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OPTIMAL VOLUNTARY "GREEN" PAYMENT PROGRAMS TO LIMIT NITRATE CONTAMINATION UNDER PRICE AND YIELD RISK

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ABSTRACT*

A model of a voluntary "green" payment program is developed to control nitrate leaching and runoff from corn production in New York. The program achieves environmental goals through self-interested choices of farmers, grouped by the productive and environmental characteristics of soils. It considers randomness in prices, production, and environmental damage. Farmers are assumed to maximize expected utility subject to chance constraints on severe levels of nitrate contamination.

This program compensates farmers for applying environmentally safe levels of nitrogen fertilizer. If information is symmetric, program participation conditions require that the post-policy expected utility is at least as large as pre-policy expected utility. Under asymmetric information payments must be set so that farmers in group i always prefer their own policy over group's policy. If information is symmetric, the two groups have separate optimal policies. If information is asymmetric, separate policies are optimal if, and only if, the group with higher marginal productivity of nitrogen can meet environmental standards more easily; otherwise only a single policy need be specified.

An empirical application of the model to three New York farming regions is based on estimated yield and environmental damage relationships from New York soils data. Asymmetric information between producers and the government would impose a cost burden on society. Separate policies are specified for the two groups, and the cost of information is as high as $11 per acre. The group most susceptible to nitrate leaching and runoff receives a windfall benefit, but this group makes up only about 10% of the total corn acreage.

Two alternative methods of defining environmental quality standards are examined. First, environmental standards impose relative (percentage) reductions from pre-policy levels of nitrate loss. The second method requires an absolute level of environmental quality.

The optimal payments range from $1 to $28 per acre. Under relative standards, payments are highest in the region with the highest level of pre-policy environmental quality. This situation is reversed when absolute standards are imposed. At an aggregate level, the program payments would range from $0.5 million to $3.5 million over the regions combined, representing between 3% and 18% of total government payments received by farmers in the three regions in 1992.

The effect of risk aversion on program payments depends on whether nitrogen fertilizer is a risk increasing or risk reducing input. For the New York case studied, nitrogen was a risk reducing input for the group with higher yielding soils, and a risk increasing input for the other. Higher levels of risk aversion increase payments for the first group and decrease payments for the second.

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INTRODUCTION

Increasing public awareness and concern for the quality of our nation's surface and groundwater supplies have, in recent years, elevated the interest in policies to control environmental damage at all levels of government. Point sources of water contamination, such as industrial dumping of wastes, or the leaching of chemicals from waste disposal sites, are often easy to identify, and traditional policies such as taxes and quantity restrictions can prove effective in dealing with such cases. Here, the process of administration and enforcement can be relatively straightforward as well.

Less is known about the extent to which non-point sources of contamination exacerbate the nation's water quality problems. National studies (Nielson and Lee, 1987; Kellog *et al.*, 1992) suggest that non-point agricultural sources do contribute to ground and surface water problems (particularly in the Midwest, in the southeast coastal plains and in the irrigated farming areas of the West), but even in those regions, the seriousness of the problem depends on soils, production practices, and the proximity of agricultural land to important surface and groundwater sources. There remains substantial disagreement as to the how widespread these problems are and the overall extent of the agricultural industry's effect of water quality. These disagreements are unlikely to be completely resolved in the near future.

The formulation of sound policies to regulate environmental damage from agricultural production has proved to be difficult as well. Recent advances in complex biophysical transport models have improved our ability to predict the movement of residues, but these vary significantly for soils with different physical properties and productivity, and alternative management practices. What is not known is the extent and geographic distribution of these circumstances and conditions across major regions of the country, within specific production areas, or across farms. The data requirements for such investigations are substantial.

Policy analysts are beginning to recognize the importance of this spatial diversity in policy formulation. Helfand and House (1996), for example, conclude, "[t]he possible cost of using uniform instruments in nonuniform conditions could be quite high; on the other hand, the cost of using nonuniform instruments, in terms of monitoring and enforcement costs, could also be quite high" (p.1016). Thus, if we are to select from the list of conventional policy tools, such as taxes or quantity restrictions on inputs or pollution, substantial inefficiencies or high administrative costs are apparently inevitable. A major cause for the problems, costs, and inefficiencies in policy implementation is the asymmetry of information between policy makers on the one hand, and the farmers on the other. Since farmers know much more about their land and other resource situations than do even the local policy makers or program administrators, the challenge is to design creative policies which recognize this fact to accomplish stated environmental policy goals at minimum social cost.

One recent proposal is an incentive-based voluntary "green" payment program under asymmetric information (Wu and Babcock, 1995). This policy was originally formulated for two groups of producers, but was also examined at a theoretical level for an arbitrary number of groups (Wu and Babcock, 1996). This type of program would offer "green" payments to farmers as an incentive to adopt environmentally sound production practices. Separate policies for different groups of farmers would be determined based on their resource situations, and payment levels would be set so that farmers have no incentive to choose a policy intended for another group. These features of the program allow policies to diverge across groups, with a limited administrative burden.

Wu and Babcock formulate their policy to maximize social welfare, which is equal to farm income less the social cost of pollution and the marginal social cost of raising tax revenue to support government payments. The analysis assumes that net returns and environmental damage are known with certainty; it was also necessary to set the unknown social costs of pollution at arbitrary levels so that tax rates needed to raise sufficient revenue could be determined. Chambers and Quiggin (1996) analyze a similar policy which incorporates production risk: in a principal-agent setting, the government formulates a crop insurance mechanism so that risk averse farmers have less of an incentive to apply fertilizer.

Objectives

This research extends the analysis of "green" payment schemes in several important ways. First, the optimal design of the program is determined both under symmetric and asymmetric information. Second, the self-selection conditions for setting program payments, which insure that producers have no incentive to select the wrong option, take account explicitly of price risk and yield risk due to weather. Finally, following Lichtenberg and Zilberman (1988) and Zhu *et al.* (1994), the government's policy objectives are articulated as a chance constraint which limits the probability of severe environmental damage.

Empirically, this policy alternative is applied to control nitrate leaching and runoff from corn production in three major production regions of New York. To facilitate the policy analysis, cropland is grouped primarily on the basis of corn productivity and the soil's potential for nitrate leaching and runoff. Although the emphasis is on a policy where "green" payments are offered as an incentive to reduce nitrogen fertilizer application, the policy design could be modified in obvious ways to examine optimal "green" payments to achieve voluntary adoption of other environmentally sound production practices.

By characterizing policies under both symmetric and asymmetric information, the analysis isolates conditions under which it is necessary to articulate different policies for each group and when a single policy is sufficient. Estimated payments for the two situations provide the basis for determining the additional government cost due to the asymmetric information about the resource endowments of farm groups.

The explicit inclusion of production and price risk is particularly timely, given the likelihood that agricultural production will become riskier as traditional farm programs are de-emphasized. Through this analysis, the effect of risk on the optimal size of program "green" payments can be studied. It is also be possible to identify the implications for the effectiveness of programs that are implemented under erroneous assumptions about the risk attitudes of farmers.

Regulating environmental quality through chance constraints accommodates the inherent uncertainty in environmental damage, and is consistent with a standards approach to environmental regulation as discussed by Baumol and Oates (1988) and as practiced by many agencies. Through this standards approach, many of the problems inherent in assigning social values to environmental damage are avoided.[1]

[1]Techniques for valuing the environment have been developed (e.g. Randall, 1987), and they have been implemented empirically (e.g. Jordan and Elnagheeb, 1993; Poe and Bishop, 1992; Sun *et al.*, 1992; Edwards, 1988; Malone and Barrows, 1990; and Boyle *et al.*, 1994), but most of this work is for small areas. It has proved extremely difficult to generalize these results to larger regions.

Organization of the Report

The remainder of this report proceeds with the development of a theoretical model of production under uncertainty, which determines farmers' tradeoffs between input reduction and compensation payments. These tradeoffs, along with chance constraints on environmental damage, are incorporated in a mechanism design model of a voluntary "green" payment program, which allows the optimal policies under different situations to be characterized. The third section contains a description of data and procedures used to estimate the corn yield and nitrate leaching and runoff functions of the policy design model. A stylized version of the empirical model is used to highlight the results. The description of three New York study regions in section 4 is followed by a presentation of the empirical results of the model's application to these three regions. The final section provides some conclusions and policy implications.

THEORETICAL MODEL

In a "green" payment program to control nitrate leaching and runoff from corn production, farmers voluntarily adopt an environmentally sound production practice in exchange for compensation payments from the government. The hypothesis underlying such a policy scheme is that different groups of producers have distinct production and pollution characteristics, implying that optimal environmental policies should also differ across groups. In the case of nitrate contamination, production and pollution characteristics differ by soil.

A "green" payment scheme would not just formulate distinct policies for each producer group, but would also achieve distinct policy outcomes when participation in the program is *voluntary*. To implement such a program, the government would present a "menu" of policies, and allow each producer to choose his or her own policy from all the menu items. Here, a *policy* refers to a particular production practice and the associated government compensation payment, and the government's problem is one of properly designing and pricing the choices on the policy menu. For each group, the government determines production practices which ensure that environmental policy goals are met, and also sets compensation payments so that a farmer will voluntarily select, from all the choices on the menu, the policy designed for his or her own group.

The model is viewed from the perspective of a government planner who must first collect information about the production and pollution characteristics of different groups of producers and then select production practices and compensation payments for each group. Environmental policy goals must be met, while limiting the cost of the program to taxpayers. To build a model with enough detail for the proper policies to actually be determined, the meaning of "producer groups", "production practices", "information", "environmental policy goals", and "compensation payments" must be made precise.

The Producer Groups

A basic assumption of the program under consideration is that producers can be separated into mutually exclusive groups on the basis of some characteristic that affects both pollution and production levels. In the case of nitrate leaching and runoff, soil type, which influences both the amount of nitrate leaching and crop yield, is a logical candidate. For simplicity, and realistically for administrative reasons, only two groups of producers are considered. In principle, of course, such a program could accommodate an arbitrary number of producer groups, and the model developed here can be extended to consider the more general case (e.g., Wu and Babcock, 1996).

Production Practices and Information

To reduce nitrate pollution, the program may require such production practices as more frequent and timely applications of fertilizer during the growing season, planting corn in narrower rows, eliminating winter manure spreading, or limiting the amount of nitrogen fertilizer applied. This study explores reductions in nitrogen fertilizer. Thus to implement this "green" payment program, the government must identify for the two groups: (1) the association between nitrogen application rates and pollution levels, and (2) the cost of adopting this "practice" (the opportunity cost, or foregone farm income associated with sub-optimal fertilization levels).

In many cases, the government may have no more information than the characteristics of a typical group member. If the government does know the group identity of each producer, we say that information is *symmetric*; the government is able to offer each farmer a policy menu with two items: "do not participate (and receive no payment)", or "adopt the production practice designed for your group and accept the associated payment". The other possibility is that information is *asymmetric*; the government either has insufficient information to determine which farmers belong to which group or avoids using this classification as an overt basis for setting program payments (Chambers, 1992). Under asymmetric information, the government must offer the same policy menu to all producers, and this menu would necessarily include policies designed for every group.

In the case of nitrate leaching and runoff, one might suppose that the government does or could collect sufficient information to classify farmers into groups on the basis of soil type or productivity. Nevertheless, ignoring this information in formulating a voluntary policy would avoid substantial administrative costs. Under asymmetric information the producers themselves would decide which policy to implement, rather than having government officials decide for them. Since the government would be able to implement the program under either symmetric or asymmetric information, the ultimate choice of the better "information regime" will hinge upon the policy outcomes from the two cases, and in particular, the relative sizes of compensation payments. Thus, it is important to characterize the optimal policies for both cases.

Environmental Quality Standards

Since the program has an environmentally-based policy goal, the policy design model must include a criterion to determine by *how much* nitrogen fertilizer should be reduced for each group of farmers to abate nitrate loss by some specified amount. The first-best criterion in this circumstance is to abate pollution until the marginal social cost of the last unit abated equals the marginal social benefits from improved environmental quality, but in the case of nitrate contamination, a first-best solution is impractical (Helfand and House, 1996). Even though the on-farm cost of reducing nitrogen fertilizer may be known, and nitrate losses can be approximated with biophysical simulation models, the association between nitrate losses and contamination levels in drinking water supplies is not known. Thus, under current procedures, marginal social cost and marginal social benefits simply cannot be linked to agricultural production practices.

A more appropriate and realistic criterion in this case is the standards approach to environmental regulation, as proposed by Baumol and Oates (1988). With this approach, the model incorporates pollution abatement as a constraint rather than as an objective; the planner implementing the program uses scientific judgment to select some level of abatement as an "environmental standard", and then determines policies necessary to achieve the standard. Since the socially optimal level of abatement is unknown, the next best alternative is to ensure that any given level of pollution abatement is achieved at least cost.

To implement the "green" payment policy, the government must determine the fertilization rates for which nitrate loss will satisfy environmental quality standards. The amount of nitrate loss generated by group i is $L_i = l_i(N_i, W, C_i)$ where N_i is per-acre fertilizer application for a producer in group i, W is a (random) vector of weather variables common to both groups, and C_i is a vector of soil characteristics for group i. Nitrate loss is a random variable because of its dependence on W, which implies that environmental quality standards must be defined over uncertain levels of environmental damage. As Lichtenberg and Zilberman (1988) have shown, an efficient regulatory device in this instance is a chance constraint which restricts the probability that harmful levels of environmental damage will occur. Applying chance constraints to the case of leaching and runoff, the fertilization level N_i (i=1,2) will satisfy the environmental quality standard specified by (L^*,α) if

(1) $$\Pr[l_i(N_i, W, C_i) > L^*] \le \alpha$$

where L^* is some critical level of leaching, and α is some small probability.

Tradeoffs Between Compensation Payments and Nitrogen Fertilizer

If farmers limit nitrogen application below unregulated pre-policy levels, they forego farm income. Thus, the compensation payments required for voluntary participation in the program depend on the relationship between nitrogen fertilizer applied and income. The model developed here incorporates the inherent uncertainty in crop production. If a farmer participates in the program, any payment he receives from the government is certain income, but the income earned from crop production is random. To derive farmers' tradeoffs between these two competing sources of income, farmers are assumed to derive utility from income, and make their decisions to maximize the expected level of utility (Mas-Collel *et al.*, 1995).

Let the net returns per acre for group i be defined as:

(2) $$R^i(N_i, W, r, p) = py^i(N_i, W) - rN_i - V, \quad i=1,2,$$

where p is the price of corn silage, y^i is the per-acre production function for group i (assumed to be twice differentiable and strictly concave), N_i is nitrogen fertilizer application per acre for group i, W is a vector of weather variables in the region, r is the price of nitrogen fertilizer, and V is (constant) non-nitrogen variable cost. The variables

W, p, and r are random, implying that net returns for both groups are also random variables.

Farmers in both groups are assumed to be risk averse, valuing net returns according to the increasing and strictly concave utility functions u_i. These preferences are defined on empirical distributions of net returns, based on historical observations of weather and (real) prices over T crop years. Used in this way, these historical observations do not describe the production process over time, but rather represent a random sample of T observations from the underlying distributions of weather and prices. That is, farmers' beliefs about the probability distributions of weather and prices are based on historical experiences. This nonparametric approach to defining a probability distribution is analytically more tractable than using a probability density function and circumvents the problem of finding the correct parametric distribution in applications (Collender and Chalfant, 1986).

In the empirical distributions, each observation R^i_t corresponds to net returns if the weather and price conditions in year t were realized (t=1,2,...,T):

(3) $$R^i_t(N_i) = R^i(N_i, W_t, r_t, p_t) = p_t y^i(N_i, W_t) - r_t N_i - V$$

where W_t is the vector of weather variables observed in year t, p_t and r_t are year t realizations of corn and nitrogen fertilizer prices, respectively, and other variables are as previously defined. Let S_i represent per-acre government payments to producers in group i, and define the function:

(4) $$\bar{u}^i(N_i, S_i) = \frac{1}{T}\sum_{t=1}^{T} u_i(R^i_t(N_i) + S_i)$$

to be mean utility for group i, based on the empirical distributions of prices and weather over years t=1,...,T. The following proposition gives the relevant properties of this function (proof in Appendix A).

PROPOSITION 1: *The function* $\bar{u}^i(N_i, S_i)$ *possesses the following properties:*

(a) strictly concave,

(b) $E[\bar{u}^i(N_i, S_i)] = E[u_i(R^i(N_i, W, p, r) + S_i)]$.

By property (*b*) and the expected utility hypothesis, the farmers' pre-policy decision problems can be written:

(5) $$\max_{N_i \geq 0} \bar{u}^i(N_i, 0)$$

where S_i has been set to zero reflecting no government payments. Property (*a*) guarantees that solutions to these problems exist and are unique. Accordingly, let N_i^0 represent the optimal pre-policy level of nitrogen fertilizer for group *i*.

The Policy Design Problem

Here, the government's policy design problem is presented for both the symmetric and asymmetric information case, and sufficient conditions are derived to guarantee the existence of solutions. Suppose, first, that information between producers and the government is symmetric. In this case, the government can identify to which group each producer belongs; policies for the two groups $\{(S_1,N_1),(S_2,N_2)\}$ must be chosen so that the nitrogen levels N_1 and N_2 will meet environmental quality standards, and the compensation payments S_1 and S_2 so that farmers in both groups are willing to participate. Formally, the government's problem is:

$$(6) \qquad \min_{\{S_1,S_2,N_1,N_2\}} A_1S_1 + A_2S_2$$

$$\text{subject to:} \quad N_i \le N_i^*, \quad i=1,2, \qquad (E_i)$$

$$\bar{u}^1(N_1,S_1) \ge \bar{u}^1(N_1^0,0), \qquad (P_1)$$

$$\bar{u}^2(N_2,S_2) \ge \bar{u}^2(N_2^0,0), \qquad (P_2)$$

$$N_i \ge 0, \; S_i \ge 0, \qquad i=1,2,$$

where A_i is the number of acres of corn in each group, N_i^* is the maximum level of N_i that meets the environmental quality standard in expression (1), and all other variables are as previously defined.

The government's objective is to minimize the total cost of the program. Constraints (E_i) ensure that on all land in corn, the probability of environmental damage exceeding L^* is no more than α. Constraints (P_i) guarantee that producers in both groups are willing to participate in the program; post-policy expected utility for group *i* producers is at least the pre-policy level.

Consider now the case where information is asymmetric. The critical difference in this case is that the government does not know the group identity of any individual producer. Thus, both policies would be available to producers in both groups, and further restrictions must be imposed on problem (6) so that farmers will voluntarily choose the policy designed for their own group. These *incentive compatibility* constraints require that:

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

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

and ensure that producers in each group have no incentive to select the policy designed for the other group. Group *i*'s post-policy expected utility is at least as great under its own policy option as it would be under group *j*'s policy option.

To guarantee that a solution to this new problem exists, the functions $\bar{u}^i$ must satisfy the "single-crossing property" (Mas-Collel *et al.*, 1995). In words, this condition requires that one of the groups must always need more compensation for the same reduction in nitrogen fertilizer. Intuitively, to meet self-selection conditions under asymmetric information, the groups' tradeoffs between *N* and *S* must differ. Without loss of generality, this property can be expressed:

$$(7) \qquad -\left.\frac{dS}{dN}\right|_{\bar{u}^2} \equiv \frac{\bar{u}_N^2(N,S)}{\bar{u}_S^2(N,S)} > \frac{\bar{u}_N^1(N,S)}{\bar{u}_S^1(N,S)} \equiv -\left.\frac{dS}{dN}\right|_{\bar{u}^1}, \forall (N,S) \in \Re_+^2,$$

where $\bar{u}_N^i$ and $\bar{u}_S^i$ are the first-order partial derivatives of $\bar{u}^i$ with respect to *N* and *S*. Geometrically, this property requires that the two groups' iso-expected-utility curves, passing through any common point in (*N*,*S*) space, cross exactly once. This condition is depicted in Figure 1, where the level set of the function $\bar{u}^2$ is steeper than that of $\bar{u}^1$. Expanding the derivatives of $\bar{u}^i$ from its definition in equation (4), this condition written in terms of producers' net return functions is:

$$(8) \qquad \frac{T^{-1}\sum_{t=1}^{T} u_2'(R_t^2(N)+S)\cdot R_{tN}^2(N)}{T^{-1}\sum_{t=1}^{T} u_2'(R_t^2(N)+S)} > \frac{T^{-1}\sum_{t=1}^{T} u_1'(R_t^1(N)+S)\cdot R_{tN}^1(N)}{T^{-1}\sum_{t=1}^{T} u_1'(R_t^1(N)+S)},$$

where R^i_{tN} is the first-order partial derivative of R^i_t with respect to *N*. After canceling T^{-1}'s and cross-multiplying terms, condition (8) becomes:

$$(9) \qquad \sum_{t=1}^{T}\sum_{s=1}^{T} u_1'(R_t^1(N)+S)u_2'(R_s^2(N)+S)[R_{sN}^2(N)-R_{tN}^1(N)] > 0,$$

which requires that in all possible pairs of years, "on average", the marginal value product of group 2 must be larger than for group 1, when the difference is weighted by the product of marginal utilities at the respective net returns.

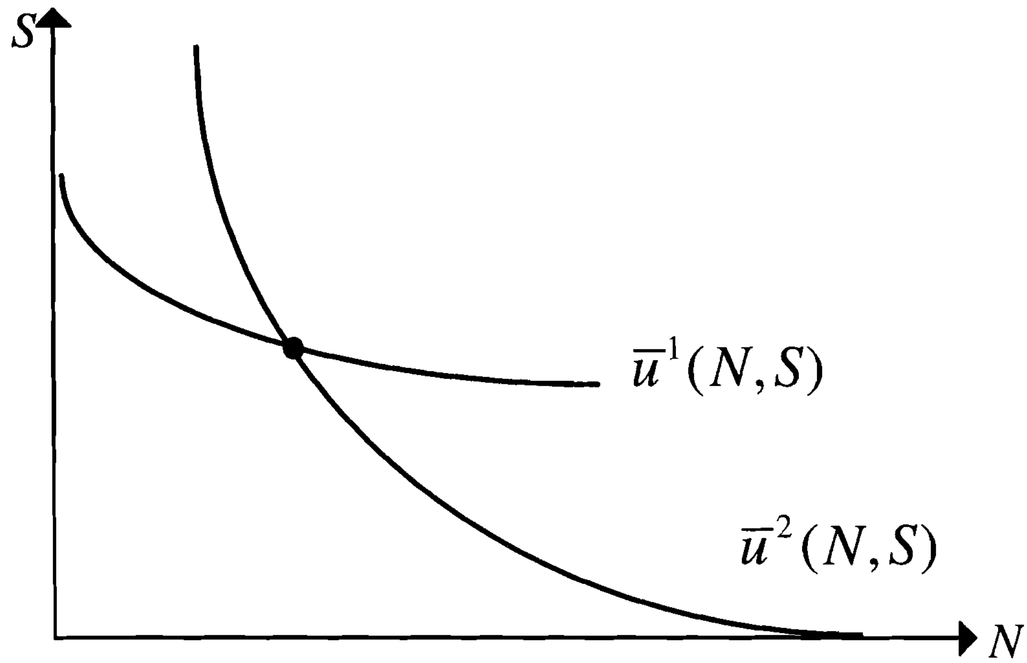

Figure 1. The Single-Crossing Property.

The following proposition relates this condition to the yield functions y^i (proof in Appendix A).

PROPOSITION 2: *If* $\frac{\partial y^2(N,W)}{\partial N} > \frac{\partial y^1(N,W)}{\partial N}$ *for all* (N,W), *the single crossing property will be satisfied.*

Intuitively, if group 2's marginal product of nitrogen is higher at every fertilization level and for all weather conditions, the average of marginal returns across years of observed weather will also be higher.

Optimal Policy Design

Having established the existence of solutions to the policy design problem, we proceed with an analysis to understand the nature of the optimal policy design. This design depends in large measure on the relationships between land productivity and initial fertilization levels for the two groups. In reality, these relationships are an empirical question, but to proceed with the analysis, we must assume that some initial conditions hold. Throughout, we also highlight the implications for policy design when the conditions are otherwise.

CONDITION 1: $\frac{\partial y^2(N,W)}{\partial N} > \frac{\partial y^1(N,W)}{\partial N}$ *for all* (N,W).

CONDITION 2: $N_2^0 > N_1^0$.

CONDITION 3: $0 < N_i^* \leq \min\{N_1^0, N_2^0\}$.

By Proposition 2, the first condition is sufficient for the single crossing property to hold and therefore guarantees that the policy design problem has a solution. The second condition is motivated by the first, but does not, in general, follow directly from it.[2] This assumption is made only for simplicity in argument; it is sufficient but not necessary for the results that follow. The third condition implies that producers in both groups must decrease fertilizer application from initial levels to meet environmental quality standards and that the standards can be met with a strictly positive level of nitrogen application; these assumptions merely rule out uninteresting cases.

The foregoing conditions specify how the production characteristics of the two groups relate to one another, but no corresponding conditions restrict environmental damage for the two groups. Since we do not know *a priori* which of the two groups causes more severe environmental damage, two cases must be considered in determining optimal policies: (1) $N_2^* \leq N_1^*$, and (2) $N_1^* < N_2^*$. In the first case, producers in group 1 may apply more nitrogen than group 2 to meet the same environmental quality standard, implying that if both groups apply nitrogen at the same rate, group 2 soils would generate more nitrate leaching and runoff. (Recall also from Condition 1 that corn yield on group 2 soils is more responsive to changes in nitrogen fertilizer.) The second case reflects the opposite circumstance: group 1 producers must apply *less* nitrogen fertilizer than producers in group 2 to meet the same environmental quality standard; for the same nitrogen application, group 1 soils generate a higher level of nitrate leaching and runoff. The following propositions describe the optimal policies in both cases.

PROPOSITION 3: *Suppose that information is symmetric and Condition 3 holds. 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* $i=1,2$.

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[2] For example, if nitrogen has a larger risk reducing effect for group 1 than for group 2, risk averse group 1 producers may use more nitrogen than would otherwise be the case. If this effect is strong enough, the optimal fertilization rate may be higher for group 1 than for group 2, even though group 2's marginal value product of nitrogen is higher.

PROOF: Since the objective function is strictly increasing in S_i, the constraints (P_i) must hold with equality: $\bar{u}^i(N_i,S_i)=\bar{u}^i(N_i^0,0)$. Since $\bar{u}_S^i(N_i,S_i)>0$, the foregoing equality implicitly defines the functions $S_i(N_i)$ such that:

$$\bar{u}^i(N_i,S_i(N_i))=\bar{u}^i(N_i^0,0),$$

with derivatives:

$$(10)\qquad S_i'(N_i)=-\frac{\bar{u}_N^i(N_i,S_i(N_i))}{\bar{u}_S^i(N_i,S_i(N_i))}<0,$$

where the foregoing inequality follows because $\bar{u}_S^i(N_i,S_i)>0$, and $\bar{u}_N^i(N_i,S_i)>0$ for all $N_i\in[0,N_i^*]\subseteq[0,N_i^0]$. Substituting the functions $S_i(N_i)$ in the objective function for S_i, the problem becomes:

$$\min_{N_i\in[0,N_i^*]} A_1S_1(N_1)+A_2S_2(N_2).$$

By (10) and the fact that $A_i > 0$, the objective function is decreasing in N_i. Therefore, the optimal policies will be set at their upper limits, N_i^*, establishing that constraints (E_i) hold with equality.

The policy outcomes under symmetric information are shown in Figures 2(a) and 2(b) for the cases $N_2^*\le N_1^*$ and $N_1^*<N_2^*$, respectively. In either case, fertilization levels are set exactly at the maximum amounts that satisfy environmental standards, and producers in both groups are indifferent between participating in the program and having no program at all.

PROPOSITION 4: *Suppose that information is asymmetric and that Conditions 1, 2, and 3 all hold. Then, whether $N_2^*\le N_1^*$ or $N_1^*<N_2^*$, the constraints (E_2) and (P_2) will bind in the optimal policy for group 2.*

PROOF: This result is most easily verified by a graphical argument. Figures 3(a) and 3(b) correspond to the cases $N_2^*\le N_1^*$ and $N_1^*<N_2^*$, respectively. In these figures, (E_2) and (P_2) are satisfied in the region aA^*b. Suppose, contrary to the claim, that an optimal policy for group 2 is chosen where (E_2) and (P_2) are slack, at a points such as A in both figures. To satisfy (I_1), (I_2), and (E_1), group 1's policy must lie in regions cAd. Consider now offering group 2 the policy A', which also satisfies (P_2) and (E_2), but with strictly lower payments. Associated with A' there is a group 1 policy B' which satisfies (I_1), (I_2), and (E_1), with lower payments than in regions cAd. Therefore, if (P_2) and (E_2)

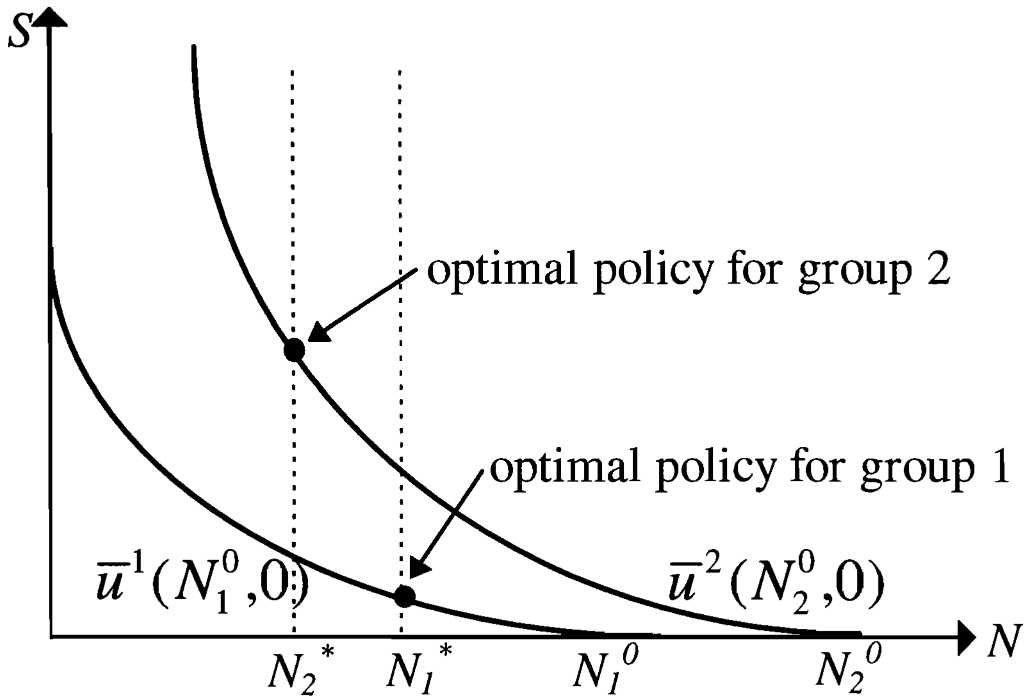

Figure 2(a)

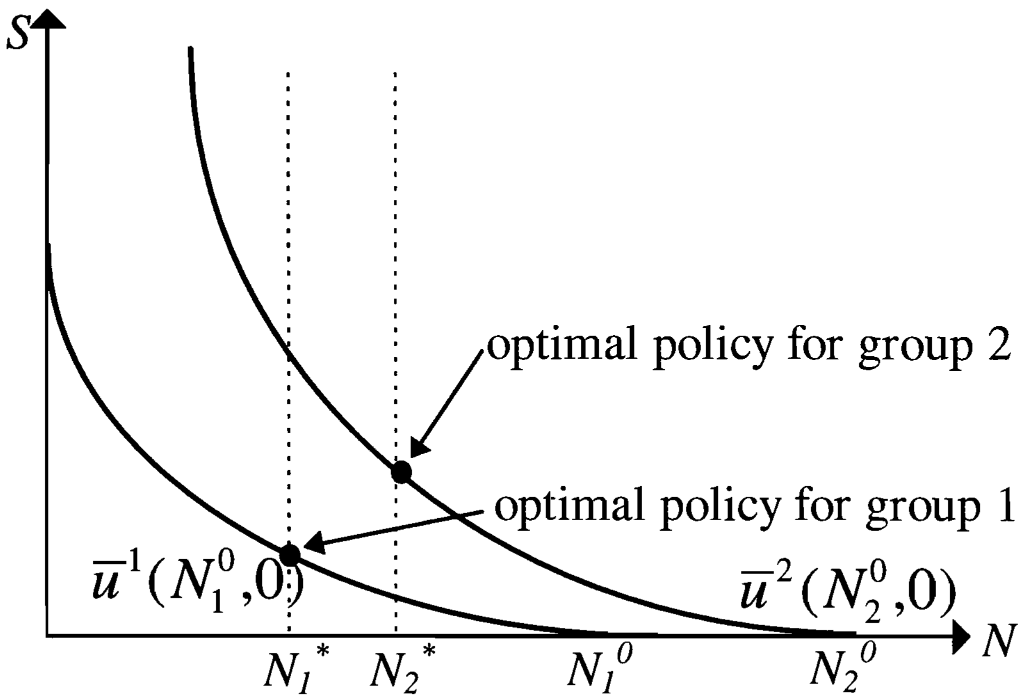

Figure 2(b)

Figure 2. Optimal Policies Under Symmetric Information.

do not bind, the solution cannot be optimal, since another feasible policy has strictly lower government cost.

PROPOSITION 5: *Suppose that information is asymmetric and that Conditions 1, 2, and 3 all hold. If* $N_2^* \leq N_1^*$*, then group 1 will share group 2's policy; if* $N_1^* < N_2^*$*, then group 1 will have a separate policy, with the constraints* (I_1) *and* (E_1) *binding, and* (P_1) *nonbinding.*

PROOF: Again, this claim is verified graphically. Figures 4(a) and 4(b) show the feasible sets that satisfy the remaining constraints (I_1), (I_2), and (E_1) as regions eA^*f, and ehB^*f, for the two cases, respectively. Parallel reasoning will verify both claims. Suppose that in the first case, group 1 does *not* share group 2's policy, and that in the second case, (I_1) and/or (E_1) are slack. Points B in the figures correspond to such policies, but B could not be optimal since the policies B' satisfy the same constraints with lower payments to group 1. To see that (P_1) is slack, suppose to the contrary that it binds at the optimal policy, at points B''. If this were true, group 2's policy would have to lie on or below the curve $\bar{u}_0^1$ to satisfy (I_1) (group 1 cannot prefer group 2's policy), but these policies are not feasible since they do not satisfy (P_2).

COROLLARY: *The nonnegativity conditions* $N_i \geq 0$, $S_i \geq 0$ *will hold in the optimal policies.*

This can be easily seen from the diagrams. The optimal policies are the points A^* in Figure 2-4(a), and A^* and B^* in Figure 2-4(b), where fertilization is set exactly at the environmentally safe levels N_1^* and N_2^*. By Condition 3, these levels are strictly positive. Condition 3, combined with the convexity of the level sets of $\bar{u}^i$, implies that S_i must be nonnegative; if producers are asked to reduce nitrogen application from N_i^0 to meet environmental standards, they must be compensated by a positive amount.

Policy Implications

These results have several important implications. First, if information is asymmetric, and if Conditions 1-3 hold and $N_2^* \leq N_1^*$ (i.e., the group whose yield is most responsive to nitrogen, group 2, is also the most prone to leaching and runoff), separate policies for the two groups cannot be supported through voluntary participation. In this case, only one policy would be optimal; producers in both groups would apply the same level of nitrogen fertilizer and receive the same payment from the government. To meet environmental quality standards, producers in group 1 will be compensated to reduce nitrogen more than necessary.

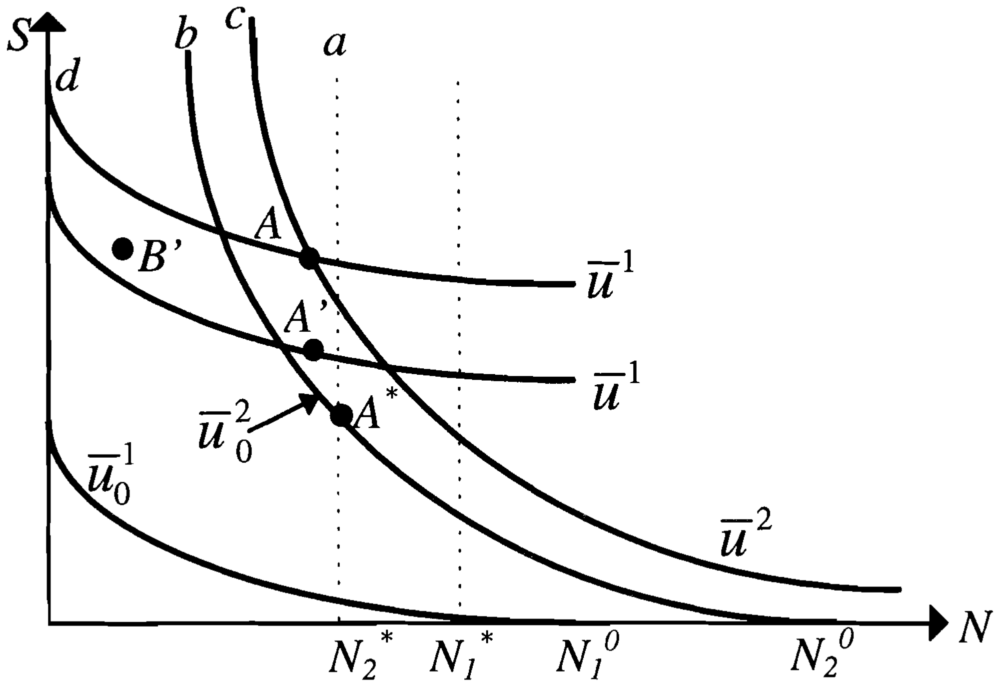

Figure 3(a)

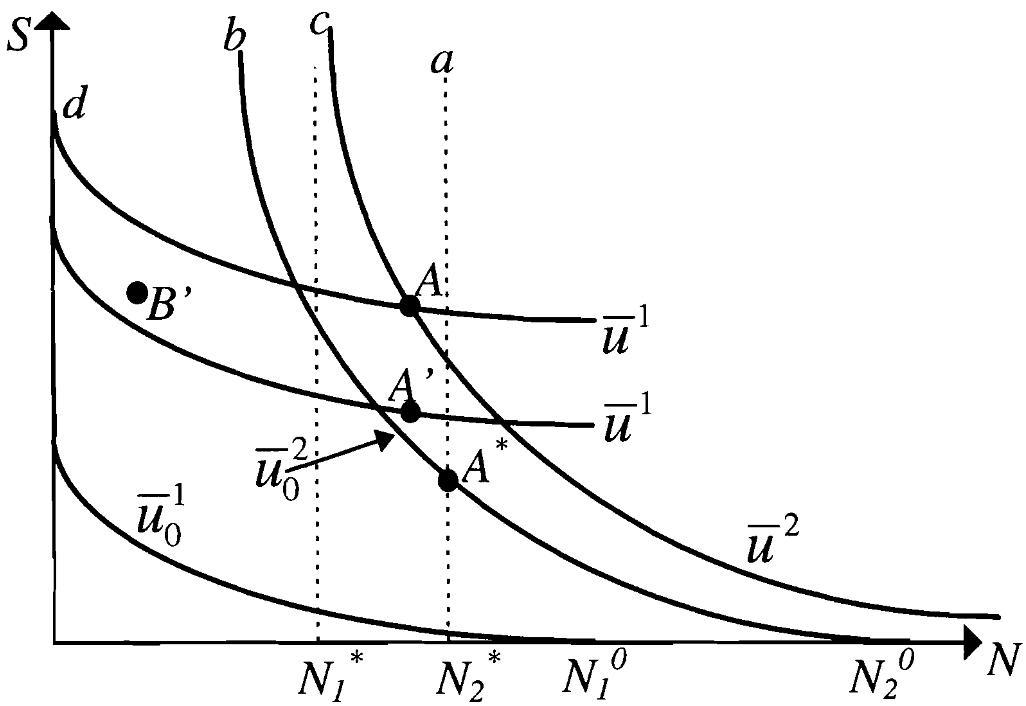

Figure 3(b)

Figure 3. Geometry of Proposition 4.

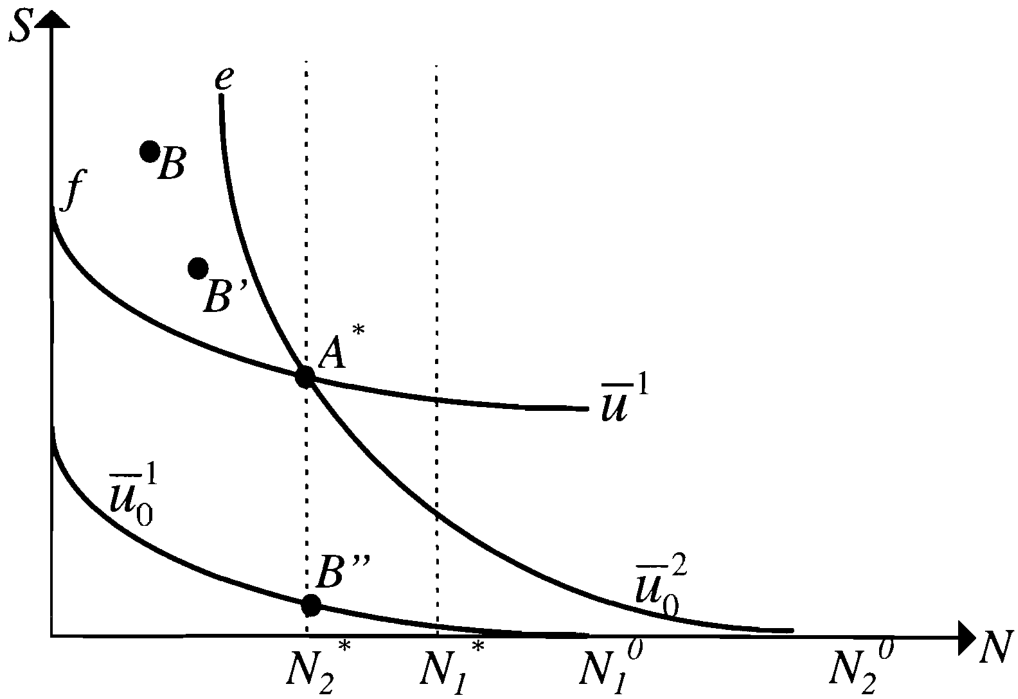

Figure 4(a)

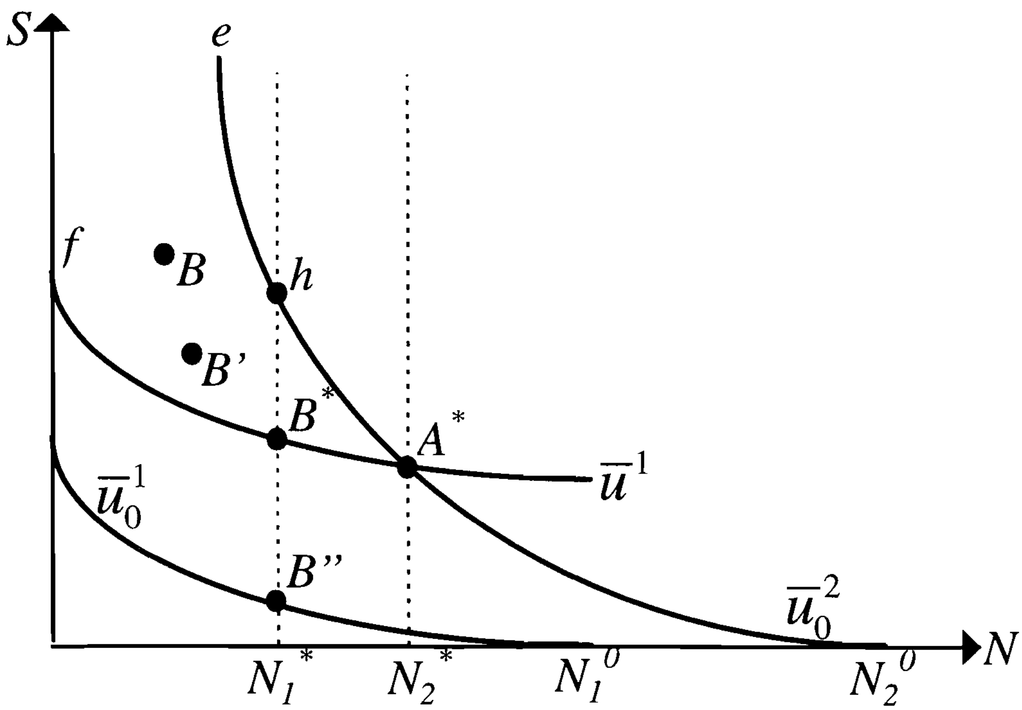

Figure 4(b)

Figure 4. Geometry of Proposition 5.

If, on the other hand, $N_1^* < N_2^*$ under asymmetric information (again assuming Conditions 1, 2 and 3 hold), the mechanism will allow policies to diverge across groups. In this case, group 2, whose yield is more sensitive to changes in nitrogen, generates a lower level of leaching and runoff *ceteris paribus*, and can therefore meet the same environmental quality standard with a higher fertilization rate. At the optimal policies in this case, the nitrogen fertilization level for both groups will meet the environmental quality standards exactly. If separate policies for the two groups are optimal, group 2 producers will be indifferent between participating in the program and having no program at all (constraint (P_2) binds), while the program will make group 1 producers strictly better off (constraint (P_1) is slack). Group 1 producers will benefit from the asymmetry of information but group 2 producers will not. If information were symmetric between producers and the government, optimal payments to group 1 producers would decrease to the level that makes them indifferent between N_1^0 and N_1^*.

In either case, a voluntary program will be more costly under asymmetric information than symmetric information. If only one policy is optimal, government costs are higher under asymmetric information because one of the groups (in this case group 1) is being compensated for a larger-than-necessary reduction in nitrogen fertilizer. If the optimal situation is for two policies, the costs to the government are higher because one group (again group 1 in this case) needs an added incentive to self-select the appropriate policy. The difference in program costs between asymmetric and symmetric information reflects the value of information to the government. The magnitude of this cost would depend on the proportion of the total resource base belonging to group 1, and would need to be weighed against the difference in administrative costs between the two information regimes.

EMPIRICAL SPECIFICATION

The policy design model is implemented empirically to formulate a voluntary "green" program to control nitrate leaching and runoff from corn silage production in New York. We begin by identifying two groups of New York corn producers based on soil characteristics. Next, there is a presentation of the data and procedures used to estimate yield functions for these two groups, where corn silage yield depends on nitrogen fertilization and weather conditions. Nitrate leaching and runoff functions, which depend on nitrogen fertilization, soil characteristics, and weather, are described also. A stylized example based on two representative New York soils is presented to highlight the consistency of the empirical results with the theory under a variety of assumptions regarding the risk attitudes of producers, the stringency of environmental standards, and information regime.

The Yield Functions

Central to the theoretical results above is the assumption that two distinct groups of farmers could be differentiated by both the productivity and pollution potential of cropland. To reflect these differences, soils on farms are distinguished by hydrologic group.[3] Group 1 is those farms with soils in hydrologic group A (which are most prone to nitrate losses), while group 2 farms have soils in hydrologic groups B and C. According to the National Resources Inventory, about 10%, 39%, and 51% of New York's cropland are in hydrologic groups A, B, and C, respectively (Boisvert et al., 1997 and Thomas, 1994).

Specification

Corn yields for the two groups of producers, $y^i = y^i(N_i, W)$, are functions of nitrogen fertilization levels, N_i, and a vector of weather variables W. To estimate these yield functions, the elements of the vector W must be specified, and a functional form for the yield relationship must also be selected. In general, W could include a large and detailed list of weather observations (such as daily observations of wind speed, humidity, precipitation, and temperature during the growing season). To achieve efficient estimation of the yield functions, it is important to search for measures that meaningfully summarize weather observations.

In a first best-scenario, W would contain a single element: a broad measure of weather conditions which has substantial explanatory power in predicting crop yields. A candidate for such a variable is the number of moisture stress days in the growing season, which has been shown to be empirically superior to other weather variables in predicting crop yields (Bailey, 1988). Moisture stress days can be calculated from daily observations of precipitation, temperature, and pan evaporation rates. Unfortunately, pan evaporation data were not available. Thus, W was specified to include two elements: a precipitation variable, and a measure of temperature during the growing season (i.e., crop yield depends explicitly on rainfall and temperature).

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[3]Hydrologic group is a classification of soils based on their capacity to permit infiltration (Smith and Cassel, 1991). Group A soils are considered to be more prone to leaching than B or C soils, and are also generally more productive (Thomas and Boisvert, 1995).

The precipitation variable, W_1, is defined as the total of daily rainfall observations from April 1 to September 30 of the crop year. Temperature conditions during the growing season, W_2, are reflected in accumulated growing degree days. On a particular day, degree days are calculated by the formula:

$$\max\left[0,\left(\frac{H-L}{2}-50\right)\right]$$

where H and L represent the daily high and low temperatures, respectively. Accumulated growing degree days between planting and harvesting determine the rate of plant growth, and hence yield. Accordingly, the variable W_2 is the total of daily observations of degree days from May 1 to September 30 of the crop year, representing typical planting and harvest times for New York farms (Cornell Field Crops and Soils Handbook, 1987).

There is little a priori justification for using any particular functional form for crop response functions (Frank et al., 1990; Liang et al., 1991; Baier, 1973); logical candidates include the Cobb-Douglas, the generalized quadratic, and the translog functions. In applications, alternative functional forms are typically fit to the data, and the final selection is based on the statistical performance of the various functional specifications; this was the strategy adopted here (Heady, 1961).

The Data

Data on corn silage yield from various nitrogen application levels were available from field trials conducted at several sites in New York by Stuart Klausner in the Department of Soil, Crop, and Atmospheric Sciences at Cornell University. The base soils at the field trial sites are a reasonable cross-section of soils from hydrologic groups A, B, and C (Thomas and Boisvert, 1995). The sources of nitrogen at these field trials were cattle manure and inorganic fertilizer; the latter was applied at several levels at each site (each of these fertilization rates was also replicated, typically four times at each level). Where manure was applied, it was spread at a constant rate of 20 tons/acre. For our estimation, total nitrogen, denoted N, is defined as the sum of inorganic and manure nitrogen, assuming that manure contributes 3.5 pounds of nitrogen per ton (Cornell Field Crops and Soils Handbook, 1987; Schmit, 1994).

These field trial data were manipulated in several ways to facilitate estimation of the yield functions. First, the corn silage yield observed across replications of the same total nitrogen level at each site were averaged, generating a data set with 66 combinations of yield and total nitrogen. Second, the data set was augmented to include weather variables, by using daily observations of precipitation and high and low temperatures from weather stations near the experimental sites. Table 1 provides the location of the experimental sites, the weather stations used as the sources of the weather data, and the mean level of the variables at each site. Finally, to alleviate collinearity among the weather variables, which have small variations relative to their means, both weather variables were centered around their long-run typical values in New York. The weather variables used in the estimation were $w_i = W_i - \overline{W}_i$ $(i = 1,2)$, where $\overline{W}_i$ is the 30-year average of W_i from the Ithaca weather station; $\overline{W}_1 = 20.35$, $\overline{W}_2 = 2022$.

Estimation Procedure

Corn silage yields (tons/acre) for the two groups (y^i) are thus hypothesized to depend on nitrogen application in lbs/acre (N), growing season rainfall (W_1) and accumulated growing degree days (W_2). The yield functions were estimated for the 66 observations using Cobb-Douglas, quadratic, and translog specifications; the quadratic statistically outperformed the other two. Since the number of observations is limited and the cross-sectional data imply that variation in the observed data occur from factors not captured by the model (such as management characteristics), several restrictions were added to the quadratic specification to aid in efficiency of estimation. The yield functions for the two groups were estimated in a pooled regression using slope and intercept dummies. The final model is:

$$y_k = \beta_0 + \delta_0 D_k + \beta_1 N_k + \beta_2 N_k^2 + \delta_2 (D_k N_k^2) + \beta_3 w_{1k} + \delta_3 (D_k w_{1k}) + \beta_4 w_{2k} + \beta_5 (w_{1k} N_k) + \varepsilon_k$$

k=1,...66; D_k = 1 for group 2 (soils from hydrologic groups B and C), 0 otherwise; y_k, and N_k, are the k^{th} observation of corn silage yield, and total nitrogen, respectively; w_{1k} and w_{2k} are the k^{th} centered observation of growing season rainfall and accumulated growing degree days, respectively; and ε_k is a mean-zero disturbance term.

The model contains the following restrictions. First, yield is assumed to respond in a *linear* fashion to changes in growing degree days.[4] Second, both groups share the change in crop yield from a given change in W_2, *ceteris paribus*. Third, yield also is

[4]This assumption can be justified by the hypothesis that plant growth responds linearly to changes in temperature between 55 and 86 degrees Fahrenheit (Cornell Field Crops and Soils Handbook, 1987).

Table 1. Means of Data for Estimating the Yield Functions, By Experimental Site.

County	Soil Name	Hydr. Group	Weather Station	Obs.[a]	Total Nitrogen[c] (N)	Growing Season Rainfall (W_1)	Accum. Growing Degree Days (W_2)	Corn Silage Yield[d] (Y)
Delaware	Tunkhannock	A	Walton	5	156.7	22.17	2233.5	26.64
Wyoming	Chenango	A	Warsaw/ Portageville[b]	7	105.7	18.35	1854.4	19.23
Cayuga	Lima	B	Aurora	16	96.3	25.02	2416.8	19.13
Chemung	Unadilla	B	Elmira	4	87.5	19.40	2360.5	17.67
Clinton	Minoa	C	Chazy	24	130.5	18.39	1964.3	22.33
Tompkins	Collamer	C	Ithaca	5	170.0	16.18	2367.0	24.67
Wyoming	Bath	C	Warsaw/ Portageville[b]	5	142.0	14.87	2082.9	20.50
				66	122.8	19.90	2146.2	21.31

[a] Since the identical replications have been averaged, the number of observations at each site is the number of unique combinations of nitrogen and weather.

[b] The Portageville weather station is nearer to the experimental site, but does not record temperature observations. Therefore, only precipitation data is taken from the Portageville weather station, and temperature data is from Warsaw.

[c] In lbs per acre.

[d] In tons per acre.

same coefficient on W_2; this assumes that both groups would experience a similar assumed to respond linearly to changes in rainfall; an interpretation of this restriction is that the yield function is linear *in the range of observed data* on rainfall. Because the hydrologic characteristics of the soils differ, the yield functions are allowed to have different shapes in nitrogen[5] and rainfall, and may also have different intercepts.

Since these data were generated under experimental conditions, the yield equations are adjusted *ex post* to reflect harvest losses, assumed to be 15% of the yield observed at the experimental sites (Thomas and Boisvert, 1995; Knoblauch and Milligan, 1981). Substituting the estimated coefficients, the two yield equations used in the model are:

$$\hat{y}^1(N,w_1,w_2) = b_0 + b_1 N + b_2 N^2 + b_3 w_1 + b_4 w_2 + b_5 w_1 N$$

$$\hat{y}^2(N,w_1,w_2) = (b_0 + d_0) + b_1 N + (b_2 + d_2)N^2 + (b_3 + d_3)w_1 + b_4 w_2 + b_5 w_1 N,$$

where $w_i = W_i - \overline{W}_i$; and b_j and d_j are OLS estimates of β_j and δ_j, scaled by the factor 0.85, and $\hat{y}^i$ is predicted on-farm yield. Table 2 contains the OLS estimates for both the original and scaled yield equations, along with the model statistics. Evaluating the estimated yield equations at average weather conditions (i.e., $w_1 = w_2 = 0$) and fertilization rates of 100 lbs/acre, a one pound increase in nitrogen fertilizer would result in a 0.038 tons/acre (76 lbs/acre) and a 0.048 tons/acre (96 lbs/acre) increase in yield for the two groups, respectively. Group 1's yield is more responsive to changes in rainfall; with nitrogen set at 100 lbs/acre, a one inch increase growing season rainfall would increase yield by 1.56 tons/acre for group 1, and increase yield by 0.07 tons/acre for group 2. For varying amounts of rainfall over several growing seasons, this implies that group 1 will experience more volatility in year-to-year yields than group 2. The response to changes in growing degree days is identical for the two groups; a 100 unit increase in accumulated growing degree days would result in a 0.66 tons/acre increase in yield for both groups.

The estimated coefficients of the model have theoretically expected signs, and the overall fit also appears adequate. Nonetheless, the numerous restrictions imply that the model used here is stark; it may provide reasonable results for the data at hand, but it is not intended to be a general specification appropriate for other situations. To develop a

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[5]The linear term on nitrogen is not significantly different across the two groups when a slope dummy is included on the quadratic term; any difference in the shape of the yield functions can apparently be captured by only allowing the quadratic term to vary.

Table 2. Estimated Yield Equations.

Variable	Base Coefficient[a] (std. error)	Dummy Coefficient[b] (std. error)	Group 2 Coefficient[c]	Group 1 Scaled[d]	Group 2 Scaled[d]
Intercept	16.32077 (1.618)	-5.14908 (1.712)	11.17171	13.87265	9.49594
N	0.09644 (0.015)		0.09644	0.08198	0.08198
N^2	-0.00029 (0.0000654)	0.00006 (0.000052)	-0.00024	-0.00025	-0.00020
w_1	1.55707 (0.284)	-1.49067 (0.280)	0.06640	1.32351	0.05644
w_2	0.00656 (0.00203)		0.00656	0.00557	0.00557
$w_1 N$	-0.00181 (0.00120)		-0.00181	-0.00154	-0.00154
Adjusted R^2	0.68332				
Observations	66				

[a] The base model corresponds to group 1.

[b] These are the coefficients on the *product* of the variables in the first column and the dummy variable D, e.g, $N^2 D$. They represent the difference between coefficients for group 1 and group 2.

[c] Calculated as the sum of the first two columns.

[d] Estimated coefficeint multiplied by 0.85.

general specification, more data would be needed, either from additional field trials or from plant-growth simulators such as EPIC (Foltz *et al.*, 1995; Helfand and House, 1996).

Of particular concern in the empirical model is the coefficient d_2 which indicates the difference in shape of the yield function in nitrogen across the two groups. Based on the results derived above, a comparison of the marginal products of nitrogen for the two groups will determine whether one or two policies should be implemented under asymmetric information. The marginal products of nitrogen for these two yield functions are:

$$\frac{\partial \hat{y}^1(N,w_1,w_2)}{\partial N} = b_1 + 2b_2N + b_5w_1\text{, and}$$

$$\frac{\partial \hat{y}^2(N,w_1,w_2)}{\partial N} = b_1 + 2(b_2 + d_2)N + b_5w_1.$$

Since the marginal products differ by only the term d_2, this coefficient will influence, directly, the government planner's choice of policies under asymmetric information.

The point estimate of d_2 is 0.00006, (Table 2), but the standard error of 0.00005 implies that this parameter was not estimated with great precision. This result is disappointing, particularly because the empirical analysis does not provide a definitive answer regarding the appropriate design of policies, and also because farmers' conventional wisdom and agronomists' scientific judgment dictate that marginal productivities of nitrogen *do* differ across soil types such as those defined here. Apparently, these differences were not manifested in the cross-sectional data used in this analysis. For the purpose of illustrating the empirical model, and also because actual productivities are likely to differ, the empirical analysis proceeds using the point estimates given in Table 2. That is, group 2's yield is more responsive to changes in fertilizer for all nitrogen levels and weather variables, satisfying the condition:

$$\frac{\partial \hat{y}^2(N,w_1,w_2)}{\partial N} > \frac{\partial \hat{y}^1(N,w_1,w_2)}{\partial N}.$$

Clearly, this issue is an empirical question—one which would need to be studied more carefully with more data if a voluntary "green" payment program were ever implemented in New York.

Other Properties of the Estimated Yield Functions

In applying the estimated yield functions to the policy design model, three key properties are of particular interest. First, by Proposition 1 from section 2, if the yield functions are strictly concave in N, the expected utility function will share the same property, which in turn ensures that farmers' pre-policy decision problems have unique solutions. To test concavity of the estimated yield functions, we examine the sign of

$$\frac{\partial^2 \hat{y}^1(N,W_1,W_2)}{\partial N^2} = 2b_2, \quad \text{and}$$

$$\frac{\partial^2 \hat{y}^2(N,W_1,W_2)}{\partial N^2} = 2(b_2 + d_2).$$

Using the estimated coefficients (scaled) from Table 2, $2b_2 = -0.00025 < 0$ and $2(b_2 + d_2) = -.00018 < 0$. Both functions are strictly concave in *N*, implying that the solutions to the pre-policy optimal fertilization levels can be uniquely determined.

Proposition 2 from section 2 states that the "single-crossing property", which is a sufficient condition for optimal policies to exist under asymmetric information, will be upheld if the marginal product of nitrogen for one group exceeds that of the other group, for all relevant fertilization rates. The estimated functions satisfy this property, as shown above. A marginal reduction in nitrogen would require a larger increase in government payments for group 2 than for group 1, to keep producers at the same level of expected utility. This divergence in tradeoffs between *N* and *S* in turn ensures that a solution to the policy design problem exists under asymmetric information.

Since production risk is incorporated in the model, the marginal effect of nitrogen on the variability of net returns (as measured by variance) will, in part, influence the compensation payments required for reductions in nitrogen. Expected yields for the two groups are:

$$E(\hat{y}^1) = b_0 + b_1N + b_2N^2 + b_3E(w_1) + b_4E(w_2) + b_5E(w_1)N, \text{ and}$$

$$E(\hat{y}^2) = (b_0 + d_0) + b_1N + (b_2 + d_2)N^2 + (b_3 + d_3)E(w_1) + b_4E(w_2) + b_5E(w_1)N,$$

and the corresponding variances are:

$$\text{var}(\hat{y}^1) = (b_3 + b_5N)^2 \text{var}(w_1) + 2b_4(b_3 + b_5N)\text{cov}(w_1,w_2) + 2b_4 \text{var}(w_2), \text{ and}$$

$$\text{var}(\hat{y}^2) = (b_3 + d_3 + b_5N)^2 \text{var}(w_1) + 2b_4(b_3 + d_3 + b_5N)\text{cov}(w_1,w_2) + 2b_4 \text{var}(w_2),$$

Taking the derivatives of yield variance with respect to *N*,

$$\frac{\partial \text{var}(\hat{y}^1)}{\partial N} = 2b_5(b_3 + b_5N)\text{var}(w_1) + 2b_4b_5 \text{cov}(w_1,w_2), \text{ and}$$

$$\frac{\partial \text{var}(\hat{y}^2)}{\partial N} = 2b_5(b_3 + d_3 + b_5N)\text{var}(w_1) + 2b_4b_5 \text{cov}(w_1,w_2).$$

Both derivatives depend on the estimated coefficients b_3, d_3, b_4, and b_5, the variance of rainfall, and the covariance between rainfall and accumulated growing degree days.

The magnitudes of these marginal effects will depend on the variance and covariance of the weather variables in the region studied. In principle, an increase in nitrogen fertilizer could lead to either an increase or a decrease in yield variability.

Nitrate Leaching and Runoff Functions

The environmental component of the model, which serves to determine the environmentally safe levels of nitrogen fertilization for two groups, requires functions relating the amount of nitrate leaching and runoff to fertilization levels and weather conditions. The functions used for this purpose are taken from Boisvert *et al.*, (1997).[6] These statistical relationships relate nitrate leaching and runoff on New York soils to nitrogen application, five soil characteristics, and several rainfall variables (Table 3). They are estimated from runoff and leaching data generated by GLEAMS (Leonard *et al.*, 1987) representing 1,350 combinations of weather, soil characteristics, and nitrogen levels. Using predicted values of runoff in the leaching equation was equivalent to an instrumental variable procedure for this recursive system (Judge *et al.*, 1988). To help in the interpretation of these functions which are quadratic in logarithms (Bailey and Boisvert, 1991), the elasticities of leaching and runoff are reported for mean levels of the important explanatory variables, and for the most part, have expected signs. Further, Boisvert *et al.* (1997) report that the leaching equation predicts well, particularly in the upper tail which is most critical for policy purposes.

An Empirical Demonstration

To illustrate the empirical model, we consider a simple example using specific but somewhat arbitrarily selected soils to represent each group. We begin by defining simulated distributions of net returns for the two groups of farmers. Farmers' preferences over these distributions are specified under alternative assumptions regarding attitudes toward risk. Next, the specific soils are described in terms of their potential to generate environmental damage, and the levels of nitrogen fertilizer that

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[6]*Nitrate loss* is defined as the sum of nitrate leaching (nitrates leached beyond the root zone of plants) and nitrate runoff (nitrates flowing off fields in rainwater and into surface water supplies). Using nitrate loss as a measure of pollution implicitly assigns equal weight to the environmental consequences of nitrate leaching and nitrate runoff. In any particular area, these weights would depend, among other factors, on the relative importance of ground and surface water for human consumption; in general the weights would not be equal and would vary from location to location. If such a program were implemented, more research would be needed to assign appropriate weights to the sources of nitrate pollution in different areas.

Table 3. Regression Equations for Nitrogen Runoff and Leaching.

Variable[a]	Units	Description
Constant		
L(NITRUN)	lbs/acre	Nitrogen runoff
L(NITRUN)SQ		
L(H1)	inches	Soil horizon depth
L(SLP)	%	Average field slope
L(SLP)L(H1)		
L(KAY)		K erodibility factor
L(KAY)L(H1)		
L(ORG)	%	Organic Matter
(LORG)SQ		
L(ORG)L(H1)		
L(MINN)	lbs/acre	Nitrogen mineralized by soil
L(RAIN)	inches	Total annual rainfall
L(PRSTM)	inches	Rainfall within 14 days of planting
(LPRSTM)SQ		
L(NIT)L(PRSTM)		
L(FRSTM)	inches	Rain within 14 days of fertilizer
(LFRSTM)SQ		
L(LBMAN)	lbs/acre	Total fertilizer
L(ROT)		Years of corn in rotation
LAGCORN		Dummy, corn previous year
L(HRSTM)	inches	Rain within 14 days of harvest
HYDA		Dummy, hydrologic soil group A
HYDB		Dummy, hydrologic soil group B
MANURE		Dummy, manure application

Source: Boisvert, *et al*. (1997).

[a] Except for the dummy variables, the variables are logarithmic transformations; some of the variables represent a square of the logarithm (sq) or the product of two logarithms. NITRUN is the logarithm of estimated runoff from the runoff equations.

Table 3. (Continued)

Variable	Runoff			Leaching		
	Coef.	t-ratio[b]	Elast.	Coef.	t-ratio[b]	Elast.
	R^2=0.509			R^2=0.494		
Constant	-4.402	-7.02		-75.568	-9.35	
L(NITRUN)[c]				-6.739	-4.38	-4.52
L(NITRUN)SQ				2.119	1.76	
L(H1)				5.638	7.33	0.21
L(SLP)				-1.154	-4.37	-0.46
L(SLP)L(H1)				0.453	2.66	
L(KAY)	0.058	2.09	0.06	-5.594	-7.91	-2.11
L(KAY)L(H1)				2.287	6.80	
L(ORG)	3.241	9.24	0.26	5.235	5.51	2.00
(LORG)SQ	-1.039	-8.47				
L(ORG)L(H1)				-2.127	-5.01	
L(MINN)	-0.581	-6.60	-0.58	5.442	5.81	5.44
L(RAIN)	0.652	15.27	0.65	5.768	9.33	5.77
L(PRSTM)	0.089	5.94	0.01			0.10
(LPRSTM)SQ	0.023	6.47		0.056	3.34	
L(NIT)L(PRSTM)				0.363	3.75	
L(FRSTM)			-0.01	0.256	5.05	0.10
(LFRSTM)SQ	0.005	5.82		0.094	6.59	
L(LBMAN)[d]	0.628	7.05	0.63	4.824	4.78	4.82
L(ROT)				-0.627	-4.55	-0.63
LAGCORN				-0.668	-6.49	
L(HRSTM)				0.039	1.18	0.04
HYDA	-0.453	-23.06		0.290	2.87	
HYDB	-0.359	-22.11				
MANURE[d]				0.235	1.62	

Source: Boisvert, *et al*. (1997).

[b] Chi-square test statistics for heteroskedasticity were 229 for the runoff equation and 246 for the leaching equations. Standard errors were recalculated as the square root of the diagonal elements of the estimated asymptotic covariance These standard errors are consistent (White, 1980).

[c] To purge the runoff variables from any unexplained random component, the predicted values from the runoff equation are used in the leaching equation (Judge *et al*., 1988).

[d] Commercial fertilizer application is combined with the nitrogen equivalent included in the various rates of manure application; any differential effect is captured through a dummy variable.

meet environmental quality standards are determined. These fertilization levels, in conjunction with farmers' preferences over the simulated net returns distributions, determine the optimal policies. The optimal policies are calculated both under *symmetric* and *asymmetric* information.

Net Return Distributions

Distributions of net returns are simulated over the 30-year period, 1963-1992. The elements of the simulated distribution are, for nitrogen level N,

$$\hat{R}_t^i(N) = p_t \hat{y}^i(N, W_{1t}, W_{2t}) - r_t N - V$$

where $t = 1, \ldots, 30$; $\hat{y}^i(N, W_{1t}, W_{2t})$ are from Table 2; p_t and r_t are the real prices of corn silage and nitrogen fertilizer in year t; and V is non-nitrogen variable cost. Data on prices, weather, and variable production costs are needed to calculate the elements of this distribution.

Because corn silage is traded in a very thin market in New York, silage prices over the 30 years, p_t, are imputed from New York corn grain prices (Thomas, 1994). Corn grain prices, corn grain yields, and silage yields are taken from *New York Agricultural Statistics*. Silage prices for each year are calculated by $p_t = \frac{y_t^c p_t^c}{y_t}$, where y_t^c and p_t^c are the reported per-acre yield and price of corn grain in year t, and y_t is the reported per-acre yield of corn silage. The computed prices are converted to constant 1992 dollars with the Index of Prices Received by Farmers (1977=100). These real prices for the 30 years are shown in Appendix Table B-1.

Similarly, real nitrogen fertilizer prices, r_t, are based on the price of urea in New York, as reported in *New York Agricultural Statistics* (Appendix Table B-2). The prices of nitrogen fertilizer are converted to a per-pound of nitrogen basis (urea contains 43% nitrogen), and are deflated by the Index of Prices Paid by Farmers (1977=100).

Typical New York variable production costs for corn, excluding nitrogen, are in Appendix Table B-3; the sum of these expenses is represented in the model as V. These expenses are taken from corn enterprise budgets in Schmit (1994), and from USDA-ERS *Economic Indicators of the Farm Sector: Field Crops and Dairy, 1992.* To maintain consistency with the price data, the costs are converted to constant 1992 dollars with the Index of Prices Paid by farmers (1977=100).

For this demonstration the Ithaca, New York weather station is used to represent regional weather conditions. Appendix Table B-4 shows the weather variables over the 30 years.

Risk Preferences

In the empirical policy design model, producers in both groups are assumed to have a *negative exponential* utility function. The policy design problem under symmetric information (described conceptually by problem (6) above) becomes:

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

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

$$\frac{1}{30}\sum_{t=1}^{30} -\exp[-a(\hat{R}_t^1(N_1) + S_1)] \geq \frac{1}{30}\sum_{t=1}^{30} -\exp[-a(\hat{R}_t^1(N_1^0) + 0)] \qquad (P_1)$$

$$\frac{1}{30}\sum_{t=1}^{30} -\exp[-a(\hat{R}_t^2(N_2) + S_2)] \geq \frac{1}{30}\sum_{t=1}^{30} -\exp[-a(\hat{R}_t^2(N_2^0) + 0)] \qquad (P_2)$$

$N_i \geq 0$, $S_i \geq 0$, i=1,2,

where A_i is the number of corn acres in each group, N_i^* are the maximum levels of N that meet environmental quality standards, a is the Arrow-Pratt coefficient of absolute risk aversion,[7] and $\hat{R}_t^i(N_i) + S_i$ represents income from corn production and government payments if weather and price conditions in year t are realized. Constraints (E_i) ensure that the post-policy nitrogen rates will satisfy environmental quality standards. Constraints (P_i) require that post-policy expected utility, calculated from the simulated net return distribution, is no less than if farmers choose not to participate in the program.

If information is asymmetric, the policy design problem is (11) with the additional *incentive compatibility* constraints:

$$\frac{1}{30}\sum_{t=1}^{30} -\exp[-a(\hat{R}_t^1(N_1) + S_1)] \geq \frac{1}{30}\sum_{t=1}^{30} -\exp[-a(\hat{R}_t^1(N_2) + S_2)] \qquad (I_1)$$

$$\frac{1}{30}\sum_{t=1}^{30} -\exp[-a(\hat{R}_t^2(N_2) + S_2)] \geq \frac{1}{30}\sum_{t=1}^{30} -\exp[-a(\hat{R}_t^2(N_1) + S_1)] \qquad (I_2)$$

The negative exponential utility function has been criticized in the literature because it imposes constant absolute risk aversion, a property which is not upheld by empirical evidence (Saha *et al.*, 1994). Despite such criticism, the negative exponential function is still used widely in applications, mainly because of its other useful properties. Since the degree of risk aversion is included explicitly as the parameter *a*, the changes in optimal policies that result from various specifications of this parameter can be interpreted as consequences of various degrees of risk aversion.

The unknown parameter *a* is varied over three alternative values: 0, 0.01, and 0.03. The first value represents the case of risk neutrality, while the second and third are selected to explore the effect of varying degrees of risk aversion. The second and third coefficients fall within the range of results from empirical investigations of risk attitudes (Simmons and Pomareda, 1975; Wiens, 1976; Brink and McCarl, 1978; Buccola, 1982; Love and Buccola, 1991). Though *a* is varied across alternative levels, both groups of producers are always assumed to share the same parameter. This is a simplification in the empirical model; as shown in section 2 above, the qualitative results are maintained even with arbitrary utility functions for both groups.[8] Using the same degree of risk aversion for both groups will allow the results to be interpreted with more clarity[9].

Initial Fertilization Levels

To determine optimal pre-policy fertilization levels for risk aversion parameters, 0, 0.01, and 0.03, the function $\sum_{t=1}^{30} -\exp[-a\hat{R}_t^i(N_i)]$ was maximized over N_i directly.[10] These fertilization rates denoted N_i^0, were determined for each of the assumptions

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[7]The Arrow-Pratt coefficient of absolute risk aversion is defined as $-(u''/u')$. For the negative exponential utility function, this coefficient remains constant across all income levels (Mas-Collel *et al.*, 1995).

[8]Appendix C describes an alternative formulation of the empirical model where the utility functions for both groups are unrestricted within the class of increasing and strictly concave functions.

[9] Even though expected utility in this model is calculated on a per-acre basis, the results can be also be interpreted in terms of a whole-farm analysis. Since the parameter *a* and income are multiplied together in the exponent of the utility function, equivalent results can be obtained by multiplying income by a constant, and dividing *a* by the same constant (Tauer, 1985). In particular, for a farm with *B* acres of corn, specifying the parameter *a* at *a** would represent an Arrow-Pratt absolute risk aversion coefficient of *a**/*B*. Fixing *B* at 100 acres, for example, the three values of *a* would correspond to Arrow-Pratt coefficients of absolute risk aversion of 0, 0.0001, and 0.0003.

[10]The case of $a = 0$ (risk neutrality) reduces to maximizing the net returns function $\hat{R}_t^i(N_i)$.

regarding risk aversion and are shown in Table 4, along with the corresponding means and standard deviations in net returns. The differences in application rates and net returns are small, but the differences gain added significance under the "green" payment policies. Optimal fertilization rates also increase as higher levels of risk aversion are assumed for group 1 but decrease with risk aversion for group 2. This result implies that nitrogen fertilizer affects the amount of risk borne by producers.

Table 4. Optimal Pre-Policy Nitrogen Levels, by Risk Aversion Level.

	Group 1			Group 2		
Risk Aversion Coef.	Nitrogen Fertilizer (lb/acre)[a]	Net Returns Mean	Net Returns Standard Deviation	Nitrogen Fertilizer (lb/acre)[a]	Net Returns Mean	Net Returns Standard Deviation
0.00	129	$188.44	$108.70	160	$121.65	$53.46
0.01	133	188.34	108.34	156	121.59	53.22
0.03	135	188.26	108.21	150	121.24	52.80

[a] These nitrogen levels are N_i^0 in the model.

If the variance of net returns is used to measure risk (Just and Pope, 1979), the changes in optimal fertilization rates can be understood in terms of the marginal variance effect of nitrogen on yield. As noted previously, the marginal effect of nitrogen on the variance of net returns depends on the estimated coefficients of the yield functions, as well as the variance and covariance of the regional weather variables. In the relevant range of fertilization rates, the derivatives are negative for group 1 and positive for group 2.[3] Accordingly, nitrogen fertilizer is a *risk-reducing* input for group 1 and a *risk-increasing* input for group 2. Group 1 producers who are more risk averse will increase fertilization levels in order to take advantage of its stabilizing effect on net returns. Conversely, risk averse group 2 producers will decrease nitrogen fertilization

[3] $\frac{\partial \text{var}(\hat{y}^1)}{\partial N} < 0$ for all $N < 827.97$; $\frac{\partial \text{var}(\hat{y}^2)}{\partial N} > 0$ for all $N > 3.37$. Inserting the appropriate yield function coefficients from Table 2, and the variance of rainfall along with the covariance between rainfall and growing degree days from Table 7, the marginal changes in yield variance with respect to nitrogen are:

$$\frac{\partial \text{var}(\hat{y}^1)}{\partial N} = (9.96 \times 10^{-5})N - 0.0824 \text{ and } \frac{\partial \text{var}(\hat{y}^2)}{\partial N} = (9.96 \times 10^{-5})N - 0.0003365$$

rates in order to avoid volatility in net returns. As one would expect, for a higher degree of risk aversion, the optimal net return distributions for both groups have lower expected values, but are also less variable.

The pre-policy optimal fertilization rates in Table 4, for group 2 exceed those of group 1 for all levels of risk aversion. This result is qualitatively consistent with optimal rates in a deterministic world; as shown above, the marginal product of nitrogen for group 2 is everywhere larger than group 1. The important implication here is that Condition 2 from the theoretical model is satisfied, i.e., $N_2^0 > N_1^0$.

Environmental Quality Standards

The soil characteristics for the two groups are based on "composite" soils, defined as a simple average of two representative soils in the appropriate group. Two hydrologic group A soils were chosen to represent group 1, and two hydrologic group B soils represent group 2 (Table 5). Distributions of leaching and runoff in the Central

Table 5. Characteristics of the Selected Soils.

		Group 1 Soils		Group 2 Soils	
Characteristic	Symbol	ChB	HdD	Ln	MoC
Hydrologic Group	HYD	A	A	B	B
Soil horizon depth (inches)	H1	2.36	9.84	14.17	10.24
Average field slope (%)	SLP	5.50	20.00	1.50	11.50
K erodibility factor	KAY	0.320	0.240	0.280	0.320
Organic Matter (%)	ORG	7.50	4.06	10.00	6.06
Nitrogen mineralized by soil (lbs/acre)	MINN	69.0	69.0	64.1	73.9

New York region can be simulated by evaluating the functions in Boisvert *et al.* (1997) at the appropriate soil characteristics, a specified fertilization level, and the weather conditions observed at the Ithaca weather station in each of the 30 years (Figures 5 and 6).

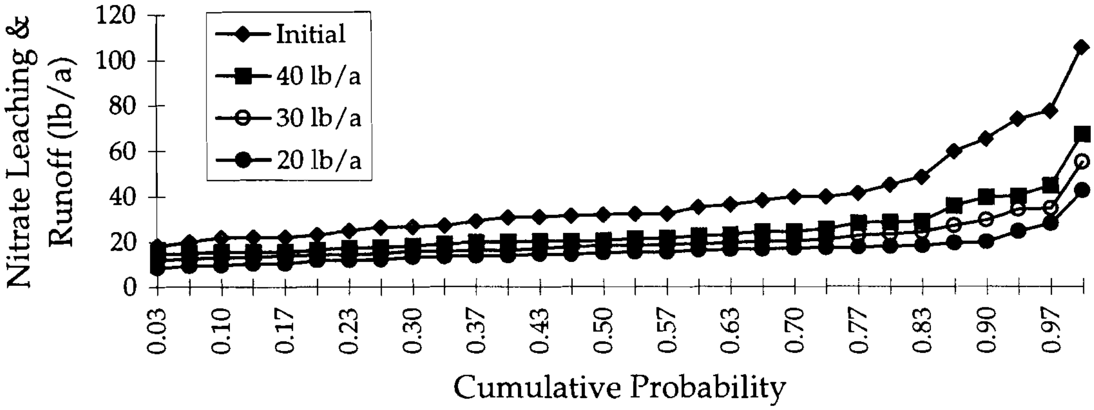

Figure 5. Distribution of Nitrate Leaching and Runoff on Group 1 Soils, Alternative Safety Levels.

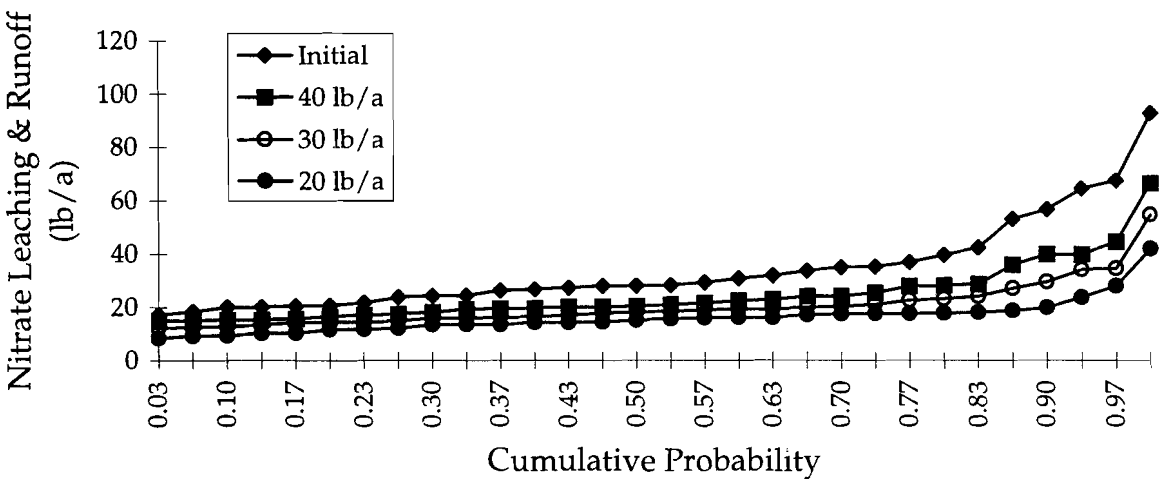

Figure 6. Distribution of Nitrate Leaching and Runoff for Group 2 Soils, Alternative Safety Levels.

Figures 5 and 6 also show the distributions for the maximum fertilization rates which satisfy three alternative chance constraints: L^*= 40, 30, and 20 lbs of combined leaching and runoff per acre, where the probability of exceeding these levels was set at $\alpha = 0.1$. Fertilization rates which meet the chance constraint (L^*,0.1), L^* = 40, 30, 20, will generate, in this empirical setting, predicted levels of leaching and runoff above L^* for at most 3 of the 30 years. To determine the nitrogen levels on these soils which will meet the specified environmental quality standards, various nitrogen rates were iteratively substituted into the nitrate leaching and runoff functions in Boisvert *et al.* (1997). The maximum nitrogen fertilization levels (to the nearest pound per acre) which meet the environmental quality standards (40,0.1), (30,0.1), and (20,0.1) are in Table 6, along with the associated means and standard deviations in net returns.

Several observations can be made from Table 6. First, as one would expect, if environmental quality standards become more stringent, fertilization rates must be reduced and there is a corresponding reduction in mean net returns for both groups. Comparing the optimal fertilization rates from Table 6 to the optimal pre-policy rates in Table 4, theoretical Condition 3 is satisfied for each safety level; i.e., $0 \leq N_i^* \leq \min\{N_1^0, N_2^0\}\,(i=1,2)$. Producers in group 1 apply less nitrogen than group 2 producers in order to meet any given environmental quality standard, i.e., $N_1^* < N_2^*$ for all L^*. These results, combined with the previous result that $\frac{\partial \hat{y}^2(\cdot)}{\partial N} > \frac{\partial \hat{y}^1(\cdot)}{\partial N}$, imply that group 2 requires more compensation for reductions in nitrogen, but can satisfy environmental quality standards with higher fertilization rates than group 1. By theoretical Proposition 4, these conditions imply that separate policies for the two groups will be optimal.

The Policies

To isolate the effect of asymmetric information, separate optimal policies for each producer group are determined both where information is symmetric and also where it is asymmetric. Each of these cases is discussed in turn, including an examination of the effect of risk aversion on optimal policies.

<u>Symmetric Information</u>: When information is symmetric, optimal compensation payments would make producers indifferent between their initial situation and the environmentally safe nitrogen levels (Table 7 and Figure 7). Payments range from \$4 to \$26/acre for group 1 and \$2 to \$25/acre for group 2. A striking feature of these payments is that payments increase with the degree of risk aversion for group 1, and decrease with risk aversion for group 2. Since nitrogen reduces risk for group 1 and pre-policy fertilization levels increase with the level of risk aversion (Table 4), this group suffers a larger reduction in fertilizer and net returns as the level of risk aversion increases. Group 2 producers decrease pre-policy fertilization levels for higher risk aversion levels; thus the reduction in fertilizer and net returns decreases with risk aversion for group 2.

Table 6. Environmentally Safe Levels of Nitrogen.

	Group 1			Group 2		
	Nitrogen Fertilizer	Net Returns		Nitrogen Fertilizer	Net Returns	
Safety Level[a]	(lbs/acre)[b]	Mean	Standard Deviation	(lbs/acre)[b]	Mean	Standard Deviation
40	99	$184.11	$110.33	128	$117.55	$51.09
30	84	178.63	110.94	109	111.29	49.29
20	63	164.87	111.51	80	96.26	45.95

[a] L^* for $\alpha = 0.1$; i.e., levels of combined leaching and runoff (lbs/acre) to be exceeded less than 10% of the time.

[b] N_i^*; i.e., maximum levels of N for the two groups that meet the standard (L^*,0.1).

Table 7. Optimal Green Payments, by Safety Level.

Safety Level (L^*)	Risk Aversion Paramete r (a)	Symmetric Information		Asymmetric Information	
		Group 1	Group 2	Group 1	Group 2
40	0.00	4.34	4.11	8.44	4.11
40	0.01	5.45	3.01	8.33	3.01
40	0.03	5.88	1.63	7.29	1.63
30	0.00	9.82	10.36	18.27	10.36
30	0.01	11.28	8.40	16.94	8.40
30	0.03	11.84	5.67	14.45	5.67
20	0.00	23.57	25.39	37.32	25.39
20	0.01	25.39	21.88	34.09	21.88
20	0.03	26.27	16.62	29.11	16.62

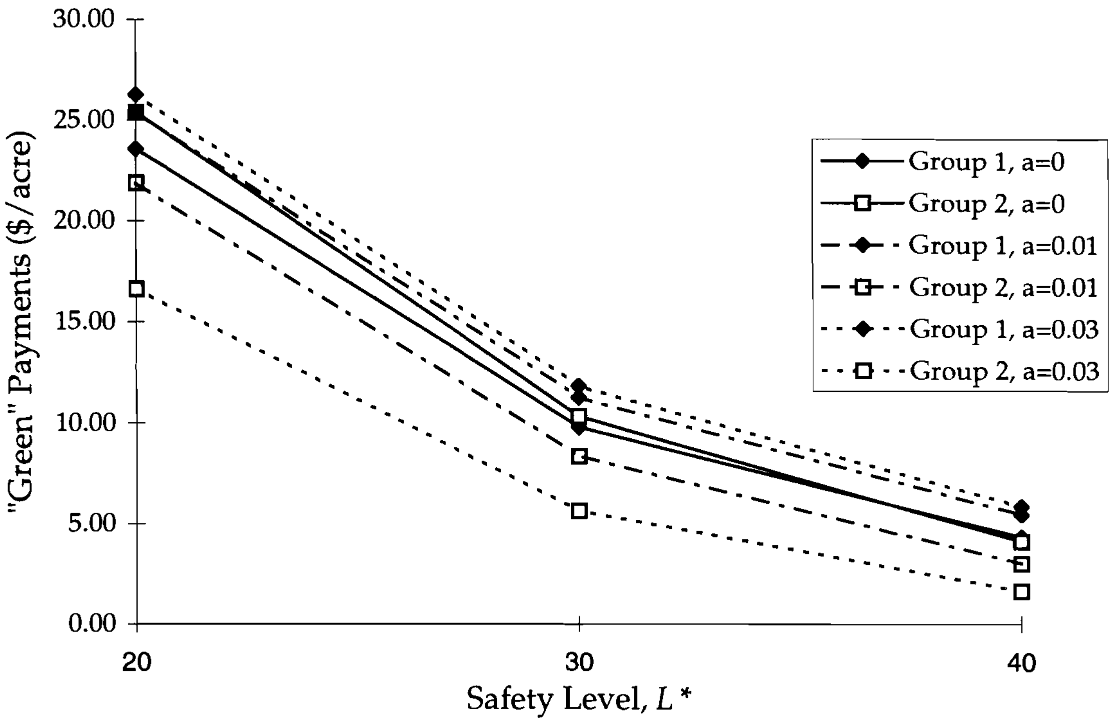

Figure 7. Green Payments Under Symmetric Information.

Payments under symmetric information could be called "equitable" because all producers are indifferent to their pre-policy situation. For the risk neutral case, the size of the government payments are similar for the two groups, but as a percentage of initial net returns, the payments are less similar: for $L^*=20$ and $a = 0$, "green" payments make up about 13% and 21% of initial net returns for the two groups, respectively.

Asymmetric Information: If information is asymmetric, "green" payments must be set so that the self-selection conditions are satisfied, in addition to the environmental and participation constraints. We might expect optimal payments to be higher in this case because additional constraints have been imposed on the policy design problem (Table 7 and Figure 8).

These payments range from $7 to $37 for group 1 and $2 to $25 for group 2. The optimal payments to group 2 are exactly the same as in the symmetric information case because the self-selection constraint for this group always binds, i.e., group 2 will never benefit from a "green" payment program. In contrast, producers in group 1 need an additional incentive to self-select their own policy over the one designed for group 2. Indeed, the "green" payments associated with group 1's policies increase by about one-half over the symmetric information case. For a safety level of 30 lbs of nitrate loss per acre, the average windfall benefit (payment in excess of the loss in net returns) to group 1 is about $6 per acre.

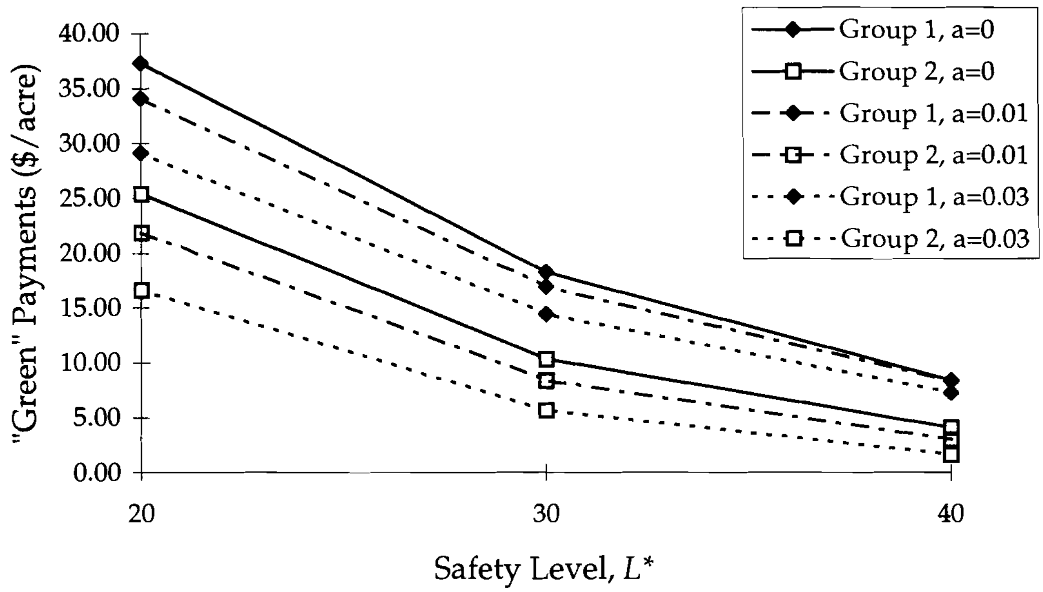

Figure 8. Green Payments Under Asymmetric Information.

Under asymmetric information optimal payments to both groups decrease as higher degrees of risk aversion are assumed. The underlying cause for this increase is the risk-increasing effect of nitrogen application for group 2; as in the case of symmetric information, pre-policy fertilization rates for this group will be smaller for higher degrees of risk aversion (Table 4), and the reduction in nitrogen and net returns will also be smaller. Group 1's payments are determined by comparing group 2's policy to their own. Since the difference in nitrogen application for these two policies is fixed for all levels of risk aversion, smaller payments to group 2 imply that payments to group 1 can also be reduced.

Two additional issues concerning risk are addressed in Appendices C and D. Appendix C describes an alternative formulation of the policy design model where the utility functions for both groups are left unspecified. In this more general formulation, the net return distributions arising from alternative fertilization levels are compared using the second-degree stochastic dominance criterion; the optimal policies from this model are sufficient for any risk averse farmer to participate in the program and choose his or her own policy. Even though this formulation is more general, it is also more complicated. No simple conditions can be derived which guarantee the existence of a solution to the policy design problem, and the properties of the solution are analytically intractable. In the New York case studied here, payments have the same qualitative structure as in the expected utility framework, and quantitatively the payments differ by no more than $2 per acre between the two models.

Besides a specific utility function, the model discussed here also assumes that two sources of risk are relevant; yield risk due to weather and price uncertainty are both explicitly incorporated in the policy design problem. In Appendix D, the variance of net returns is decomposed into price and yield components, and the effects of ignoring one or both sources of risk are analyzed. Both sources of risk make up an important share of overall net return variability, and if either source of risk is ignored, the quantitative results of the model are substantially changed.

APPLICATION TO CORN PRODUCTION IN THREE NEW YORK REGIONS

Having used a stylized example to illustrate the models' consistency with the theory and to better understand the relative importance of the two sources of risk, we turn designing a voluntary "green" payment program to control nitrate leaching and runoff in three New York regions. To simulate the policy response within each region, information on representative soils defined for two groups of producers from data on the distribution of soils over a sample of New York farms (Boisvert *et al.*, 1997) are combined with weather data from each region to solve for optimal region-level policies for various environmental quality standards.

The analysis proceeds by first defining the parameters of the regional policy design models, the three farming regions in New York, and the data used to simulate the program. Representative distributions of environmental damage and net returns are generated within each region, based on representative soils and weather conditions. Pre-policy optimal nitrogen levels are then determined from the simulated net return distributions, under the assumption that farmers maximize expected utility.

In the following sections, the regional models are solved to determine optimal policies which achieve various environmental quality standards. In the first of these scenarios, environmental quality standards require *relative* reductions from initial levels of environmental damage within each region. As an alternative approach, the next section employs *absolute* standards, which impose uniform levels of post-policy environmental quality across all regions. Finally, the findings are summarized, and the major implications of the regional policies are briefly highlighted.

Parameters of the Regional Models

Production Regions and Soils Data

The production regions in New York (Figure 9 and Table 8) chosen for this analysis approximately follow some of the farm management regions used in the Cornell Dairy Farm Business Records Project (Smith *et al.*, 1993). Data from a sample of 142 New York farms across these regions provide the basis for the simulation. These data are taken from a larger survey of 300 farms conducted by the Niagara Mowhawk Power Company, and are described more fully in Boisvert *et al.* (1997) and Kelleher and Bills (1989). The data include, among other variables, each farm's location, the acreage of individual soils on each farm and crops grown, and the characteristics of each soil.

Table 8. Agricultural Production Characteristics, By Region.

	CENNY	EASPLT	WESPLN
Total Cropland (acres)	954811	662563	888931
Number of Farms	5499	4590	4641
Average Farm Size (acres)	174	144	192
Value of Products Sold ($1000)[a]	466095	312620	447438
Value of Products per Acre ($)	488	472	503
Value of Products per Farm ($)	84760	68109	96410
Net Cash Return ($1000)[b]	76833	62706	57609
Net Cash Return per Acre ($)	80	95	65
Net Cash Return per Farm ($)	13972	13661	12413
Corn Acreage	289443	123883	227508
Proportion of Corn Acreage[c]	30%	19%	26%

Source: 1992 Census of Agriculture.

[a] Gross value of all agricultural products, before taxes.

[b] Value of Products Sold less operating expenses. These operating expenses do not include depreciation and changes in inventory.

[c] Corn acreage as a percentage of total cropland.

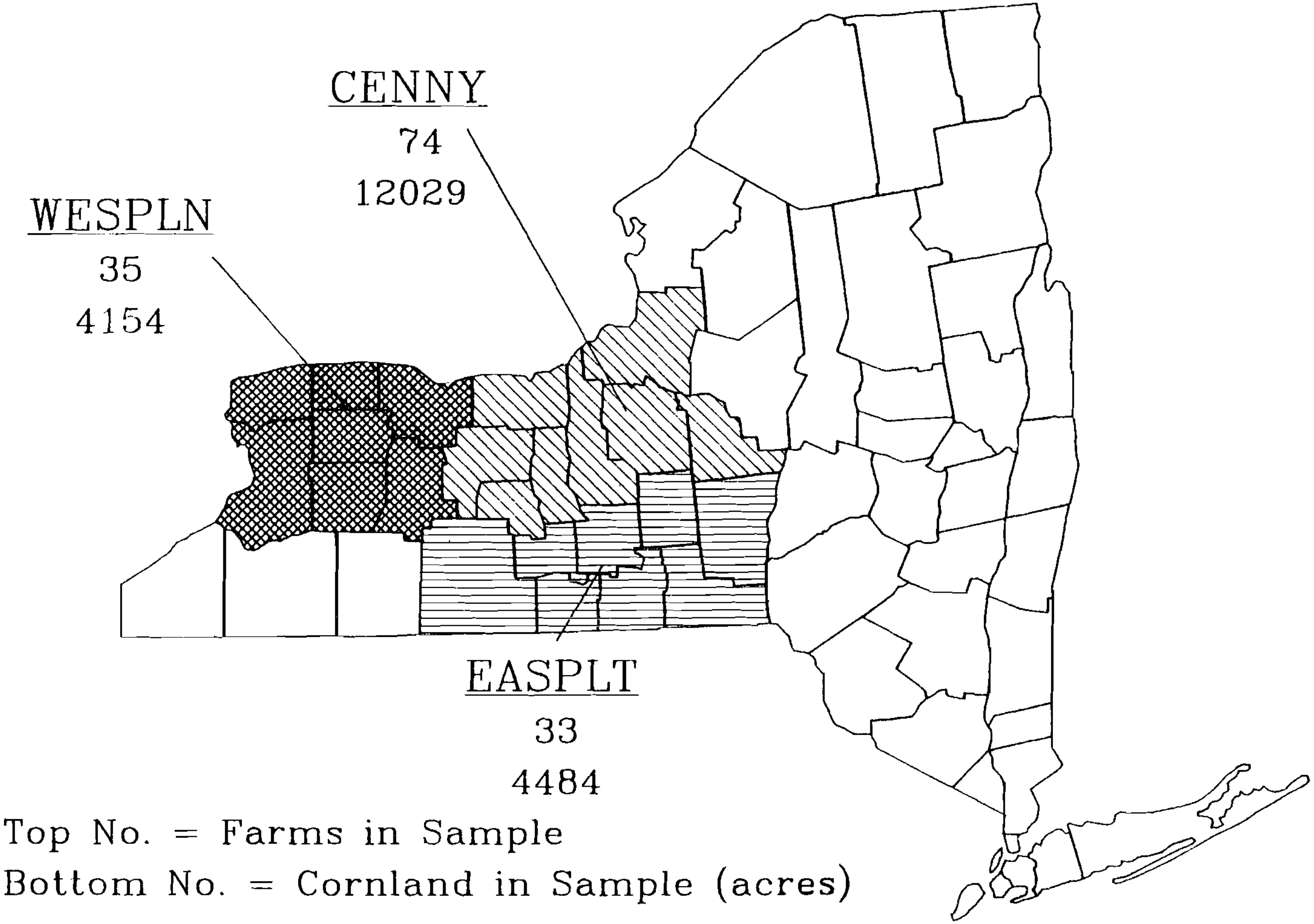

Figure 9. Three Production Regions in New York.

Table 9. Average Soil Characteristics by Region[a].

Variable	Descripton	Region		
		CENNY	EASPLT	WESPLN
HYDA	Proportion of Hydrologic Group A Soils[b]	0.04	0.21	0.07
		(0.01)	(0.11)	(0.08)
HYDB	Proportion of Hydrologic Group B Soils[b]	0.71	0.38	0.31
		(0.66)	(0.14)	(0.43)
HYDC	Proportion of Hydrologic Group C Soils[b]	0.25	0.41	0.62
		(0.32)	(0.75)	(0.48)
H1	Soil Horizon Depth (in)	4.725	7.296	6.169
MINN	Nitrogen mineralized by soil (lbs/acre)	71.322	72.008	70.071
SLOPE	Average field slope (%)	6.093	6.514	4.825
KAY	K erodibility factor	0.306	0.299	0.296
OG	Organic matter (%)	4.554	4.397	4.742

Source: Boisvert, *et al.* (1997).

[a] Weighted average, by the number of acres of each soil in the sample.

[b] Proportion of soils in sample (the 1982 National Resource Inventory) in each of the hydrologic groups

The regions reflect differences in topography, soils, climate, and land use (Table 9). The Eastern Plateau (EASPLT) region lies entirely in the Appalachian Uplands physiographic province, known in New York as the Allegheny Plateau. This region is characterized by flat-topped hills with long slopes and large, flat valleys. The valley sides are often relatively steep, especially at the upper slopes (SCS, 1973). The southern section of Central New York (CENNY) is also part of the Allegheny Plateau; the northern part is in the Erie-Ontario Plain, made up of deep soils with gentle to moderate slope (SCS, 1977). The Western Plain (WESPLN) region also lies partly in the Allegheny Plateau, but much of the region is in the Ontario Lowlands. The Ontario Lowlands have a gently rolling topography, with differences in elevation usually less than 30 feet (SCS, 1974).

The soils in WESPLN are generally quite productive and well-suited for growing the crops used on dairy farms (SCS, 1974). Wyoming county in this region, with 350 dairy farms, is one of the most highly concentrated dairy areas in New York. Farms tend to be larger in WESPLN than in the other two regions, both in terms of acreage and gross sales. Corn is an important crop in all three regions, consuming one-fifth or more of total agricultural cropland.

Table 10 contains the average values of selected soil characteristics for the farms in each region, based on the 142-farm sample. The averages of the variables HYDA, HYDB, and HYDC are the proportions of the sample acreage which belong to each hydrologic group. For comparison with these sample-based proportions, the corresponding proportions from the 1982 National Resources Inventory are also reported. The 142-farm sample is fairly representative of the actual distribution of soils across hydrologic groups, with the possible exception of the EASPLT region, which appears to have too high a proportion of hydrologic group A soils (Boisvert *et al.*, 1997).

The weather variables in each region are defined by observations at a selected weather station. Weather conditions in the CENNY region, taken from the Ithaca weather station, were used in the empirical demonstration above (Appendix Table B-4). Appendix Tables B-5 and B-6 contain the weather variables for the EASPLT and WESPLN regions, respectively. The remaining parameters in the policy design model, corn prices, nitrogen prices, and variable production costs, are assumed not to vary by region and are reported in Appendix Tables B-1, B-2, and B-3, respectively.

Representative Soils for Producer Groups

The policies are simulated for two groups of producers within each region, assuming there is a "representative agent" for each group of producers in each region. The amount of leaching and runoff generated by each group is calculated from the characteristics of a "representative" soil, which are a weighted average of the soils in the group from the 142-farm sample. As in the demonstration above, group 1 corresponds to hydrologic group A soils, while hydrologic group B and C soils constitute group 2.

For the three regions, a corn acreage weighted average of five soil characteristics, which are the independent variables in the leaching and runoff equations, was calculated for each group (Table 10). One noticeable difference in these characteristics across regions is the proportion of hydrologic group B and C soils in group 2.

Table 10. Average Soil Characteristics by Region and Group.

		CENNY Region			EASPLT Region			WESPLN Region		
		Group 1	Group 2		Group 1	Group 2		Group 1	Group 2	
Variable	Description	(A)	(B)	(C)	(A)	(B)	(C)	(A)	(B)	(C)
HYD1	Proportion of Group 1 from each Hyd. Group	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00
HYD2	Proportion of Group 2 from each Hyd. Group	0.00	0.74	0.26	0.00	0.48	0.52	0.00	0.34	0.66
H1	Soil Horizon Depth (in)	4.2	4.7	4.7	5.9	6.5	3.0	8.5	6.3	5.8
MINN	Nitrogen mineralized by soil (lbs/acre)	63.9	73.5	66.3	69.9	70.7	67.0	69.7	70.9	69.7
SLOPE	Average field slope (%)	5.2	6.9	3.9	7.5	8.6	7.1	6.3	5.1	4.5
KAY	K erodibility factor	0.20	0.29	0.36	0.24	0.28	0.22	0.24	0.30	0.30
OG	Organic matter (%)	3.9	4.6	4.6	4.1	4.9	4.1	4.1	4.6	4.9

Hydrologic group B soils make up the largest proportion of group 2 in the CENNY region. These proportions of B and C soils are nearly reversed in the WESPLN region, and in EASPLT group 2 is split almost equally between B and C soils. Many of the remaining soil characteristics are similar across regions and groups; based on inspection of the soil characteristics alone, it is difficult to predict the relative severity of leaching and runoff among the groups.

From the representative soil characteristics and regional weather conditions, simulated 30-year distributions of leaching and runoff can be generated. As described earlier, the leaching and runoff functions in Table 3 are evaluated at the representative regional soil characteristics (Table 10), for weather conditions in each of the 30 years (Appendix Tables B-4, B-5, and B-6). In these leaching and runoff functions, the variable ROTN was set to 4 years, representing a typical rotation pattern on New York farms (Schmit, 1994), and the variable LAGCORN was set to 0.75 (with a four year corn rotation, 25% of corn acreage will be first-year corn).[12] The leaching and runoff for group 2 is calculated as a weighted average of B and C soils, with the proportions of soils in group 2 as weights.

Pre-Policy Levels of Nitrogen and Environmental Quality

Assuming that farmers maximize expected utility, optimal pre-policy fertilization rates are determined from the 30-year distributions of net returns. These distributions are generated from the estimated yield equations (Table 2), weather data (Appendix Tables B-4, B-5, and B-6), corn prices (Appendix Table B-1), nitrogen prices (Appendix Table B-2), and production costs (Appendix Table B-3). A negative exponential utility function is assumed, where the Arrow-Pratt coefficient of absolute risk aversion is varied over the values 0, 0.01, and 0.03. Once the pre-policy fertilization rates are known, the simulated distributions of leaching and runoff which correspond to these nitrogen levels will represent the pre-policy probability distribution of environmental damage.[13] As a measure of pre-policy environmental quality, we

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[12]Thus, the calculated quantities of leaching and runoff represent average levels of nitrate loss over the corn rotation.

[13]The nitrogen rates on first year corn are likely to be lower than the calculated optimal rates, which are for continuous corn. Consequently, the pre-policy levels of environmental damage may be overestimated, since nitrogen levels are assumed fixed throughout the rotation. However, this does not affect relative comparisons of alternative fertilization levels.

examine the *implied initial safety levels*; i.e., the amount of nitrate loss which is exceeded 10% of the time at initial fertilization rates.

Table 11 provides the pre-policy fertilization levels, per acre average net returns, and implied safety levels, by producer group and region. The fertilization rates for group 1 range from 129 to 145 lbs/acre, while those for group 2 range from 150 to 165 lbs/acre; variation in these optimal rates across regions is due to the different distributions of regional weather conditions. In all three regions, group 1's optimal fertilization levels increase for higher degrees of risk aversion, and group 2's rates decrease. This phenomenon implies that the different distributions of weather variables across regions do not alter the marginal risk effects of nitrogen, always reducing risk for group 1 and increasing risk for group 2. As one would expect, risk averse farmers are willing to trade off average levels of net returns in exchange for less volatility in net returns.

Not surprisingly, the implied safety levels on nitrate loss increase with initial nitrogen fertilization rates. The safety levels, however, vary across regions much more than optimal fertilization rates, implying substantial spatial variation in the severity of pre-policy nitrate loss levels. For both groups, the implied safety levels in CENNY and WESPLN are nearly double those in EASPLT, even though the nitrogen fertilization levels in all three regions are similar. These substantial differences in pollution levels arise both from the varying weather conditions across regions and from differences in representative soil characteristics.

The implied safety levels in Table 11 are somewhat lower than those in the example above because those soils were more prone to nitrate losses than the representative soils within the three production regions. Further, the safety levels represent *predicted* levels of combined leaching and runoff from the GLEAMS simulator. The precision of these predictions, in absolute terms, are not known since actual leaching and runoff cannot be measured. However, relative changes in these predictions are assumed to be associated with proportional changes in actual nitrate loss. For example, the estimated initial safety level in the WESPLN region for group 1 ($a = 0.03$) is 24 lbs/acre. The absolute magnitude of this estimate is not as important as its *relative* value: in WESPLN, group 2 producers generate about half the amount of pre-policy nitrate loss (12 lbs/acre) as does group 1.

Table 11. Pre-Policy Levels of Production and Environmental Damage.

Risk Parameter[a]	Optimal Nitrogen (Implied Safety Level)[b] Group 1	Optimal Nitrogen (Implied Safety Level)[b] Group 2	Mean Net Returns (Standard Dev.) Group 1	Mean Net Returns (Standard Dev.) Group 2
		CENNY Region		
0.00	129 lb/a	160 lb/a	$188.44	$121.65
	(14 lb/a)	(15 lb/a)	($108.65)	($53.46)
0.01	133	156	188.34	121.59
	(15)	(14)	(108.33)	(53.22)
0.03	135	150	188.26	121.24
	(16)	(13)	(108.21)	(52.80)
		EASPLT Region		
0.00	132	165	173.53	135.98
	(10)	(8)	(106.13)	(56.77)
0.01	137	159	173.44	135.88
	(10)	(7)	(105.83)	(56.38)
0.03	138	151	173.37	135.28
	(10)	(7)	(105.71)	(55.71)
		WESPLN Region		
0.00	131	164	178.7	135.08
	(18)	(14)	(110.20)	(57.81)
0.01	138	158	178.51	134.95
	(21)	(13)	(109.73)	(57.32)
0.03	145	151	177.8	134.43
	(24)	(12)	(109.21)	(56.68)

[a] Arrow-Pratt coefficient of absolute risk aversion.

[b] Amount of combined leaching and runoff exceeded in 3 out of 30 (i.e., with (probability 0.1) at initial fertilization rates.

Optimal Policies to Achieve Relative Reductions in Environmental Damage

Optimal payments are determined when the environmental policy objective is to achieve relative reductions in pre-policy leaching and runoff levels within each region. To accomplish this objective, the nitrate loss safety levels are used as measures of environmental damage, and two alternative environmental standards are examined: a 20% and a 40% reduction from pre-policy regional safety levels. Since the absolute levels of leaching and runoff vary substantially by region (Table 12), these relative standards provide a consistent basis for comparing the costs of improved environmental quality across diverse regions.

Table 12. Safety Levels for Relative Reductions in Leaching and Runoff, by Region.

	Safety Level (lbs leaching & runoff/acre)		
Standard	CENNY	EASPLT	WESPLN
Initial	14.0	8.2	14.3
20% Reduction	11.2	6.5	11.4
40% Reduction	8.4	4.9	8.6

Nitrogen Levels Under Environmental Standards

To determine pre-policy safety levels within a region, each group's pre-policy safety levels are first averaged across risk aversion levels to estimate each group's safety level. Then, a weighted average of these group-level estimates is calculated, where the proportions of regional corn acreage in each group are used as weights. The CENNY and WESPLN regions have similar pre-policy safety levels of about 14 lbs/acre, which is almost twice as large as those in the EASPLT, region 8 lbs/acre (Table 12). This implies that the relative environmental standards studied in this section, if imposed uniformly on all three regions, will result in significantly higher *absolute* levels of environmental quality in EASPLT than in WESPLN and CENNY.

The maximum fertilization rates which meet the relative environmental standards in each region were determined by iterative comparisons of simulated distributions of leaching and runoff as described above. These "environmentally safe" fertilization rates are in Table 13. To accomplish a 20% reduction in nitrate loss, the allowable nitrogen levels for group 1 vary from 104 to 117 lbs/acre, and from 143 to 151 lbs/acre for group 2. For the 40% standard, fertilization levels range from 78 to 101 lbs/acre for group 1, and from 119 to 133 lbs/acre for group 2. For each environmental standard and all three regions, the environmentally safe nitrogen levels are smaller for group 1. From theoretical Proposition 4, this implies that if information is asymmetric, separate policies for the two groups will be optimal in every region.

Table 13. Environmentally Safe Nitrogen Levels, Relative Reductions in Nitrate Loss.

Env. Standard (Safety Level)	Nitrogen (lbs/acre) Group 1	Nitrogen (lbs/acre) Group 2	Mean Net Returns (Standard Dev.) Group 1	Mean Net Returns (Standard Dev.) Group 2
		CENNY Region		
20% Reduction (11.2 lbs/acre)	117	143	$187.77 ($109.39)	$120.48 ($52.30)
40% Reduction (8.4 lbs/acre)	101	126	184.67 (110.24)	117.02 (50.92)
		EASPLT Region		
20% Reduction (6.5 lbs/acre)	104	146	169.63 (107.81)	134.62 (55.26)
40% Reduction (4.9lbs/acre)	78	119	159.12 (108.92)	127.79 (52.60)
		WESPLN Region		
20% Reduction (11.4 lbs/acre)	106	151	175.51 (111.98)	134.44 (56.69)
40% Reduction (8.6 lbs/acre)	90	133	170.25 (112.95)	131.36 (54.88)

Optimal Payments

To study the program costs resulting from asymmetric information between producers and the government, optimal policies are calculated both under symmetric and under asymmetric information. If information is initially asymmetric, the difference in optimal payments between these two cases represents the decline in government cost from being able to classify individual farms. Thus, this difference is termed the "information premium;" it is the part of compensation payments strictly due to asymmetry of information. For policy purposes, the information premium would need to be weighed against the cost of collecting and/or using the information necessary to identify each farmer's group.

Symmetric Information: If information is symmetric, government compensation 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 utility levels, where post-policy nitrogen application rates are set at the "environmentally safe" levels in Table 13. Table 14 shows the per-acre payments to meet the two environmental quality standards for both groups, and the average payments per acre in each region. Supposing the policy goal is a 20% reduction in nitrate loss, the payments range from $0.67 to $7.15 for group 1 and $0 to $1.37 for group 2. The next increment in improved environmental quality comes at a substantially greater cost; for a 40% reduction in nitrate loss, payments to group 1 range from $3.77 to $16.37 for group 1 and $1.13 to $8.20 for group 2. Because the reduction in nitrogen to meet environmental standards is generally larger for group 1, this group must receive greater compensation payments to restore pre-policy levels of expected utility. Average payments per acre are the largest in the EASPLT region; both groups suffer the largest reduction in net returns to meet the environmental quality standards in this region.

Asymmetric Information: In each of the three regions, the policy design under asymmetric information is analogous to the stylized example: group 2's yield is more responsive to nitrogen fertilizer at the margin than is group 1's yield, optimal pre-policy fertilization rates are lower for group 1, and group 1 must also apply less nitrogen than group 2 to meet environmental quality standards. When these conditions hold, group 2's optimal payment is determined by a binding participation constraint (pre- and post-policy expected utility will be equal), and group 1's payment is determined by a binding self-selection constraint (a farmer in group 1 will have the same expected utility under his own policy as he would under group 2's policy).

If information is asymmetric, payments include not only the cost of lost farm income, but also the information premium; Group 1 must receive an additional incentive to voluntarily select the appropriate policy, essentially giving these producers a windfall benefit because the government cannot identify which farmers belong to that group. The information premium ranges from $0 to $0.44 per acre for the 20%

Table 14. Green Payments , Relative Reductions in Nitrate Loss.

Env. Std.[c]	Risk Param.	Symmetric Information Gr. 1	Symmetric Information Gr. 2	Symmetric Information Avg.[a]	Asymmetric Information Gr. 1	Asymmetric Information Gr. 2	Asymmetric Information Avg.[a]	Info. Premium (Group 1)[b]
				CENNY Region				
20%	0.00	$0.67	$1.18	$ 1.16	$0.85	$1.18	$1.17	$0.18
20%	0.01	1.23	0.67	0.69	1.46	0.67	0.70	0.23
20%	0.03	1.46	0.17	0.22	1.46	0.17	0.22	0.00
40%	0.00	3.77	4.63	4.60	8.37	4.63	4.78	4.60
40%	0.01	4.83	3.45	3.51	8.03	3.45	3.63	3.20
40%	0.03	5.24	1.94	2.07	6.82	1.94	2.14	1.58
				EASPLT Region				
20%	0.00	3.90	1.37	1.90	4.34	1.37	1.99	0.44
20%	0.01	4.92	0.68	1.57	5.18	0.68	1.63	0.26
20%	0.03	5.25	0.09	1.17	5.25	0.09	1.17	0.00
40%	0.00	14.42	8.20	9.51	21.76	8.20	11.05	7.34
40%	0.01	15.97	6.18	8.24	20.73	6.18	9.24	4.76
40%	0.03	16.37	3.62	6.30	18.35	3.62	6.71	1.98
				WESPLN Region				
20%	0.00	3.19	0.64	0.82	3.19	0.64	0.82	0.00
20%	0.01	4.66	0.18	0.49	4.66	0.18	0.49	0.00
20%	0.03	7.15	0.00	0.50	7.15	0.00	0.50	0.00
40%	0.00	8.44	3.72	4.05	12.15	3.72	4.31	3.71
40%	0.01	10.58	2.36	2.94	12.84	2.36	3.09	2.26
40%	0.03	14.24	1.13	2.05	14.69	1.13	2.08	0.45

[a] Weighted average payment per acre; weights are the proportion of acreage in each group (Table 8).

[b] Difference between payments under symmetric information and asymmetric information for group 1.

[c] Percentage reduction from pre-policy implied safety levels.

standard[14] and $0.45 to $7.34 per acre for the 40% standard (Table 14). A striking feature of these results is that the information premium increases as environmental standards become more stringent.

Average payments per acre generally decrease with the level of risk aversion because of the marginal risk effects of nitrogen. Since group 2 producers can meet environmental quality standards with smaller reductions in nitrogen as the risk aversion level increases, compensation to this group declines with the degree of risk aversion. Group 1's payments, which depend on the optimal policies for group 2, generally decrease with the level of risk aversion.

The estimated aggregate government cost to achieve environmental standards in each of the regions and the information premium are in Table 15. To put these aggregate costs in context, total government payments to all producers from existing government programs in 1992 are also reported. The largest aggregate costs are in the EASPLT region, even though this region is significantly smaller in terms of corn acreage. This results because average payments per acre are largest in this region and group 1, which receives larger payments than group 2, makes up a more significant share of corn acreage than in the other two regions. Even though the costs are highest in EASPLT, the relative environmental standards and pre-policy conditions imply that the absolute level of environmental quality is also the highest. Aggregate costs in all regions are substantially larger for the 40% standard than for the 20% standard. However, even for the more stringent standard, the aggregate cost of the "green" payment program is relatively small in comparison to total government payments in these regions.

The information premium varies substantially across regions. Like payment levels, the information premium is highest in the EASPLT region where group 1 makes up a large share of corn acreage compared to the other two regions. For all three

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[14]A zero information premium arises when group 2's environmentally safe fertilization level is only slightly below optimal, and their compensation payment is relatively small (Tables 12 and 13). From group 1's perspective, group 2's policy provides a small amount of compensation for nitrogen levels that are substantially supra-optimal (see Table 11). In such a case, group 1 would prefer its pre-policy situation to group 2's policy. Therefore, group 1's payments are determined by a binding participation constraint, and are equivalent to the symmetric information case.

Table 15. Aggregate Cost of Relative Reductions in Environmental Damage.

	Land in Corn[b]			Payments for 20% Standard[a] / Payments for 40% Standard[a]							Gov't
				Symmetric Information			Asymmetric Information			Info.	Payments
Region	Gr. 1	Gr. 2	Tot.	Gr. 1	Gr. 2	Tot.	Gr. 1	Gr. 2	Tot.	Premium	1992[b]
	--- 1000 acres ---			--- $1000 ---							
CENNY	12	277	289	14	186	200	17	186	203	3	7050
				56	957	1013	93	957	1050	37	
EASPLT	26	98	124	128	67	195	135	67	202	7	3338
				416	605	1021	540	605	1145	124	
WESPLN	16	212	228	74	38	113	74	38	113	0	9124
				169	500	669	205	500	705	36	

[a] Based on per-acre payments for a risk aversion parameter of 0.01.

[b] Based on the 1992 Census of Agriculture.

regions, the aggregate information premium is higher for the 40% standard than for the 20% standard; the costs imposed by asymmetric information are more of a concern as environmental standards become more stringent. If the program were implemented in these three regions, the overall cost of asymmetric information would be about $10,000 for the 20% standard and about $200,000 for the 40% standard. This implies that 2% and 7% of program costs would be attributable to asymmetric information for the two standards, respectively.

Optimal Policies to Achieve Absolute Levels of Environmental Quality

In this section, the policy goal is to attain some uniform level of environmental quality across all regions, however large or small a reduction from initial levels this standard may impose. Here, the safety levels themselves define the policy objective. In particular, the two alternative environmental standards examined here require that nitrate losses fall below 10 and 7 lbs/acre with a 90% probability in all regions.

Nitrogen Levels Under Environmental Standards

The maximum fertilization rates which meet the 10 and 7 lbs/acre safety levels are in Table 16 for the three regions. The fertilization rates indicate significant spatial diversity in nitrate loss, even across contiguous regions in New York. For group 1, the absolute environmental standards are the most restrictive in the WESPLN region, where fertilization rates must be reduced to as little as 69 lbs/acre to meet the 7 lbs/acre chance constraint. Group 2, on the other hand, must bear the largest reduction in nitrogen application in the CENNY region, where environmentally safe levels are as low as 115 lbs/acre. The absolute environmental standards can be met most easily in the EASPLT region; even the pre-policy optimal fertilization rates would satisfy the 10 lb chance constraint for both groups. The nitrogen levels in Table 16 are always smaller for group 1 than for group 2; here, two policies will also be optimal.

Optimal Payments

Table 17 provides optimal payments to achieve the absolute environmental standards. To meet the absolute environmental standards, not only does the average payment size differ across regions much more than the payments for relative standards, but so too do the loss in farm net returns, the information premium, the influence of risk aversion, and the distribution of payments between groups.

Table 16. Environmentally Safe Nitrogen Levels, Absolute Nitrate Loss Safety Levels.

Safety Level	Nitrogen (lbs/acre) Group 1	Nitrogen (lbs/acre) Group 2	Mean Net Returns (Standard Dev.) Group 1	Mean Net Returns (Standard Dev.) Group 2
		CENNY Region		
10 lbs/acre	110	136	$186.72 ($109.79)	$119.33 ($51.76)
7 lbs/acre	86	115	179.49 (110.86)	113.58 (49.90)
		EASPLT Region[a]		
10 lbs/acre	---	---	---	---
7 lbs/acre	110	---	171.11 (107.50)	---
		WESPLN Region		
10 lbs/acre	99	143	173.52 (112.42)	133.39 (55.92)
7 lbs/acre	69	121	159.20 (114.08)	127.89 (53.53)

[a] Except for group 1 and the 7 lbs/acre standard, the environmental quality standards are not applicable to this region; producers can meet the standards at pre-policy optimal fertilization rates.

Table 17. Green Payments, Absolute Nitrate Loss Standards.

Env. Std.[c]	Risk Param.	Symmetric Information Gr. 1	Symmetric Information Gr. 2	Symmetric Information Avg.[a]	Asymmetric Information Gr. 1	Asymmetric Information Gr. 2	Asymmetric Information Avg.[a]	Info. Premium (Group 1)[b]
				CENNY Region				
10 lb/a	0.00	$1.72	$2.32	$ 2.30	$3.79	$2.32	$ 2.38	$2.07
10	0.01	2.51	1.55	1.59	4.03	1.55	1.65	1.52
10	0.03	2.83	0.66	0.75	3.48	0.66	0.77	0.65
7	0.00	8.96	8.08	8.12	16.11	8.08	8.40	7.15
7	0.01	10.38	6.40	6.56	15.23	6.40	6.75	4.85
7	0.03	10.93	4.13	4.40	13.25	4.13	4.49	2.32
				EASPLT Region				
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	2.42	0.00	0.51	2.42	0.00	0.51	0.00
7	0.01	3.27	0.00	0.69	3.27	0.00	0.69	0.00
7	0.03	3.56	0.00	0.75	3.56	0.00	0.75	0.00
				WESPLN Region				
10	0.00	5.18	1.69	1.93	6.22	1.69	2.01	1.04
10	0.01	6.95	0.85	1.28	7.67	0.85	1.33	0.72
10	0.03	9.95	0.22	0.90	10.16	0.22	0.92	0.21
7	0.00	19.49	7.19	8.05	26.15	7.19	8.52	6.66
7	0.01	22.37	5.17	6.37	26.26	5.17	6.65	3.89
7	0.03	27.55	3.17	4.88	28.01	3.17	4.91	0.46

[a] Weighted average payment per acre; weights are the proportion of acreage in each group (Table 8).

[b] Difference between payments under symmetric information and asymmetric information for group 1.

[c] Safety levels required by the program.

Symmetric Information: As one might expect from the nitrogen levels in Table 16, group 1 suffers the greatest loss in net returns in the WESPLN region; compensation payments range from $19.49 to $27.55 per acre. In comparison, the symmetric information payments to group 1 in the CENNY region range from $8.96 to $10.93 per acre. For group 2, the situation is reversed, but the cost of environmental improvement is much smaller in both regions; in WESPLN, the payments to group 2 range from $0.22 to $1.69, compared with $0.66 to $2.32 in CENNY. In the EASPLT region, group 2 producers need not reduce nitrogen to achieve either of the environmental standards, and group 1 producers will receive payments ranging from $2.42 to $3.56 only for the 7 lbs/acre safety level.

Asymmetric information: Asymmetric information imposes additional costs on the program in WESPLN and CENNY. The information premium for the 10 lb standard ranges from $0.21 to $1.04 in WESPLN and from $0.65 to $2.07 in CENNY, while the 7 lb standard generates information premiums ranging from $0.46 to $6.66 in WESPLN and from $2.32 to $7.15 in CENNY. The value of information appears to be similar in both regions, but is slightly higher in CENNY. The EASPLT region has a zero information premium. In this region, only group 1's policy is offered for the 7 lbs/acre standard, but this policy is still incentive compatible; the information premium is zero because group 2 has no incentive to volunteer for group 1's policy.

The effect of risk aversion differs across the three regions. In the CENNY region, payments to both groups under asymmetric information are lowest for the most risk averse case. In contrast, payments in the EASPLT region (where only group 1's policy is offered) increase with the risk aversion parameter. In the WESPLN region, risk aversion increases payments for group 1 and decreases payments for group 2. These changes in payments across regions demonstrate that the impact of risk aversion is difficult to generalize. Though it will always influence payments and should not be ignored, the direction and magnitude of its effects depend on the particular yield functions used and regional weather conditions. In our case, even with the same specification of yield functions across regions, differences in weather caused the effect of risk aversion to differ.

As in the case of relative standards, aggregate payments and information premiums differ across regions, but the pattern of payments is nearly reversed (Table 18). While EASPLT generated the largest program cost under relative standards, the payments all but disappear when environmental standards are absolute; payments are

Table 18. Aggregate Cost of Absolute Reductions in Environmental Damage.

	Land in Corn[b]			Payments for 10 lb/acre Standard[a] / Payments for 7 lb/acre Standard[a]							Gov't
				Symmetric Information			Asymmetric Information			Info.	Payments
Region	Gr. 1	Gr. 2	Tot.	Gr. 1	Gr. 2	Tot.	Gr. 1	Gr. 2	Tot.	Premium	1992[b]
	--- 1000 acres ---			$1000							
CENNY	12	277	289	29	430	459	47	430	477	18	7050
				120	1776	1896	176	1776	1952	56	
EASPLT	26	98	124	0	0	0	0	0	0	0	3338
				85	0	85	85	0	85	0	
WESPLN	16	212	228	111	180	291	122	180	303	11	9124
				357	1096	1453	419	1096	1515	62	

[a] Based on per-acre payments for a risk aversion parameter of 0.01.

[b] Based on the 1992 Census of Agriculture.

zero in EASPLT under the 10 lbs/acre standard, and are only 4% and 6% of the aggregate payments in CENNY and WESPLN, respectively, under the 7 lbs/acre standard. The value of information, totaled across the three regions, is $29,000 for the 10 lbs/acre standard and $118,000 for the 7 lbs/acre standard. Under absolute standards, about 4% of program costs are attributable to asymmetric information.

Summary and Conclusions

A number of important conclusions can be drawn from this region-level voluntary program to reduce nitrate loss from corn production under two alternative methods of defining environmental standards. Optimal payments differ substantially depending of the environmental standard regime chosen. In the EASPLT region, average payments per acre under the most stringent relative standards range from $7 to $11, versus a range of $2 to $5 per acre in CENNY and WESPLN. On the other hand, when absolute standards are imposed, the average payments in EASPLT are less than $1 per acre, versus $4 to $9 in CENNY and EASPLT. Thus, the distributional consequences of the government payments are sensitive to the type of environmental standard imposed. This is an additional dimension to the policy debate in designing such programs: even if the overall size of the program remains the same, the payments to each particular region would vary dramatically depending upon the standard regime chosen.

Even under the same set of environmental standards, optimal payments still vary substantially by region. For absolute standards, average payments to meet the same environmental standard (for the same risk aversion level) differ by as much as $8 per acre between regions, and for relative standards this difference is as large as $13. These results are not entirely surprising; they support the notion that pollution levels differ between even relatively small geographic areas, indicating that the overall cost of such an environmental program could be significantly lowered by narrowing the regional focus of implementation. Of course, these cost savings would need to be weighed against the additional administrative costs from increased localization of the program.

The information premium, or program costs attributable to asymmetric information, vary depending on the stringency of environmental standards. As environmental standards become more strict, the information premium increases. If information is asymmetric and environmental standards are very stringent, not only will the cost of the program be large because farmers must dramatically reduce nitrogen, but also because the group identity of each producer is unknown. For large reductions in nitrogen, the government would benefit substantially from knowing which producers belong to which group. Nonetheless, in the New York case studied here, the aggregate information premium is not large in comparison to total program costs.

The information premium affects the outcome of the policy in at least two ways. First, at an aggregate level, higher information premiums directly influence the taxpayer cost of the program. If the aggregate cost of asymmetric information were large, it may be in the government's interest to collect (and/or use) the information necessary to implement the program under symmetric information. If the government so chooses, the information premium would disappear, but additional administrative costs would be incurred. As mentioned above, these costs savings do not appear to be significant in New York, but this may not be the case in the Midwest where leachable soils are more common.

Second, at the farm level, the size of the information premium per acre reflects the amount of windfall benefit one of the producer groups receives simply because the government cannot identify the producers in that group (in the case studied here, group 1 receives the windfall benefit). Thus, there is a distributional consequence of asymmetric information; one group of farmers will necessarily benefit more than the other group because the government fails to identify them. Even if the aggregate cost savings alone did not warrant implementing the program under symmetric information, these distributional concerns may be presented as justification for doing so.

The overall effect of risk aversion is difficult to generalize. For the various scenarios of the New York model, the payments to group 1 generally increase with the level of risk aversion, and the payments to group 2 generally decrease. However, aggregate (or equivalently, average) payments decline with the level of risk aversion in some cases, but increase with risk aversion in others. Even though average payment levels exhibit no consistent pattern with respect to risk aversion, the information premium is always larger for risk neutrality than for risk aversion. Nonetheless, the results obtained here are likely to be sensitive to the particular specification and data used. While risk aversion affects the outcome of the model, both qualitatively and quantitatively, its impact is largely an empirical question which must be addressed in each region.

POLICY IMPLICATIONS

The purpose of this research is to develop a model of a voluntary "green" payment program to limit nitrate leaching and runoff from corn production in New York. At a conceptual level, the model can be modified or extended in obvious ways to consider any production practice which generates reductions in nitrate contamination or other environmental benefits; in this case, the application is to voluntary reductions in nitrogen fertilizer application rates.

The program allows environmental goals to be achieved through self-interested choices of farmers. These choices and program payments can differ by productivity and environmental vulnerability of the soils. The model allows for asymmetric information between farmers and the government, explicitly considering the stochastic nature of prices, agricultural production, and environmental damage. Farmers are assumed to maximize expected utility, and the government's environmental quality goals are articulated as chance constraints on severe levels of nitrate leaching and runoff.

Based on the theoretical analysis, separate policies are necessary if the group whose soils are more productive at the margin to changes in nitrogen also generate less nitrate contamination at the margin. These separate policies would avoid the inefficiencies in conventional uniform taxes and quantity restrictions that fail to recognize differences in resource endowments across farms. When government officials have sufficient information about soils to assign farmers to payment groups (symmetric information), environmental standards can be met exactly at minimum cost. If information is asymmetric, then policy makers cannot assign farmers to groups, and the group which is more susceptible to nitrate loss must be compensated by more than their loss in net returns for participation to be voluntary. This windfall to this group is an additional cost to society which must be balanced against the administrative cost of collecting information about differences in soils by farm.

This model was applied empirically to three New York farming regions, where farmers were divided into two groups on the basis of soil type. Based on estimated yield and environmental damage functions, optimal "green" payments were determined to meet two types of environmental standards: relative (20 and 40%)

reductions from pre-policy levels of nitrate loss in each region, and absolute standards of 7 and 10 lbs of nitrate loss per acre. Required reductions in nitrogen rates would insure that these standards are exceeded with a probability of less than 10%.

From the empirical analysis, optimal payments would differ significantly by environmental standard, region, group, and risk aversion level. When relative reductions are imposed, payments were largest in the region where crop yields and existing levels of nitrate contamination were both lowest. Across all regions, payments ranged from less than $1 to as high as $22 per acre, representing up to 13% of pre-policy net return. The windfall benefit resulting from asymmetric information ranged from $0 to $7 per acre and increased with the stringency of environmental standards. Reductions in nitrogen were between 0 and 60 lbs per acre, representing as much as a 43% decline from initial levels for the most stringent standard.

Under absolute standards, the pattern of payments across regions would change dramatically. When an absolute level of environmental quality is sought, the reductions in fertilizer and concomitant payments are highest in the regions most susceptible to environmental damage. The region with the lowest pre-policy levels of contamination would have essentially no program at all (estimated average payments per acre were less than $1), while the payments in the other regions ranged from $1 to $28 per acre, or up to 16% of initial net returns. The cost of information does not appear to be sensitive to the type of environmental standard; estimated windfall benefits were between $0 and $7, falling within the same range as for relative standards. The absolute standards would require decreases in nitrogen fertilizer between 0 and 76 lbs per acre, or up to a 52% reduction from pre-policy levels.

Risk aversion significantly complicates the policy design problem, and its impact is difficult to generalize because nitrogen is a risk reducing input for farmers with the highest yielding soil and slightly risk increasing for the other group. If, in implementing this program, the government incorrectly assesses producers' risk attitudes, we cannot say *a priori* whether total program payments needed to satisfy farmers' self-selection conditions are over- or under-estimated.

At an aggregate level, there are an estimated 641,000 acres of corn in these three regions. If one assumes complete participation, the estimated program payments would range from $0.5 million to $3.5 million over the regions combined, depending on the stringency of environmental standards. Even under these high participation rates, this program is not terribly expensive, representing only 3% to and 18% of total government payments received by farmers in the three regions in 1992. Further, the cost of asymmetric information represents only 10% of total program outlays. In New York, where the agricultural use value assessment program already requires that local agricultural offices have the capacity to place farmland into ten soil productivity groups (Thomas and Boisvert, 1995), much of this cost might be avoided.

Although this research has articulated several advantages of this type of policy, the main disadvantage of a "green" payment scheme is that improvements in environmental quality rely on the voluntary participation of farmers. One could hardly expect anywhere close to 100% participation for these large regions, especially in light of the relatively small payment levels in some regions and the substantial required reductions in nitrogen fertilizer application rates. The situation could be quite different if the program were designed around another kind of management practice or if the program targeted localized areas with extremely vulnerable soils. In a stylized example of targeting soils for reductions in nitrogen application rates, estimated payments were substantially higher; payments to the most leachable group ranged from $7 to $37, and payments to the second group ranged from $2 to $25. But even in this case, there is a need for additional research to better understand the factors that influence voluntary farmer participation. Further, if the programs are to target soils effectively, more research is needed to identify soil characteristics which more sharply isolate the vulnerable soils, and to refine the nitrogen yield response functions particularly in terms of the effect on risk. Finally, the administrative procedures and costs of implementing voluntary programs would need to be investigated thoroughly.

Appendix A: Proofs of the Propositions

Proof of Proposition 1:

To show property (*a*), we must verify that the Hessian matrix of the function $\overline{u}^i$ is negative definite. That is, we must have

$$\overline{u}^i_{NN} < 0, \quad \overline{u}^i_{SS} < 0, \text{ and}$$

$$\begin{vmatrix} \overline{u}^i_{NN} & \overline{u}^i_{NS} \\ \overline{u}^i_{SN} & \overline{u}^i_{SS} \end{vmatrix} = \overline{u}^i_{NN}\overline{u}^i_{SS} - \overline{u}^i_{SN}\overline{u}^i_{NS} > 0, \quad i = 1,2.$$

where, $\overline{u}^i_{SN}$ is the second order cross-partial derivative of $\overline{u}^i$ with respect to S and N, and other terms defined analogously. Using the definition of $\overline{u}^i$ from equation (2-4), the first derivatives with respect to N and S are

$$\overline{u}^i_N = \frac{1}{T}\sum_{t=1}^{T} u_i'(R_t^i(N_i) + S_i)R_{tN}^i(N_i), \text{ and}$$

$$\overline{u}^i_S = \frac{1}{T}\sum_{t=1}^{T} u_i'(R_t^i(N_i) + S_i),$$

where R^i_{tN} is the first derivative of R^i_t with respect to N. The second derivatives are

$$\overline{u}^i_{NN} = \frac{1}{T}\sum_{t=1}^{T}\left\{u_i''(R_t^i(N_i) + S_i)[R_{tN}^i(N_i)]^2 + u_i'(R_t^I(N_i) + S_i)R_{tNN}^i(N_i)\right\},$$

$$\overline{u}^i_{SS} = \frac{1}{T}\sum_{t=1}^{T} u_i''(R_t^i(N_i) + S_i),$$

$$\overline{u}^i_{NS} = \overline{u}^i_{SN} = \frac{1}{T}\sum_{t=1}^{T} u_i''(R_t^i(N_i) + S_i)R_{tN}^i(N_i),$$

where R^i_{tNN} is the second derivative of R^i_t with respect to N. In the expression for $\overline{u}^i_{NN}$, the first term in the sum is negative because $u''<0$ and the second term is also negative since u' is positive and R^i_{tNN} is negative ($R^i_{tNN} = p_t y^i_{NN}(N_i, W_t) < 0$). Thus $\overline{u}^i_{NN} < 0$, and $\overline{u}^i_{SS}$ is also explicitly negative. To check the remaining condition $\overline{u}^i_{NN}\overline{u}^i_{SS} - \overline{u}^i_{SN}\overline{u}^i_{NS} > 0$, we must determine the sign of

(12) $$\frac{1}{T^2}\sum_{t=1}^{T}\left\{u_{it}''[R_{tN}^i]^2+u_{it}'R_{tNN}^i\right\}\sum_{t=1}^{T}u_{it}''-\frac{1}{T^2}\sum_{t=1}^{T}u_{it}''R_{tN}^i\sum_{t=1}^{T}u_{it}''R_{tN}^i,$$

where u_{it}' represents the derivative of u_i evaluated at $(R^i{}_t + S_i)$. This expression can be rewritten

$$\frac{1}{T^2}\left\{\sum_{t=1}^{T}\sum_{s=1}^{T}u_{it}''u_{is}''[R_{tN}^i]^2+\sum_{t=1}^{T}\sum_{s=1}^{T}u_{is}''u_{it}'R_{tNN}^i-\sum_{t=1}^{T}\sum_{t=1}^{T}u_{it}''u_{is}''R_{tN}^iR_{sN}^i\right\}$$

$$=\frac{1}{T^2}\left\{\sum_{t=1}^{T}\sum_{s=1}^{T}u_{is}''u_{it}'R_{tNN}^i+\sum_{t=1}^{T}\sum_{s=1}^{T}u_{it}''u_{is}''R_{tN}^i[R_{tN}^i-R_{sN}^i]\right\}.$$

The first sum is positive since $u_i''<0$, $u_i'>0$ and $R_{tNN}^i<0$. The second sum can be separated into terms where t=s and where t≠s. The terms where t=s will equal zero since $[R^i{}_{tN} - R^i{}_{sN}]=0$. For the remaining terms, note that any two years k≠l will appear in the sum exactly twice. That is,

$$\sum_{t=1}^{T}\sum_{s\neq t}u_{it}''u_{is}''R_{tN}^i[R_{tN}^i-R_{sN}^i]=\cdots+u_{ik}''u_{il}''R_{kN}^i[R_{kN}^i-R_{lN}^i]+\cdots$$

$$\cdots+u_{ik}''u_{il}''R_{lN}^i[R_{lN}^i-R_{kN}^i]+\cdots$$

Combining these two terms,

$$\sum_{t=1}^{T}\sum_{s\neq t}u_{it}''u_{is}''R_{tN}^i[R_{tN}^i-R_{sN}^i]=\cdots+u_{ik}''u_{il}''[R_{kN}^i(R_{kN}^i-R_{lN}^i)-R_{lN}^i(R_{kN}^i-R_{lN}^i)]+\cdots$$

$$=\cdots+u_{ik}''u_{il}''(R_{kN}^i-R_{lN}^i)^2+\cdots>0,$$

since $u_i''<0$. Since each pairwise combination of terms is strictly positive, their sum must also be positive. This establishes that (12) > 0, which completes the proof of property (*a*).

To prove property (*b*), take the expectation of $\bar{u}^i$ from its definition in equation to obtain

$$E[\bar{u}^i(N_i,S_i)]=E\left[\frac{1}{T}\sum_{t=1}^{T}u_i(R_t^i(N_i)+S_i)\right]=E\left[\frac{1}{T}\sum_{t=1}^{T}u_i(R^i(N_i,W_t,p_t,r_t)+S_i)\right]$$

$$= \frac{1}{T}\sum_{t=1}^{T} E[u_i(R^i(N_i, W_t, p_t, r_t) + S_i)].$$

Since the sample observations $\{(W_1,p_1,r_1),\ldots,(W_T,p_T,r_T)\}$ will be identically and independently distributed, this becomes

$$= \frac{T \cdot E[u_i(R^i(N_i, W, p, r) + S_i)]}{T} = E[u_i(R^i(N_i, W, p, r) + S_i)].$$

Proof of Proposition 2:

Suppose that $\frac{\partial y^2(N,W)}{\partial N} > \frac{\partial y^1(N,W)}{\partial N}$. Multiplying both sides of this inequality by p_t and subtracting r_t from both sides, we have

$$p_t \frac{\partial y^2(N,W_t)}{\partial N} - r_t > p_t \frac{\partial y^1(N,W_t)}{\partial N} - r_t,$$

which means that, for any N, $R^2_{tN} - R^1_{tN} > 0$. Summing across years we have

$$\sum_{t=1}^{T} R^2_{tN} - \sum_{t=1}^{T} R^1_{tN} > 0, \text{ and } \sum_{s=1}^{T}\sum_{t=1}^{T} R^2_{tN} - \sum_{s=1}^{T}\sum_{t=1}^{T} R^1_{tN} > 0.$$

Interchanging the roles of s and t in the first sum, and reversing the order of summation, this can be equivalently stated

$$\sum_{t=1}^{T}\sum_{s=1}^{T} R^2_{sN} - \sum_{t=1}^{T}\sum_{s=1}^{T} R^1_{tN} > 0 \quad \Leftrightarrow \quad \sum_{t=1}^{T}\sum_{s=1}^{T} [R^2_{sN} - R^1_{tN}] > 0.$$

This implies the desired result that

$$\sum_{t=1}^{T}\sum_{s=1}^{T} u_i'(R^1_t + S) u_i'(R^2_s + S)[R^2_{sN} - R^1_{tN}] > 0,$$

since $u_i' > 0$.

Appendix B:

Table B-1. Corn Silage Prices, 1963-1992.

Year	Corn Grain Price ($/bu)[a,b]	Corn Grain Yield (bu/a)[b]	Corn Silage Yield (tons/a)[b]	Imputed Corn Silage Price ($/ton)	Index of Prices Rec'd by Farmers (1977=100)[c]	Real Corn Silage Price (1992 $/t)
1963	1.26[d]	62.0	12.0	6.52	53	17.22
1964	1.34	64.0	11.0	7.80	52	20.99
1965	1.34	61.0	12.0	6.81	54	17.66
1966	1.43	75.0	12.5	8.58	58	20.71
1967	1.17	87.0	15.5	6.57	55	16.72
1968	1.18	80.0	12.5	7.55	56	18.88
1969	1.34	85.0	14.0	8.14	59	19.31
1970	1.47	88.0	14.0	9.24	60	21.56
1971	1.20	87.0	14.0	7.46	62	16.84
1972	1.71	70.0	10.5	11.40	69	23.13
1973	2.76	77.0	12.5	17.00	98	24.29
1974	3.03	80.0	13.0	18.65	105	24.86
1975	2.57	87.0	13.5	16.56	101	22.96
1976	2.42	81.0	12.0	16.34	102	22.42
1977	2.20	87.0	13.5	14.18	100	19.85
1978	2.44	86.0	13.5	15.54	115	18.92
1979	2.75	92.0	13.5	18.74	132	19.88
1980	3.50	93.0	14.5	22.45	134	23.45
1981	2.66	93.0	14.5	17.06	139	17.18
1982	2.95	92.0	13.5	20.10	133	21.16
1983	3.54	90.0	13.5	23.60	135	24.47
1984	2.85	91.0	13.5	19.21	142	18.94
1985	2.45	95.0	14.0	16.63	128	18.18
1986	1.76	99.0	14.0	12.45	123	14.17
1987	2.20	109.0	15.0	15.99	127	17.62
1988	2.83	85.0	13.0	18.50	138	18.77
1989	2.80	93.0	13.0	20.03	147	19.08
1990	2.44	98.0	15.0	15.94	149	14.98
1991	2.70	98.0	14.0	18.90	145	18.25
1992	2.30	92.0	14.5	14.59	140	14.59

[a] Season average.

[b] Source: *New York Agricultural Statistics*, various issues.

[c] Source: *USDA Agricultural Statistics*, various issues.

[d] In 1963, New York corn price data were unavailable. The reported price is the national corn price in 1963, $1.11 (*Agricultural Statistics*) times the average ratio of New York to national corn prices from 1964-1968, 1.136.

Table B-2. Nitrogen Fertilizer Prices, 1963-1992.

Year	Urea Price ($/ton)[a]	Urea Price ($/lb N)[b]	Index of Priced Paid by Farmers (1977=100)[c]	Imputed Real Urea Price (1992 $/lb N)
1963	114.09[d]	0.13	47	0.47
1964	110.00	0.12	47	0.44
1965	110.00	0.12	48	0.44
1966	110.00	0.12	50	0.42
1967	105.00	0.12	50	0.40
1968	100.00	0.11	50	0.38
1969	86.50	0.10	52	0.32
1970	85.00	0.09	54	0.30
1971	86.00	0.10	57	0.29
1972	86.50	0.10	61	0.27
1973	96.00	0.11	73	0.25
1974	215.00	0.24	83	0.49
1975	230.00	0.26	91	0.48
1976	180.00	0.20	97	0.35
1977	180.00	0.20	100	0.34
1978	189.00	0.21	108	0.33
1979	213.00	0.24	125	0.32
1980	259.00	0.29	138	0.36
1981	275.00	0.31	148	0.35
1982	278.00	0.31	153	0.35
1983	249.00	0.28	152	0.31
1984	250.00	0.28	155	0.31
1985	238.00	0.26	151	0.30
1986	200.00	0.22	144	0.26
1987	190.00	0.21	148	0.24
1988	208.00	0.23	157	0.25
1989	227.00	0.25	165	0.26
1990	215.00	0.24	171	0.24
1991	243.00	0.27	173	0.27
1992	221.00	0.25	174	0.24

[a] Source: New York Agricultural Statistics, various issues.

[b] Assumes that 1 ton of urea contains 900 lbs of nitrogen (45%).

[c] Source: *USDA Agricultural Statistics*, various issues.

[d] In 1963, New York urea price data were unavailable. The reported price is the national urea price in 1963, $107 (*Agricultural Statistics*) times the average ratio of New York to national urea prices from 1964-1968, 1.066.

Table B-3. Variable Production Costs for Corn Silage, 1992[a].

Item	Units	Appl. Rate per Acre	Cost per Unit (1992 $)	Cost per Acre (1992 $)
Lime	tons	0.5	29.07	14.53
Herbicide	gallons	0.6	25.14	15.09
Insecticide	gallons	0.4	20.12	8.05
Soil Testing		1	0.75	0.75
Fuel	gallons	10.56	1.00	10.51
Lubrication		1	1.01	1.01
Repair and Maintenance		1	27.16	27.16
Manure Application	tons	20	1.33	26.55
Seed	1000 kernels	25	0.90	22.44
Phosphorous	lb. P_20_5	40	0.23	9.12
Potassium	lb. K_20	50	0.12	6.20
Hired Labor		5.56	6.03	33.55
Custom Operations		1.00	5.83	5.83
Other		1.00	2.51	2.51
Operating Interest		183.31	0.12	6.20
Total				189.52

Sources: Schmit (1994) and USDA-ERS, *Economic Indicators of the Farm Sector: Field Crops and Dairy* (1992).

[a] Excluding nitrogen fertilizer cost.

Table B-4. Weather Variables at the Ithaca Weather Station, 1963 - 1992.

Year	Growing Season Rainfall (W_1)[a,b]	Acccum. Growing Degree Days (W_2)	Total Annual Rainfall (RAIN)[b]	Rain w/in 14 days of Planting (PRSTRM)[b]	Rain w/in 14 days of Fertilizer (FRSTRM)[b]	Rain w/in 14 days of Harvest (HRSTRM)[b]
1963	17.50	1802.5	30.12	0.54	1.55	0.00
1964	16.46	2115.0	30.78	0.01	1.41	0.00
1965	14.17	2046.0	32.86	0.01	0.01	0.00
1966	17.38	2027.0	37.48	0.01	0.85	0.85
1967	22.88	1980.5	38.91	0.69	0.58	0.58
1968	18.97	2043.0	42.44	0.56	1.31	0.00
1969	14.90	2073.0	37.87	0.91	3.26	0.97
1970	19.38	2072.5	46.33	1.60	2.37	2.18
1971	16.00	1970.0	35.75	0.65	0.01	1.37
1972	27.35	1920.0	51.62	0.01	6.46	1.34
1973	20.41	2143.5	38.87	0.56	0.51	0.86
1974	20.77	1920.5	42.71	1.12	1.71	2.15
1975	25.82	2130.5	45.90	0.60	0.01	5.18
1976	27.06	1841.5	48.71	1.64	2.42	0.86
1977	26.52	2049.5	47.81	0.01	2.10	9.53
1978	15.03	1998.5	36.38	0.01	0.01	1.67
1979	19.25	1949.0	39.80	1.74	0.94	0.79
1980	17.47	2123.0	34.88	0.01	1.48	0.59
1981	21.19	2018.0	41.39	0.97	0.70	2.36
1982	20.01	1906.0	32.39	1.26	1.65	1.43
1983	18.80	2113.5	33.66	0.01	0.78	1.27
1984	26.51	1912.0	41.68	2.97	1.13	2.67
1985	17.67	1880.0	37.61	1.42	1.23	0.00
1986	21.75	1997.0	39.72	2.43	0.73	0.76
1987	21.19	2182.5	33.94	0.01	0.64	1.60
1988	17.33	2132.0	34.38	1.04	0.01	1.12
1989	24.91	2102.5	40.16	0.01	0.51	4.03
1990	22.31	2027.5	40.47	1.20	0.67	1.09
1991	16.18	2367.0	36.83	0.88	0.01	1.90
1992	25.44	1816.0	40.82	0.01	0.01	2.06
Mean	20.35	2021.98	39.08	0.76	1.17	1.64
Std. Dev.	3.900	118.978	5.250	0.77	1.28	1.85
Maximum	27.35	2367.00	51.62	2.97	6.46	9.53
Minimum	14.17	1802.50	30.12	0.01	0.01	0.00
Cov(W_1,W_2)	-138.72					

Source: Northeast Regional Climate Center.

[a] This rainfall variable is total rainfall from April 1 to Septermber 30.

[b] In inches per year.

Table B-5. Weather Variables for the EASPLT Region, 1963 - 1992.

Year	Growing Season Rainfall (W_1)[a,b]	Acccum. Growing Degree Days (W_2)	Total Annual Rainfall (RAIN)[b]	Rain w/in 14 days of Planting (PRSTRM)[b]	Rain w/in 14 days of Fertilizer (FRSTRM)[b]	Rain w/in 14 days of Harvest (HRSTRM)[b]
1963	17.50	1802.5	30.85	0.01	0.01	0.00
1964	16.46	2115.0	32.74	1.18	0.54	0.54
1965	13.11	2108.0	33.59	0.01	0.01	0.00
1966	17.11	2046.5	39.34	0.01	0.58	0.58
1967	21.52	1936.5	46.99	0.01	1.55	1.55
1968	22.72	2020.0	32.03	3.05	3.58	3.58
1969	15.90	2061.5	44.24	1.59	3.32	3.32
1970	18.24	2173.5	44.09	2.21	1.09	1.09
1971	15.03	2076.5	37.85	0.01	3.36	3.36
1972	24.67	2033.5	45.44	0.01	6.59	6.59
1973	22.14	2226.5	38.96	0.97	0.59	0.59
1974	17.24	1881.5	17.39	0.01	0.01	0.00
1975	27.49	2146.5	11.47	0.01	0.01	0.00
1976	19.53	1776.0	48.81	2.10	1.05	1.05
1977	24.52	1922.0	51.36	0.62	1.02	1.02
1978	17.57	2085.5	35.97	1.56	0.01	0.00
1979	18.01	2019.5	44.89	0.55	0.62	0.62
1980	13.64	2330.5	38.21	0.01	2.03	2.03
1981	17.43	2104.0	41.58	0.01	3.10	3.10
1982	17.81	2043.0	36.04	0.01	0.78	0.78
1983	19.57	2213.5	37.08	0.01	1.21	1.21
1984	28.40	1981.0	44.46	3.16	3.48	3.48
1985	16.28	1910.0	46.11	1.10	0.73	0.73
1986	17.82	2319.0	40.89	2.97	1.22	1.22
1987	20.52	2499.0	38.97	0.66	2.76	2.76
1988	19.42	2514.0	19.95	0.01	0.01	0.00
1989	19.40	2360.5	41.78	1.33	3.70	3.70
1990	19.56	2217.0	43.51	1.96	0.01	0.00
1991	11.70	2681.5	37.15	1.12	0.01	0.00
1992	26.25	1987.5	53.71	0.55	0.01	0.00
Mean	19.22	2119.72	38.52	0.89	1.43	1.43
Std. Dev.	4.006	205.320	9.25	1.00	1.58	1.59
Maximum	28.40	2681.50	53.71	3.16	6.59	6.59
Minimum	11.70	1776.00	11.47	0.01	0.01	0.00

Source: Northeast Regional Climate Center, Elmira weather station.

[a] This rainfall variable is total rainfall from April 1 to September 30.

[b] In inches per year.

Table B-6. Weather Variables for the WESPLN Region, 1963 - 1992.

Year	Growing Season Rainfall (W_1)[a,b]	Acccum. Growing Degree Days (W_2)[c]	Total Annual Rainfall (RAIN)[b]	Rain w/in 14 days of Planting (PRSTRM)[b]	Rain w/in 14 days of Fertilizer (FRSTRM)[b]	Rain w/in 14 days of Harvest (HRSTRM)[b]
1963	14.56	1802.5	30.85	0.01	0.01	0.00
1964	15.32	2115.0	32.74	1.18	0.54	0.54
1965	14.19	2108.0	33.59	0.01	0.01	0.00
1966	16.69	2046.5	39.34	0.01	0.58	0.58
1967	18.76	1936.5	46.99	0.01	1.55	1.55
1968	16.35	2020.0	32.03	3.05	3.58	3.58
1969	23.06	2061.5	44.24	1.59	3.32	3.32
1970	24.38	2173.5	44.09	2.21	1.09	1.09
1971	14.95	2076.5	37.85	0.01	3.36	3.36
1972	20.21	2033.5	45.44	0.01	6.59	6.59
1973	19.74	2226.5	38.96	0.97	0.59	0.59
1974	17.81	1881.5	17.39	0.01	0.01	0.00
1975	21.78	2146.5	11.47	0.01	0.01	0.00
1976	23.14	1776.0	48.81	2.10	1.05	1.05
1977	32.34	1922.0	51.36	0.62	1.02	1.02
1978	16.19	2085.5	35.97	1.56	0.01	0.00
1979	16.40	2019.5	44.89	0.55	0.62	0.62
1980	16.19	2330.5	38.21	0.01	2.03	2.03
1981	26.22	2104.0	41.58	0.01	3.10	3.10
1982	17.75	2043.0	36.04	0.01	0.78	0.78
1983	17.35	2213.5	37.08	0.01	1.21	1.21
1984	25.57	1981.0	44.46	3.16	3.48	3.48
1985	11.50	1910.0	46.11	1.10	0.73	0.73
1986	22.17	2319.0	40.89	2.97	1.22	1.22
1987	22.89	2499.0	38.97	0.66	2.76	2.76
1988	16.43	2514.0	19.95	0.01	0.01	0.00
1989	24.76	2360.5	41.78	1.33	3.70	3.70
1990	20.96	2217.0	43.51	1.96	0.01	0.00
1991	14.87	2681.5	37.15	1.12	0.01	0.00
1992	23.28	1987.5	53.71	0.55	0.01	0.00
Mean	19.53	2119.72	38.52	0.89	1.43	1.43
Std. Dev.	4.513	205.320	9.25	1.00	1.58	1.59
Maximum	32.34	2681.50	53.71	3.16	6.59	6.59
Minimum	11.50	1776.00	11.47	0.01	0.01	0.00

Source: Northeast Regional Climate Center, Portageville weather station.

[a] This rainfall variable is total rainfall from April 1 to September 30.

[b] In inches per year.

[c] From the Elmira weather station, since temperatures are not recorded at Portageville.

Appendix C: Policy Design With Unspecified Utility Functions

This appendix presents an alternative formulation of the empirical policy design model. Rather than specifying a utility function for the two groups of farmers, the model assumes only that the functions u_i are increasing and strictly concave. These assumptions are equivalent to farmers preferring more income to less and being risk averse, and the policy design problem may be formulated in terms of *second-degree stochastic dominance* (SSD) (Hadar and Russell, 1969).

The SSD criterion compares the entire distributions of uncertain alternatives.[15] Assuming that ($u_i' > 0$ and $u_i'' < 0$), if the distribution F dominates G in terms of second-degree stochastic dominance, then the expected utility of alternative F is higher than the expected utility of G (Hadar and Russell, 1969). SSD conditions correspond to risk aversion coefficients anywhere in the interval $[0,\infty)$. If payment levels are chosen so that post-policy distributions of net returns for both groups are preferred in terms of SSD, we are guaranteed that *every* risk averse decision maker will choose the correct policy.

The Model

In formulating the model using SSD, the constraints involve the cumulative distribution function (c.d.f.) of income for both groups, $F_i(R^i + S|N)$, where the random variable $R^i + S$ (i.e., the sum of random net returns and fixed government payments) is income, which is conditioned on the nitrogen level N. The model becomes:

$$\min_{\{N_1,N_2,S_1,S_2\}} A_1S_1 + A_2S_2$$

subject to $N_i \le N_i^*$ $\quad (E_i)$

$$F_1(R^1 + S_1|N_1) \text{ SSD } F_1(R^1 + 0|N_1^0) \qquad (P_1)$$

$$F_2(R^2 + S_2|N_2) \text{ SSD } F_2(R^2 + 0|N_2^0) \qquad (P_2)$$

$$F_1(R^1 + S_1|N_1) \text{ SSD } F_1(R^1 + S_2|N_2) \qquad (I_1)$$

[15]For two cumulative distribution functions, F and G, the alternative F dominates G if the area under F is nowhere more than that of G, and somewhere less than the area under G.

$$F_2(R^2 + S_2|N_2) \text{ SSD } F_2(R^2 + S_1|N_1) \qquad (I_1)$$

$$N_i \geq 0, S_i \geq 0,$$

where A_i is the number of acres in group i. (E_i) are environmental quality constraints, and constraints (P_i) require that the post-policy distributions of net returns dominate the respective pre-policy distributions, ensuring that farmers in both groups have an incentive to participate in the program. The self-selection conditions (I_i) require that the distribution of net returns, if each group chooses its own policy, will dominate the net return distributions had the other group's policy been chosen. Because this formulation of the model involves the conditions for SSD, it cannot be solved analytically, and its properties are difficult to derive. Thus, we will explore its properties through empirical results.

An Empirical Application

The model in this appendix is applied to the stylized empirical example above, which was for central New York. Observations from the Ithaca weather station define the 30-year distribution of weather variables (Table 7), and soil characteristics for each group are determined by a simple average of two representative soils in each group (Table 9). The maximum nitrogen fertilization levels which meet the environmental quality standards (20,0.1), (30,0.1), and (40,0.1) for these representative soils are in Table 10. Using these "environmentally safe" fertilization rates, optimal policies are determined under both the assumption of symmetric and asymmetric information.

Before the optimal policies can be calculated, we must determine the pre-policy fertilization rates for the two groups. Since farmers' utility functions are not specified in the SSD formulation, these nitrogen levels cannot be derived from the maximization of a function. Rather, entire distributions arising from alternative levels of nitrogen must be compared in an iterative fashion. In particular, candidates for optimal pre-policy fertilization levels are those in the *second-degree stochastic efficient* (SSE) set, which are the nitrogen application rates generating distributions of net returns that are not dominated by any other distribution. For the two groups, the SSE fertilization rates were determined using a program in Anderson *et al.* (1977); it seemed reasonable to set the pre-policy fertilization levels at the midpoint of the SSE ranges. The SSE ranges and midpoints are reported, along with the associated means and standard deviations in net returns, in Table C-1. The fertilization rates fall within the range of optimal rates that result from maximizing expected utility in the stylized examples above.

Table C-1. Optimal Pre-Policy Nitrogen Levels.

			Net Returns at SSE Midpoint	
Group	SSE Range (lb/acre)	Midpoint (lb/acre)[a]	Mean	Standard Deviation
1	129-138	133	\$188.35	\$108.35
2	142-160	151	\$121.31	\$52.87

[a] Theses nitrogen levels are N_i^0 in the model.

The Policies

For comparison with the above results, optimal policies are determined under both the assumptions of symmetric and asymmetric information. We first describe the procedures used to calculate policies for each situation, then compare the results obtained here to those in the text, and highlight the implications of this comparison.

Symmetric Information: If information is symmetric between farmers and the government, the constraints (E_i) and (P_i) will bind for i=1,2. At the optimal policies, nitrogen levels will be exactly N_i^*, and compensation payments $\tilde{S}_i$ will be set so that the distribution of net returns under $(N_i^*, \tilde{S}_i)$ *just* dominates the pre-policy distribution from nitrogen level N_i^0. That is, constraints (P_i) must hold at the optimal policies, but government payments are not minimized unless $\tilde{S}_i$ are the smallest payments that satisfy the constraints; a small reduction in the optimal payment $\tilde{S}_i$ would violate the participation condition.

The optimal policies were calculated by an iterative method, using the program in Anderson *et al.* (1977). In this iterative search, post-policy nitrogen levels were fixed at N_i^*, and the compensation payment $\tilde{S}_i$ was varied (in increments of $0.25) to determine the minimum payment that satisfies the participation constraint. At the optimal policy $(N_i^*, \tilde{S}_i)$, the distribution of net returns dominates the pre-policy distribution, but if compensation payments are reduced to $S_i' = \tilde{S}_i - 0.25$, the post-policy distribution would no longer dominate (Table C-2).[16] The third and fourth columns of Table C-2 contain the optimal payments under symmetric information.

Table C-2. Optimal Green Payments.

Safety Level (L*)	Risk Aversion Parameter (a)	Symmetric Information		Asymmetric Information		
		Group 1	Group 2	Group 1	Group 2	Difference
40	0.00	4.34	4.11	8.44	4.11	4.33
40	0.01	5.45	3.01	8.33	3.01	5.32
40	0.03	5.88	1.63	7.29	1.63	5.66
40	SSD	6.75	3.77	10.25	3.77	6.48
30	0.00	9.82	10.36	18.27	10.36	7.91
30	0.01	11.28	8.40	16.94	8.40	8.54
30	0.03	11.84	5.67	14.45	5.67	8.78
30	SSD	13.00	10.02	20.00	10.02	9.98
20	0.00	23.57	25.39	37.32	25.39	11.93
20	0.01	25.39	21.88	34.09	21.88	12.21
20	0.03	26.27	16.62	29.11	16.62	12.49
20	SSD	27.75	25.05	38.50	25.05	13.45

[16]For group 2 producers, optimal payments were directly calculated using the properties of the net return distributions. In particular, for $\tilde{S}_2$ to be optimal, it is necessary and sufficient that $\tilde{S}_2 = E[R^2(N_2^0)] - E[R^2(N_2^*)]$. To see this, first note that the mean of the post policy distribution must be no less than the mean of the pre-policy distribution, if the SSD condition is to be satisfied (Anderson *et al.*, 1977). For sufficiency, recall that nitrogen is a risk increasing input for group 2 and that post-policy nitrogen levels are lower than the initial levels. These two facts imply that the variance in post-policy net returns will be *lower* than the variance in pre-policy returns. If $\tilde{S}_2$ is set so that the mean of both distributions are equal, then the post- policy distribution is a *mean-preserving shrink* of the pre-policy distribution and will dominate by SSD (Mas-Collel *et al.*, 1995).

Asymmetric Information: For this particular example, the nitrogen levels that meet environmental quality standards indicate, by theoretical Propositions 3 and 4, that two separate policies are optimal under asymmetric information. Furthermore, the propositions imply that these optimal policies satisfy the constraints (E_1), (I_1), (E_2), and (P_2) with equality. As in the symmetric information case, post-policy nitrogen levels are set at the environmentally safe levels N_i^*. In this case, however, the compensation payments $\hat{S}_1$ and $\hat{S}_2$ must satisfy a different set of conditions. Compensation levels to both groups must be the smallest payments such that: (1) the distribution of net returns for group 1 producers, under its own policy, dominates the distribution if group 2's policy is chosen (constraint (I_1)); and (2) group 2 producers' post-policy distribution dominates their own pre-policy distribution (constraint (P_2)).

Like the symmetric information payments, optimal payment levels were determined by iteratively comparing distributions of net returns, where each alternative post-policy distribution corresponds to a unique government payment. Unlike the previous case, however, payments to the groups cannot be determined independently, since group 1's payment depends on the payment to group 2. Thus, payments for the two groups were calculated recursively: group 2's optimal payment was determined first (since it does not depend on group 1's payment), and group 1's payment was calculated based on the result. Note that the "asymmetric information payments" to group 2, $\hat{S}_2$, are equal to the "symmetric information payments", $\tilde{S}_2$, since they satisfy exactly the same constraints. Group 1's payments were determined by comparing the distributions under the policy $(N_2^*, \hat{S}_2)$ and $(N_1^*, \hat{S}_1)$, where $\hat{S}_1$ was iteratively varied.

The optimal payments under asymmetric information are in Table C-2, both for the SSD model used here and the expected utility model developed in the text. It should be noted that the optimal polices reported for the SSD model in Table C-2 are not, strictly speaking, solutions to the policy design problem. Under the reported policies, the distribution of net returns for group 2 does not dominate their net return distribution if group 1's policy is chosen. This implies that some risk averse producers in group 2 may choose group 1's policy over their own policy.[17] If this is the case, the environmental quality standards would still not be violated, since group 1's policy corresponds to a lower level of nitrogen than group 2's policy. Nonetheless, if a significant proportion of group 2 producers "defect" to the higher paying policy, the impact on program costs could be substantial.

In comparing the payments in Table C-2 to those obtained from the expected utility model, we observe essentially no change in the qualitative results. The "symmetric information payments" are quite similar across groups, and group 1 producers benefit substantially if information is asymmetric. Quantitatively, the payments to group 2 lie within the range of payments in the expected utility model, as the risk aversion parameter is varied at each safety level. Group 1's optimal payments are somewhat larger in the SSD model than in the expected utility model, uniformly about $1.75 higher than the risk neutral case under asymmetric information.

[17]While group 2's own policy does not dominate group 1's policy, nor does group 1's policy dominate group 2's own policy; the SSD ranking is simply inconclusive for these two distributions. The fact that these alternatives cannot be distinguished by SSD means that some group 2 farmers will choose their own policy, and some will select the one designed for group 1.

Appendix D: Decomposition of Net Return Risk

Both yield risk due to uncertain weather conditions, and price risk due to the randomness in prices are important components of the policy design model. This appendix examines the relative importance of these two sources of risk and their effect on optimal policies. In the first section, we calculate optimal policies, for the stylized empirical example above, under three alternative assumptions about randomness in weather and prices. The first assumption is the base case where both prices and weather conditions are assumed random. The second and third assumptions are, respectively, that either weather conditions or prices are deterministic. The differences in optimal policies arising from these alternative assumptions are discussed, and the implications of ignoring either price or weather uncertainty are highlighted. In the second section, the variance in net returns is decomposed into price and yield components, using an asymptotic approximation. This decomposition makes explicit the contribution of each of the two sources of uncertainty

Changes in Optimal Polices from Alternative Sources of Risk

The stylized empirical model presented above is solved two additional times, once with prices fixed at their mean levels over the 30 years but allowing weather conditions to vary according to the historical observations, and once with prices varying according to the historical observations over the 30 years but with weather conditions fixed at their 30 year mean. The optimal policies for symmetric and asymmetric information under these assumptions are reported in Tables D-1 and D-2.

If weather conditions are assumed fixed rather than random, the production process is deterministic; the amount of corn silage produced from a given level of nitrogen is known with certainty. Net returns are still random because of price uncertainty, but the marginal effects of nitrogen on yield risk, which is crucial in determining relative payments for the two groups, is ignored. In particular, note that the optimal payments to group 1 under symmetric information (Table D-1) will, like the payments to group 2, decrease with higher degrees of risk aversion. This directly

Table D-1. Optimal Green Payments Under Symmetric Information.

Safety Level (L^*)	Risk Aversion Parameter (a)	Random Weather, Random Prices		Fixed Weather, Random Prices		Random Weather, Fixed Prices	
		Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
40	0.00	4.34	4.11	4.37	4.15	4.37	4.15
40	0.01	5.45	3.01	3.65	3.45	7.00	3.53
40	0.03	5.88	1.63	2.99	2.72	9.50	2.45
30	0.00	9.82	10.36	9.87	10.43	9.87	10.43
30	0.01	11.28	8.40	8.55	9.10	13.69	9.51
30	0.03	11.84	5.67	7.22	7.58	17.11	7.78
20	0.00	23.57	25.39	23.66	25.50	23.66	25.50
20	0.01	25.39	21.88	21.17	22.94	29.18	24.21
20	0.03	26.27	16.62	18.33	19.77	33.88	21.71

contradicts the result above: under symmetric information, the payments to group 1 should *increase* with the degree of risk aversion because nitrogen fertilizer reduces yield risk.[18] In the case where information is asymmetric (Table D-2), ignoring weather variability causes the difference in payments, $\hat{S}_1 - \hat{S}_2$, to increase with the risk aversion level, again contradicting the earlier result. In sum, ignoring the variability in weather conditions ignores out important information in determining optimal "green" payments and could have important implications for the size of any windfall gains to either group or to overall program costs.

Consider now the case where weather conditions vary over the 30 years, but prices are held fixed at their mean levels. Because yield is assumed random, the important marginal risk effects of nitrogen are still considered. Thus, the qualitative

[18]This is because nitrogen must necessarily be reduced to satisfy environmental quality standards, and lower levels of N imply an increase variability of yield. Risk averters therefore require larger compensation to accept this added risk.

Table D-2. Optimal Green Payments Under Asymmetric Information.

Safety Level (L^*)	Risk Aversion Parameter (a)	Random Weather, Random Prices			Fixed Weather, Random Prices			Random Weather, Fixed Prices		
		Group 1	Group 2	Difference	Group 1	Group 2	Difference	Group 1	Group 2	Difference
40	0.00	8.44	4.11	4.33	8.52	4.15	4.37	8.52	4.15	4.37
40	0.01	8.33	3.01	5.32	7.09	3.45	3.64	10.16	3.53	6.63
40	0.03	7.29	1.63	5.66	5.69	2.72	2.97	10.86	2.45	8.41
30	0.00	18.27	10.36	7.91	18.37	10.43	7.94	18.37	10.43	7.94
30	0.01	16.94	8.40	8.54	16.12	9.10	7.02	19.43	9.51	9.92
30	0.03	14.45	5.67	8.78	13.61	7.58	6.03	19.23	7.78	11.45
20	0.00	37.32	25.39	11.93	37.44	25.50	11.94	37.32	25.50	11.82
20	0.01	34.09	21.88	12.21	33.91	22.94	10.97	37.53	24.21	13.32
20	0.03	29.11	16.62	12.49	29.44	19.77	9.67	36.09	21.71	14.38

results are consistent with the original payments where all factors are random (Tables D-1 and D-2). The influence of price variability appears to be in the *magnitude* of the estimated payments to farmers; "green" payments for fixed prices are larger than when prices are random, particularly for group 1. This suggests that price variability lessens the *change* in variability of net returns in response to *changes* in nitrogen fertilizer. When prices are assumed fixed, the more dramatic changes in yield variability generate a need for larger compensation payments, especially for risk averse producers in group 1. This phenomenon is explained in greater detail in the next section, where the variance in net returns is decomposed into price and yield components at various nitrogen rates. Variability in prices has an important influence on the optimal payments for both groups, and significantly alters results if ignored.

Decomposition of Net Return Variance

This section describes the decomposition of net return variance into price and yield components. The variance of net returns is

(13) $$\mathrm{var}(R_i) = \mathrm{var}(py^i) - 2N_i \,\mathrm{cov}(py^i, r) + N_i^2 \,\mathrm{var}(r),$$

which consists of three terms: the variance of revenue, the covariance of revenue and cost, and the variance of cost. Using the Kendall-Stuart asymptotic approximation, the variance of revenue can be written:

(14) $$\mathrm{var}(py^i) = E^2(y^i)\,\mathrm{var}(p) + 2E(y^i)E(p)\,\mathrm{cov}(y^i, p) + E^2(p)\,\mathrm{var}(y^i) + \delta_{\mathrm{var}},$$

where the term δ_{var} involves higher order terms (Burt and Finley, 1968). The covariance of revenue and cost can be written:

(15) $$-2N_i \,\mathrm{cov}(py^i, r) = -2N_i[E(p)\,\mathrm{cov}(y^i, r) + E(y^i)\,\mathrm{cov}(p, r) + \delta_{\mathrm{cov}}],$$

where δ_{cov} involves higher order terms (Bohrnstedt and Goldberger, 1969). If the remainder terms δ_{var} and δ_{cov} are small, equations (14) and (15) will provide a useful decomposition of the yield and price effects on the first two terms in (13).

Table D-3. Decomposition of Variance in Net Returns.[a]

Nitrogen Level	Description	Variance of Revenues: Price Variance	Variance of Revenues: Price-Yield Covar.	Variance of Revenues: Yield Variance	Covar. Between Revenue and Cost	Variance of Cost	Approx. Net Return Variance	Actual Net Return Variance	Relative Error
Group 1:									
133	N_1^0 for a = 0.01	3406.77	993.26	6791.47	-55.53	100.98	11236.95	11735.73	-4.25%
		0.303	0.088	0.604	-0.005	0.009			
99	N_1^* for L^*=40	3139.59	987.47	7462.94	-20.79	55.73	11624.94	12173.44	-4.51%
		0.270	0.085	0.642	-0.002	0.005			
84	N_1^* for L^*=30	2967.90	974.54	7767.02	-7.91	40.12	11741.66	12306.66	-4.59%
		0.253	0.083	0.661	-0.001	0.003			
63	N_1^* for L^*=20	2679.06	945.13	8203.14	5.92	22.57	11855.81	12435.52	-4.66%
		0.226	0.080	0.692	0.000	0.002			
Group 2:									
156	N_2^0 for a = 0.01	2489.31	101.72	474.48	-368.87	138.99	2835.62	2832.32	0.12%
		0.878	0.036	0.167	-0.130	0.049			
128	N_2^* for L^*=40	2292.65	121.62	366.31	-279.62	93.15	2594.12	2610.70	-0.64%
		0.884	0.047	0.141	-0.108	0.036			
109	N_2^* for L^*=30	2117.29	132.34	306.21	-222.64	67.55	2400.74	2429.84	-1.20%
		0.882	0.055	0.128	-0.093	0.028			
80	N_2^* for L^*=20	1794.33	143.55	233.64	-143.00	36.39	2064.91	2111.27	-2.20%
		0.869	0.070	0.113	-0.069	0.018			

[a] Numbers beneath the variances are the proportion of (approximated) net return variance attributable to the factor in question.

The results of this decomposition, at the net returns for selected nitrogen fertilization rates, are in Table D-3. The third, fourth, and fifth columns in the table correspond to the terms in equation (14); they decompose the variance of revenue into price variance, price-yield covariance, and yield variance effects. The sixth and seventh columns in Table D-3 correspond to the covariance between revenue and cost (equation 15), and the variance in cost (the third term in equation 13), respectively. Before interpreting the components, we first note that the decomposition was relatively accurate; the relative errors were 4.5% and 0.4% for groups 1 and 2, respectively.

For both groups, the variance of revenue is overwhelmingly the most important of the three effects on the variance of net returns, generally representing over 90% of the approximated net return variance. In determining the variance of revenues, both yield and price variability are significant determinants for both groups. For group 1, yield variance increases as nitrogen fertilizer is reduced, owing to the risk-reducing effect of nitrogen. Furthermore, the *proportion* of net return variance attributable to yield increases as fertilizer is reduced. This implies that if price variability is ignored, relative changes in net return variability due to changes in nitrogen would be overstated. For group 2, price variability is the single most important component of net return variance, more than five times as large as the variability due to yield. Because nitrogen is a risk-increasing input for group 2, yield variance declines as fertilization rates are reduced.

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