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Cheating on the Nonpoint Margin

How Much Might it Cost?

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ABSTRACT

The trading of pollution permits has been shown to achieve an optimal distribution of abatement across agents and time. However, when the environmental constraint is binding under imperfectly observed abatement practices, there is an incentive for sources to misrepresent their activities. This problem of asymmetric information and moral hazard can erode the efficiency of a permit system in achieving an environmental standard. It is hypothesized that this incentive to cheat causes similar or greater efficiency losses for a policy of uniform reductions.

This paper seeks to investigate the general properties of emissions trading efficiency as compared to uniform reductions when nonpoint sources can misrepresent their abatement activities. These abatement activities occur on two production margins: the extensive margin and the intensive margin. Earlier studies have investigated this issue, but have not specified or provided empirical examples of particular types of cheating and effects on abatement costs. Several propositions are developed here to describe how the difference in abatement efficiencies (as measured by cost-effectiveness or net benefits) of emissions trading and uniform reductions increase or decrease in magnitude when point and nonpoint sources are regulated simultaneously.

An empirical analysis of phosphorus abatement efficiencies for a minor watershed in the Minnesota River Valley reveal how cheating by nonpoint sources serves to shift the abatement burden onto the point sources, which will in turn shift the total cost curve for regulation. In addition, it is shown that the potential to cheat decreases at higher abatement levels. As a result both cost-effectiveness and net benefits decrease to a greater degree under uniform reductions than under emissions trading. The percentage difference then between the two policies describing the efficiency gains to regulating with emissions trading are 1.5 times greater for cost-effectiveness and more than 3 times greater when measuring deadweight losses. These results indicate that a system of tradable emissions permits to achieve abatement goals for this region should not be discounted based on the argument that asymmetric information will erode the efficiency of such a policy.

Keywords: Nonpoint pollution, emissions trading system, asymmetric information.

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1. INTRODUCTION

Permit trades between pollution sources across time have been studied extensively. In a competitive, deterministic market, sources will buy and sell permits such that the market price of permits is equal to marginal abatement costs. Furthermore, when banking and borrowing of permits are allowed, the net present value of marginal abatement costs is equalized across time periods (Kling and Rubin, 1997; Hagem and Westskog, 1998). In the absence of transaction costs it can be shown that an emissions trading system using intertemporal permits can achieve first-best solutions (Leiby and Rubin, 1998).

One criticism of nonpoint permit markets, however, is that emissions and abatement are difficult to monitor and enforce due to the very disperse nature of the nonpoint pollution. This asymmetric information problem can lead to a moral hazard; i.e., farmers may over-report actual abatement efforts (Shortle and Dunn, 1986; Smith and Tomasi, 1995, 1999). It has been argued that this same difficulty would be manifest in typical command-and-control regulation (Xepapadeas, 1992) and many have examined methods of monitoring and enforcement to deal with this problem (Xepapadeas, 1991; Van Egteren and Weber, 1996; Stranlaund and Dhanda, 1999). It is the objective of this paper to examine the effects of cheating on ambient level pollution monitoring when both point and nonpoint phosphorus sources are required to invest in abatement effort.

The cost effectiveness and net benefits to comply with environmental standards are compared analytically and empirically for an emissions trading system (ETS) and for a uniform reduction mechanism (UR). When polluters do not cheat and abatement costs are heterogeneous, an emissions trading system is shown to have a higher cost effectiveness than a standard command-and-control regulatory approach that mandates uniform phosphorus reductions across sources. These gains in compliance efficiency (measured in average costs of abatement) are shown to increase when cheating is incorporated. Furthermore, when the marginal benefits of pollution abatement are known, it is possible to evaluate the welfare implications of cheating. Under certain general conditions the deadweight loss of regulating emissions by uniform reductions also increases with cheating.

The paper is organized as follows. Section 2 develops the model environment including a description of point and nonpoint sources and related abatement cost functions. Section 3 derives the total cost of compliance for naïve polluters (cheating not allowed) under an ETS and CAC phosphorus regulation. Section 4 derives the total cost of compliance for savvy polluters (cheating allowed) under an ETS and CAC phosphorus regulation. Section 5 defines compares compliance efficiency and develops the analytic properties of efficiency under naïve and savvy polluters. Section 6 evaluates these efficiency properties using an empirical example from the Minnesota River Valley. Section 7 concludes. The appendix contains proofs of the propositions and a table of variables for convenient notational reference.

2. MODEL SETTING

This paper uses a static and two-period model (t = 1, 2) to illustrate the gains to trading and the potential losses associated with asymmetric information. There are n sources (i = 1,…, n) that emit phosphorus into a river. Of those sources there are m point sources (i = 1, …, m) and n-m nonpoint sources (i = m+1, …, n). The regulator has observed historical emissions by sources and given expected weather patterns and can assume that total emissions in the absence of regulation are: $E(t) = \sum_{i=1}^{n} E_i(t)$ for t = 1 and 2. The regulator chooses an environmental standard (S) that is a function of historical emissions. The environmental standard can therefore be written as: $S = \alpha(E(1) + E(2))$, where α represents the proportion of historical emissions allowable under the two-period environmental standard. To reach this standard the regulator either issues tradable permits (Q) representing the right to emit phosphorus into the river that are equal in quantity to S, or she requires each source to reduce emissions by (1-α)% over the period of regulation.

For point sources, the abatement cost function is given by $C_i(a_i(t))$ where a represents the number of pounds (lbs) abated by the source. This function maps the cost of adopting management activities required to achieve a lbs of abatement in time, t. This cost is given as the difference between unconstrained profits and constrained profits (Montgomery, 1972; Just and Zilberman, 1988; Malik et al., 1993). We assume that emission monitors are already installed on these sources or could be at low cost. The regulator is therefore well aware of point source emissions.

Similarly, for nonpoint sources, the abatement cost function is given by $C_i(a_i(t))$. However, here abatement is a function of two parameters: abatement effort on the extensive margin (r) and abatement effort on the intensive margin (z).[1] Abatement effort on the extensive margin includes practices such as crop choice and tillage practice, and method of fertilizer application. Abatement effort on the intensive margin primarily refers to rate of fertilizer application. 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. In fact, the regulator can readily observe actual r-abatement efforts. The only parameter that the regulator cannot observe is the farm choice of z.[2]

[1] See Yiridoe and Weersink (1998) for an empirical discussion of abatement costs on the intensive and extensive margins.

[2] Unlike many other treatments of asymmetric information, it is the choice of abatement effort with which the regulator is uncertain, not the cost function.

For a two-period model[3] we can describe the abatement cost functions as follows: $C_i(a_i(t))$ for $i = 1, \ldots, m$; and $C_i(a_i(r(t), z(t))$ for $i = m+1, \ldots, n$. Assume that abatement costs are increasing in abatement at an increasing rate: $C'_a(a_i(t)) > 0$ and $C''_{aa}(a_i(t)) > 0$. Assume also $C'_t(a_i(t)) = 0$,[4] or that the abatement cost functions are not changing over time. It also is sensible that nonpoint abatement is increasing in abatement effort: $a'_r > 0$, $a'_z > 0$[5] for $i = m+1, \ldots, n$. This implies, $\dfrac{\partial C_i(a_i(r(t), z(t))}{\partial r} = \dfrac{\partial C}{\partial a}\dfrac{\partial a}{\partial r} > 0$ and $\dfrac{\partial C_i(a_i(r(t), z(t))}{\partial z} = \dfrac{\partial C}{\partial a}\dfrac{\partial a}{\partial z} > 0$.[6]

3. NAÏVE POLLUTERS (Full Information)

When sources behave naively in this model, it is to say that they do not engage in cheating, i.e., sources will correctly report levels of abatement effort.

Two-Period Emission Trading

Under the permit system sources are allowed to bank, borrow, and trade permits subject to the non-negativity constraint on the bank account in the terminal period. Formally, given an endowment of permits, $(q_i(t))$, each source will choose abatement levels, $(a_i(t))$, and permit purchases/sales, $(x_i(t))$, in each period to solve the following cost-minimization problem, $J^{ETS/N}$, where superscript *ETS/N* indicates an emissions trading system with naïve polluters:

$$J^{ETS/N} \equiv \min_{a(t),x(t)} (C_i(1) + P(1)x_i(1)) + \delta(C_i(2) + P(2)x_i(2)),$$

$$\text{subject to:} \qquad \begin{aligned} &B_i(0) = 0 \\ &B_i(1) = q_i(1) + a_i(1) + x_i(1) - E_i(1) \\ &B_i(2) \geq 0, \end{aligned}$$

where *P(t)* represents the equilibrium price in periods 1 and 2, δ represents the discount factor, and *B(t)* represents the number of emissions permits in the bank account initially and in periods 1 and 2.

Given the assumption about the convexity of the abatement cost function we know that the first order Lagrangian conditions for cost minimization are necessary and sufficient. Given that the sum of

[3] Henceforth, we will assume that t = 1 and 2, unless otherwise specified.
[4] Increasing abatement cost functions over time might correspond to growing populations serviced by wastewater treatment facilities. Decreasing abatement cost functions over time might correspond to better seed varieties that respond better to conservation tillage or lower fertilizer applications. For now we consider the case where this differential is zero, i.e., status quo.
[5] It should be noted that *z* represents abatement effort on the intensive margin. Increasing *z* corresponds to a lower fertilizer application rate.
[6] The derivatives of the nonpoint cost function with respect to both *r* and *z* are important and will be addressed later.

permit sales/purchases in each period equal zero and that the sum of permits are equal to the environmental standard, we can solve for the cost-minimizing values of $a_i^{ets/n}(t)$ and $x_i^{ets/n}(t)$ that characterize a solution to the equilibrium price condition: $P(1)=\delta P(2)=P^n$. Total cost of compliance is the sum of point source costs and nonpoint source costs in each period:

$$TC^{ETS/N} = \sum_{i=1}^{m}[C_i(a_i^{ets/n}(1) + d(C_i(a_i^{ets/n}(2))] + \sum_{i=m+1}^{n}[C_i(a_i^{ets/n}(1) + d(C_i(a_i^{ets/n}(2))]$$

Uniform Reduction

Under regulation requiring a uniform reduction in emissions by some given percentage over a two-year period, naï ve sources will simply solve the following cost-minimization problem, $J^{UR/N}$, where superscript *UR/N* indicates uniform reduction with naï ve polluters:

$$J^{UR/N} \equiv \min_{a(t)} (C_i(1) + d(C_i(2),$$

$$\text{subject to: } a_i^{ur/n}(1) + a_i^{ur/n}(2) \geq (1-a)(E_i(1) + E_i(2)).$$

Given known abatement cost functions, total cost of compliance is given by:

$$TC^{UR/N} = \sum_{i=1}^{m}[C_i(a_i^{ur/n}(1) + d(C_i(a_i^{ur/n}(2))] + \sum_{i=m+1}^{n}[C_i(a_i^{ur/n}(1) + d(C_i(a_i^{ur/n}(2))]$$

4. SAVVY POLLUTERS (Asymmetric Information)

When we allow sources to deviate from naï ve behavior, there is a range of options available to them. It is assumed that point sources do not cheat, because it is too easy for the regulator to catch them and impose punishment. For the same reasons, it is assumed that nonpoint sources do not cheat on the extensive margin. However, the nonpoint sources can cheat on the intensive margin without fear of regulator observation and/or punishment. Solving the emissions trading system and the uniform reduction system allowing for savvy behavior may yield a different level of compliance efficiency as cheating on the intensive nonpoint margin will serve to shift the percentage of total abatement towards the point sources. When the point sources have higher abatement costs than the nonpoint sources, the result will be to increase the slope of the total cost (marginal cost) function.

Two-Period Emission Trading

Under the permit system sources are allowed to bank, borrow, and trade permits subject to the non-negativity constraint on the bank account in the terminal period. Formally, given an endowment of permits, $(q_i(t))$, each *point* source will choose abatement levels, $(a_i(t))$, and permit purchases/sales, $(x_i(t))$, in each period to solve the following cost-minimization problem, $J^{ETS/S} \equiv J^{ETS/N}$.

Due to the savvy nature of nonpoint sources, they will not cheat on the extensive margin. Furthermore, because the regulator has accurate knowledge of nonpoint abatement cost functions, the savvy nonpoint source will not be able to deviate from naï ve, cost-minimizing choices of permit sales/purchases.[7] This implies that the nonpoint sources will first solve $J^{ETS/S}$ as if naï ve. He/she will then report $a_i^n(r_i^n(t), z_i^n(t))$ and $x_i^n(t)$ to the regulator taking P^n as given. However, actual abatement levels will reflect cheating on the intensive margin; the polluter will set intensive abatement levels to zero to minimize costs, i.e., $a_i^s(r_i^s(t), z_i^s(t)) = a_i^s(r_i^n(t), 0) \le a_i^n(r_i^n(t), z_i^n(t))$. Given the assumptions about the nature of marginal abatement efforts on costs, this inequality is strictly "less than" if the potential for cheating exists, i.e., if $z_i^n(t) \ne 0$.

Given that the sum of permit sales and purchases in each period equal zero and that the sum of permits are equal to the environmental standard, we the solve cost-minimizing values of $a_i^{ets/s}(t)$ and $x_i^{ets/s}(t)$ that characterize a solution to $P(1)=\delta P(2)= P^s$. Total cost of compliance is given by:

$$TC^{ETS/S} = \sum_{i=1}^{m}[C_i(a_i^{ets/n}(1) + \boldsymbol{d}(C_i(a_i^{ets/n}(2))] + \sum_{i=m+1}^{n}[C_i(a_i^{ets/s}(1) + \boldsymbol{d}(C_i(a_i^{ets/s}(2))]$$

Uniform Reduction

Under command-and-control regulation requiring a reduction in emissions by some given percentage over a two-year period, sources will solve as before the cost-minimization problem, $J^{UR/S} \equiv J^{UR/N}$. As before, savvy nonpoint sources will[8] select abatement efforts equal to zero on the intensive margin, so that $a_i^s(r_i^s(t), z_i^s(t)) = a_i^s(r_i^n(t), 0) < a_i^n(r_i^n(t), z_i^n(t))$ or $a_i^s(r_i^s(t), z_i^s(t)) = a_i^n(r_i^n(t), z_i^n(t))$ when $z_i^n(t) = 0$. Total cost of compliance is given by:

$$TC^{UR/S} = \sum_{i=1}^{m}[C_i(a_i^{ur/n}(1) + \boldsymbol{d}(C_i(a_i^{ur/n}(2))] + \sum_{i=m+1}^{n}[C_i(a_i^{ur/s}(1) + \boldsymbol{d}(C_i(a_i^{ur/s}(2))].$$

[7] In this case the regulator assumes that the savvy nonpoint source is capable of solving for cost-minimizing levels of abatement and permit transactions.
[8] I think it appropriate here to note that "will" does not imply that these farmers would cheat in reality; it just implies that they have incentives to cheat when behaving optimally given these assumptions.

5. EFFICIENCY

When examining policies aimed at achieving an environmental standard it is important to define concepts, which enable comparisons amongst these policies. An *efficient* policy would maximize the net present benefits to society of reducing pollution. This entails maximizing the discounted distance between the total benefit function and the total cost function for the appropriate years. This will occur with well-behaved total benefits and total cost functions when the discounted marginal benefits of pollution reduction are equal to the discounted marginal cost of reducing an extra unit of pollution. For one period this is simply the intersection of the demand curve for pollution reduction with the supply curve for pollution reduction (i.e., when the slope of the total benefit function equals the slope of total cost function). Often it is difficult for a regulatory agency to correctly assess the actual benefits to pollution reduction or to assess the cost to reduce pollution, making the task of choosing an efficient environmental standard nearly impossible.

To sidestep this issue, often an environmental standard is often chosen without considering discounted abatement costs. Instead, various factors such as the health of the affected human, animal and resource populations are used to determine a minimum standard for the pollutant, under which is determined "unacceptable" by society. Once the standard has been chosen the generally accepted method for comparing policy alternatives is *cost effectiveness*.

Cost Effectiveness

One means to compare the cost effectiveness of regulation is to examine the average cost per pound of abatement under a particular regulation. For simplicity assume there is a single period (t = 1), a single point source (m) with convex abatement cost function, $C_m(a_m)$, and a single nonpoint source (n) with convex abatement cost function, $C_n(a_n)$, such that $C_m(a) > C_n(a)$. The regulator either mandates a uniform reduction of $S_i = \alpha(E_i)$ for $i = m$ and n or distributes permits to each source equal to S_i and allows trading of these permits. Furthermore, assume that the point source is a net buyer of permits and the nonpoint source is net seller of permits. Given these definitions and assumptions the properties of the abatement efficiencies can be developed. Let average cost of abatement be given by: $ACA \equiv TC/TA$ (where TA represents total abatement). The gains (losses) in cost effectiveness due to emissions trading (CE) can then be defined as the percentage difference between average abatement costs: $CE^{N,S} \equiv (ACA^{UR/N,S} - ACA^{ETS/N,S})/ACA^{ETS/N,S}$, where n and s refer to naï ve and savvy respectively.

If sources have heterogeneous abatement costs (i.e., $C_m(a_m) \neq C_n(a_n)$) then regulation, which allows sources to shift emissions between sources and time periods, has compliance costs equal to or less than a uniform reduction policy (i.e., $CE^N \geq 0$). This follows directly from the intuitive reasoning behind permit markets in general: as long as there are heterogenous abatement cost functions, there will be incentives under a permit system to trade in order to minimize costs. As stated earlier these trades will seek to equalize the net present value of marginal abatement costs across sources and periods.

When cheating is observed, it is much more difficult to determine analytic properties of cost effectiveness and potential gains to emissions trading. For example, it is difficult to know to what degree CE^N is greater/less than CE^S. A movement from $z^n(t) > 0$ to $z^s(t) = 0$ under cheating will cause *TC* and *TA* to fall deviating from the environmental standard. The effect on average abatement costs and efficiency depends on the relative magnitude of these changes.

To explore these further a short discussion of the abatement effort on the intensive and extensive margins is necessary. The specific functional form for nonpoint abatement is not known given extensive and intensive abatement investments, however it is reasonable to assume that abatement is increasing in abatement efforts, $a'_r > 0$ and $a'_z > 0$. The second derivatives are not known however, and may vary depending on the discrete combinations of management practices and soil type.[9] As intensive efforts are unobservable, consider the three cases of interest: (A) $\dfrac{\partial^2 a_i^{n,s}(r(t),z(t))}{\partial z(t)^2} > 0$ (the marginal effect on abatement increases with intensive margin efforts at an increasing rate); (B) $\dfrac{\partial^2 a_i^{n,s}(r(t),z(t))}{\partial z(t)^2} = 0$ (the marginal effect on abatement increases with intensive margin efforts at constant rate); and (C) $\dfrac{\partial^2 a_i^{n,s}(r(t),z(t))}{\partial z(t)^2} < 0$ (the marginal effect on abatement increases with intensive margin efforts at a decreasing rate). These cases can be thought of in a Cobb-Douglas framework for the production of abatement given *r* and *z* as inputs, where case (A) corresponds to the coefficient of *z* being greater than one, case (B) corresponding to the coefficient of *z* being equal to one, and case (C) corresponding to the coefficient of *z* being less than one.

Proposition 1

If the potential for cheating is not changing at different levels of abatement (i.e., $a_n^{ets/s}(r_n^s(t), z_n^s(t)) - a_n^{ets/n}(r_n^n(t), z_n^n(t)) = a_n^{ur/s}(r_n^s(t), z_n^s(t)) - a_n^{ur/n}(r_n^n(t), z_n^n(t))$) then the percentage difference between abatement costs under uniform reductions and permit trading increases with cheating,

[9] See Johansson et al. (2000) for estimation of nonpoint abatement cost functions with discrete management practices.

or $CE^N < CE^S$. That is, if sources with typical convex abatement cost functions are engaged in permit trading given at higher levels of abatement the amount of potential cheating is constant (i.e., case (B)), then the gains in cost effectiveness due to emissions trading increases with savvy polluters.[10]

Net Benefits

As mentioned earlier, if the marginal benefit function is known (the inverse demand function for environmental amelioration) and the marginal cost function is known (the supply function for environmental amelioration) it is possible to determine the efficient level of pollution abatement and the deadweight loss due to deviations from that standard. For the above case, assume that the standard ($S^{N,S}$) is chosen such that the marginal benefits of abatement is equal to the marginal cost of abatement for the emissions trading system (with naï ve or savvy polluters). Net benefits under a regulatory mechanism are defined as the sum of consumer surplus and producer surplus bounded by the environmental standard (*S*). As is shown above the emissions trading system is more cost effective than a uniform reduction system and therefore, the gain in efficiency due to emissions trading can then be defined as the difference between net benefits under a uniform reductions and emissions trading. This difference is simply the deadweight loss (*DWL*) of choosing S for the uniform reductions system (see Figure 1 for an example). The relationship of interest for this paper is then whether the measure of deadweight loss increases or decreases when polluters act in a savvy manner.

Proposition 2

Let the total benefit function and the total cost function be denoted

$TB = TB(a)$ and $TC = TC(a)$, where a is the abatement level.

Assume *TB*’ > 0, *TB*” is a negative constant, *TC*’ > 0, and *TC*” is a positive constant. Assume also $\frac{\partial^2 a_i^{n,s}(r(t), z(t))}{\partial z(t)^2} = 0$. A sufficient condition for $DWL^N < DWL^S$ is

$$\left(\frac{\partial^2 TC^{ETS/S}}{\partial a^2}\right)^{-1} - \left(\frac{\partial^2 TC^{UR/S}}{\partial a^2}\right)^{-1} \geq \left(\frac{\partial^2 TC^{ETS/N}}{\partial a^2}\right)^{-1} - \left(\frac{\partial^2 TC^{UR/N}}{\partial a^2}\right)^{-1}.$$

This proposition states that under certain conditions the deadweight loss found when using uniform reductions as opposed to emissions trading increases when nonpoint polluters are allowed to behave strategically if the difference in the inverse slopes of the supply functions is greater with savvy behavior than with naï ve behavior.[11]

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[10] This relationship is further developed in the proof found in the appendix.
[11] See proof in the appendix.

6. APPLICATION

The Minnesota Pollution Control Agency (MPCA) and the United States Environmental Protection Agency (USEPA) have targeted the Minnesota River for phosphorus reductions. The Minnesota River Basin encompasses approximately 10 million acres and hosts a population of approximately 700,000 in Central and Southern Minnesota before joining the Mississippi River in Saint Paul, Minnesota. The majority of the region is involved with agriculture, contributing about 50% of the state's corn and soybean production and hosting more than 20% and 40% of beef and hog production respectively. The Minnesota River has been classified as one of America's most endangered rivers due to agricultural runoff (American Rivers, 2000). Contributions of sediment, nitrogen, and phosphorus by the Minnesota River to the Mississippi River have been linked to severe eutrophication and hypoxia problems downstream (USEPA, 1997). Specifically, It has been estimated that the phosphorus levels need to be reduced by 40% to provide a livable environment for aquatic plants and animals (MPCA, 1999). Current elevated levels of phosphorus resulting from wastewater treatment discharge and from agricultural runoff generate eutrophic conditions that severely reduce biologically available oxygen necessary for these aquatic species. In addition, the eutrophication problem adversely affects recreational, industrial, and consumptive purposes.

For this section a stylized model will be developed using data gathered from the Sand Creek sub-watershed of the Lower Minnesota River Basin. This region was chosen for several reasons. First, the Lower Minnesota contributes significant amounts of phosphorus to the total load of the Minnesota River. This contribution has been estimated to be between 17.2 % and 32.5% (Faeth, 1998; Mulla, 1998). These estimates reflect that the Lower Minnesota is the largest source of phosphorus in the Minnesota River. Second, the Sand Creek is one of the largest sub-basins of the Lower Minnesota Basin. Its total phosphorus contribution is 115,000 lbs/year or 11% of the Lower Minnesota total load. The acreage and phosphorus loading values are summarized in Table 1.

Abatement cost functions for the point and nonpoint sources were estimated using stochastic frontier analysis (Johansson et al., 2000). Abatement costs are found to be heterogeneous and convex in abatement, however the second derivative of nonpoint abatement with respect to intensive marginal efforts was found to be discontinuous between discrete management choices and soils. A weighted average of soils for the watershed reveals that case (B) best describes the effect of intensive margin changes. This indicates on average that both cost effectiveness and deadweight loss measures of the gains to emissions trading should increase with cheating. The total cost and marginal cost functions for the four scenarios are presented in Table 2. The lowest total and marginal costs for a given abatement levels is found under an emissions trading system with naïve polluters, the highest costs are under uniform reductions with savvy polluters.

Cost Effectiveness

An environmental standard of 40% was chosen and the average cost of abatement was calculated using the values from Table 2. From these, values for CE^N and CE^S were determined holding the standard constant, showing that with savvy behavior efficiency gains attributable to using an emissions trading system increase from 55% to 84% (see Table 3).

For a typical 343-acre farm in this region the cost per year per acre to comply with the 40% phosphorus abatement regulation would be $4.82 and $3.68 respectively for uniform reduction and emissions trading with naïve polluters. For savvy polluters the cost per year per acre becomes $5.43 and $3.88 respectively. It is interesting to compare these values to current Conservation Reserve Program contracts paid to farmers in this region. In 1988, farmers in this region were willing to accept $70 per acre for CRP contracts. Current CRP contracts range between $73 and $109 per acre for this area. The estimated area in this region under CRP contracts is approximately 2500 acres per year (Taff, 1999). Assuming that this area represents marginal production acres, we can assume a resulting abatement of 4500 lbs/year, or 4%, at a cost of $53 per pound (assuming $100 per acre CRP contract). By comparison a similar level of uniform abatement with savvy polluters would cost $3.01 per pound.

Net Benefits

To calculate deadweight loss measures it was necessary to first estimate a marginal benefit function for phosphorus abatement in the Sand Creek. Fortunately, a recent study has looked at this issue for the Minnesota River Valley (Mathews et al., 2000). Combining revealed and stated preferences, Mathews et al. (2000) estimate random effects probit model for phosphorus abatement in the Minnesota River similar to Loomis (1997). Using these estimates it is possible to estimate the mean willingness-to-pay for a 40% phosphorus abatement level and the marginal effect of water quality on willingness-to-pay. Calibrating these results to the Sand Creek (i.e., 3.5% of the total phosphorus load in the Minnesota River) it is possible to determine the total benefits to 3.5% of the regional population for a 40% reduction in Sand Creek emissions. To generate the inverse demand function that corresponds to these results it is necessary to assume several things. First it is reasonable to assume that the marginal willingness-to-pay approaches zero as abatement approaches 100%. Also the form of the inverse demand function is assumed to be semi-log, which approximates the estimate of total benefits and has a slope that approaches zero as abatement approaches 100%.[12] Using this function form, the total benefits area, and slope results the marginal benefit function is estimated to be

$$MB = 585 - 50.2024 * LN(abatement) \text{ (see Figure 1).}$$

Using the slopes of the marginal cost functions from Table 2, the sufficient condition for *Proposition 3* is satisfied (the difference of the inverse slopes for savvy polluters is 629 lb/acre and is 533 lb/acre for naï ve polluters). The resulting deadweight losses should indicate that efficiency gains from emissions trading regulation increase when polluters behave in a savvy manner. In fact the deadweight loss values are three times greater for savvy polluters (Table 4).

Dynamic Efficiency

Up to this point the empirical application has focused on static measures of efficiency. There are some interesting features of the dynamic model that should be explained as well. First, abatement effort with naï ve polluters will be shifted to later periods such that the discounted abatement costs are equalized across time, abatement constraints permitting. The analysis of the above scenarios will only change marginally. When polluters are constrained to maintain permit trading levels and prices to avoid detection by the regulator as in the above analysis, the cheating involved is somewhat passive. As sources can shift abatement (in either uniform reductions or emissions trading) to later periods, the effect of this passive form of cheating will be to decrease cheating potential in later periods if case C holds (i.e., $\frac{\partial^2 a_i^{n,s}(r(t), z(t))}{\partial z(t)^2} < 0$) and to increase cheating potential in later periods if case A holds ($\frac{\partial^2 a_i^{n,s}(r(t), z(t))}{\partial z(t)^2} > 0$). The marginal cost of abatement will change accordingly; if case C, marginal costs of abatement will approach naï ve costs; and if case A, marginal costs of abatement will increase with time. If a more strategic form of cheating was observed (i.e., polluters can choose optimal levels of cheating and trading across periods), then in case C (case A) polluters will shift abatement from naï ve levels to earlier (later) periods to maximize their cheating potential.[13]

[12] See Deaton and Muellbauer (1980) for discussion of functional forms for demand functions.
[13] See Johansson (2000) for further comparisons between the static and dynamic models.

7. IMPLICATIONS

This paper was motivated by the argument that the regulation of nonpoint nutrient emissions could be undermined by asymmetric information and possible noncompliant behavior by nonpoint polluters. However, in order to achieve the substantial nutrient reductions necessary to meet federal water standards it is now necessary to include agricultural nonpoint pollution in any meaningful abatement strategy. There are potential cost savings by regulating point and nonpoint sources using an emissions trading system. The question this paper seeks to answer is whether the efficiency gains to point-nonpoint emissions trading when compared to a command-and-control approach increase or decrease when farmers misrepresent their abatement efforts.

The implication of *Proposition 1* is that the cost effectiveness of an emissions trading system as compared to uniform reductions may becomes greater in magnitude when polluters have the incentive to cheat due to asymmetric information about their abatement efforts. If the ability to cheat is constant as abatement effort increases this condition will always hold. This implies that if the regulator can hold the cheating of polluters to a bounded range, the attractiveness of an emission permit trading system increases when compared to a command-and-control approach. Finally, *Proposition 3* describes sufficient conditions that generalize the cost effectiveness relationships from *Propositions 1* and *2* to welfare measures of efficiency.

These propositions can be considered extensions to the relationships found by Shortle and Dunn (1986) and Smith and Tomasi (1995, 1999), who find that with asymmetric information estimated runoff incentives (i.e., permits) are superior to runoff standards (i.e., uniform reductions), but do not examine the magnitude this superiority in a second-best world with observable point sources. Specifically in the case of phosphorus pollution in the Minnesota River Valley, where the extensive margin is observable and the intensive margin is not, an emissions trading system should not be discounted solely on the basis of possible moral hazard. First, abatement costs under uniform reduction or emissions trading is much less costly than current programs that target marginal lands for abatement practices. Second, *Propositions 1-2* are shown to hold for phosphorus reductions in the Sand Creek: when farmers do not (do) cheat the percentage difference between cost effectiveness is 55.17% (84.08%). Using an estimated marginal benefit and marginal cost functions for phosphorus abatement *Proposition 3* also holds for the Sand Creek illustrating that the gains to regulating with emissions trading increase when polluters misrepresent abatement efforts as compared to regulating with uniform reductions: when farmers do not (do) cheat the DWL associated with uniform reductions is $103,082 ($368,033).

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APPENDIX

Proof Proposition 1

(1.1) $CE^{N} \equiv (ACA^{UR/N} - ACA^{ETS/N})/ACA^{ETS/N}$

(1.2) $CE^{S} \equiv (ACA^{UR/S} - ACA^{ETS/S})/ACA^{ETS/S}$

(1.3) $CE^{n} < CE^{S} \Rightarrow \dfrac{(TC^{UR/N}/TA^{ER/N})}{(TC^{ETS/N}/TA^{ETS/N)}} < \dfrac{(TC^{UR/S}/TA^{UR/S})}{(TC^{ETS/S}/TA^{ETS/S})}$

(1.4) $\Rightarrow \dfrac{TC^{UR/N}}{TC^{ETS/N}} < \dfrac{TC^{UR/S}}{TC^{ETS/S}} \times \dfrac{TA^{ETS/S}}{TA^{UR/S}}$

Let $a_n^{ets/s}(r_n^s(t), z_n^s(t)) - a_n^{ets/n}(r_n^n(t), z_n^n(t)) = a_1$ and $a_n^{ur/s}(r_n^s(t), z_n^s(t)) - a_n^{ur/n}(r_n^n(t), z_n^n(t)) = a_0$.

Let $TC^{ETS/N} - TC^{ETS/S} = c_1$ and $TC^{UR/N} - TC^{UR/S} = c_0$. Let $\dfrac{TC^{UR/N}}{TC^{ETS/N}} = k$.

Recall from Section 5 the discussion of the cross-derivatives of abatement effort on the extensive margins. Given convex abatement cost function Case A $\Rightarrow a_1 > a_0 \cap c_1 > c_0$. Similarly, Case B $\Rightarrow a_1 = a_0 \cap c_1 > c_0$ and Case C $\Rightarrow a_1 < a_0 \cap c_1 ? c_0$.

(1.5) $k = \dfrac{TC^{UR/S} + c_0}{TC^{ETS/S} + c_1}$, which yields the following conditions:

(2.5.1) $k > \dfrac{TC^{UR/S} + c_0}{TC^{ETS/S} + c_1}$ if $c_0 - kc_1 > 0$,

(2.5.2) $k = \dfrac{TC^{UR/S} + c_0}{TC^{ETS/S} + c_1}$ if $c_0 - kc_1 = 0$, and

(2.5.3) $k < \dfrac{TC^{UR/S} + c_0}{TC^{ETS/S} + c_1}$ if $c_0 - kc_1 < 0$.

(1.6) $\dfrac{TA^{ETS/S}}{TA^{UR/S}} = \dfrac{TA^{ETS/N} - a_1}{TA^{UR/N} - a_0}$.

Let A represent the *rhs* of (2.6), which yields the following conditions:

(1.6.1) A < 1 if $a_1 > a_0$,

(1.6.2) A = 1 if $a_1 = a_0$, and

(1.6.3) A > 1 if $a_1 < a_0$

(1.7) Then, $CE^{N} < CE^{S}$

(1.7.1) if (1.5.2) and (1.6.3) hold,
(1.7.2) if (1.5.3) and (1.6.2) hold, or
(1.7.3) if (1.5.3) and (1.6.3) hold;

(1.8) $CE^{N} ? CE^{S}$

(1.8.1) if (1.5.3) and (1.6.1) hold;
(1.8.2) if (1.5.3) and (1.6.1) hold;

(1.9) $CE^{N} = CE^{S}$

(1.9.1) if (1.5.2) and (1.6.2) hold; and

(1.10) $CE^{N} > CE^{S}$

(1.10.1)	if	(1.5.1) and (1.6.1) hold,
(1.10.2)	if	(1.5.1) and (1.6.2) hold, or
(1.10.3)	if	(1.5.2) and (1.6.1) hold.

(1.11) Case A implies condition (1.8.2) $\Rightarrow CE^{N} ? CE^{S}$;
Case B implies condition (1.7.2) $\Rightarrow CE^{N} < CE^{S}$; and
Case C implies (1.7.1) or (1.7.3)) $\Rightarrow CE^{N} < CE^{S}$, and
Case C implies (1.8.1) $\Rightarrow CE^{N} ? CE^{S}$.

Examining these conditions, (1.9) and (1.10) will never occur. The proposition holds under Case B always, and conditionally under Case A and C.

■

Proof Proposition 2

Deadweight loss is given by the expression

(2.1) $DWL = \frac{1}{2} * (TA^{ETS} - TA^{UR})(MC^{ETS} - MC^{UR})$, where *TA* and *MC* correspond to the abatement and price level at the intersection of the emissions trading and uniform reduction marginal cost function with the marginal benefit function. Then, $DWL^{S} > DWL^{N}$ implies

(2.2) $(TA^{ETS/S} - TA^{UR/S})(MC^{UR/S} - MC^{ETS/S}) > (TA^{ETS/N} - TA^{UR/N})(MC^{UR/N} - MC^{ETS/N})$.

If $\frac{\partial^2 a_i^{n,s}(r(t), z(t))}{\partial z(t)^2} = 0$, then $\frac{(TC^{UR/N} / TA^{ER/N})}{(TC^{ETS/N} / TA^{ETS/N})} \leq \frac{(TC^{UR/S} / TA^{UR/S})}{(TC^{ETS/S} / TA^{ETS/S})}$. This implies

(2.1) $(MC^{UR/S} - MC^{ETS/S}) > (MC^{UR/N} - MC^{ETS/N})$. It remains only to show

(2.2) $(TA^{ETS/S} - TA^{UR/S}) > (TA^{ETS/N} - TA^{UR/N})$.

Let the marginal cost function be denoted: $MC(a) = \boldsymbol{b}_i * a_i$, where *i = ur/s, ur/n, ets/s, or ets/n*, then (2.2) implies $(\boldsymbol{b}_{ets/s}^{-1} - \boldsymbol{b}_{ur/s}^{-1}) > (\boldsymbol{b}_{ets/n}^{-1} - \boldsymbol{b}_{ur/n}^{-1})$, which is the sufficient condition for *Proposition 2*.

■

Table 1: Sand Creek Emissions.

Sources	Acres/Units	Emissions (lbs/year)
WWTF-Jordan	1	2,285
WWTF-New Prague	1	8,649
Feedlots	92	29,180.07
MN079a	59,014.11	20,160.70
MN080a	11,673.41	4,776.51
MN081a	8,476.38	3,452.01
MN163a	8,300.38	2,180.18
MN165a	2,524.88	3,070.03
MN169a	1,432.91	1,685.10
MN171a	507.53	243.05
MN178a	549.11	155.11
MN196a	34,952.74	16,648.11
MN079b	9,218.94	8,188.49
MN080b	1,806.33	1,921.69
MN081b	1,372.59	1,453.36
MN163b	1,928.40	1,316.94
MN165b	499.50	1,579.09
MN169b	365.59	1,117.84
MN171b	32.61	40.60
MN178b	72.90	53.54
MN196b	5,665.42	7,016.00
TOTALS	**148,394**	**115,000**

Source: Johansson et al. (2000).

WWTF=wastewater treatment facility; MN--- a = aggregate acreage per soil group outside of 300 feet buffer; MN---b = aggregate acreage per soil group within 300 feet of a streambed or drainage ditch.

Table 2: Estimated Cost Functions for Sand Creek Abatement

Mechanism / Behavior	Total Cost Function	Marginal Cost Function
Uniform Reductions – Naïve	$TC^{URN} = 0.00051774 * a^2$	$MC^{URN} = 0.00103548 * a$
Emissions Trading System - Naive	$TC^{ETSN} = 0.000333668 * a^2$	$MC^{ETSN} = 0.000667335 * a$
Uniform Reductions - Savvy	$TC^{URS} = 0.0006684 * a^2$	$MC^{URS} = 0.0013368 * a$
EmissionsTrading System – Savvy	$TC^{ETSS} = 0.0003631 * a^2$	$MC^{ETSS} = 0.0007262 * a$

Source: Johansson et al. (2000).

Table 3: Cost Effectiveness Measures

Mechanism / Behavior	Average Cost of Abatement ($/lb)	Cost Effectiveness Gains to Emissions Trading	Total Cost of Abating 46,000 lbs of Phosphorus
UR – Naïve	$23.81	55.17%	$1,094,936
ETS - Naive	$15.34		$705,653
UR - Savvy	$30.74	84.08%	$1,413,558
ETS – Savvy	$16.70		$767,898

Figure 1: Demand and Supply for Phosphorus Abatement

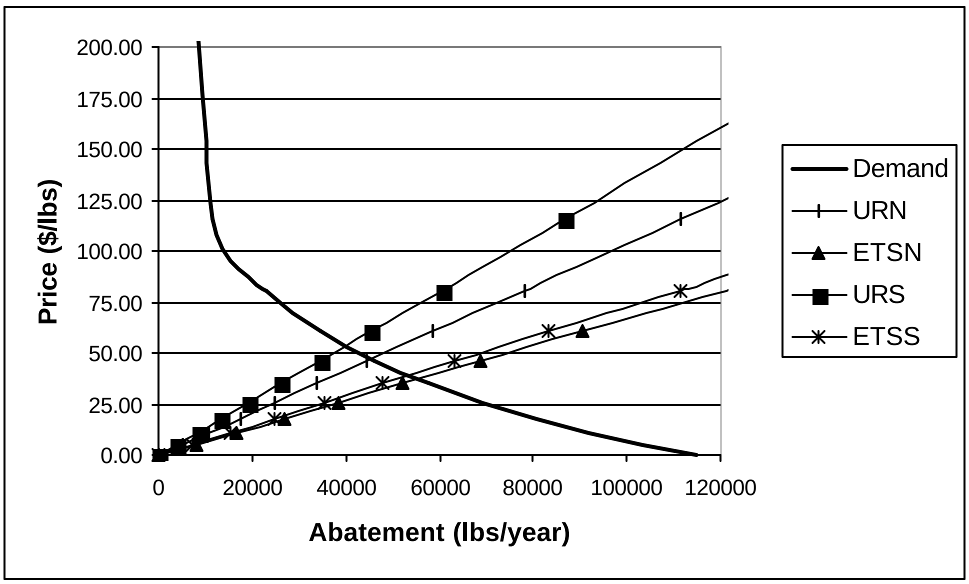

Table 4: Measures of Abatement Efficiency

Mechanism / Behavior	Efficient Level of Abatement	Environmental Standard (*S*)	Deadweight Loss	% Difference
UR – Naïve	45,251 lb/year (39%)	55,228 lb/year	$103,082	257%
ETS - Naive	55,228 lb/year (48%)			
UR - Savvy	39,837 lb/year (35%)	53,259 lb/year	$368,033	
ETS – Savvy	53,259 lb/year (46%)			

Table 5: Important Variables and their Definitions

Total point and nonpoint emissions in time (t)	$E(t)$
Emissions for source (i) in time (t)	$E_i(t)$
The environmental standard	S
Abatement cost functions:	
for point source (i) in time (t)	$C_i(a_i(t))$ for $i = 1, \ldots, m$
for nonpoint source (i) in time (t)	$C_i(a_i(r(t), z(t))$ for $i = m+1, \ldots n$
Abatement effort on the extensive margin	$r(t)$
Abatement effort on the intensive margin	$z(t)$
Total number of permits issues in time (t)	$Q(t)$
Permit endowment to source (i) in time (t)	$(q_i(t))$
Purchase or sale of permits by source (i) in time (t)	$(x_i(t))$
Equilibrium price for permits in time (t)	$P(t)$
Average cost of abatement	*ACA*
Total benefits from abatement	*TB*
Marginal benefits from abatement	*MB*
Total cost of abatement	*TC*
Marginal cost of abatement	*MC*
Total abatement	*TA*
Cost Effectiveness	*CE*
Deadweight Loss	*DWL*
Super(sub)scripts:	
Naïve	*N*, *n*
Savvy	*S*, *s*
Uniform reduction regulation	*UR*, *ur*
Emissions permit trading system	*ETS*, *ets*