d) \leq \$B$.

For each trading mechanism, $m \in (0,1,2)$, the first-order conditions are:

[4a] $B'_d(\tilde{\tilde{A}}^{dm}) - C'_d(\tilde{\tilde{A}}^{dm}) - \tilde{\tilde{I}} \geq 0$ n $\tilde{\tilde{d}}[B'_d(\tilde{\tilde{A}}^{dm}) - C'_d(\tilde{\tilde{A}}^{dm}) - \tilde{\tilde{I}}] = 0$, and

[4b] $\$B - CC(\tilde{\tilde{d}}) \geq 0$ n $\tilde{\tilde{I}}[\$B - CC(\tilde{\tilde{d}})] = 0$.

Here, ? can be interpreted as the shadow value of increasing the budget to allow the purchase of increasing investments in monitoring efforts. Optimal investment is characterized by equating the marginal net benefits of increased abatement due to monitoring efforts with ?. Given the discrete nature of monitoring investments and relative effects on the cost function the optimal

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[8] For the moment the control costs are not a function of abatement levels, but are simply fixed costs required each year to monitor the relevant nonpoint source management practice (e.g., the purchase of LandSat imagery of the region to determine timing or type of tillage practice).

choice of $\tilde{\tilde{A}}^{dm}$ will always be the maximum allowable under B. The optimization required by the regulator in this sense has no explicit incentive to weigh the marginal welfare gains from having monitoring devices and their related investment costs.

To better model the regulator's choice set, suppose now that the regulator must levy a lump-sum tax (T) on the $(n-j)$ nonpoint sources to pay for the monitoring device(s). The regulator facing a balanced budget constraint will choose [d, m] to solve (RP^3):

[5] $RP^3 \equiv \max_{d,m} SW(A^{dmT}) = \max_{d,m} B(A^{dmT}) - C^{dmT}(A^{dmT}) - (n-j)T$

subject to $CC(d) \leq (n-m)T$.

For each trading mechanism, $m \in (0,1,2)$, the first-order conditions are:

[5a] $B_d'(\tilde{A}^{dmT}) - C_d'(\tilde{A}^{dmT}) - \tilde{I} \geq 0$ n $\tilde{d}[B_d'(\tilde{A}^{dmT}) - C_d'(\tilde{A}^{dmT}) - \tilde{I}] = 0$, and

[5b] $(n-m)T - CC(d) \geq 0$ n $\tilde{I}[(n-m)T - CC(d)] = 0$.

The solution to [5], $\tilde{A}^{dmT}$, will be equivalent to [3]. That is to say, the regulator will invest in monitoring devices so long as the gains in social welfare achievable under the monitored regime exceed the cost of purchasing the device.

Sand Creek Application

To illustrate these changes in social welfare across mechanisms and controls this paper utilizes data gathered from the Sand Creek watershed of the Lower Minnesota Basin. The Lower Minnesota is the largest source of the 1,000+ tons of phosphorus deposited by the Minnesota River (Faeth, 1998; Mulla, 1998) into the Mississippi River. The Sand Creek is one the largest sub-basins in the Lower Minnesota, draining 148,394 acres of agricultural land and contributing on average 115,000 lbs./year of phosphorus to the Minnesota River (MPCA, 1994). These are

substantial and important quantities given that the Minnesota Pollution Control Agency has targeted the Minnesota River for 40+% reductions in phosphorus emissions (MPCA, 1999). Individual sources in the Sand Creek and their average, annual contributions of phosphorus are listed in Table 1. Estimated costs and benefits for watershed abatement under the three trading mechanisms are listed in Table 2.

Evaluating the first-order conditions, [5a] and [5b], for all $m \in (0,1,2)$ it is possible to derive solutions to RP^3 given $CC(d)$. Marginal costs, abatement levels, and social welfare are listed in Table 3. Given a balanced budget constraint the optimal choice of permit mechanism and monitoring investment are described in Table 4 for ranges of monitoring costs. Treating each acre of agricultural land as a nonpoint source, it can be shown from Table 4 that if the cost per acre to monitor fertilizer application methods exceeds $2.81/acre, the regulator will choose to employ the restricted trading program (ETS-1) with no investments in monitoring.

Examining 14 current National Monitoring Programs (USEPA, 2001b), intensity of monitoring can be broadly separated into two categories: low intensity and high intensity (Table 5). Choosing values of $1.50/acre/year and $4.00/acre/year respectively for these two categories would correspond to monitoring costs of $222,000/year and $592,000/year for the Sand Creek.[9] Suppose these two values approximate $CC(1)$ and $CC(3)$. The solution to the balanced budget social welfare maximization will be $SW(\tilde{A}^{11T}) = \$3,231,394$ with $T = \$1.50/acre$. In this case, under asymmetric information the second-best mechanism ETS-1 outperforms the first-best mechanism, ETS-2.[10]

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[9] Recall the 148,394 acres of agricultural land.

Extension

Hitherto the optimization process is somewhat passive motivated by discrete control costs and trading mechanisms. The regulator simply chooses from the six social welfare outcomes possible under the possible combinations of $d \in (0,1,3)$ and $m \in (0,1,2)$. An extension to the regulator's choice set is possible under a permit trading mechanism. Following the distribution of permit endowments and the establishment of a permit market, assume that the regulator taxes nonpoint sources and uses this budget to purchase monitoring devices or to buy back permits (X) to maximize social welfare. This regulator will now choose $[\hat{d}, \hat{m}, \hat{X}]$ optimally subject to the balanced budget constraint so that $\hat{A} = A(d, m, X)$ solves RP^4:

[6] $\qquad RP^4 \equiv \max_{d,m,X} SW(A) = \max_{d,m,X} B(A) - C(A) - (n-m)T$

$\qquad$ subject to $P_\ell X + CC(d) \leq (n-m)T$.

The Lagrangean for RP^4 can be written:

[6a] $\qquad L(d, m, X) \equiv B(A) - C(A) + \mathbf{1}((n-m)T - CC(d) - P_\ell X)$.

The first-order conditions characterizing the solution to [6] are:

[6b] $\qquad B'_d(\hat{A}) - C'_d(\hat{A}) - \hat{I} \geq 0$ n $\hat{d}[B'_d(\hat{A}) - C'_d(\hat{A}) - \hat{I}] = 0$,

[6c] $\qquad B'_x(\hat{A}) - C'_X(\hat{A}) - \hat{I}P_\ell \geq 0$ n $\hat{X}[B'_x(\hat{A}) - C'_X(\hat{A}) - \hat{I}P_\ell] = 0$, and

[6d] $\qquad (n-m)T - CC(\hat{d}) - P_\ell \hat{X} \geq 0$ n $\hat{I}[(n-m)T - CC(\hat{d}) - P_\ell \hat{X}] = 0$.

It can be seen that at a solution, for positive monitoring investments or permit purchases the net the marginal benefits of abatement must equal ?, the shadow value on the budget constraint.

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[10] Note that given an exogenous budget greater than $592,000 the regulator will choose the first-best trading system resulting in $SW(\tilde{\tilde{A}}^{32}) = \$3,500,049$.

Of particular interest is the comparison between [6] and [5] when $CC(1) = \$222{,}000$; and $CC(3) = \$592{,}000$. Assume the regulator must choose between taxing nonpoint sources, $T = \$1.50/$acre or $\$4.00/$acre, respectively, employing ETS-1 or ETS-2,[11] investing in monitoring devices or buying back permits. Let the social welfare of the permit buy-back be denoted $SW(\hat{A}^{bm})$, where $b = H$ ($\$B = \$592{,}000$) or L ($\$B = \$222{,}000$) (Table 6). Comparing the social welfare outcomes under a balanced budget constraint the regulator preferences are given by:

$$[7] \qquad SW(\tilde{A}^{11T}) \; ™ \; SW(\hat{A}^{L2}) \; ™ \; SW(\hat{A}^{L1}) \; ™ \; SW(\tilde{A}^{01T}) \; ™ \; SW(\tilde{A}^{32T}) \; ™ \; SW(\hat{A}^{H2}) \; ™ \; SW(\hat{A}^{H1}).$$

Conclusions

It is clear from the burgeoning literature on both nonpoint pollution and mechanism design that the effects of asymmetric information on social welfare are both interesting and important topics to jointly consider. Furthermore the movement towards regulating nonpoint pollution via market mechanisms must overcome numerous critiques, one being that they are not appropriate for uncertain nonpoint emissions. This paper develops a simple regulator's problem for controlling point and nonpoint phosphorus emissions. Regulatory efficiency can be improved by using market mechanisms to target abatement efforts (e.g., ETS), but social welfare may be compromised when nonpoint sources are able to misrepresent abatement efforts.

Subject to a balanced budget constraint and known costs and benefits of abatement, the regulator can address deadweight losses due to moral hazard by investing in monitoring equipment or by implementing a quasi-cost-share mechanism (a permit buy-back scheme). Using water quality monitoring budgets under the National Water Quality Monitoring Program it is possible to determine back-of-the-envelope costs needed to evaluate a permit trading system

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[11] ETS-0 is strictly dominated by ETS-1 or ETS-2 (Table 2).

for regulating phosphorus emissions in a sub-watershed of the Minnesota River. Using these monitoring costs and a balanced budget constraint it is shown the restricted trading system (ETS-1) that taxes agricultural land (T = $1.50/acre) in order to monitor fertilizer application mechanisms ($CC(1)$) results in the highest social welfare ($3,231,394). This result holds even if the regulator is given the option to tax and buy-back permits.

Employing the restricted permit trading system, ETS-1 and not taxing or investing in monitoring equipment results in an estimated 10.7% deadweight loss or $2.50 per acre. Therefore if $CC(1)$ is greater than $370,174 it may be preferable for the regulator to tax and implement a permit buy-back scheme to circumvent the lump-sum nature of the monitoring costs modeled here. For example, if $CC(1) > \$B = \$222,000$, the buy-back option results in marginal social welfare gains (less than 1% over ETS: $d = 0$, $m = 1$).

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Table 1
Point and Nonpoint Sources of Phosphorus Loads in the Sand Creek

Point Sources	Emissions	Operations	Abatement Cost (C(a)/operation)
Wastewater Treatment Facility – Jordan	2,285	1	$0.033166(a)^2$
Wastewater Treatment Facility – New Prague	8,445	1	$0.004903(a)^2$
Feedlots	29,180	92	$0.839657(a)^2$
TOTALS	40,114 lbs/year		

Nonpoint Sources	Emissions	Acres	Abatement Cost (C(a)/acre)
Soil Map Unit - MN079A (>300')[a]	20,161	59,014	$136.56\,(a)^2$
Soil Map Unit - MN080A (>300')	4,777	11,673	$230.90\,(a)^2$
Soil Map Unit - MN081A (>300')	3,452	8,476	$87.73\,(a)^2$
Soil Map Unit - MN163A (>300')	2,180	8,300	$350.76\,(a)^2$
Soil Map Unit - MN165A (>300')	3,070	2,525	$14.85\,(a)^2$
Soil Map Unit - MN169A (>300')[b]	1,685	1,433	$-2.69\,(a)^2$
Soil Map Unit - MN171A (>300')	243	508	$155.69\,(a)^2$
Soil Map Unit - MN178A (>300')	155	549	$593.47\,(a)^2$
Soil Map Unit - MN196A (>300')	16,648	34,953	$131.74\,(a)^2$
Soil Map Unit - MN079B (<300')	8,188	9,219	$20.20\,(a)^2$
Soil Map Unit - MN080B (<300')	1,922	1,806	$34.16\,(a)^2$
Soil Map Unit - MN081B (<300')	1,453	1,373	$12.98\,(a)^2$
Soil Map Unit - MN163B (<300')	1,317	1,928	$51.89\,(a)^2$
Soil Map Unit - MN165B (<300')	1,579	499	$2.20\,(a)^2$
Soil Map Unit - MN169B (<300')[b]	1,118	366	$-0.40\,(a)^2$
Soil Map Unit - MN171B (<300')	41	33	$23.03\,(a)^2$
Soil Map Unit - MN178B (<300')	54	73	$87.97\,(a)^2$
Soil Map Unit - MN196B (<300')	7,016	5,665	$19.49\,(a)^2$
TOTALS	**75,058 lbs/year**	**148,394 acres**	

Source: Johansson (2000). [a] The values in parentheses refer to the distance separating the source of a water transport channel (Sharpley et al., 1999). [b] The nonpoint source abatement cost functions are estimated over the intensive management margin. In certain instances over this range the estimation indicates that the constrained profit exceeds the unconstrained profit (i.e., negative abatement costs). This phenomenon is reflected in actuality (adoption of conservation tillage regimes), but does revert to the expected convex form when extensive management practices are included (Johansson, 2000).

Table 2

Aggregate Costs and Benefits of Abatement for $m \in (0,1,2)$

Mechanism	Aggregate Costs	Aggregate Benefits
ETS-2	$C(A^{m=2}) = 0.000441\,(A^{m=2})$	$B(A^{m=2}) = 635.2024\,A^{m=2} - 50.2024(A^{m=2} * \ln A^{m=2})$
ETS-1	$C(A^{m=1}) = 0.000461\,(A^{m=1})$	$B(A^{m=1}) = 635.2024\,A^{m=1} - 50.2024(A^{m=1} * \ln A^{m=1})$
ETS-0	$C(A^{m=0}) = 0.001242\,(A^{m=0})$	$B(A^{m=0}) = 635.2024\,A^{m=0} - 50.2024(A^{m=0} * \ln A^{m=0})$

Source(s): Mathews et al. (2000), Johansson (2000).

Table 3

Marginal Costs, Abatement levels, and Social Welfare for RP^3

Mechanism	Monitoring Device	Abatement [a]	Social Welfare
	3	48,800	$3,500,049 -$CC(3)
ETS-2	1	41,690	$3,154,926 -$CC(1)
	0	30,801	$3,079,450
ETS-1	1	47,804	$3,453,394 -$CC(1)
	0	31,094	$3,083,220
ETS-0	0	28,323	$2,418,186

[b] Abatement levels correspond to the expected level of aggregate abatement given the regulator's choice of [d, m] and source choice of actual abatement given the presence of moral hazard.

Table 4

Optimal Mechanism/Monitoring Choices

CC(d)	Mechanism	Device	Social Welfare
$416,829 = CC(1) + \$46,655 > CC(3)$	ETS-2	3	$SW(\tilde{A}^{32T}) = \$3,500,049 - CC(3)$
$370,174 = CC(3) - \$46,655 > CC(1)$	ETS-1	1	$SW(\tilde{A}^{11T}) = \$3,453,394 - CC(1)$
$CC(1) = \$370,174$	ETS-1	0	$SW(\tilde{A}^{01T}) = \$3,083,220$

Table 5

Monitoring Costs for Different Watershed Size and Intensity

Location	Monitoring Cost	Acres	Monitoring Intensity ($/ac/yr)
Elm Creek, NE	$18,125	35,800	0.5063
Lake Pittsfield, IL	$88,540	7,000	12.6486
Sny Magill Watershed, IA	$111,116	22,780	4.8778
Otter Creek, WI	$25,000	7,040	3.5511
Lake Champlain Basin, VT	$109,718	7,576	14.4823
Waukegan River, IL	$1,441	7,640	0.1886
Morro Bay Watershed, CA	$62,000	48,450	1.2797
Lightwood Knot Creek, AL	$181,429	47,300	3.8357
Long Creek, NC	$71,648	28,480	2.5157
Totten and Eld Inlet, WA	$94,167	67,200	1.4013
Sycamore Creek, MI	$84,500	67,740	1.2474
Bad River, SD	$16,728	2,053,760	0.0082
Swatara Creek, PA	$35,000	27,520	1.2718
Walnut Creek, IA	$110,100	24,570	4.4811

Source: USEPA (2001b).

Table 6

Optimal Abatement, Government Buy-Back, and Social Welfare for RP^4

Budget	ETS	Abatement	Buy-Back	Tax/acre	Social Welfare
$222,000	1	39,484 lbs	3,742	$1.50	$SW(\hat{A}^{L1}) = \$3,092,258$
	2	32,633 lbs	3,879	$1.50	$SW(\hat{A}^{L2}) = \$3,092,579$
$592,000	1	39,685 lbs	8,605	$4.00	$SW(\hat{A}^{H1}) = \$2,707,709$
	2	38,828 lbs	9,094	$4.00	$SW(\hat{A}^{H2}) = \$2,734,604$