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Control of Nonpoint Source Pollution Through Voluntary Incentive-Based Policies: An Application to Nitrate Contamination in New York

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A voluntary program is developed to achieve environmental goals through the self-interested choices of farmers under environmental risk and asymmetric information. Farmers behave to maximize expected net returns, and environmental quality standards are formulated through chance constraints. Because the government may not know each farmer's soil type, policy options must be self-selecting. The model is applied empirically to nitrate leaching and runoff from corn production in three New York regions. Asymmetric information between producers and the government would impose additional cost burdens on society, but these costs are modest in the context of other farm programs.

Agricultural nonpoint source pollution now accounts for a large share of water quality problems in the United States (Ribaudo et al. 1999), and remains one of the most difficult policy challenges. Uniform policies, such as taxes or limits on polluting inputs, have been shown to be inefficient because farms are so heterogeneous (Braden et al. 1991; Carpentier et al. 1998). However, standard cost-efficient remedies such as discharge fees or tradable permits are impossible since emissions cannot be observed.

Because the benefits and costs of reducing farm pollution vary over space, an optimal policy would require adjustments in production to differ across farms. Yet, by definition, the benefits of controlling nonpoint pollution at each site may never be known and policies must concentrate on reducing

pollution at minimum cost within regions. In recent years, there has been an increased capacity for governments to implement cost-efficient production changes through command-and-control (CAC) policies, which would account for heterogeneity of farms by using existing soil maps, improved geographic information systems (GIS) databases, and biophysical simulation models of pollutants. Such a strategy is often criticized for being too intrusive and administratively costly.

As an alternative that is more consistent with the voluntary nature of past farm programs, Wu and Babcock (1995, 1996) proposed a decentralized scheme that allows farmers to choose from a set of predetermined policies. In their policy setting, farm pollution (e.g., nutrient leaching) differs by soil type, but each farmer's type is private information. Rather than assigning policies based on observable characteristics, the government must design a mechanism that gives farmers the proper incentives to self-select appropriate policies. Such a strategy has already been attempted in small regions as part of the Water Quality Incentive Program (Wu and Babcock 1996). Analytically, the government's problem is to maximize social welfare by finding a policy schedule that relates polluting input levels to "green" payments. Under some conditions, the schedule can be designed so that farmers of different types select distinct poli-

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cies, as efficiency requires. This result is an important conceptual achievement, but it relies on several assumptions that would need to be relaxed if the program were implemented. Namely, it assumes that the social cost of pollution is known, and that pollution and farm profits are certain for each input level. Given the “noise” in a real policy setting, we still do not know whether self-selecting policies are possible, and a framework for estimating the cost of these policies is still absent.

In this paper, we design and estimate a voluntary “green” payment program to reduce agricultural pollution under uncertainty. As a base of comparison, we assume that the government is capable of calculating soil-specific policies to meet some emissions standard, and that it also knows which soils are present on each farm from soil maps. In principle, the government could therefore assign regulations to each farm by CAC. We derive the conditions under which these regulations could instead be self-selected through voluntary “green” payments. We also show that the payments needed for self-selection exceed farmers’ pollution control costs. Assuming that assigned policies would compensate for control costs exactly, this implies that self-selection imposes some additional cost on the government. One interpretation of the additional cost is the value of having the soils information, or what the government could afford to pay to collect it. Alternatively, any comparative evaluation of these two policy strategies must weigh the additional cost of self-selection against the administrative cost and intrusiveness of CAC.

The empirical application is for reductions in nitrogen fertilizer to reduce nonpoint nitrate leaching and runoff in three regions of New York, but the model could easily be applied to other environmental goals or other production practices. To account for uncertain pollution, we set emissions standards that limit the probability of severe emissions, in the spirit of the chance constraints of Lichtenberg and Zilberman (1988). This second-best strategy circumvents the need to determine the social cost of pollution, and is consistent with the standards approach to environmental regulation discussed by Baumol and Oates (1988) and practiced by many agencies. We find that control costs to reduce nitrate residuals in New York differ by region, but are not large when compared with the costs of other farm programs, particularly if they were targeted at especially vulnerable areas. The added cost of self-selection is not large in this case, although it may be larger for a similar program applied to regions in another part of the country.

We proceed with a theoretical analysis to characterize optimal policy outcomes. The empirical

results are next presented and are followed by some policy implications.

Theoretical Model

Consider two groups of farmers ($i = 1, 2$) producing corn using nitrogen fertilizer; land differs by group, both by productivity and nitrate contamination potential.¹ Land can be meaningfully classified into soil groups because both productivity and nutrient losses depend on hydrologic characteristics (Thomas and Boisvert 1995; Crutchfield et al. 1992). Group i ’s corn yield per acre is $y^i(N_i, W)$, where y^i is a twice differentiable and strictly concave production function, N_i is nitrogen fertilizer, and W is a vector of (uncontrollable) weather variables. For simplicity, other inputs are assumed to be fixed. The prices of corn and fertilizer are p and r , respectively, and the total cost of other inputs is V . Under a government water quality program, farmers may be eligible to receive a “green” payment of S_i per acre. Note that y^i , N_i , and S_i differ by group, but prices, weather, and other costs do not.

At the time N_i must be chosen, prices and weather conditions are uncertain. Farmers seek to maximize expected net return per acre, but do not know the exact joint distribution of p , r , and W . Following Collender and Chalfant (1986), assume that input decisions are based on a minimum-variance unbiased estimator of net returns from a random sample of J prices and weather conditions:

$$(1) \quad \bar{R}^i(N_i, S_i) = \frac{1}{J} \sum_{j=1}^J (p_j y^i(N_i, W_j) - r_j N_i - V + S_i)$$

where the sample $\{p_j, r_j, W_j\}$, $j = 1, \dots, J$ may be drawn, for example, from historical observations over J years. Before any government program, payments S_i are zero, and farmers solve: $\max_{N_i \geq 0} \bar{R}^i(N_i, 0)$. Because strict concavity of \bar{R}^i in N_i follows from the same property of y^i , a solution to this problem must be unique. We assume the solution exists and denote it N_i^0 .

Group i ’s nitrate emissions are $e^i(N_i, W)$, which are random because they depend on W . Assuming the region is small enough so that the damages from nitrate emissions are similar everywhere, economic efficiency can be achieved by establishing some standard on group i ’s fertilizer use. This standard may be set, for example, based on the ex-

¹ For simplicity, and realistically for administrative reasons, we consider only two groups, but an arbitrary number of groups could be considered (e.g., Wu and Babcock 1996).

pected level of emissions or on the probability that emissions exceed some given amount e^* . Denote the fertilizer standard for group i by N_i^* .² To set these standards, the government either knows or can estimate e^i . Assume also that y^i can be estimated from research trials on different soils. If, in addition, the government knows to which group each farmer belongs, then information is *symmetric*; if not, information is *asymmetric*.

Setting Policies in the Short Run

In the short run, the number of corn acres in each group A_i is fixed. To minimize the cost of program under asymmetric information, the government must solve:

$$(2) \quad \min_{\{S_1, S_2, N_1, N_2\}} A_1 S_1 + A_2 S_2$$

subject to: $N_i \geq 0, S_i \geq 0, N_i \leq N_i^*, i = 1, 2, \quad (E_i)$

$$\bar{R}^1(N_1, S_1) \geq \bar{R}^1(N_1^0, 0), \quad (P_1)$$

$$\bar{R}^2(N_2, S_2) \geq \bar{R}^2(N_2^0, 0), \quad (P_2)$$

$$\bar{R}^1(N_1, S_1) \geq \bar{R}^1(N_2, S_2), \quad (I_1)$$

$$\bar{R}^2(N_2, S_2) \geq \bar{R}^2(N_1, S_1), \quad (I_2)$$

The government minimizes the cost of ensuring that emissions standards are met (constraints (E_i)), through changes in nitrogen fertilizer. Since the program is voluntary, the participation constraints (P_i) require post-policy expected returns to be at least at the pre-policy levels. Because the government does not know each farmer's group, both policies would be available to all producers. For farmers to self-select the policy designed for their group, S_1 and S_2 must also satisfy the incentive compatibility constraints (I_i) , guaranteeing that group i 's post-policy expected net return is at least as great under its own policy as it would be under group j 's policy. If information is symmetric, then the government offers only one policy to each group and the constraints (I_i) can be ignored.³

² Nitrate emissions themselves only have an indirect effect on damages, which depend on the ambient concentration of nitrates in drinking water. Nonetheless, emissions are almost always used as the pollution variable in the literature because the physical flow of nutrients into and within aquifers is so poorly understood (Teague, Bernardo, and Mapp 1995; Helfand and House 1995; Johnson, Adams, and Perry 1991). Conceptually, if emissions from each farm within a type affect social damages differently, then there are as many types as farmers. Policies could theoretically be designed for this case (Wu and Babcock 1996) but they would be difficult to implement in practice.

³ Another potential source of asymmetric information may be the diversity of per-acre net returns within a soil group. We have abstracted from this complexity because the policy incentives are based only on

Geometrically, the solution depends on the level sets of \bar{R}^i , i.e., the locus of all combinations of N_i and S_i for which expected net return is constant. Figure 1(a) depicts examples of these level sets, where \bar{R}_0^i traces out the pairs (N_i, S_i) that generate the pre-policy level of expected net returns $\bar{R}^i(N_i^0, 0)$. Note that the pre-policy solutions are at the intersections with the horizontal axis where $S_i = 0$.

For a solution to exist when information is asymmetric, the level sets of \bar{R}^1 and \bar{R}^2 must satisfy the "single-crossing property" (Mas-Collel et al. 1995); one of the groups must always need more compensation for the same reduction in nitrogen fertilizer. This property holds in figure 1(a) because \bar{R}_0^2 is steeper than \bar{R}_0^1 . More generally, the property requires:

$$(3) \quad - \frac{dS}{dN} \Big|_{\bar{R}^2} \equiv \frac{\bar{R}_N^2(N, S)}{\bar{R}_S^2(N, S)} > \frac{\bar{R}_N^1(N, S)}{\bar{R}_S^1(N, S)}$$

$$\equiv - \frac{dS}{dN} \Big|_{\bar{R}^1}, \forall (N, S) \in \mathbb{R}_+^2$$

where subscripts denote derivatives. At all points in N - S space, the slope of one level set must exceed the slope of the other; with no loss in generality, we have assigned the indexes i so that \bar{R}^2 is steeper than \bar{R}^1 . Substituting the derivatives of \bar{R}^i from equation (1) into (3):

$$(4) \quad \frac{1}{J} \sum_{j=1}^J p_j y_{NM}^2(N, W_j) - r_j > \frac{1}{J} \sum_{j=1}^J p_j y_{NM}^1(N, W_j) - r_j$$

For a solution to exist in the asymmetric case, the mean of marginal net returns for group 2 must be larger than for group 1. It follows immediately that the single crossing property is satisfied if $y_{NM}^2(N, W) > y_{NM}^1(N, W)$, for all (N, W) ; if group 2's marginal product of nitrogen is higher at every fertilization level and for all weather conditions, the mean marginal returns across weather observations is also higher.

This result underscores the fact that "green" payments depend on land productivity and fertil-

marginal changes in returns (movements along the net return functions) due to changes in fertilizer, not the levels of returns. Conceptually, variation within groups could be accommodated by adding a disturbance term to the changes in returns. From the government's point of view, the constraint (P_i) , for example, would then involve the stochastic change $\Delta_R = \bar{R}^i(N_i^0, 0) - \bar{R}^i(N_i, S_i) + \epsilon_i$, where ϵ_i represents the variation across farms in group i , (defined such that $E[\epsilon_i] = 0$); the precise statement of (P_i) would be in probabilistic terms: $\Pr\{\Delta_R \geq 0\} > \beta$, where β is some confidence level close to 1. Such constraints describe confidence intervals around the constraints in problem (2) that represent the government's uncertainty over the change in each producer's net returns.

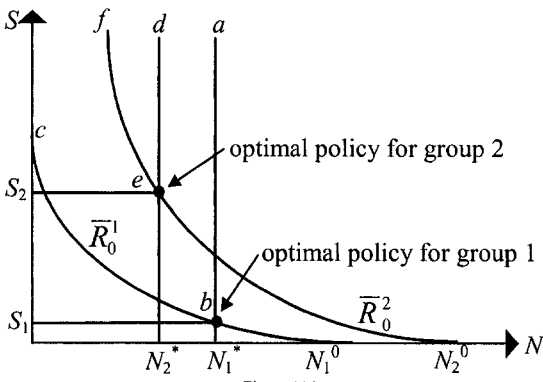


Figure 1(a)

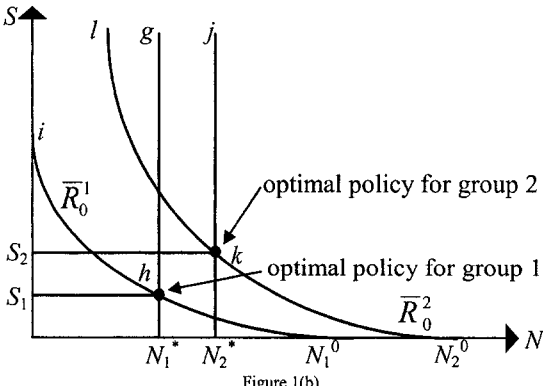


Figure 1(b)

Figure 1. Policies under Symmetric Information

ization levels. In reality, these relationships are empirical questions, but we assume two conditions:

$$C1: y_N^2(N, W) > y_N^1(N, W), \quad C2: 0 \leq N_i^* \leq N_i^0$$

From above, C1 is sufficient for the single crossing property to hold. C2 means producers decrease fertilization rates to meet environmental standards, which rules out uninteresting cases.

The nature of the “green” payments can be summarized in the three statements below. Since we do not know *a priori* which group must fertilize at a lower rate to satisfy environmental standards, we must consider two cases: $N_2^* \leq N_1^*$ and $N_1^* < N_2^*$. While Peterson and Boisvert (1998) establish these statements formally, they are also easily verified by graphical arguments because N and S are the only decision variables.

STATEMENT 1: *Suppose that information is symmetric and C2 is satisfied. Then, whether $N_2^* \leq N_1^*$ or $N_1^* < N_2^*$, the constraints (E_i) and (P_i) will bind in the optimal policies for $i = 1, 2$.*

Figures 1(a) and 1(b) correspond to the cases $N_2^* \leq N_1^*$ and $N_1^* < N_2^*$, respectively. Because expected revenue along the curves \bar{R}_0^1 and \bar{R}_0^2 are the pre-

policy levels, the participation constraints (P_1) and (P_2) are met on and above \bar{R}_0^1 and \bar{R}_0^2 , respectively. In figure 1(a), a policy for group 1 (N_1, S_1) satisfies (E_1) if it lies on or to the left of the vertical line at N_1^* , and the feasible set that satisfies both (P_1) and (E_1) is region abc . The minimum payment in this region is point b ; both constraints bind. Similarly, the feasible set for group 2’s policy is region def , lying to the left of N_2^* and above \bar{R}_0^2 . Point e is the policy that minimizes payments. Parallel reasoning leads to the optimal policies h and k in figure 1(b).

STATEMENT 2: *Suppose information is asymmetric and C1–C2 are satisfied. Then, whether $N_2^* \leq N_1^*$ or $N_1^* < N_2^*$, constraints (E_2) and (P_2) bind in the optimal policy for group 2.*

Figures 2(a) and 2(b) correspond to $N_2^* \leq N_1^*$ and $N_1^* < N_2^*$, respectively. Based on the same reasoning as above, group 2’s constraints (E_2) and (P_2) are satisfied in regions mno in figure 2(a) and pqr in figure 2(b); payments are minimized at n and q . The extra self-selection constraints, (I_1) and (I_2) require that group 1’s policy lie on or above the iso-expected revenue curves \bar{R}^1 passing through n and q . Choosing n and q as group 2’s policies also minimizes group 1’s payment; any higher payment to group 2 would raise the minimum bound on the payment to group 1.

STATEMENT 3: *Suppose that information is asymmetric and C1–C2 are satisfied. If $N_2^* \leq N_1^*$, group 1 will share group 2’s policy, with (E_1) nonbinding; if $N_1^* < N_2^*$, group 1 will have a separate policy, with constraints (I_1) and (E_1) binding, and (P_1) nonbinding.*

In figures 2(c) and 2(d), group 2’s optimal policies are again at points n and q , respectively. In both figures, a policy for group 1 (N_1, S_1) satisfies (E_1) on or to the left of the vertical line at N_1^* , (I_1) on or above the curve \bar{R}^1 , and (I_2) on or below the curve \bar{R}_0^2 . In figure 2(c), where $N_2^* \leq N_1^*$, the feasible set that satisfies these constraints is region snt . The minimum payment to group 1 is at n , verifying the groups will share the same policy, and that (E_1) is nonbinding. In figure 2(d), where $N_1^* < N_2^*$, the feasible region is uvw . Here, the minimum payment occurs at w , where the constraints (E_1) and (I_1) bind. Finally, note that w lies strictly above the curve \bar{R}_0^1 , implying the constraint (P_1) is nonbinding.

These results have important implications. If information is symmetric, fertilization levels for both of the cases satisfy the environmental standards exactly and producers in both groups are indifferent between participating or not (figure 1). If information is asymmetric and group 2 (whose yield function is steeper) is the most prone to pollute, only one policy is optimal; both groups fertilize at

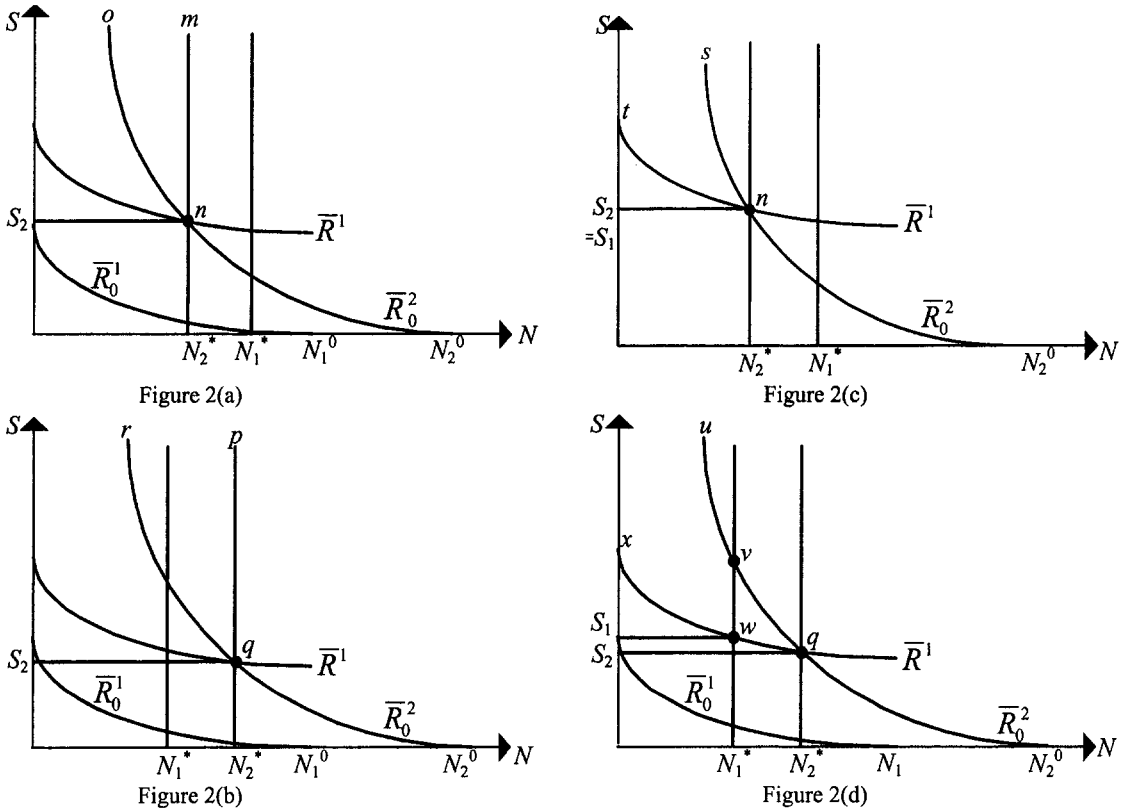


Figure 2. Policies under Asymmetric Information

the same rate and receive the same payment. To ensure this fertilization level meets the environmental standards, group 1 is compensated to reduce fertilizer more than necessary (figure 2(c)). If information is asymmetric and if group 2 generates less leaching and runoff than group 1, the mechanism allows policies to diverge. At the optimal policies in this case, the fertilization levels for both groups meet environmental standards exactly. Group 2 is indifferent between participating or not, while group 1 is strictly better off.

It follows that asymmetric information always leads to higher payments. If the government offers a uniform policy, it must pay group 1 to reduce fertilizer more than necessary; if separate policies are offered, group 1's payment is more than their loss in net returns to self-select. Empirically, this extra government cost, or "information premium," can be found by estimating payments in both the asymmetric and symmetric cases. If the government already has soils information, the difference in costs is society's "price" of allowing farmers to choose their own policies. Otherwise, it represents the opportunity value of information, which would need to be weighed against the cost of collecting it.

Setting Policies in the Long Run

In the long run, the number of acres in corn production depends on expected net returns, and policy targets on total emissions require that limits also be placed on corn acreage. The government's long-run problem can be written:

$$\min_{\{S_1, S_2, N_1, N_2\}} A_1(\bar{R}^1(N_1, S_1))S_1 + A_2(\bar{R}^2(N_2, S_2))S_2$$

subject to: $(E_i), (P_i), (I_i), i = 1, 2$

$$A_i(\bar{R}^i(N_i, S_i)) \leq A_i^0 \quad i = 1, 2$$

where $A_i^0 = A_i(\bar{R}^i(N_i^0, 0))$ is group i 's pre-policy corn acreage. If information is symmetric, the optimal short-run policies are also optimal in the long run. Since the self-selection constraints (I_i) can be ignored in this case, post-policy returns per acre for both groups are equal to the pre-policy levels (statement 1), generating no additional incentive to change acreage ($A_i = A_i^0$). If information is asymmetric, there is again no incentive for group 2 to change acreage, but under some conditions the constraint (P_1) is nonbinding in the optimal short-run policy (statement 3), so that group 1's post-

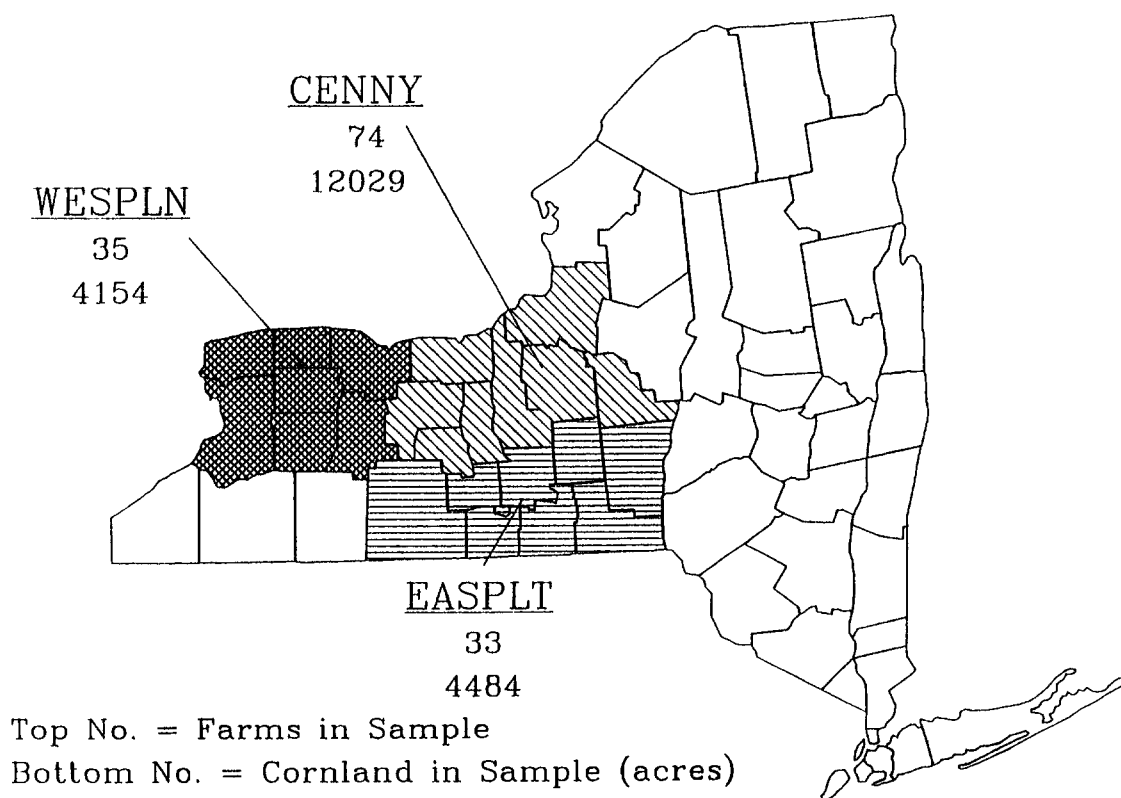


Figure 3. Three New York Farming Regions

policy net returns per acre exceed the pre-policy level. This may provide a sufficient incentive for group 1 to expand acreage in the program (e.g., $A_1 > A_1^0$).

This “entry problem” is an inherent property of environmental subsidies (Baumol and Oates 1988; Spulber 1985), which could be avoided by eliminating the incentive to expand acreage through other means. For example, program eligibility could be limited to historical base acreage as for past commodity payments. Yet, the severity of the entry problem is an empirical question. We estimate the potential severity in the application below, by finding the optimal short-run policies and then simulating the long-run adjustments based on empirical corn acreage-response functions from the literature.

An Application to Corn Production in New York

Our model is applied to simulate policies to reduce nitrate leaching and runoff from corn production in three regions of New York, which correspond roughly to production regions in the Cornell Co-

operative Extension dairy farm business project (figure 3). Although farmland in much of New York, as in other dairy regions, is primarily made up of heavier soils situated on hillsides, these regions do reflect differences in topography, soils, climate, and land use.

The Eastern Plateau (EASPLT) is in the Appalachian Uplands, characterized by flat-topped hills with long, relatively steep slopes and large, flat valleys. The southern section of Central New York (CENNY) is also part of the Appalachian Uplands, while the northern part is in the Erie-Ontario Plain, made up of deep soils with gentle to moderate slope. Much of the Western Plain (WESPLN) lies in the Ontario Lowlands with a gently rolling topography and differences in elevation usually less than 30 feet. Farms tend to be largest in WESPLN. By region, between one-fifth and one-third of the cropland is in corn.

To estimate “green” payments for these regions, corn acreage is classified into two soil groups and corn yields are estimated for each. Based on these functions, along with observations of weather and prices, and soil characteristics by parcel for a sample of New York farms, payments are computed from the theoretical framework above. Ni-

trate emissions are estimated for over 47,000 parcels to obtain fertilizer standards by group, and payments are estimated for each group based on the two yield functions.

Data and Estimation

Throughout the empirical model, corn acreage is divided into group 1 (soils from Hydrologic group A) and group 2 (soils from Hydrologic groups B and C).⁴ Hydrologic A soils have a coarser texture and are more vulnerable to leaching than B or C soils (Crutchfield et al. 1992). Corn silage yield functions for these groups are estimated from field trial data collected at several sites by the Department of Soil, Crop, and Atmospheric Sciences at Cornell University and from weather stations near the trial locations. These data contain 66 combinations of yield, fertilization rates, and weather, with 12 observations from group 1 soils and 54 from group 2. To gain efficiency, the function was estimated in a pooled regression (*t*-ratios):

$$y = 16.32 - \frac{5.15 D}{(-3.01)} + \frac{0.096N}{(6.43)} - \frac{0.0003N^2}{(-4.43)} + \frac{0.00006DN^2}{(1.15)} + \frac{1.56W_1}{(5.48)} - \frac{1.49 DW_1}{(-5.32)} + \frac{0.0066W_2}{(3.23)} - \frac{0.0018W_1N}{(-1.51)} \quad R^2 = 0.72$$

Silage yields (tons per acre) (*y*) depend on a dummy variable for soils (*D* = 1 for group 2, 0 otherwise), total nitrogen applied (*N*),⁵ growing season rainfall in inches (*W*₁), and growing degree days (*W*₂). See Peterson and Boisvert (1998) for specification and estimation details.

The estimated coefficients of the model have theoretically expected signs and the fit also appears adequate. At average weather and fertilization rates of 100 lbs. per acre, a one-pound increase in nitrogen fertilizer increases yield by 0.038 tons and 0.048 tons per acre for groups 1 and 2, respectively. A one-inch increase in growing season rainfall increases yield by 1.56 and 0.07 tons/acre for the two groups, respectively. A 100-unit increase in accumulated growing degree days results in a 0.66 ton/acre increase in yield for both groups. The yield functions are adjusted *ex post* to allow for 15% harvest and other losses.

The specification is based on previous agonomic evidence (New York State College of Ag-

riculture and Life Sciences 1987) that light and heavy soils represent distinct yield groups, allowing the marginal products of nitrogen and rainfall to differ across groups. The small value (and relatively small *t*-ratio) of the coefficient on the slope dummy term *DN*² suggests that the expected productivity differential of nitrogen was not well manifested in our cross-sectional data of the two soil groups. By maintaining this specification in the analysis below, however, we show that even this small difference in productivity leads to a substantial difference in payments. Clearly, if such a program were to be implemented, the yield functions would need to be estimated more precisely from more comprehensive field trials on a larger sample of soils.

Expected net returns are simulated in each region by equation (1), using the estimated yield functions above and a sample of time series observations on (real) prices and weather for the 30-year period 1963–1992. The prices *p_j* and *r_j* in this series are imputed from corn grain and urea prices from *New York Agricultural Statistics*,⁶ and the weather variables are taken from a central weather station in each region. Variable costs other than nitrogen *V* are based on enterprise budgets from Schmit (1994) and the USDA (1994). All prices and costs are converted to constant 1992 dollars. Because New York farmers typically apply manure, a 70-pound nitrogen credit (from 20 tons of manure per acre) is assumed. Optimal pre-policy fertilization levels *N_i⁰* are found by maximizing *Rⁱ(N_i, 0)* numerically. These optimal rates for group 1 range from 129 pounds per acre in CENNY to 132 pounds in EASPLT, while those for group 2 are about 30 pounds higher (table 1).

Nitrate emissions for group *i* are simulated from estimated functions that relate nitrate runoff (*e_Rⁱ*) and leaching (*e_Lⁱ*) on New York soils to nitrogen application, soil characteristics, and rainfall variables (Boisvert et al. 1997). This system of equations has a recursive structure:

$$e_R^i = e_R(N_i, w; c_i)$$

$$e_L^i = e_L(N_i, w; c_i, e_R^i)$$

where the vector *w* contains four rainfall variables (inches of annual rainfall and rain within 14 days of planting, fertilizer, and harvest); and *c_i* is a vector of five soil characteristics (pounds of nitrogen mineralized by the soil per acre, average percent

⁴ Hydrologic group is a classification of soils based on their capacity to permit infiltration.

⁵ *N* is pounds of nitrogen from manure and inorganic fertilizer; manure is assumed to contain 3.5 pounds of nitrogen per ton.

⁶ While the production functions were estimated from silage yields, only about 40% of corn acreage is harvested for silage in New York, with the remainder for corn grain. The imputed silage prices represent the opportunity value in terms of foregone sales in the grain market.

Table 1. Estimated Pre- and Post-Policy Fertilizer, Returns, and Payments, by Region and Group

Description	CENNY		EASPLT		WESPLN	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
Pre-policy variables						
Fertilizer (pounds per acre)	129	160	132	165	131	164
Implied critical emissions level (pounds per acre)	28.7	32.4	21.6	14.6	35.9	30.9
Corn silage yield, mean (tons per acre)	20.3	17.5	19.6	18.3	19.9	18.2
Net returns from corn production, mean (\$ per acre)	188.44	121.65	173.53	135.98	178.70	135.08
Post-policy variables, 20% standard						
Fertilizer (pounds per acre)	123	147	93	154	113	152
Critical emission level (pounds per acre) ^a	25.8	25.8	12.8	12.8	25.0	25.0
Corn silage yield, mean (tons per acre)	20.2	17.2	18.5	18.1	19.5	18.0
Net returns from corn production, mean (\$ per acre)	188.28	120.96	165.99	135.54	177.02	134.54
Payment, symmetric information (\$ per acre)	0.16	0.69	7.54	0.44	1.68	0.54
Payment, asymmetric information (\$ per acre)	0.86	0.69	7.99	0.44	2.22	0.54
Information premium (\$ per acre) ^b	0.70	0.00	0.45	0.00	0.54	0.00
Post-policy variables, 40% standard						
Fertilizer (pounds per acre)	107	131	76	129	98	135
Critical emission level (pounds per acre) ^a	19.3	19.3	9.6	9.6	18.8	18.8
Corn silage yield, mean (tons per acre)	19.8	16.8	17.8	17.4	19.1	17.6
Net returns from corn production, mean (\$ per acre)	186.13	118.28	158.03	130.99	173.19	131.83
Payment, symmetric information (\$ per acre)	2.32	3.38	15.50	4.91	5.50	3.25
Payment, asymmetric information (\$ per acre)	5.69	3.38	20.36	4.91	8.75	3.25
Information premium (\$ per acre) ^b	3.37	0.00	4.86	0.00	3.25	0.00

^aBased on a 20% or 40% reduction from the weighted average pre-policy safety level in each region, with proportions of corn acreage as weights.

^bDifference between payments under symmetric information and asymmetric information for group 1.

field slope, percent organic matter, soil horizon depth, and the erodibility factor K). The translog specification of this model, along with the estimated coefficients and regression statistics are detailed in Boisvert et al. (1997).

Distributions of total nitrate emissions $e^i = e_R^i + e_L^i$, are simulated for both groups in each region from the above equations over the 30-year sample of rainfall observations and a 142-farm sample of soil characteristics (Kelleher and Bills 1989), conditional on the fertilization level.⁷ Table 2 reports selected statistics of the sample and of the distributions of pre-policy emissions. The distribution of soils in the sample is fairly representative of the actual distribution (as reflected in the 1982 National Resources Inventory) with the possible exception of the EASPLT region, where the proportion of soils in hydrologic group A appears high (Boisvert et al. 1997).

The simulated distributions of emissions have 30 observations, where each observation is a weighted average of emissions across soils for one year of weather observations, with soil acreages as weights. Reported in table 2 are the means of the

30-year distributions and their 90th percentiles (the amount of soil-averaged emissions exceeded for 3 observations out of 30). We specify environmental standards as chance constraints that limit the probability of severe emission levels. That is, fertilizer use N_i must be set so that $\Pr[e^i > e^*] \leq \alpha$, where e^* is some critical "safety level" of nitrate loss and α is a small probability. We set $\alpha = 0.1$ and choose e^* for each region as reductions from the 90th percentiles in table 2.

Across the three regions, pollution differs much more than fertilizer, reflecting the differences in soil, topography, and weather. Because of the large hills in the Appalachian Uplands, cropland in EASPLT is steeper than the other two regions; about 40% and 30% of fields in EASPLT have a slope of 8% or more for the two groups, respectively, substantially more than the other regions (table 2). However, the EASPLT region receives the least rainfall and soils there have the highest capacity to mineralize nitrogen, resulting in the lowest simulated levels of both runoff and leaching. In all three regions, there is also a clear difference between groups. Group 1 soils mineralize less nitrogen and have smaller K-factors (i.e., are less erosive), and therefore emit less runoff than group 2. However, the coarser textured soils in group 1 leach significantly more than group 2, even though fertilizer is

⁷ This measure of emissions implicitly assigns equal weight to the damages from leaching and runoff. Unequal weights that vary by location could easily be accommodated.

Table 2. Soil Characteristics and Pre-Policy Pollution Levels from a Sample of New York Farms, by Region and Group

Description	CENNY		EASPLT		WESPLN	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
Sample statistics						
Number of observations	1020	23970	2160	8070	1050	11370
Proportion of sample acreage in group, by region	0.04	0.96	0.21	0.79	0.07	0.93
Proportion of acreage in group, by region, NRI ^a	0.01	0.99	0.11	0.89	0.08	0.92
Selected soil and weather characteristics						
Proportion with field slope of 3% or more	0.71	0.76	0.68	0.66	0.67	0.65
Proportion with field slope of 8% or more	0.13	0.23	0.40	0.29	0.26	0.11
Total annual rainfall, mean (inches)	39.1	39.1	32.9	32.9	38.5	38.5
Nitrogen mineralized by soil, mean (pounds per acre)	63.9	71.6	69.9	72.6	69.7	70.1
K erodibility factor, mean	0.20	0.31	0.24	0.31	0.24	0.30
Pre-policy pollution levels ^b						
Nitrogen fertilizer (pounds per acre)	129	160	132	165	131	164
Nitrate runoff, mean (pounds per acre)	1.9	2.6	1.7	2.6	1.9	3.1
Nitrate leaching, mean (pounds per acre)	14.5	13.4	12.7	8.3	18.6	12.9
Nitrate loss, mean (pounds per acre)	16.3	16.0	14.4	10.9	20.4	16.0
Nitrate loss safety level (pounds per acre) ^c	28.7	32.4	21.6	14.6	35.9	30.9

^aFrom the 1982 National Resources Inventory.

^bComputed across soils and weather conditions over the period 1963–1992.

^cQuantity exceeded 10% of the time (3 of 30 observations).

about 30 pounds lower. Because leaching makes up a much larger share of total emissions than runoff, group 1 is the more polluting soil group in every region.

The Policy Experiment

Applying the theoretical results from above, the policy experiment is to determine the optimal “green” payments to each group to achieve 20% and 40% reductions in pre-policy safety levels of nitrate emissions. Since absolute levels of emissions vary substantially by region (table 2), these relative standards provide a consistent basis for comparing the costs of improved environmental quality across diverse regions.⁸ The pre-policy 90th percentiles of emissions in CENNY and WESPLN (about 30 lbs/acre) are much larger than in EASPLT (15–22 lbs/acre). If the same relative reduction is imposed on all three regions, the *absolute* level of environmental quality will be significantly higher in EASPLT.

The fertilization rates that meet the relative environmental standards are determined by iterative

comparisons of simulated distributions of leaching and runoff. To accomplish a 20% reduction in nitrate loss, the allowable nitrogen levels vary from 93 to 123 lbs./acre for group 1 and from 147 to 154 lbs./acre for group 2 (table 1). For the 40% reduction, fertilization levels range from 76 to 107 lbs./acre and from 129 to 135 lbs/acre for the two groups, respectively. The environmentally safe nitrogen levels are always smaller for group 1, implying that separate policies will be optimal in every region if information is asymmetric (statement 3).

Optimal Payments

To study program costs, optimal policies are calculated under symmetric information (meeting only conditions (E_i) and (P_i) in equation (2)) and under asymmetric information (meeting conditions (E_i), (P_i), and (I_i)). If information is symmetric, government payments reflect the cost of foregone production income to improve environmental quality. Payments for both groups are determined by equating the respective pre- and post-policy expected levels of net return, where post-policy fertilization rates satisfy environmental standards. For a 20% reduction in nitrate loss, the payments are as high as \$7.54 per acre for group 1, but are less than \$1 for group 2 (table 1). The next increment in environmental quality comes at a substantially greater cost; for a 40% reduction in nitrate loss, payments to group 1 range from about \$2 to \$16

⁸ To ensure that post-policy emissions are the same for both groups in each region, the 20% and 40% reductions are based on the weighted average of pre-policy critical levels across the two groups, with group acreages as weights. Peterson and Boisvert (1998) also examine policies to meet absolute standards, where post-policy emissions are equal across regions as well as groups. The differences in fertilization levels and payments across regions are generally similar to those for relative standards, but are slightly more dramatic.

Table 3. Aggregate Corn Acreage and Estimated Payments, by Region and Group

Description	CENNY			EASPLT			WESPLN		
	Group 1	Group 2	Total	Group 1	Group 2	Total	Group 1	Group 2	Total
Corn Acreage (thousand acres) ^a	12	277	289	26	98	124	16	212	228
Aggregate Payments, 20% Standard									
Symmetric Information (\$000)	2	191	193	196	43	239	27	115	141
Asymmetric Information (\$000)	10	191	201	208	43	251	35	115	150
Information Premium (\$000)	8	0	8	12	0	12	9	0	9
Aggregate Payments, 40% Standard									
Symmetric Information (\$000)	12	938	949	404	481	885	88	689	777
Asymmetric Information (\$000)	12	938	949	530	481	1011	140	689	829
Information Premium (\$000)	12	0	12	127	0	127	52	0	52
Commodity Payments, 1992 (\$000) ^{a,b}			6525			2907			8605

^aBased on the 1992 Census of Agriculture.

^bDirect federal payments to producers, excluding Conservation and Wetland Reserve payments.

per acre for group 1 and \$3 to \$5 per acre for group 2. Because the reduction in fertilizer is generally larger for group 1, this group receives larger payments to restore pre-policy levels of expected net returns; payments are highest in EASPLT, where fertilizer must be reduced the most.

If information is asymmetric, the payments above will not lead to self-selection. To see this, consider group 1's policy decision in CENNY for the 40% standard. The payment of \$2.32 reflects group 1's lost income from reducing fertilizer to 107 pounds. But group 1 would prefer group 2's policy if given the choice, because it restricts fertilizer to no more than 131 pounds and includes a larger payment of \$3.38. For farmers in group 1 to self-select, their payment must be raised until their own policy makes them just as well off as group 2's policy. The computed payment to group 1 under asymmetric information (\$5.69) is made up of two components: a compensation for lost net returns (\$2.32), and an information premium (\$3.37) needed to ensure self-selection because the government cannot identify groups.

By statements 2 and 3, the payments for the asymmetric case can be computed from binding constraints in the policy problem. Group 1's payments in table 1 are solutions to a binding self-selection constraint (I_1), and group 2's payments are solutions to a binding participation constraint (P_2). The information premium to group 1 is less than \$1 for the 20% standard and ranges from about \$3 to \$5 per acre for the 40% standard, raising payments to as high as \$20 per acre. Group 2's payments do not change from the symmetric case.

Program Costs

Table 3 contains the estimated aggregate government cost (excluding administrative costs) to

achieve environmental standards in each region. Interestingly, estimated aggregate costs are largest in EASPLT, the region with the smallest corn acreage. The share of corn acreage in group 1, which receives a larger payment than group 2, is larger in EASPLT than in the other two regions, causing the average payment per acre to be much higher. In all three regions, aggregate costs are substantially larger for the 40% reduction, but are still small relative to commodity program payments. The estimated aggregate information premium is about \$30,000 for the 20% standard and about \$200,000 for the 40% standard, representing only about 5% and 7% of the cost of the proposed program, respectively.

Aside from excluding administrative costs, the estimated payments in table 3 rest on several simplifying assumptions that may have affected the results. First, all inputs except nitrogen fertilizer were assumed fixed. While agronomic evidence suggests that other inputs cannot be easily substituted for nitrogen (Paris 1992), the possibility of substitution means that payments may have been over-estimated somewhat because net returns will not fall as much as predicted. Similarly, environmental constraints were met by reducing fertilizer only, but payments may be smaller for a program that combined these input reductions with abatement activities (such as more efficient application methods) in a least-cost way. Such a program is conceivable, but would require the government to have data to estimate the cost and environmental effect of each practice.

Second, the payments are solutions to the short-run policy problem and do not consider farmers' long-run decisions to allocate land. Under symmetric information, the program generates no incentive to expand corn acreage because the payments just compensate for lost net returns. In the asymmetric

case, only group 1 sees an increase in net returns that may alter decisions at the extensive margin, but some simple computations suggest the effect on acreage would be negligible. In the most extreme case (the 40% standard in EASPLT), the increase in group 1's returns is equivalent to a 1.3% increase in the average corn price. Assuming an acreage elasticity of 0.2 (Tegene et al. 1988; Lee and Helmlinger 1985), acreage increases by about 0.25%; for the region as a whole this represents a change of less than 100 acres out of 124,000 and a consequent increase in payments of about \$1,300 out of \$1 million.

Finally, farmers are assumed to be risk neutral. If they are instead risk averse, the effect on payments depends on whether nitrogen is a risk-increasing or risk-reducing input (Ramaswami 1992). If it increases risk (so that fertilizer reductions reduce risk), payments based only on average returns are over-estimated; analogously, payments are under-estimated if nitrogen is risk-reducing. If farmers' risk attitudes were identical and known, Peterson and Boisvert (1998) estimate the risk bias in payments would range from less than \$1 to about \$5 per acre. Estimates of the true bias would require a model that incorporates each farmer's unknown risk attitude as another piece of private information.

Summary and Policy Implications

In this paper, we model a "green" payment program to improve water quality by reducing nitrogen fertilizer, where environmental goals are achieved through self-interested choices of two groups of farmers. Distinct policies can be self-selected by group if, at the margin, the most productive group pollutes the least. In this case, the pollution-intensive group receives a payment that exceeds their loss in net returns. This excess portion is an information premium that could be avoided if soils information were used to assign policies by farm.

Payments are estimated to achieve both 20% and 40% reductions in nitrate loss from pre-policy levels for three New York farming regions. These payments differ by environmental standard, region, and group. Across all regions, payments ranged from less than \$1 to as high as \$20 per acre, representing up to 12% of pre-policy net return. The information premium increased with the stringency of environmental standards, reaching a high of \$5 per acre. If one assumes complete participation, aggregate payments would range from \$0.6 million to \$2.4 million over the regions combined, depend-

ing on the stringency of environmental standards. Even under these high participation rates, this program is not terribly expensive, representing less than 15% of the commodity payments for the three regions in 1992.

Because the group of pollution-prone soils is relatively small, the information premium represents only about 10% of payments. In New York, the administrative capacity to eliminate this premium is already in place; the use value assessment program requires agricultural offices to classify farmland by tax parcel into several soil groups (Thomas and Boisvert 1995). The cost to taxpayers of allowing farmers to select policies is not large in the case examined, but it may be much larger in other areas like the Midwest where vulnerable soils are more common.

While it is important to estimate the costs of full participation for comparison purposes, 100% voluntary participation could hardly be expected in these large regions. Based on the relatively small enrollment in other agro-environmental programs in New York (Poe 1998), the estimated payments may be too small to overcome farmers' transaction costs of participating. Still, allowing farmers to self-select may increase participation levels, *ceteris paribus*.

Clearly, such programs are most effective if targeted to small areas where damages are severe. In a somewhat stylized example targeting only the most vulnerable soils, Peterson and Boisvert (1998) estimate substantially higher per acre payments and information premiums, but substantially lower total costs. The program's effectiveness may also be quite different if it imposed another kind of management practice. But, even in these cases, we must understand better the factors that influence voluntary farmer participation. More research is needed to identify soil characteristics that more sharply isolate the vulnerable soils, to refine the nitrogen yield response functions, and to understand the administrative costs of voluntary programs.

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