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A Group Incentive Contract to Promote Adoption of Best Management Practices

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The control of agricultural nonpoint source pollution is emerging as a priority of state and national pollution control programs. Best management practices (BMPs) are often proposed as a method of control. Many BMPs are perceived by farmers as having economic disadvantages when compared to conventional management systems. In the absence of tougher environmental restrictions on farmer behavior and complete observability of individual farmer actions, it may be necessary to provide economic incentives to encourage farmer adoption of BMPs within environmentally sensitive watersheds. This study investigates the use of a group incentive contract to encourage adoption of BMPs. The idea behind the group incentive contract is to compensate farmers for actual damages due to adoption of BMPs while avoiding moral hazard problems and exploiting the correlated risks that farmers in a watershed face. Simulation results indicate that the majority of the nitrate pollution generated by central Illinois corn growers could be eliminated at little or no cost.

Key words: best management practices, incentive contract, nonpoint source pollution

Introduction

The control of agricultural nonpoint source pollution is emerging as a priority of state and national pollution control programs. Best management practices (BMPs) are often proposed as a method of control. Since pollution control practices benefit society, farmers will not capture all the benefits associated with BMP adoption (Duttweiler and Nicholson). Thus, as suggested by economic theory, suboptimal levels of adoption occur. Additionally, many BMPs are perceived by farmers as having economic disadvantages when compared to conventional management systems—even though the U.S. Department of Agriculture (USDA) believes that many environmentally friendly management practices would increase farm profits (Cooper and Keim). In the absence of tougher environmental restrictions on farmer behavior and complete observability of individual farmer actions, it may be necessary to provide economic incentives to encourage farmer

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adoption of BMPs. Cooper and Keim confirm this assumption by estimating nonzero willingness-to-accept payments for five water quality-enhancing practices that the USDA believes will actually increase profits.

If this lack of farmer adoption is due to misperceptions, a lack of management experience, biased subjective yield expectations, or risk aversion, then farmers are likely to overstate damages to farm profits from adoption of BMPs, and thus incentive program payments would be higher than necessary to compensate farmers for their actual damages. This study investigates the use of a group incentive contract to encourage adoption of BMPs. The idea behind the group incentive contract is to compensate farmers for actual damages due to adoption of BMPs while avoiding moral hazard problems and while exploiting the correlated risks that farmers in a watershed face. The group incentive contract has the potential to induce BMP adoption at no cost to the government (or other sponsor) when "win-win" (i.e., reduced emissions and non-decreased profits) possibilities exist. In an era of tightened government budgets, there is a need to exploit these possibilities if continuing improvements in environmental quality are to be realized.

Incentive Contracts and Moral Hazard

Economists often employ mechanism design to address nonpoint source pollution problems (e.g., Xepapadeas; Segerson; Byström and Bromley). While appealing from an economic theory perspective, to our knowledge the mechanism design approach to incentive programs has failed to produce a program to reduce nonpoint source pollution that is workable in the real world. As discussed below, model assumptions are not supported by reality and/or these proposed programs may not be politically or legally enforceable for actual nonpoint source pollution problems.

Much of the previous work on incentive contracts does not directly address nonpoint source pollution problems. However, some contracts have been applied to nonpoint source pollution problems. Holmstrom requires that agents (i.e., farmers in the present context) be risk neutral even though moral hazard is often present due to risk aversion (Rasmusen), and Holmstrom's equilibrium fails with a large number of agents. Nalebuff and Stiglitz, and Rasmusen assume that each agent's output (i.e., pollution in our context) is observable. The defining characteristic of nonpoint source pollution is that it cannot be traced to any one source. Additionally, as Rasmusen notes, many contracts proposed in the literature are politically and/or legally unenforceable. For example, Rasmusen's "scapegoat" and "massacre" contracts stand little chance of ever being passed by either state or federal lawmakers, and would not likely stand up to legal challenges.

Under the scapegoat contract, if output does not meet requirements, one agent is selected for punishment. In a nonpoint source pollution context, that means punishing one farmer for the pollution of his/her neighbors. If that farmer can prove that his/her nitrogen applications could not have caused the level of pollution observed, it is unlikely that this punishment would be legally enforceable. Under the massacre contract, if output does not meet requirements, all but one agent are punished. But if any of these agents can demonstrate that they applied inputs which complied with the program's requirements, then Rasmusen's equilibrium fails.

Xepapadeas; Segerson; and Byström and Bromley specifically address the nonpoint source pollution problem. Xepapadeas assumes that aggregate output is observable, but that individual input and output levels are not observable. His contract employs subsidies and penalties in order to achieve efficiency. However, in the current political environment, it seems unlikely that penalties are acceptable. Segerson also uses an incentive contract to address the nonpoint source pollution problem. Her contract is based on Holmstrom's contract with risk-neutral agents. Byström and Bromley suggest an innovative penalty scheme that encourages farmers to trade abatement services. Their approach punishes all farmers in the watershed if water quality objectives are not met. But, as previously noted, penalties may not be politically acceptable.

Our approach differs from these previous studies, as we do not design a mechanism to ensure compliance; rather, as discussed below, we use a proposed policy as our starting point. Also in contrast to these previous studies, we assume that the principal can observe the nitrogen application levels of farmers (agents), but not other management actions.

This assumption is not without justification. In many areas, such as central Illinois, custom application of fertilization is widespread, and use of computerized application equipment is increasing. Program participants (agents) would be required to employ custom application services, and the records of the applicators would need to be provided to the sponsor (principal). Other management actions, however, are still assumed to be unobservable. The principal has no way of determining if the farmer is taking other appropriate management actions, such as scouting for pests and providing treatment when required. Our incentive program accounts for risk-averse agents and does not depend upon the number of agents. Our program employs only subsidies, and so should be politically acceptable and legally enforceable. Finally, in the event that the action being promoted increases farmers' well-being, the subsidy payment is zero. We accomplish this by tying the subsidy to the level of lost profits associated with the adoption of a best management practice.

The notion of compensating farmers for realized losses due to the adoption of BMPs was first brought to our attention by Steven John, formerly of the Decatur City Council. John proposed compensating farmers for *yield* losses if farmers agreed to reduce nitrogen fertilization.[1] One of the difficulties with John's program is that moral hazard is present: How do you pay individual farmers for yield loss due to nitrogen fertilizer reduction and not for mismanagement? Also, how do you avoid paying for random reductions in yield due to pests or bad weather? Further, if farmers are currently applying fertilizer in excess of the economic optimum, does it make sense to pay them to improve their own economic well-being?

The objective of our study is to improve on John's proposal by developing a voluntary incentive program to induce a reduction in nitrogen fertilization levels that also (*a*) avoids moral hazard; (*b*) is politically acceptable to the farm community and legally enforceable; (*c*) only pays for realized, not expected, losses in *profits* (so if the action increases farmer profits, no payment is necessary) due to the reduction in nitrogen

[1] The Decatur City Council initially supported the idea and allocated $20,000 for a limited test of the program. While the City Council later chose not to fund the program, it has not been ruled out. Decatur is investigating methods by which the city can comply with Safe Drinking Water standards for nitrate. Incentive programs are still being considered for use in controlling nitrate pollution.

fertilizer application rates; and (*d*) can result in a Pareto-improvement when the potential exists. The group incentive program described here accomplishes this objective.

The proposed program is described and modeled in the context of reducing the use of nitrogen fertilizer in a central Illinois watershed. Excess nitrogen in Illinois pollutes potable water supplies from surface reservoirs and may contribute to the growing hypoxia problem at the mouth of the Mississippi River. Moreover, the program can be generalized to other BMPs and locations.

Evidence of Nitrogen Fertilizer Overapplication

The problem of nitrate would be less difficult to solve if it could be demonstrated that farmers apply fertilizer in excess of the expected profit-maximizing level. There is evidence that farmers, at least in some areas plagued with nitrate pollution, overapply nitrogen fertilizer. Bullock and Bullock report that agronomic recommendations are as much as 97% above the expected profit-maximizing level for one Illinois location, and roughly equal to it at another location. However, according to a recent survey (USDA 1995), most central Illinois farmers apply nitrogen fertilizer in excess of agronomic recommendations. The survey of farmers in the Big Ditch watershed (Champaign County, Illinois) indicates that 80% of farmers apply at least 20% more nitrogen fertilizer than is recommended by the *Illinois Agronomy Handbook* [University of Illinois, Cooperative Extension Service (CES)]. The average application rate is 50 pounds per acre over the *Handbook*'s recommendation. Yadav, Peterson, and Easter report that in southeastern Minnesota both agronomic recommendations and current application levels exceed the profit-maximizing nitrogen fertilizer rate. Reasons for this overapplication warrant investigation, but regardless of the motive, it may be possible that a potential Pareto-improvement can be found.

The Model

Moral hazard[2] potentially exists in any program that compensates farmers for yield or profit losses when some subset of management actions is unobservable. While we assume that nitrogen fertilizer application levels are observable, we assume that other management actions, such as the decision to treat a pest infestation, are unobservable. Hence, the incentive contract needs to be designed to eliminate incentives for moral hazard. We demonstrate moral hazard does not exist for risk-neutral and risk-averse program participants in our proposed program. We provide an illustration of the program, simulate the program, and derive cost and nitrate reduction estimates.

To demonstrate that moral hazard does not exist for our incentive program, we consider a farmer's decision to treat a pest infestation given that the treatment decision is unobservable and that nitrogen fertilizer application levels are capped for participating

[2] Moral hazard, in the current context, refers to the distorted incentives that crop insurance can have on farmers' management decisions. For example, with crop insurance, treating pest infestations may be suboptimal where it would have been optimal to treat the infestation without crop insurance.

farmers. Let $\mathbf{P} = (P_1, \ldots, P_m)$ and $\mathbf{N} = (N_1, \ldots, N_k)$ denote a group of m farmers that have chosen to participate in the incentive program and a group of k nearby nonparticipating farmers, respectively. Let $\mathbf{n}^P = (n^{P_1}, \ldots, n^{P_m})$ denote the nitrogen fertilizer application levels of participating farmers. Let $\mathbf{S}^P = (S^{P_1}, \ldots, S^{P_m})$ denote an indicator variable for economic/noneconomic levels of a pest infestation. If $S^{P_i} = 1$, then it is economically optimal for farmer i to treat the infestation in the absence of the program; otherwise, $S^{P_i} = 0$.

Our incentive program potentially distorts the incentive to treat a pest infestation. For example, assuming that prior to the incentive program it is optimal to treat a pest infestation for a farmer ($S^{P_i} = 1$), it might not be optimal to treat an infestation once the farmer is enrolled in the incentive program. Alternatively, it might be optimal to treat an infestation with the program that would not be optimal to treat without the program. To allow for these possibilities, let $\mathbf{T}^P = (T^{P_1}, \ldots, T^{P_m})$ denote the vector of treatment choice variables for participating farmers with the incentive program. If $T^{P_i} = 1$, then farmer i chooses to treat the infestation; otherwise, $T^{P_i} = 0$. Let $\mathbf{e}_j^P = (e_j^{P_1}, \ldots, e_j^{P_m})$ denote other random effects on the profits of participating farmers in year j. In the absence of the program, profits for farmer i in year j are given as $\Pi_j^{P_i}(n_j^{P_i}, S_j^{P_i}, e_j^{P_i})$. Define the historical (over T years) or long-run average profit of each participating farmer as

$$(1) \qquad \overline{\Pi}_{LR}^{P_i} = \frac{\sum_{j=1}^{T} \Pi_j^{P_i}\left(n_j^{P_i}, S_j^{P_i}, e_j^{P_i}\right)}{T}.$$

Define the historical or long-run average profit for the group of participating farmers as

$$(2) \qquad \overline{\Pi}_{LR}^{P} = \frac{\sum_{i=1}^{m} \overline{\Pi}_{LR}^{P_i}}{m}.$$

The long-run average profit for nonparticipating farmers, $\overline{\Pi}_{LR}^{N}$, is similarly defined. The incentive program caps participating farmers' nitrogen application levels at $\hat{\mathbf{n}}^P = (\hat{n}^{P_1}, \ldots, \hat{n}^{P_m})$. With the incentive program, the individual participating farmer's profits are now a function of the treatment variable T^{P_i}, and for the current year t are given as $\pi_t^{P_i}(\hat{n}_t^{P_i}, S_t^{P_i}, T_t^{P_i}, e_t^{P_i})$. The average profit for the group of participating farmers in year t is denoted

$$(3) \qquad \bar{\pi}_t^{P} = \frac{\sum_{i=1}^{m} \pi_t^{P_i}\left(\hat{n}_t^{P_i}, S_t^{P_i}, T_t^{P_i}, e_t^{P_i}\right)}{m}.$$

Define the average profit for nonparticipating farmers as

$$(4) \qquad \overline{\Pi}_{LR}^{N_i} = \frac{\sum_{j=1}^{T} \Pi_j^{N_i}\left(n_j^{N_i}, S_j^{N_i}, e_j^{N_i}\right)}{T}.$$

Define the incentive payment in any given year, I_t, for agreeing to limit nitrogen application to be the maximum of zero and the difference in percentage deviation from long-run profits between participating farmers and nonparticipating farmers times the long-run average profit for participating farmers, or

$$(5) \qquad I_t = \max\left[0, \left(\frac{\left(\overline{\Pi}_{LR}^P - \bar{\pi}_t^P\right)}{\overline{\Pi}_{LR}^P} - \frac{\left(\overline{\Pi}_{LR}^N - \overline{\Pi}_t^N\right)}{\overline{\Pi}_{LR}^N}\right) * \overline{\Pi}_{LR}^P\right].$$

Equation (5) states that the incentive payment is always the larger of zero and the difference between the percentage deviation from long-run profits for participants and nonparticipants.[3] The incentive payment should have the effect of "insuring" farmers' profits from loss due to the adoption of the best management practice.

We divide the incentive payment into two cases, with the incentive payment being either zero or greater than zero. Consider first the case when the incentive payment is zero. Then, the treatment decision degenerates to the individual's decision in the absence of the program (i.e., there is no moral hazard).

Next, consider the case when the incentive payment is greater than zero. We need to demonstrate that when it is optimal to treat the infestation in the absence of the program ($S_t^{P_i} = 1$), it is optimal to treat with the program ($T_t^{P_i} = 1$). We approximate risk-averse farmers using mean-variance analysis. In the absence of an incentive program, the necessary and sufficient condition for treatment by a risk-neutral farmer is specified as

$$E\left[\pi_t^{P_i}\left(\hat{n}_t^{P_i}, 1, 1, e_t^{P_i}\right)\right] \geq E\left[\pi_t^{P_i}\left(\hat{n}_t^{P_i}, 1, 0, e_t^{P_i}\right)\right],$$

and a sufficient condition for treatment by a risk-averse farmer is

$$E\left[\pi_t^{P_i}\left(\hat{n}_t^{P_i}, 1, 1, e_t^{P_i}\right)\right] \geq E\left[\pi_t^{P_i}\left(\hat{n}_t^{P_i}, 1, 0, e_t^{P_i}\right)\right]$$

and

$$\mathrm{var}\left[\pi_t^{P_i}\left(\hat{n}_t^{P_i}, 1, 1, e_t^{P_i}\right)\right] \leq \mathrm{var}\left[\pi_t^{P_i}\left(\hat{n}_t^{P_i}, 1, 0, e_t^{P_i}\right)\right]$$

(Markowitz). To ease notation, assume there are two participating farmers. Then there are four possible treatment combinations: (*a*) farmer 1 does not treat and farmer 2 does not treat (0, 0); (*b*) farmer 1 treats and farmer 2 does not treat (1, 0); (*c*) farmer 1 does not treat and farmer 2 treats (0, 1); and (*d*) farmer 1 treats and farmer 2 treats (1, 1). Since we have assumed that treatment of the pest infestation is optimal for both farmers (in the absence of the program), any equilibrium that admits a nontreatment outcome by either farmer has moral hazard present.

Since the incentive payment depends on the treatment strategies employed, redefine I_t so that it is explicitly a function of those strategies: $I_t(l, k)$; $l, k \in \{0, 1\}$, where l denotes

[3] The incentive program is similar to the Group Risk Plan (GRP) crop insurance (Baquet and Skees). Under GRP, farmers are compensated based on the average loss of the insured farmers as compared to the county average.

the treatment strategy for farmer 1, and k denotes the treatment strategy for farmer 2. Note that this does not mean these variables are observable, so the principal cannot condition the incentive payment accordingly. However, the incentive payment will vary depending on each farmer's unobservable treatment strategy.

In the appendix, we provide necessary and sufficient conditions with a risk-neutral agent, and sufficient conditions with a risk-averse agent for equilibria that preclude moral hazard. Using the notation defined above, this says that given $S_t^{P_1} = S_t^{P_2} = 1$, then treatment is optimal for both farmers when participating in the program $(T_t^{P_1} = T_t^{P_2} = 1)$. Similarly, if $S_t^{P_1} = S_t^{P_2} = 0$, treatment is not optimal with the program $(T_t^{P_1} = T_t^{P_2} = 0)$. The same argument used in the appendix can easily be used to show that if one participant has an infestation while the other does not, then optimal strategies do not differ from the pre-incentive program optimal strategies. So, moral hazard, provided our assumptions hold, is not induced by this incentive program.

The generalization to an arbitrary number of participating farmers poses little problem, except for cumbersome notation. The equilibrium strategy of treatment/nontreatment is still supported with any number of farmers, because each farmer receives all the benefits of treating his/her own crop, and the cost (in terms of reduced incentive payment) is spread among all participants. In fact, as the number of farmers approaches infinity, it is easy to show the farmer's treatment/nontreatment decision has no effect on the size of the incentive payment. So, the outcome is a dominant strategy that precludes moral hazard.

As our equilibrium relies on the existence of nearby nonparticipating farmers, we need to address where these farmers are found. Nonparticipating farmers could be found in the targeted watershed due to budget constraints of the sponsor or if the sponsor's water quality objectives can be met with a subset of the farms in the watershed. However, the nonparticipating farmers need not be within the targeted watershed. They could be from a nearby watershed with highly correlated weather and yields.

An Illustration

To further illustrate how the incentive program works and the payment is calculated, consider the following hypothetical case. There are two farmers who have agreed to participate in the nitrogen fertilizer reduction program. The long-run average profit for each of the two farms is \$200/acre. Historical data from nearby farms indicate a long-run average profit[4] of \$205/acre. Assume both participating farmers experience a pest infestation. Without treatment, profits before the incentive payment decline by \$25/acre (12.5%). With treatment, their before-incentive payment profit declines by \$10/acre (5%). So, it is optimal, without the incentive program, to treat the infestation. Assuming that nearby nonparticipating farmers experience a similar infestation and treat the infestation, their profits are similarly affected (−5%).

The per acre incentive payment without treatment is $(-5\% + 12.5\%) * \overline{\Pi}_{LR}^{P} = 7.5\% *$ \$200 = \$15. So, the after-incentive-payment profit without treatment is \$190 (= \$175 +

[4] Actually, no assumption needs to be made regarding the level of long-run average profit for nonparticipating farmers. What is needed is an assumption regarding the deviation from long-run average profit, as the example demonstrates.

\$15). The per acre incentive payment with treatment is $(-5\% + 5\%) * \overline{\Pi}_{LR}^{P} = \$0$. Thus, the after-incentive-payment profit with treatment is \$190/acre.

It appears that participating farmers are indifferent between treating and not treating the infestation. But, consider the effect of one of the participating farmers treating the infestation while the other farmer does not treat. The treating farmer has a profit before incentive payment of \$190/acre (5% below the long-run average), and the nontreating farmer has a profit before incentive payment of \$175/acre (12.5% below the long-run average). The average deviation from the long-run average is −8.75%. Since the nonparticipating farmers have an average deviation of −5%, the incentive payment is $3.75\% * \overline{\Pi}_{LR}^{P} = \$7.50$/acre. The after-incentive-payment profit for the treating farmer is \$197.50 (= \$190 + \$7.50), while the nontreating farmer receives \$182.50 (= \$175 + \$7.50). Therefore, there is an incentive for each farmer to move away from not treating to treating, so moral hazard is not present.

By comparing participating to nearby nonparticipating farmers, correlated risks are actually exploited. If participating farmers' profits are reduced due to weather or pests, it is likely that nearby nonparticipating farmers are similarly affected. Therefore, the percentage deviation in long-run profits for both groups will be lower. Participating farmers receive compensation only if their relative deviation is larger than that of nonparticipating farmers. Both groups of farmers can be expected to suffer (or benefit) from similar decreases (or increases) in yields and profits due to weather and pests, and so the percentage deviation from long-run average profit for both groups is similar. Therefore, the sponsor is less likely to pay for random reductions in profit.

The incentive payment as described in (5) allows for two types of "losses." The first is when the percentage deviation in average profit of the participating group is below the long-run average by an amount greater than the deviation from long-run average profit for the nonparticipating group. The second type of loss is when average profit is above the long-run average, but less than the percentage deviation for nonparticipating farmers. If participating farmers had applied nitrogen in excess of $\hat{n}$, it is assumed that they would achieve an above-average profit similar in magnitude to the average profit of nonparticipating farmers.

Simulation

The group incentive program is simulated using EPIC (USDA 1990) to generate yields and nitrate pollution for a common central Illinois soil, Drummer. EPIC is used to simulate 80 years of continuous corn yields and annual nitrate emissions for various levels of nitrogen fertilizer application. A baseline rate of 185 pounds of actual nitrogen is assumed based on the long-run average yield of corn grown on Drummer soil (about 152 bushels/acre) and the *Illinois Agronomy Handbook* (University of Illinois, CES) recommendation of 1.2 pounds of nitrogen per bushel of average corn yield. (Actual rates may be even higher, as discussed previously. The recommended level for corn grown in rotation with soybeans is lower.)

The first 40 years of EPIC simulations are used to establish long-run average profit for both participating and nonparticipating farmers. (Both groups are assumed to have the same long-run average profit.) The simulations of the next 40 years are used to establish group annual average yields and emission levels.

Table 1. Per Acre Expected Profits and Incentive Payments with 185-Pound Baseline N Application Rate

N Rate (lbs. per acre)	Expected Profit w/o Incentive ($)	Expected Incentive Payment ($)	Minimum Incentive Payment ($)	Maximum Incentive Payment ($)	Expected Profit with Incentive ($)	Variance of Profit with Incentive [a]
185	291.73	0.00	0.00	0.00	291.73	5,045.73
180	292.78	0.00	0.00	0.00	292.78	5,052.00
175	293.73	0.00	0.00	0.00	293.73	5,075.73
170	294.67	< 0.01	0.00	0.11	294.67	5,039.00
165	295.67	0.00	0.00	0.00	295.67	5,038.93
160	296.50	< 0.01	0.00	1.22	296.50	5,021.48
155	297.22	0.02	0.00	3.33	297.24	4,994.01
150	297.77	0.07	0.00	5.44	297.83	4,951.54
145	297.92	0.37	0.00	13.77	298.29	4,904.49
140	297.56	0.98	0.00	22.10	298.54	4,848.54
135	296.35	1.97	0.00	33.55	298.32	4,761.13
130	293.90	3.91	0.00	41.88	297.81	4,691.22

[a] The variance of profits without the incentive payment (i.e., variance of the baseline nitrogen rate of 185 pounds/acre) is 5,045.73.

A 10-year series of real corn prices (1986–95) is taken from *Illinois Agricultural Statistics* (Illinois Department of Agriculture). Prices are assumed to be independent of local yields. Nitrogen is priced at $0.20 per pound, phosphorous at $0.24 per pound, and potassium at $0.13 per pound (University of Illinois, FaRMLab).

The only costs considered are fertilization costs. Phosphorous and potassium uptake rates are assumed to be 0.43 and 0.28 pounds per bushel of yield (University of Illinois, CES), respectively. All other costs are assumed to remain constant for participating and nonparticipating farmers (and thus net out in the computation of the incentive payment). Although a mulch tillage system is simulated, the program can be easily modified to consider differences in profits and pollution emissions for different tillage systems.

Results

In table 1, profits with and without the incentive program are reported. These numbers demonstrate that it costs farmers very little to overapply fertilizer. The difference in the maximum expected profit ($297.92 for 145 pounds of N) and the baseline expected profit ($291.73 for 185 pounds of N) is only about $6 per acre. The cost (in terms of lost expected profit) of overapplying fertilizer by 20 pounds is only about $2 per acre. The difference between the maximum expected profit with the incentive payment and the baseline expected profit is less than $7/acre. The variance of profits with the incentive

Table 2. Reduction in N Loadings per Acre from 185-Pound Baseline

N Rate (lbs./acre)	Average Reduction in Loading (%)	Minimum Reduction in Loading (%)	Maximum Reduction in Loading (%)
185	0.00	0.00	0.00
180	14.18	5.53	28.83
175	28.62	9.96	48.77
170	43.10	14.21	61.24
165	54.62	18.77	69.63
160	61.81	23.25	76.07
155	67.41	27.71	82.86
150	70.73	32.02	84.08
145	73.05	36.16	85.24
140	75.18	40.03	86.30
135	77.18	43.64	87.28
130	79.02	46.75	88.31

payment, also reported in table 1, is declining as the nitrogen rate declines. This is due to two factors. First, the EPIC simulator treats nitrogen as risk increasing (at least through some range). Second, the incentive program truncates the downside tail of the profit distribution for participating farmers.

Also in table 1, the expected minimum and maximum (over the 40 years) incentive payments are reported. The expected incentive payment is $0 for all rates between 160 and 185 pounds per acre, except for 160 and 170 pounds. There is one yield and price combination (out of 400) for which the 160- and 170-pound application rates have a nonzero incentive payment ($0.11), but the expected (or average) payment is less than $0.01 per acre. This says that, for all the price and yield combinations simulated with N rates between 160 and 185 pounds, there are only two cases where 185 pounds of N had the highest profits. Hence, there is an opportunity for a win-win outcome. In all cases, the minimum incentive payment is $0. For application rates below 150 pounds, the maximum incentive payment rapidly climbs. At 130 pounds (roughly a 30% reduction in nitrogen application), the maximum incentive payment is $41.88 per acre, although the average payment is only $3.91 per acre.

The impacts of reducing nitrogen application are reported in table 2. Average N loading decreases rapidly, but at a decreasing rate as application rates decrease. At 180 pounds (a five-pound reduction in application rate), the expected reduction in N loading is over 14%. The incremental reduction from 180 to 175 pounds is also 14%. Then, the incremental reduction declines rapidly to about 2% as the nitrogen application rate is reduced from 135 to 130 pounds. This indicates that the expected cost of abatement curve is weakly convex and the marginal cost of abatement curve is upward sloping. The expected cost of abatement (i.e., the expected incentive payment) curve is presented in figure 1.

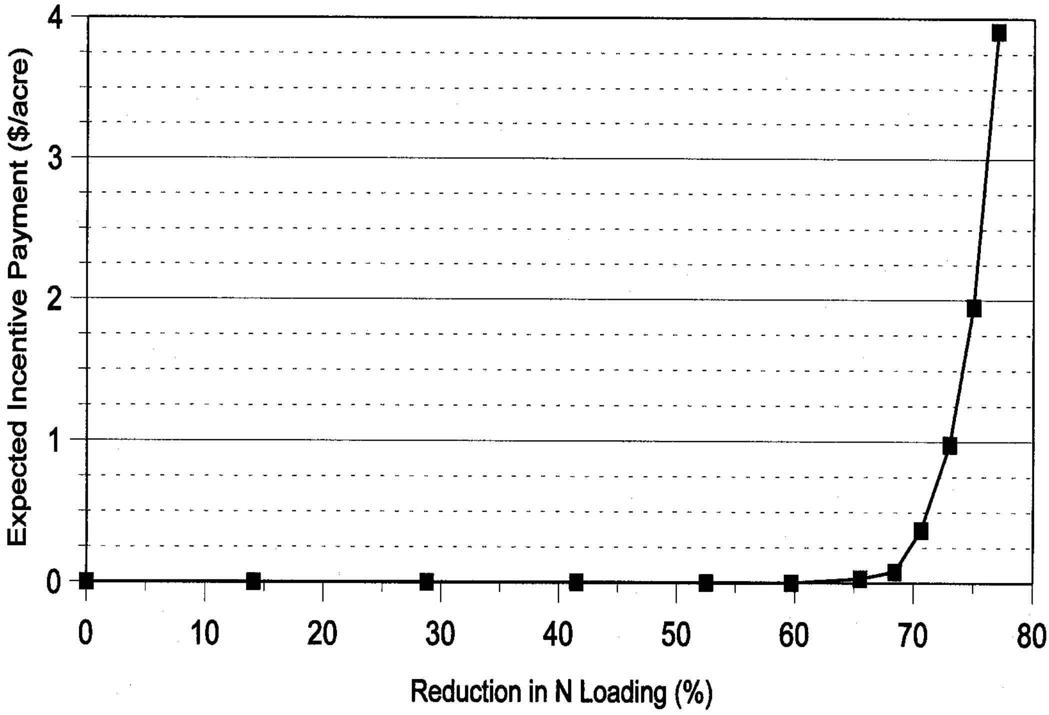

Figure 1. Per acre expected incentive payments for the 185-pound baseline N application rate

These results indicate that the majority of the nitrate pollution generated by central Illinois corn growers could be eliminated at no or low cost. If participating farmers cut application rates to 160 pounds (less than a 14% reduction in application rate), the resulting reduction in N reaching surface and ground water would average almost 60%. The simulations indicate that an incentive payment would never be made. However, the sponsor would still bear the costs associated with establishing and administering the program. Ultimately, it is reasonable to expect that participating farmers would become educated to the positive impacts on their individual profits and would no longer require an incentive program to maintain lower application levels. If this information spreads to nonparticipating farmers, the impacts could reach even more widely.

Implementation of the Group Incentive Contract

To implement the proposed program, a sponsor would need to know historical and current profits for both participating and nonparticipating farmers. For each farmer group, historical profits could be approximated using farm yield data from the USDA Farm Service Agency, historical price series for corn and fertilizers, a common rate for nitrogen, and agronomic data regarding the uptake of other nutrients (i.e., phosphorous and potassium). Current profits could be estimated by estimating standing corn yields with standard techniques[5] [see, e.g., the *Illinois Agronomy Handbook* (University of Illinois, CES)], the capped nitrogen rate times the local price of nitrogen, an accounting of other nutrient costs, and a local harvest price for corn (such as average November on-farm price).

The calculation of long-run average profits could be problematic if, at the conclusion of the program, the same group of farmers wished to participate again. We expect this average to change over time, particularly since nitrogen rates for this group of farmers are lower than past rates. However, if, as we hypothesize, farmers are applying excessive amounts of nitrogen fertilizer, participating farmers should eventually realize that program payments are not necessary (as the incentive payment might never be greater than zero). When their contract expires (say after 5–10 years), it should not be necessary to offer this same set of farmers a new contract, if a true win-win situation existed at the time the original contract was implemented. By fixing the long-run average profit at the beginning of the contract and perhaps allowing for a time trend, we would not need to recalculate long-run average profit over the life of a single contract.

Final Comments and Conclusions

The need for reducing agricultural pollution is keenly felt in many communities throughout the U.S. The drinking water from surface and ground water sources is frequently unfit for consumption without treatment or dilution. Further, many of these communities lack the financial resources needed to provide advanced water treatment and/or find an alternative clean water supply to comply with drinking water regulations. Additionally, hypoxia in the Gulf of Mexico may cause the U.S. government to become more active in reducing agricultural contributions of nutrients to surface water.

Due to skepticism, noneconomically based recommendations, and incomplete information, farmers may be reluctant to adopt many management practices that have the potential to improve both farm profits and environmental quality. Incentive programs could be used to induce farmers to adopt such practices. This study introduces an incentive program that eliminates moral hazard issues and exploits correlated risks. The incentive program is demonstrated, via simulation, to provide a low-cost approach of reducing nitrate pollution from corn farms. This approach could be applied to other BMPs.

Over a significant range, the program actually benefits farmers at no cost (excluding monitoring, enforcement, and administration costs) to government or other sponsors. Prior to implementation, a program sponsor, such as a municipal water supply utility, would need to weigh the costs of the program—including monitoring, enforcement, and administration—with the costs of alternative methods of achieving similar water quality improvements—including other control measures, advanced treatment, and finding alternative water supply.

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[5] Yield data might eventually be collectable using yield monitors. This technology is becoming widespread. Participating farmers could be required to provide the sponsor with access to these data.

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Appendix

Here we provide necessary and sufficient conditions for a Nash equilibrium under risk neutrality, and sufficient conditions for a Nash equilibrium under risk aversion. These equilibria preclude moral hazard.

We start with the assumption that both farmers have a pest infestation that, in the absence of the program, is optimal to treat (i.e., $S_t^{P_1} = S_t^{P_2} = 1$). We then evaluate the expected profits and variance of profits for each participant, allowing the participants to vary their treatment strategies (T^{P_i}). For the first treatment strategy (0, 0), farmer 1's expected return is given by

(A1)
$$E\left[\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right) + I_t(0,0)\right]$$
$$= E\left[\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right) + \overline{\Pi}_{LR}^P - \frac{\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right)}{2} - \frac{\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 0, e_t^{P_2}\right)}{2} - \frac{\left(\overline{\Pi}_{LR}^N - \overline{\Pi}_t^N\right)\overline{\Pi}_{LR}^P}{\overline{\Pi}_{LR}^N}\right].$$

Assuming that the expected profits of individual nonparticipating farmers do not change over time, $E[\overline{\Pi}_t^N] = \overline{\Pi}_{LR}^N$, then text equation (5) reduces to

(A2)
$$E\left[\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right) + I_t(0,0)\right] = E\left[\frac{\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right)}{2}\right] - E\left[\frac{\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 0, e_t^{P_2}\right)}{2}\right] + \overline{\Pi}_{LR}^P.$$

The variance of farmer 1's returns is given by

(A3)
$$\begin{aligned}
&\operatorname{var}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right) + I_t(0,0)\right) \\
&= \operatorname{var}\left(\frac{\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right)}{2} + \overline{\Pi}_{LR}^P - \frac{\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 0, e_t^{P_2}\right)}{2} - \left(\frac{\overline{\Pi}_{LR}^N - \overline{\Pi}_t^N}{\overline{\Pi}_{LR}^N}\right)\overline{\Pi}_{LR}^P\right) \\
&= \frac{\operatorname{var}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right)\right)}{4} + \frac{\operatorname{var}\left(\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 0, e_t^{P_2}\right)\right)}{4} + \left(\frac{\overline{\Pi}_{LR}^P}{\overline{\Pi}_{LR}^N}\right)^2 \operatorname{var}\left(\overline{\Pi}_t^N\right) \\
&\quad - \frac{\operatorname{cov}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right), \pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 0, e_t^{P_2}\right)\right)}{2} + \left(\frac{\overline{\Pi}_{LR}^P}{\overline{\Pi}_{LR}^N}\right)\operatorname{cov}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right), \overline{\Pi}_t^N\right) \\
&\quad - \left(\frac{\overline{\Pi}_{LR}^P}{\overline{\Pi}_{LR}^N}\right)\operatorname{cov}\left(\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 0, e_t^{P_2}\right), \overline{\Pi}_t^N\right).
\end{aligned}$$

Now consider the expectation and variance of farmer 1's returns under treatment strategy (1, 0):

(A4)
$$E\left[\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 1, e_t^{P_1}\right) + I_t(1,0)\right] = E\left[\frac{\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 1, e_t^{P_1}\right)}{2}\right] - E\left[\frac{\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 0, e_t^{P_2}\right)}{2}\right] + \overline{\Pi}_{LR}^P$$

and

(A5)
$$\begin{aligned}
&\operatorname{var}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 1, e_t^{P_1}\right) + I_t(1,0)\right) \\
&= \frac{\operatorname{var}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 1, e_t^{P_1}\right)\right)}{4} + \frac{\operatorname{var}\left(\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 0, e_t^{P_2}\right)\right)}{4} \\
&\quad + \left(\frac{\overline{\Pi}_{LR}^P}{\overline{\Pi}_{LR}^N}\right)^2 \operatorname{var}\left(\overline{\Pi}_t^N\right) - \frac{\operatorname{cov}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 1, e_t^{P_1}\right), \pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 0, e_t^{P_2}\right)\right)}{2} \\
&\quad + \left(\frac{\overline{\Pi}_{LR}^P}{\overline{\Pi}_{LR}^N}\right)\operatorname{cov}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 1, e_t^{P_1}\right), \overline{\Pi}_t^N\right) - \left(\frac{\overline{\Pi}_{LR}^P}{\overline{\Pi}_{LR}^N}\right)\operatorname{cov}\left(\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 0, e_t^{P_2}\right), \overline{\Pi}_t^N\right).
\end{aligned}$$

Since $E[\pi_t^{P_1}(\hat{n}_t^{P_1}, 1, 1, e_t^{P_1})] \geq E[\pi_t^{P_1}i(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1})]$, the expected return from treatment with the program as given in equation (A4) is greater than the expected return from not treating with the program as given in equation (A2). If we assume that corresponding covariances in equations (A3) and (A5) are approximately equal (which is reasonable unless there is a large interaction between treatment/nontreatment and nitrogen fertilization levels), the variance from treating is less than the variance from not treating under the program. Thus, farmer 1, whether risk neutral or risk averse, has the incentive to move away from the (0, 0) strategy to (1, 0). So, the strategy (0, 0) cannot be an equilibrium strategy. The rationale is, when a farmer does not treat and profit is lower, the farmer shares the benefits (i.e., the larger incentive payment) with other participants. But, if the farmer treats the pest infestation, that farmer alone enjoys the benefits while the cost (i.e., lower incentive payment) is shared with all participants. Since the incentives are symmetric, farmer 2 also has the incentive to move from strategy (0, 0) to (0, 1).

Next we compute the expectation and variance of farmer 1's returns under strategy (1, 1):

(A6)
$$E\left[\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 1, e_t^{P_1}\right) + I_t(1, 1)\right] = E\left[\frac{\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 1, e_t^{P_1}\right)}{2}\right] - E\left[\frac{\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 1, e_t^{P_2}\right)}{2}\right] + \overline{\Pi}_{LR}^P$$

and

(A7)
$$\begin{aligned}\operatorname{var}&\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 1, e_t^{P_1}\right) + I_t(1, 1)\right)\\ &= \frac{\operatorname{var}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 1, e_t^{P_1}\right)\right)}{4} + \frac{\operatorname{var}\left(\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 1, e_t^{P_2}\right)\right)}{4}\\ &+ \left(\frac{\overline{\Pi}_{LR}^P}{\overline{\Pi}_{LR}^N}\right)^2 \operatorname{var}\left(\overline{\Pi}_t^N\right) - \frac{\operatorname{cov}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 1, e_t^{P_1}\right), \pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 1, e_t^{P_2}\right)\right)}{2}\\ &+ \left(\frac{\overline{\Pi}_{LR}^P}{\overline{\Pi}_{LR}^N}\right) \operatorname{cov}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 1, e_t^{P_1}\right), \overline{\Pi}_t^N\right) - \left(\frac{\overline{\Pi}_{LR}^P}{\overline{\Pi}_{LR}^N}\right) \operatorname{cov}\left(\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 1, e_t^{P_2}\right), \overline{\Pi}_t^N\right).\end{aligned}$$

We then compare equations (A6) and (A7) to farmer 1's mean and variance of returns under strategy (0, 1):

(A8)
$$E\left[\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right) + I_t(0, 1)\right] = E\left[\frac{\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right)}{2}\right] - E\left[\frac{\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 1, e_t^{P_2}\right)}{2}\right] + \overline{\Pi}_{LR}^P$$

and

(A9)
$$\begin{aligned}\operatorname{var}&\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right) + I_t(0, 1)\right)\\ &= \frac{\operatorname{var}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right)\right)}{4} + \frac{\operatorname{var}\left(\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 1, e_t^{P_2}\right)\right)}{4}\\ &+ \left(\frac{\overline{\Pi}_{LR}^P}{\overline{\Pi}_{LR}^N}\right)^2 \operatorname{var}\left(\overline{\Pi}_t^N\right) - \frac{\operatorname{cov}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right), \pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 1, e_t^{P_2}\right)\right)}{2}\\ &+ \left(\frac{\overline{\Pi}_{LR}^P}{\overline{\Pi}_{LR}^N}\right) \operatorname{cov}\left(\pi_t^{P_1}\left(\hat{n}_t^{P_1}, 1, 0, e_t^{P_1}\right), \overline{\Pi}_t^N\right) - \left(\frac{\overline{\Pi}_{LR}^P}{\overline{\Pi}_{LR}^N}\right) \operatorname{cov}\left(\pi_t^{P_2}\left(\hat{n}_t^{P_2}, 1, 1, e_t^{P_2}\right), \overline{\Pi}_t^N\right).\end{aligned}$$

The expected profit from strategy (1, 1) is greater than from strategy (0, 1). If we assume that corresponding covariance terms in equations (A7) and (A9) are approximately equal, the variance from (1, 1) is less than from (0, 1). So, farmer 1 would move from (0, 1) to (1, 1). Similarly, farmer 2 would move from (1, 0) to (1, 1). Hence, the dominant strategy, under the incentive program, is to treat the infestation if it is optimal to treat the infestation without the incentive program—regardless of whether the payment is zero or greater than zero.

A similar argument can be made when treatment is not optimal without the incentive program. In that case, it can be demonstrated that treatment is not optimal with the program. Also, it is straightforward to show that if one farmer has an infestation and the other does not, then optimal treatment strategies are unaffected by participation. Therefore, we have demonstrated, for both risk-neutral farmers and risk-averse farmers (provided our assumption regarding covariances holds), that moral hazard is not present in the program.