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Comparing Policies to Improve Water Quality when Dischargers of Pollutants are Strategic

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Abstract: *Market-based instruments such as fees or tradable permits can be used to simultaneously regulate point and nonpoint sources of pollution discharge into a river. However, sources of pollution discharge often have more information about their own costs of pollution abatement than do regulators. This information asymmetry may lead to strategic behavior, which can lead to different outcomes under different policies. This paper estimates a Nash payoff of a two-period strategic game using econometrically estimated abatement costs for point and nonpoint source phosphorus discharges in the Minnesota River Basin. Results show that when dischargers of pollutants are strategic, discharge permits may yield lower deadweight losses than discharge fees.*

Keywords: *nonpoint source, pollution permits, trading, phosphorous*

Introduction

Water pollution policy in the United States has mostly been command-and-control since the passage of the Clean Water Act in 1972. Command-and-control regulations are essentially explicit requirements on the quantity of pollutant allowed or for the processes and technology involved in production. This type of policy has been moderately successful in regulating point sources (PSs) of water pollution (those that discharge pollution at a specific location such as wastewater treatment facilities), reducing biochemical oxygen demand and total suspended solids by 30 percent (CEQ, 1996). However, command-and-control has failed to adequately address the increasing levels of water pollution originating from many, dispersed nonpoint sources (NPSs), such as runoff from agricultural production.

Based upon the areas it monitors, the U.S. Environmental Protection Agency (EPA) estimates that agriculture is the leading cause of pollution in rivers, streams, lakes, and reservoirs (USEPA, 2000). Furthermore, more than 40 percent of the current water impairments are due only to NPS pollutant discharge and an additional 40 percent have both NPS and PS contributions (USEPA, 2004a). Thus, achieving the Clean Water Act (1972) goal of "swimmable, boatable, and fishable" waters by regulating point sources alone is likely infeasible for many impaired waters. The question remains of how to regulate *all* sources of pollution discharge in a cost-effective manner.

Most studies of environmental regulation and their costs have focused separately on PS pollution or NPS pollution. The literature addressing simultaneous regulation of both PSs and NPSs is thin (Shortle, 1987; Letson, 1992; Malik et al., 1993; Hoag and Hughes-Popp, 1997). However, recent judicial and legislative developments pertaining to Total Maximum Daily Load (TMDL) requirements for impaired watersheds highlight the importance of coordinating PS and NPS pollution control efforts (USEPA, 2003).

One promising avenue of addressing PSs and NPSs simultaneously is to invoke various market mechanisms to achieve water quality goals for impaired watersheds at least cost. Economists have long promoted such first-best policies, believing that environmental externalities require "appropriate" prices to provide the proper incentives for pollution abatement. Such prices reveal the efficient level of abatement where the marginal damage from an additional unit of abatement is equal to the marginal cost of achieving that reduction. Two market mechanisms for controlling water pollution are discharge fees and tradable discharge permits (Baumol and Oates, 1988). In fact, tradable discharge permits have been recently promoted as potential means to address many nonpoint source impairments (USEPA, 2004b). Both offer similar outcomes

in theory, achieving at lowest cost the optimal level of pollution abatement, which is the level at which the benefit of keeping one more unit of pollution from entering the water is equal to the cost of achieving that reduction.

However, these policies require a great deal of information to work correctly. For example, to set an efficient discharge fee or permit allocation, the regulator must know the marginal costs and benefits of abatement. In practice, this information is not always known with certainty, which may lead to a variety of problems. We focus here on one important concern, the issue of imperfect information about the costs of pollution abatement. For this, we assume that sources of pollution (henceforth "dischargers") have an information advantage over regulators and may use this information to their advantage in trying to minimize the costs of pollution abatement imposed by the regulator (Johansson, 2002). In the one-period case, when dischargers do not act strategically but the regulator is uncertain about abatement costs, the preferred policy instrument (i.e., discharge fees or tradable permits) will depend on the relative slopes of the marginal benefit and marginal cost curves (Weitzman, 1974). However, when dischargers act strategically, this result does not necessarily hold.

Moledina et al. (2003) examine the case when the regulator must choose between Pigouvian taxes and a tradable permit system in a dynamic setting. They find that strategic incentives play out differently under a tax or permit system; taxes being preferred only when the low-cost discharger exhibits market power in the market for tradable permits. Moledina et al. (2003) provide a convenient framework in which to examine market mechanisms for PS and NPS water-quality management in watersheds. First, we assume that we can use permits or fees to regulate PS and NPS discharge of nutrients or pollution. Second, we assume there is likely information asymmetry between the regulator and the regulated dischargers in a watershed. The fact that PSs and NPSs often have better information than regulators regarding abatement costs indicates there may be an incentive to mislead regulators concerning actual abatement efforts. Third, while there is no generic watershed, it is often the case that there are relatively few PSs in an impaired watershed and relatively many NPSs. In such a case, market power may be evident. In other words, if the regulator chose to use discharge permits as a policy instrument, the point sources by virtue of their size may have the ability to affect the permit price. Malik (2002) illustrates that market power incentives, if they exist, may serve to counter strategic behavior in permit markets. Therefore, given that the EPA is promoting tradable permit programs for watershed management (USEPA, 2003), it is important to develop insights regarding strategic behavior and watershed management of PSs and NPSs.

This paper seeks to add to the theory and application of regulating point and nonpoint sources in a strategic environment. Because of the information asymmetry between regulators and sources, the preferred policy instrument may be different from what one would expect in theory. We pose this question for a phosphorus-impaired watershed in southern Minnesota, incorporating PS phosphorus discharge from wastewater treatment plants and animal feeding operations as well as NPS phosphorus discharge from crop production. Next, we develop the policy environment for regulating PS and NPS discharge of phosphorus when dischargers have an incentive to behave strategically and misrepresent their abatement efforts. We calculate welfare (benefits of reducing phosphorus discharge minus the costs of achieving those reductions) under a full-information scenario and the loss in welfare (deadweight loss) due to possible strategic behavior under discharge fees and tradable discharge permits in order to compare policy instruments. We conclude with a discussion of how these results might apply to the development of PS-NPS regulation in the context of TMDLs.

Background and Estimations

Under the Clean Water Act, states are now required to develop comprehensive management strategies for impaired water resources, detailing how nutrient discharge will be reduced to comply with federal water quality standards (Boyd, 2000). Policies incorporating previously-regulated PS and unregulated NPS of nutrient discharge will be particularly important in agricultural river basins such as the Minnesota River Basin, classified as one of America's most endangered rivers (American Rivers, 2000).

The Minnesota River drains approximately 10 million acres in central and southern Minnesota before joining the Mississippi River in Saint Paul. Many of the 700,000 inhabitants and approximately 92 percent of the basin's area are involved in agricultural production – about 50 percent of the state's corn and soybean production and more than 20 percent and 40 percent of beef and hog production, respectively. Loadings of sediment, nitrogen, and phosphorus from the Minnesota River into the Mississippi River have been linked to severe eutrophication and hypoxia problems downstream (MPCA, 1999).

Recently, the Minnesota Pollution Control Agency (MPCA) adopted the goal of reducing biochemical oxygen-demanding substances in the Minnesota River by 40 percent (MPCA, 2000), which, in theory, would enable this river to meet state water-quality standards. To accomplish this, nonpoint phosphorus discharge has been targeted for more than a 40 percent reduction from current levels (MPCA, 2000). This region provides an excellent opportunity to examine regulation of PS and NPS phosphorus discharge for watersheds that require substantial phosphorous abatement.

For our paper, we develop a stylized watershed model using data gathered from the Sand Creek Watershed of the Lower Minnesota Basin (Figure 1). Loadings from the

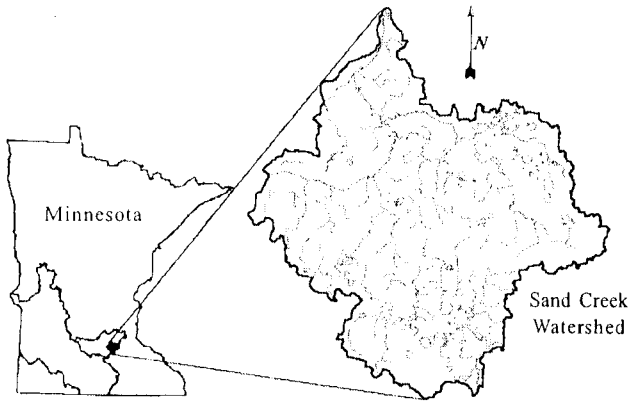

Figure 1. Sand Creek Watershed in the State of Minnesota (148,000 acres) (Source: Johansson et al., 2004)

Lower Minnesota Basin are the largest source of phosphorus in the Minnesota River (Mulla, 1998), and the Sand Creek Watershed is one of the largest watersheds of the Lower Minnesota Basin, draining 148,000 acres, or 14 percent of the Lower Minnesota watershed (MPCA, 1998). Average phosphorus discharge in the Sand Creek is 115,000 lbs/year or 11 percent of the Lower Minnesota total load (MPCA, 1994). Point sources account for approximately 35 percent of the total phosphorus discharged in the watershed; the remaining 65 percent originates from agricultural cropland.

To simplify our analysis of a policy environment with strategic dischargers, we treat PS discharge and NPS discharge in aggregate similar to the treatment of point and nonpoint sources in the Tar-Pamlico discharge program (Hoag and Hughes-Popp, 1997). The aggregate point source can be thought of as a decision-making organization that is comprised of previously regulated PSs. The aggregate nonpoint source can be thought of as a decision-making organization that is comprised of previously unregulated NPSs.

Estimating Point Source Abatement Costs

The main point source dischargers of phosphorus into the Sand Creek are wastewater treatment plants and feedlots. There are reliable sources documenting the annual contributions of the two wastewater treatment plants in the Sand Creek (Metropolitan Waste Control Commission, 1993; MPCA, 1994; MPCA, 2000). However, estimating feedlot contributions is more difficult, calling into question the categorization of feedlots as point source dischargers. Here we characterize feedlots as point source dischargers of phosphorus for the purposes of exposition. This is technically not the case for many small and medium-sized animal feeding operations at the federal level (USEPA, 2004c). The Minnesota Pollution Control Agency has been compiling a list of licensed feedlots for Minnesota. The most current database lists 92 reported feedlots in the Sand Creek (MPCA, 1998), which contain approximately 14,903 animal units (at 1,000 lbs/animal). Using generic conversion ratios for beef cattle, this corresponds to an annual ·duction of 583,601 pounds of phosphorus. We assume ›wer bound on the percentage of manure that annually off of feedlots due to rainfall into the Sand Creek to be ercent of feedlot production (MPCA, 1999). While these ıplifying assumptions may be debatable, when choosing its for both assumptions, care was taken to choose lower ınds; i.e., a five percent lagoon or feedlot contribution was reported to be conservative by MPCA analysts. initial point source discharges sum to approximately 40,000 'year, or 35 percent of the total Sand Creek load. This is ısistent with earlier watershed estimates (MPCA, 2000).

Sources of data to estimate individual point source abatement costs include Senjem (1997) for wastewater treatment facilities and the Minnesota Institute of Sustainable Agriculture "Payment for Pounds" program for livestock (Tiffany, 1999). The aggregate PS abatement cost function is calculated as the horizontal sum of least cost abatement practices undertaken by the sources to achieve a desired level of phosphorus abatement. This cost is given as the difference between unconstrained profits and constrained profits (Johansson, 2000). In keeping with previous literature (Kling and Rubin, 1997; McKitrick, 1999; Leiby and Rubin, 2000), we assume strict convexity for abatement costs in the form of a second-degree polynomial (Figure 2a).

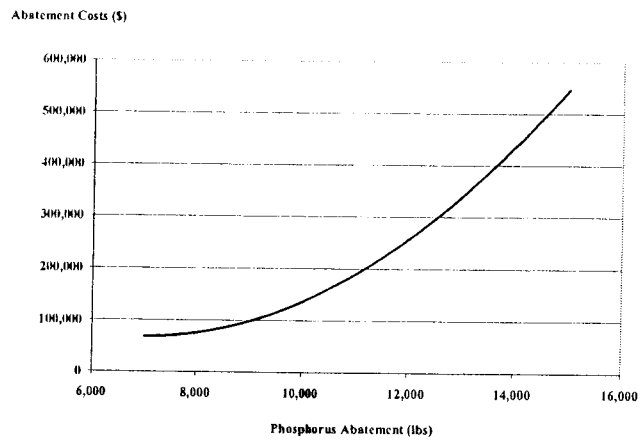

Figure 2a. Point Source Aggregate Abatement Cost Curve

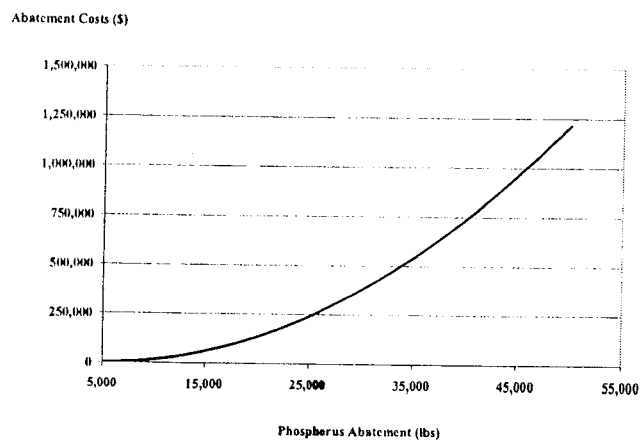

Figure 2b. Nonpoint Source Aggregate Abatement Cost Curve

Estimating Nonpoint Abatement Costs

A biophysical soils model was used to generate the effect of phosphorus best management practices (BMPs) on agricultural discharge of phosphorus on heterogeneous Sand Creek soils (Johansson et al., 2004). The Agricultural Drainage and Pesticide Model (ADAPT) was selected due to its ability to account for major surface and subsurface hydrologic processes including agricultural subsurface tile drainage systems, useful for the tile-drained soils of the Upper Midwest (Gowda et al., 1998). Soils, distinguished by land use, slope, tillage practice, and soil group, can then be thought of as representative farms on a per acre basis. Holding these representative farms constant, a variety of policy experiments were conducted to determine the phosphorus-loading effects of different BMPs using 50 years of climate conditions. Next, the least-cost abatement efforts across Sand Creek's 148,000 acres were simulated for various levels of desired phosphorus abatement, allowing for land retirement, variable crop rotations, and variable fertilizer application rate and technology. The resulting abatement levels and costs were used to map the aggregate abatement cost function for the entire watershed assuming strict convexity for abatement costs in the form of a second-degree polynomial (Figure 2b).

Estimating Abatement Benefits

For welfare comparisons across the policies, an estimate of the benefits function for abatement in the Sand Creek is required. Mathews (1998) examined the benefits to phosphorus abatement in this region. Combining revealed and stated preferences, Mathews estimated a random-effects probit model for phosphorus abatement in the Minnesota River. Using these estimates and following Loomis (1997), Johansson (2000) calibrated the willingness-to-pay for marginal improvements in water quality from phosphorus abatement to the Sand Creek region (Table 1).

Policy Environment

Our analysis assumes two policy instruments are available to the policymaker: discharge fees and tradable discharge permits. To illustrate the dynamic nature of this problem, we evaluate different assumptions about behavior and uncertainty using a two-period model (Moledina et al. [2003] generalize the two-period approach for multiple periods). The first period represents the first year of the policy and the second period represents the second year of the policy and is indicative of subsequent years (see Figure 3).

Table 1. Costs and benefits estimates

		Aggregate	
		Point Source	Nonpoint Source
Abatement Costs	Intercept	430,701.1755	20,032.1635
	Linear Term	-103.9480	-6.3275
	Quadratic Term	0.0074	0.0006
Marginal Costs	Intercept	-103.9480	-6.3275
	Slope	0.0149	0.0012
Marginal Benefits	Intercept	92.0899	
	Slope	-0.0009	

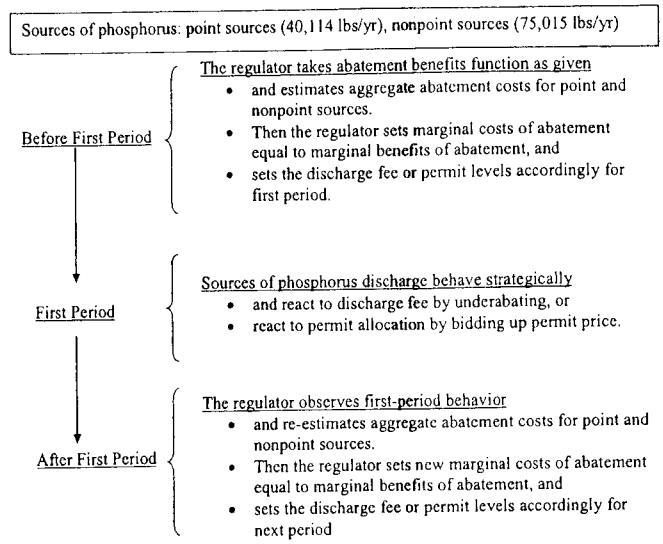

Figure 3. Policy Environment for Strategic Interaction

Behavioral Assumptions – Dischargers

We assume the goal of the PS and NPS is to minimize the present value of compliance costs. Dischargers are strategic in that they take account of how first-period actions may influence future regulatory policy (see next subsection). This is a key assumption borrowed from Moledina et al. (2003). Knowing that the regulator will update their beliefs in the second period based on first-period observations, dischargers choose their abatement efforts in both periods to minimize the total cost of abatement. An example of this type of behavior is when polluters lobby for grandfathering provisions, where current or past behavior is used as a signal for future policy. Anticipating this, polluters may affect their treatment under the policy in the future by modifying their current behavior. For example, the animal feeding operations and compliance with the Clean Air Act, presented in Environmental Defense (2003) and Helland (1998), show that regulators can accommodate preferences of both local citizen and industry groups in setting regulation. In this context, dischargers have a strategic incentive to abate relatively more phosphorus at first under a policy of discharge fees, pretending to have low abatement costs in order to encourage the regulator to set a low discharge fee in the next period. However, over-abatement is costly, and therefore the dischargers must balance the competing desire to pay lower fees with the desire to minimize abatement costs. Under a tradable permit market, dischargers have the opposite strategic incentive: they will attempt to reveal a high abatement cost by bidding up the price of first period permits in order to encourage a higher endowment of discharge permits in future periods, thereby lowering abatement costs in the following period.

We also assume that the aggregate PS acts as a price-setter, because the aggregate point source organization has

significantly fewer members: two municipal wastewater treatment facilities and 92 feedlots compared to approximately 430 farms. Furthermore, we expect that the point sources are net-buyers of permits because of their high pollution abatement costs relative to those of nonpoint sources. Essentially, we are examining the case when the point source is a monopsony (i.e., the reverse of monopoly) permit buyer.

In most cases, a price-setting discharger will have an incentive to set a high price because that sends the appropriate signal to the regulator and leads to more permits in the next period, thereby reducing future abatement costs. Recall that the regulator is interested in maximizing welfare, so a higher price signals higher abatement costs. When regulators observe this, they oblige by distributing more permits up to the point where marginal benefits equals expected marginal costs. However, buyers of permits want to exploit their market power and lower the price of permit purchases. This effect can dampen the impulse to reveal a high first-period permit price. Depending on the strength of these two effects, the permit price can be set either above or below marginal abatement cost.

Behavioral Assumptions - Regulator

We assume the regulator's objective is to maximize welfare net benefits of phosphorus abatement. However, the regulator is not strategic in the same way that dischargers are. Prior to the first period, the regulator chooses a type of policy, either discharge fees or marketable discharge permits (we assume permits are evenly distributed to sources, but alternative distribution rules are easily incorporated into our analysis and would not change our conclusions). In the first period, the regulator sets the level of discharge fee or the number of permits issued to each firm. The regulator then observes the discharge levels of the PS and NPS in the case of discharge fees. In the case of marketable discharge permits, the regulator observes the price of permits. She then updates her belief about PS and NPS costs based upon their behavior. The regulator's updating rule follows Moledina et al. (2003). That is to say, the regulator believes that the dischargers are nonstrategic and behave so that marginal cost equals the fee (in the case of discharge fees) or the permit price (in the case of tradable discharge permits). Having observed their behavior in the first period, the regulator derives a new estimate of marginal costs and sets the policy in the second period so that marginal benefits equal the new expected marginal cost (recall Figure 3).

Uncertain Abatement Costs

Regulator uncertainty regarding the actual abatement cost function for the aggregate point and nonpoint source is essential for our model of strategic behavior. For both policies, the regulator chooses fees or permits in the first period to reflect imperfect, ex-ante beliefs about the PS and NPS abatement cost functions. There are several sources of regulator uncertainty in the aggregate cost estimations. For example, the biophysical simulations for representative farm units may introduce measurement errors and bias into abatement cost estimations (Dosi and Moretto, 1993), the estimates of feedlot contributions may not be correct or smooth abatement cost curves may not accurately represent "lumpy" investments necessary for wastewater abatement (recall Figures 2a and 2b).

We assume that these sources of uncertainty serve to shift the *linear polynomial term* in the abatement cost function in an additive manner, shifting the intercept for the marginal cost functions. Because of this uncertainty, the regulator sensitizes her estimates of the marginal cost intercept for point and nonpoint sources by 5 percent. A downward shift in abatement cost estimates to account for uncertainty errs on the side of water quality under a permit trading policy (i.e., lower expected marginal costs translate into fewer initial permit allocations) and on the side of phosphorus discharge in the case of discharge fees (i.e., lower expected marginal costs translate into lower initial discharge fees). An upward shift in abatement cost estimates to account for uncertainty errs on the side of water quality under a discharge fee (i.e., higher marginal abatement costs translate into higher discharge fees), but also errs on the side of phosphorus discharge in the case of tradable permits (i.e., higher expected marginal costs translate into more initial permit allocations).

Results

We present the findings of the case when the regulator shifts her initial abatement cost assumptions down by 5 percent (the case for the upward shift yields consistent results and does not affect our conclusions). We find that for our stylized watershed depiction, abatement is suboptimal in the first period under both discharge fees and with tradable discharge permits (Table 2). When dischargers act strategically, permits outperform discharge fees in terms of welfare: the deadweight loss (representing the reduction in welfare from the full-information case) with fees is about 2.81 percent, while with discharge permits the proportionate deadweight loss is 0.11 percent.

With discharge fees, aggregate abatement is inefficient in both periods. Strategic dischargers over-abate by 11,109 pounds of phosphorus, relative to the efficient amount in the first period, to signal the regulator into believing that abatement costs are low. This saves in effluent fees, but comes at the expense of higher abatement costs. However, dischargers then face a low second-period discharge fee – $39.96 per pound versus $45.71 per pound – and can take advantage by under-abating in period two by 4,875 lbs.

With discharge permits, the buyer or point source makes a "take-it or leave-it" offer price of $46.03, higher than the efficient permit price of $45.41. This is done in order to encourage the regulator into thinking that the dischargers have high-abatement costs. The regulator obliges by issuing 62,277 permits in the next period, 501 more than if the point source had not manipulated the permit price.

Table 2. Simulation results

Variable	Full information efficient	Discharge fees: Non-strategic firms	Discharge fees: Strategic firms	Discharge permits: Non-strategic firms	Discharge permits: Strategic firms: Buyer power
First period abatement	53,396 lbs	53,664 lbs	64,774 lbs	53,664 lbs	53,054 lbs
Second period abatement	53,396 lbs	53,396 lbs	48,525 lbs	53,396 lbs	52,896 lbs
First period discharge fee or permit price	$45.41/lb	$45.71/lb	$45.71/lb	$45.71/lb	$46.03/lb
Second period discharge fee or permit price	$45.41/lb	$45.41/lb	$39.96/lb	$42.41/lb	$44.97/lb
First period discharge permits	-	-	-	62,118	62,118
Second period discharge permits	-	-	-	61,776	62,277
Net benefits	$5,434,280	$5,406,470	$5,281,490	$5,434,210	$5,428,360
Deadweight loss	$0.00	$27,812	$152,789	$71.42	$5,923
Deadweight loss as a percentage of (efficient) net benefits	0.00	0.51%	2.81%	0.00%	0.11%

Conclusions

We have made the case for using discharge permits and discharge fees to regulate both point and nonpoint sources simultaneously. However, in the presence of imperfect information, the dischargers can use the informational asymmetry to their advantage. We explore this possibility for phosphorus abatement policies, where dischargers know that abatement behavior in a given time period provides signals to the regulator for formulating policy in subsequent periods. We consider how this strategic behavior may influence the costs and benefits of phosphorus discharge fees and tradeable phosphorus discharge permits. Our results from a stylized watershed in southern Minnesota confirm the theoretical findings from Malik (2002) and Moledina et al. (2003) for point and nonpoint source water-quality policies.

We constructed a stylized watershed following Johansson et al. (2004). We assumed quadratic costs and estimated the aggregate abatement costs for phosphorus in the Sand Creek watershed of the Lower Minnesota River Basin. This region was chosen for several reasons; chief among them is that it is the largest source of phosphorus into the Minnesota River, which in turn is the largest source of phosphorus into the Mississippi River. The results from the estimated abatement cost functions were used in a two-period simulation of a strategic game between a regulator and two aggregate sources of pollution: a point source and a nonpoint source.

Our results show that when facing a discharge fee, dischargers may over-abate in the first period, face lower taxes in the second period, and under-abate in the second period relative to the efficient outcome. When facing a permit market, dischargers may bid up the price of permits in the first period in order to obtain more permits in the second period. However, this incentive is countered by a competing desire to exploit market power when it exists. Overall, we find that in our stylized watershed, discharge permits outperform taxes from a welfare perspective. One could make the argument that the estimated deadweight losses are small and hence the welfare implications of strategic firms in our policy environment are small. However, as the amount of uncertainty between the regulator and firm increases, the deadweight losses increase as well.

Furthermore, the emphasis of this paper is less on the magnitude of the deadweight loss and more on the comparison of policy instruments from a welfare perspective. Given that tradable discharge permits are often a more palatable framework politically to organize conservation efforts when compared to taxes (McCann and Easter, 1999), our results lend support to the notion of using nutrient permit trading to meet water quality goals for U.S. water resources.

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