Working Papers Series

WORKING PAPER WP96/05 January 1996

CROP PRICE AND RISK EFFECTS ON FARMER ABATEMENT COSTS OF REDUCING NITRATE LEVELS IN GROUNDWATER IMPOSED BY ENVIRONMENTAL POLICY INSTRUMENTS

by

Alfons Weersink
Charray Dutka
Michael Goss

UNIVERSITY of GUELPH

Department of Agricultural Economics and Business

University of Guelph
Guelph, Ontario
Canada
N1G 2W1

CROP PRICE AND RISK EFFECTS ON FARMER ABATEMENT COSTS OF REDUCING NITRATE LEVELS IN GROUNDWATER IMPOSED BY ENVIRONMENTAL POLICY INSTRUMENTS

by

Alfons Weersink
Charray Dutka
Michael Goss

WORKING PAPER WP96/05
Department of Agricultural Economics and Business
University of Guelph
Guelph, Ontario

January 1996

The authors are an associate professor and former graduate research assistant, Department of Agricultural Economics and Business, and Professor of Land Stewardship, Centre for Land and Water Stewardship, University of Guelph.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of the Eco-Research Program of the Tri-Council of Canada, through the Agroecosystem Health Project at the University of Guelph, and the University-Based Research Program on Economic Instruments through Environment Canada.

Crop Price and Risk Effects on Farmer Abatement Costs of Reducing Nitrate Levels in Groundwater Imposed by Environmental Policy Instruments

Introduction

Nitrate (NO_3^-) contamination originating from agriculture is a major source of groundwater pollution in rural areas of Ontario. In the winter of 1991/92, the Ontario Farm Groundwater Quality Survey found that 13% of the 1300 domestic farm wells tested had NO_3^- concentrations above the maximum acceptable concentration in Ontario of 10 mg NO_3^--NL^{-1} (Rudolph *et al.* 1992). The survey was repeated in the summer of 1992 to verify the previous study's results and found that 14% of wells sampled for a second time contained NO_3^- concentrations above the Ontario drinking water quality objective (Rudolph and Goss 1993). Contamination of groundwater by NO_3^- can have serious impacts on human and environmental health. High NO_3^- levels in groundwater have been linked to methaemoglobinaemia, or 'blue baby syndrome', in bottle-fed infants and young animals (Addiscott *et al.* 1991). Other suspected, but unproven, human health effects linked to NO_3^- include birth defects, gastric cancer, and nervous system impairment. Environmental health effects stemming from excessive nitrate levels are associated with eutrophication of water systems thereby encouraging excess plant growth and declining aquatic life in rivers and lakes.

Because the current property rights structure designates groundwater an open access resource, producers are not required to pay the full cost of environmental pollution caused by their agricultural practices. With no possible market solution under the present structure of property rights, government intervention is required to regulate use of the groundwater resource, either in the form of redesigning the current property rights structure to allow for a private market solution or implementing policy instruments that will emulate the desired property rights structure. Recent books edited by Russel and Shogren (1993) and Dosi and Tomasi (1994) present a number of theoretical papers that focus on the design of such pollution control instruments in view of the information problems concerning observing and monitoring emissions and the uncertainty surrounding the social and physical system associated with pollutants generated by agricultural production. Empirical evaluations of alternative instruments specifically in terms of reducing nitrate leaching include McSweeny and Shortle (1989), Hanley (1990), Heatwole *et al.* (1990), Johnson *et al.* (1991), Taylor *et al.* (1992), Wossink *et al.* (1992), Huang and Latin (1993), Schnitkey and Miranda (1993), Mapp *et al.* (1994), Moxey and White (1994), Pan and Hodge (1994), Swinton and Clark (1994), Giraldez and Fox (1995), Helfand and House (1995) and Teague *et al.* (1995). All these theoretical and empirical studies ignore the effects of changes in crop prices on the farm abatement costs of responding to the alternative instruments. An exception is the study at the aggregate level by Wu and Segerson (1995) who examine the impact of alternative policies including farm support programs on the acreage response of highly polluting land rather than on farm abatement costs directly.

Crop prices, however, play a significant role in determining the compliance costs of nitrate regulations and even the need for such regulations. Crop prices can influence the intensity of input use and subsequently residual pollutants from those inputs (Just and Antle 1990). While applying excess nitrogen (N) on crops is indeed a source of potential NO_3^- leaching into groundwater, which can be reduced through measures such as soil-N testing (Bosch *et al* (1995) and Musser *et al* (1995)) or residual nitrogen taxes (Huang and LeBlanc (1994)), another major source is made at the extensive margin in terms of crop choice. Nitrate levels in groundwater generally increase with the proportion of crops having a large requirement for nitrogen in rotation. In 1993, Ontario farmers planted a record amount of soybeans in response to a corn-soybean price ratio of approximately 0.43. The fall of 1995 has seen prices for corn almost double from their 1993 average and the corn-soy price ratio rise to approximately 0.5. Thus, cropping pattern in the next year is likely to shift to more N-requiring corn and away from N-fixing soybeans with a subsequent increase in the potential for NO_3^- leaching.

The purpose of this paper is to determine the crop price and risk effects on the on-farm abatement costs of four alternative environmental policy instruments designed to encourage producers to reduce nitrate levels in groundwater. Informational requirements and asymmetries along with the stochastic nature of the nitrate problem are ignored in the analysis of the alternative instruments. Instead, the focus is on highlighting the importance of price changes on compliance costs which thus has impacts on design issues of pollution control instruments such as political feasibility and equity considerations. The paper proceeds by presenting a theoretical model of nitrate abatement. On-farm abatement costs for four alternative instruments are assessed, and the effects of price and risk on these costs noted. An empirical model of a representative cash crop farm in southwestern Ontario is then developed. Risk aversion and a physical accounting of nitrogen movement are incorporated into the farm-scale model. Results of the empirical model are then presented with special emphasis on comparing the abatement costs of meeting the drinking water guideline for nitrate under alternative scenarios for crop prices and risk aversion. The final section discusses the policy implications.

This research also discusses what implications that agroecosystem health management has on determining the cost to producers of environmental policy instruments. The overall effects of nitrogen use on farm incomes and groundwater quality can be assessed in terms of an agroecosystem health approach. Agroecosystems are defined as "regionally defined entities, managed for the purpose of producing food, fibre, and other agricultural products, comprised of domesticated plants and animals, biotic and abiotic elements of underlying soils, drainage networks, and adjacent areas that support natural vegetation and wildlife" (Waltner-Toews, 1993). This definition assumes agroecosystems include people, both as producers and consumers, thereby having economic, social health, and environmental dimensions. Numerous indicators can be developed for each dimension that reflect health in the economic, environmental, and social health dimensions, and in combination with indicators from other dimensions, reflect the overall health of the agroecosystem. Following the holistic research methodology, as implied by agroecosystem health management, this research identifies the relationship between two indicators of agroecosystem health; economic health (farm profits) and environmental health (groundwater quality). Furthermore, this research identifies the impacts of agricultural support and environmental policies on the relationship between economic and environmental health. By determining the relationship, policy-makers are able to determine, ex ante, the impacts of policy instruments on agroecosystem health and revise the policy instruments to minimize or eliminate unwanted impacts.

Theoretical Model of Nitrate Abatement

To illustrate the effects of output prices on environmental regulatory policy, we begin with the standard Baumol and Oates (1988) type of framework. The producer is assumed to maximize profits through the selection of management choices, X. Maximum profit, $\pi(X)$, is assumed to be a concave function of these practices. In the absence of regulations on the choices, the producer will optimize by equating marginal profit across activities. However, the activities generate emissions, L, according to the function $L=L(X)$ that are a burden to individuals other than the producer. The cost of this negative externality can be represented by the damage function $D(L)=D(L(X))$. Optimal management choices by the producer for all concerned would involve maximizing net benefits which is the individual profit function less the damage function. In doing so, marginal profits across activities would be equated to marginal damages rather than zero as in the absence of any constraints. Effective environmental policies involve determining the incentive or regulation so that the firm internalizes the marginal damage cost of their actions.

Relevant management choices for reducing groundwater nitrate levels largely involve crop selection. The lumpy nature of the abatement technology can be denoted by expressing the management practice variable X as a vector of discrete choices representing crop rotations rather than a continuous variable. An element of X, X_i, is the area (hectares) allocated to rotation i with $i=1,2,\ldots,n$. The total amount of hectares that can be sown to the n rotations is limited to the individual producer at $\overline{X}$, . $\overline{X}=\sum_{i=1}^{n}X_i$.

The decision on crop selection determines the total amount of nitrogen applied, N. The inverse production relationship, $N=N(X)$., is assumed to be linear, $N=\sum_{i=1}^{n}a_iX_i$ where a_i represents the nitrogen application rate for rotation i. The linear functional form assumes that the application rates are not affected by area planted and relative prices. Rates do vary, particularly with nitrogen prices, but the analysis to follow shows that this effect on leaching levels is overwhelmed by rotational shifts from a similar change in crop prices.

With these assumed production relationships, the management problem for the individual producer can be summarized through the following Lagrangean, ζ;

$$\zeta(X,\mu) = \underset{X,\mu}{Max} \sum_{i=1}^{n} (p_i X_i - p_N a_i X_i) + \mu(\overline{X} - \sum_{i=1}^{n} X_i) \tag{1}$$

where p_i is the net returns excluding nitrogen cost per ha for rotation i, p_N is the unit price of nitrogen fertilizer, and μ is the Lagrange multiplier or the value of an extra hectare to the producer. The Kuhn-Tucker conditions for this simple problem indicate, that in the absence of environmental policies, the producer will plant all his farm to the rotation with the highest net returns including fertilizer costs. To define a solution, it is assumed that rotations are ordered on the basis of their nitrogen intensity with $i=1$ being the most intensive (i.e. continuous corn) and $i=n$ representing the least intensive (i.e. continuous soybeans) so that $a_1 > a_2 > \ldots > a_n$. For the present time, let us assume that net returns excluding and including fertilizer costs for the rotations are also in descending order; $p_1 > p_2 > \ldots > p_n$ and $(p_1 - p_N a_1) > (p_2 - p_N a_2) > \ldots > (p_n - p_N a_n)$. In this scenario, the entire farm will be planted to rotation 1 ($X_1 = \overline{X},\ X_j = 0,\ j = 2,3,\ldots,n$).

The optimal rotation chosen by the producer results in nitrate leaching levels of $L_1 = L(X_1)$) These residuals impose damages of the value $D(L(X_1)))$ to affected water users. Given that the nitrogen application rates are assumed fixed for each crop, the relationship between leachate levels and management practices can also be assumed to be linear, $L = L(X) = \sum_{i=1}^{n} l_i X_i$ where l_i is the nitrates leached per hectare for rotation i.

The optimal rotation for all concerned would account for the nitrate damages to water users and be the solution to the following net benefit problem;

$$\zeta'(X,\mu') = \underset{X,\mu}{Max} \sum_{i=1}^{n} (p_i X_i - p_N a_i X_i) - D(L(X)) + \mu'(\overline{X} - \sum_{i=1}^{n} X_i) \tag{2}$$

where μ' is the value of an extra hectare of land to the producer accounting for all benefits and costs including environmental costs. Provided these damages are not excessive, the producer will still plant all the farm to one rotation which will be the one for which net marginal profits $(p_i - p_N a_i)$ less marginal damages $(D_L L_X)$ are greatest. Note that assessing marginal damages from a management choice involves determining the marginal impact of rotational choices on leaching levels (L_X) and the marginal cost of those levels (D_L). Let us assume that rotation 2 maximizes net benefits. Thus, $(p_2 - p_N a_2 - D_L l_2) > (p_1 - p_N a_1 - D_L l_1)$ but $(p_1 - p_N a_1) > (p_2 - p_N a_2)$. The socially optimal nitrate level associated with this rotation is L_2. The task for the government is to determine the instruments by which the farmer switches rotations from X_1 to X_2.

Abatement Costs under Alternative Instruments

The instruments available to the government agency can be distinguished by the base on which they are applied, design (practices) or performance (emissions) and the form of inducement, regulations or incentives.[1] Each will be considered in turn. The analysis proceeds along the lines of Griffin and Bromley (1982) in the sense that returns and emissions are known. As a result, the four strategies assessed below all are equally efficient in achieving least-cost pollution control. The efficiency result across strategies does not hold if differential information about the costs of changes in farm practices exists or if emissions are stochastic (Shortle and Dunn 1986). In addition, a single effluent source is assumed rather than the mutliple, heterogeneous sources considered by Helfand and House (1995). Instead, the focus here is on abatement costs and the influence of price changes rather than on other elements of efficient instrument design such as enforceability and targetability (Braden and Segerson 1993).

One means by which the government could achieve the desired water quality objective is to restrict the amount of nitrogen applied $(\overline{N})$. In order for nitrate to be no greater than L_2, total nitrogen for the farm must be set at the level required for rotation 2, $\overline{N} = a_2 X_2$. The restriction does not allow the producer to grow the rotation chosen under the private solution without any

---

[1] The number of regulatory instruments to achieve the social optimum environmental target varies with the number of pollution sources and inputs that affect the pollutant levels (Griffin and Bromley 1982). Helfand and House (1995) determine the welfare costs of reducing nonpoint nitrate levels with second-best (uniform) regulatory instruments under heterogeneous conditions.

government intervention, $\overline{N} < a_1X_1$. The per hectare abatement costs to the producer represent the difference in profits including fertilizer costs between the two rotations,

$$[(p_1 - p_Na_1) - (p_2 - p_Na_2)]. \tag{3}$$

Note that if the total nitrogen restriction fell between the amount necessary for the two rotations, $a_2X_2 < \overline{N} < a_1X_1$, then the producer will likely grow a portion of both rotations rather than use all available fertilizer to grow as much of the more profitable X_1 as possible and leave the remaining land idle $(\overline{X} - (\overline{N}/a_1))$. The decision depends on relative profits for the management choices. Also note that abatement costs given by (3) would be the same if the restriction was placed on rotational choice rather than on the inputs associated with those rotations. The agency could more easily determine if the producers are abiding to a restriction on outputs than a restriction on total nitrogen applied.

Rather than command the producer to follow certain practices that are associated with reducing nitrates to the desired levels, the government could also impose a tax on nitrogen use.[1] The producer will grow all rotation 2 if the profits less taxes are greater than associated returns for the private solution in the absence of taxes, $[p_2 - (p_N + t_N)a_2] > [(p_1 - (p_N + t_N)a_1]$ where t_N is the per unit nitrogen tax. The tax rate that will induce the switch in rotations is slightly greater than $[(p_1 - p_Na_1) - (p_2 - p_Na_2)]/(a_1 - a_2)$ This value representing the difference in profits divided by the difference in application rates ($/kg) is also the shadow value on the nitrogen restriction if it is set at the level necessary to produce rotation 2. Abatement costs associated with the nitrogen tax will be the difference between the returns of the private and social solution,

$$[(p_1 - p_Na_1) - (p_2 - p_Na_2)] + \{\frac{(p_1 - p_Na_1) - (p_2 - p_Na_2)}{(a_1 - a_2)}\}a_2 \tag{4}$$

The first term represents the loss in profits from growing rotation 2 as opposed to rotation 1 and the second term represents the tax paid on the nitrogen used in rotation 2.

The government could also choose to apply the regulation or incentive to the observed emissions from the producer's practices instead of indirectly attempting to control emissions

---

[1] Taxes on fertilizer have been applied in some US states and European countries but generally as a source of revenue for promoting the adoption of farm practices associated with lower nitrate leaching levels (OECD 1989, Ribaudo and Woo 1991).

through instruments applied to the management choices. A performance-based regulation could involve restricting leaching levels to be no greater than the environmental objective of L_2. Since this objective could only be achieved by growing rotation 2, abatement costs per hectare for this performance standard would be the difference in profits between the private and social solution,

$$(5) \qquad [(p_1 - p_N a_1) - (p_2 - p_N a_2)].$$

Thus, abatement costs for the performance (5) and design (3) based standards are the same.

An incentive type of performance-based instruments would be a tax on the level of nitrate found in the groundwater. In order to attain the desired level of L_2, the tax rate must be set at the marginal environmental cost of the nitrates, D_L. A Pigovian tax of this level results in an abatement cost to the producer of

$$(6) \qquad [(p_1 - p_N a_1) - (p_2 - p_N a_2)] + D_L l_2.$$

The term in brackets represents the difference in net profits for the producer between the rotation chosen without the tax and the rotation chosen with the tax. The other term is the taxes paid. Note that total abatement costs must be less than the tax burden $D_L l_1$ otherwise rotation 1 would still be the optimal private solution.

Effects of Price Changes on Abatement Costs

On-farm abatement costs associated with the four environmental instruments (equations (3)-(6)) vary directly with net returns of the management choices. Increases in net returns for the rotation under the private (social) solution increase (decrease) abatement costs. To show the effects of price changes in abatement costs, net returns for rotation i can be decomposed into $NR_i = (p_i - p_N a_i) = (p_c^i Y_c^i - VC_i - p_N a_i)$, where p_c^i is the price of the crop(s) in rotation i, Y_c^i is the yield of that crop, and VC_i is the variable costs other than nitrogen for rotation i. In the case of standards, increases in crop price for the N-intensive crop increase per hectare abatement costs by yield (Y_c) while increases in N price increase those costs by the difference in N application rates $(a_1 - a_2)$. While the signs are the same, the relative effects differ significantly and depend upon the share due to the differences gross revenues and nitrogen expenses represent of net returns.

Using a continuous corn rotation as an example with average prices for the last twenty years, a 10% increase in corn price increases net returns for that rotation by 20%. In contrast, a 10% increase in N price decreases net returns by approximately 2%. A similar effect on net returns would have been observed if N application rates had been increased by 10%.[1] Thus, a given percentage change in crop price has a much larger impact than a similar change in nitrogen price on the management choice and consequently on potential nitrate leaching. It also implies that an incentive instrument applied to nitrogen must be relatively large in order to induce the desired rotational shifts.

Effects of Risk Aversion[2]

Risk aversion can increase or decrease abatement costs depending upon the relative variability of the management choices. To illustrate, let us assume the risk averse producer maximizes expected utility which is characterized in terms of expected values and variance of net returns. Thus, the producer optimizes by selecting the management choice that maximizes certainty equivalent income subject to the land constraint,

$$\zeta^R(X,\mu^R)=\underset{X,\mu^R}{Max}\{\sum_{i=1}^{n}(p_i-p_N a_i)X_i-\frac{\lambda}{2}(\sum_{j=1}^{n}cov(X_i,X_j))+\mu^R(\overline{X}-\sum_{i=1}^{n}X_i). \tag{7}$$

where λ is the Pratt-Arrow coefficient of absolute risk aversion, $cov(X_i,X_j)$ is the covariance of returns between management choices *i* and *j*, and superscript *R* denotes the problem is for a risk averse producer. The optimal rotation will be the one that maximizes the difference between expected returns and the risk premium which depends upon the producer's level of risk aversion (λ) and on the level of risk ($cov(X_i,X_j)$). For example, if we focus only on the private solution under risk neutrality (X_1) and the social solution (X_2), the respective Kuhn-Tucker first order conditions for these management choices are;

$$[(p_1-p_N a_1)-\lambda(\mathrm{var}(X_1)+\mathrm{cov}(X_1,X_2))]X_1=0,\ [(p_2-p_N a_2)-\lambda(\mathrm{var}(X_2)+\mathrm{cov}(X_1,X_2))]X_2=0.$$

---

[1] Yield is assumed fixed under both the decrease in nitrogen price and an increase in the application rate.

[2] Risk aversion is analyzed in terms of its effect on rotational choice. Babcock (1992) and Choi and Feinerman (1995) show that optimal fertilizer rates increase with uncertainty about weather or about soil nitrogen levels.

Rotation 1 will still be the private solution provided that $(NR_1 - NR_2) > \lambda(\text{var}(X_1) - \text{var}(X_2))$. In this case, abatement costs for the design and performance standards are unaffected by risk aversion and will still be represented by the difference in net returns between the two rotations (equations 3 and 5). However, abatement costs associated with the incentive schemes are inversely related to the size of the difference in risk premiums assuming that $\text{var}(X_1) > \text{var}(X_2)$. The tax required to induce the shift to rotation 2 decreases the greater the relative variability associated with rotation 1 or the greater the degree of risk aversion exhibited by the producer. On-farm abatement costs are thereby reduced. Indeed, if the level of risk of the socially desired rotation 2 is sufficiently less than that of the nitrogen intensive rotation, rotation 2 becomes both the private and social solution. Consequently, abatement costs are zero regardless of the instrument.

Empirical Economic Model for Nitrate Abatement

On-farm abatement costs of a representative cash crop farm in southwestern Ontario are examined under alternative price and risk scenarios for four policy instruments designed to reduce groundwater nitrate concentrations. The 162 hectare (400 acre) representative farm is assumed to consist of sandy-loam soil and grows grain corn, soybeans and soft white winter wheat. Seven rotations of these three crops are considered; continuous corn, corn-soybeans, corn-wheat, corn-soybeans-wheat, corn-soybeans-wheat/clover, corn-corn-soybeans-wheat/clover, and corn-soybeans-wheat-soybeans. Red clover is planted in the spring as a cover crop and ploughed down in the fall when the winter wheat crop is planted. It is assumed that the crops in each rotation are planted equally. For example, in the corn-soybeans-wheat-soybeans rotation the 162 hectare farm is divided into 4 equal areas with 81 hectares planted to soybeans and the remaining 81 hectares split evenly between corn and wheat.

The theoretical model of the risk averse producer developed in the previous section can be summarized as;

$$(8) \qquad \underset{X}{Maximize}\, E(U) = \sum_{i=1}^{7}\{(p_i - p_N a_i)X_i - \frac{\lambda}{2}(\sum_{j=1}^{7}\text{cov}(X_i, X_j)\}$$

subject to

$$\sum_{i=1}^{7} X_i \le \overline{X},$$

$$\sum_{i=1}^{7} a_i X_i \le \overline{N},$$

$$\sum_{i=1}^{7} l_i X_i \le \overline{L},$$

$$X_i \ge 0, \ \forall \ i$$

where *E(U)* is expected utility which is the difference between net returns and the risk premium. The constraints on the decision variable deal respectively with land availability, nitrogen application levels, leaching losses, and non-negativity. Each component of the model is described below.

Net returns were calculated for three different crop pricing scenarios. The first scenario assumed the producer faced average market prices for the period 1975 to 1993 expressed in 1993 dollars using the Farm Product Price Index. Average returns were also determined for the 1975-1993 period under the assumptions that the Gross Revenue Insurance Program (GRIP) was in place. GRIP is the present agricultural support program for Ontario crop farmers. GRIP allows producers to insure a target revenue per hectare for each crop grown. GRIP payouts are based on 80% of the current crop yield multiplied by the difference between the 15 year moving average of market prices lagged 3 years and the current market price. The final scenario used the effective 1993 price which is defined as the maximum of the market or GRIP price for that year. A 5 year moving average of yields was used to determine average gross returns under the market and GRIP price scenarios (OMAF, various issues). Effective gross returns in 1993 were found by multiplying the effective prices by projected crop yields which are assumed to be an average of the previous 5 years. Gross revenues for each of the three price scenarios are calculated for each rotation by summing the gross revenue for each crop and then dividing by the number of crops in the rotation to obtain average returns on a per hectare basis. Resulting gross returns for the seven rotations are listed in Table 1.

Variance-covariance matrices for returns among the seven rotations are calculated for each of the three price scenarios. These matrices are calculated using the appropriate prices under each scenario, converted to 1993 dollars, over the years 1975 through 1993. The variability of each rotation's revenue is indicated by the coefficient of variation in Table 1.

Variable costs given in Table 1 are based on the projected 1994 average Ontario farm variable costs obtained from 1993 summer and fall surveys for the three crops in all rotations (OMAF, 1994a). The \$35.75 ha^{-1} seed price for red clover, which is spread with spring fertilizer on wheat, is incorporated into wheat production costs when this cover crop is used in the rotation. Variable costs are a weighted average for each rotation with the weights determined by the proportion of each crop in the rotation.

Variable costs in Table 1 do not include nitrogen fertilizer expenses. Nitrogen costs are separated out so the effects of a taxation policy on nitrogen can be examined later. Nitrogen fertilizer application levels for each crop are based on provincial recommendations. Corn is assumed to be side-dressed with anhydrous ammonia at a rate of 145 kg of actual N ha^{-1} since this method generally results in a slight yield advantage (3-5%) over preplanted fertilizer applications of ammonium nitrate and urea in southwestern Ontario (OMAFb, 1994). Ammonium nitrate is assumed to be applied on winter wheat at a rate of 85 kg of actual N ha^{-1}, while no fertilizer is applied to the soybean crops. Nitrogen application to wheat is reduced if red clover is undersown. The N reduction of 4 kg ha^{-1}, reducing application to 81 kg ha^{-1}, is based on the level of N fixation by the red clover crop transferred to the wheat crop (Barry *et al.* 1993). The N application to corn, when following soybeans in rotation, is reduced by 40 kg ha^{-1} to 105 kg ha^{-1} (OMAF, 1994b). Crop yield is not assumed to increase as a result of including red clover and soybean crops in the rotation. The positive effects of these crops in a rotation stem exclusively from the reduction in N fertilizer costs. Total N fertilizer application levels per hectare for each of the seven rotations are calculated by taking N applications for each crop in the rotation and dividing this sum by the number of crops in the rotation. Application level is multiplied by the N price of \$0.55 kg^{-1} to obtain N costs for each rotation.

The extent of leaching from management choices depends on the nitrate leaching coefficients for each crop rotation (Table 1). The leaching coefficients were estimated using the nitrogen budget developed by Barry *et al.* (1993) which calculates nitrogen balances for individual farms. Using the N potentially available for leaching and the average groundwater recharge, the model is able to predict the maximum NO_3^--N concentrations in the groundwater for a representative farm for the period equal to the duration of one rotation of a cropping system. For continuous corn this period will be 1 year whereas it will be 3 years for a corn-soybean-wheat rotation. The budgeting program assumes the annual groundwater recharge rate for Ontario is 160 mm year^{-1}. It assumes that there is a constant recharge of the groundwater equal to the discharge rate. Consequently, denitrification is not a significant factor in the nitrogen budget of cash-crop farms. In addition, the program assumes that continued agricultural practices result in stabilized N levels, such that the soil organic matter is the same at the start and end of a rotation. This assumption implies that when averaged over the course of the rotation, the mineralization of organic-N equals the rate of immobilization of mineral-N. Finally, the program also assumes that the volatilization of ammonia from ammoniacal fertilizer is equal to zero. Consequently, the model assumes that all excess N will be lost by leaching to the groundwater. Thus, excess nitrogen or potential leaching losses, expressed in units of kg ha^{-1} yr^{-1}, are the difference between N inputs (seed, fertilizer, symbiotic and non-symbiotic N fixation, and atmospheric deposition) and N outputs, which for cash crop farm with crop residues remainin gon the field is equal to the N removed in harvested crops. A constant value of 18 kgN ha^{-1} yr^{-1} was used for the atmospheric deposition, and non-symbiotic N-fixation was assumed to be 5 kgN ha^{-1} yr^{-1} (Barry *et al.* 1993). Symbiotic N-fixation was calculated from a regression equation relating the N-fixation and crop yield (Barry *et al.* 1993).

Results

Base Scenarios

The empirical economic model was run under three pricing scenarios; average market and GRIP prices and 1993 effective prices, and with four alternative risk aversion levels.

Environmental policies, such as restrictions on nitrogen application and nitrate leaching levels, were not considered in these base scenarios . Crop choices from the optimal rotations selected by the base model along with the resulting producer net income and predicted nitrate concentrations draining to the groundwater are presented in Table 2.

A risk neutral producer facing prices that are the average of the past 20 year market prices would chose to plant all 162 hectares in rotation 2 (corn and soybeans). As risk aversion initially increases, land is switched from corn to wheat due to the lower absolute variance of wheat revenue. At moderate levels of risk aversion, only rotation 7 (corn-soybean-wheat-soybean) is planted. Land is taken out of production at an increasing rate from this rotation with further increases in the level of risk aversion.

A risk neutral producer facing average GRIP prices if the program had been in place for the last 20 years would grow continuous corn (rotation 1). The optimal rotation involves splitting available land between corn and soybeans (rotation 2) when risk averse behaviour is considered. Increases in risk aversion have no effect on this optimal rotational choice except at extreme (unreported) levels of risk aversion when land is taken out of production.

Assuming that the effective price the producer faces is the 1993 maximum of the market or GRIP price, rotation 2 is chosen under risk neutrality. Increases in risk aversion lead to a shift into rotation 7 which replaces one-quarter of the planted corn into rotation 2 with wheat due to the difference in the variability of crop revenues. At high levels of risk aversion, land is taken out of production and the planted area sown to rotation 7.

The price scenario and risk aversion parameter selected has a significant impact on the excess nitrogen available for leaching (Table 2). Government support programs do not necessarily result in higher leaching levels. A direct effect would be noted if programs such as GRIP provided larger relative support to the N-requiring crops of corn and wheat and less to soybeans which fixes its own N. However, the level of support varies annually with no consistent pattern established in terms of relative support. Environmental effects of government support appear to stem from the reduction in revenue variability. Increases in risk aversion tend to reduce nitrate leaching as more wheat and less corn is planted due to the lower variance in wheat returns. The lower variability of all crop returns with government support programs and consequently lower risk premium dampens the reduction in leaching from increases in the degree of risk aversion.

Environmental Policy Instrument Analysis

Design Based Instruments

On-farm impacts of imposing standards or taxes on nitrogen use are listed in Table 3. Restricting the amount of N the producer can apply to his farm causes a risk neutral producer facing average prices to gradually shift from a corn-soy rotation (rotation 2) to a corn-soy-wheat-soy rotation (rotation 7). The only way that the standards can be met under increasing restrictions is to take land out of production from the latter rotation. A risk averse producer with the same price scenario idles land directly from rotation 2 rather than first moving it into rotation 7 with decreases in the amount of N that can be used on the farm. Under average GRIP prices, the risk neutral producer moves land out of the nitrogen intensive rotation of continuous corn (rotation 1) with decreases in N availability into first the corn-soy rotation and then eventually into rotation 7. A risk averse producer under the same price scenario would follow the same pattern with the exception that the base solution is rotation 2 and not continuous corn. The shift from the corn-soy rotation to the corn-soy-wheat-soy rotation and then to idle land is also noted for the current effective price scenario. Under risk aversion more land is initially in rotation 7.

In general, nitrogen taxes have a much smaller effect on production choices than do nitrogen restrictions. Optimal rotational choice does not change even with a tax rate of 50% for risk neutral producers regardless of the price scenario. Risk averse producers facing average GRIP prices also do not alter their optimal rotation with changes in the price of N. With average market prices, a N tax reduces the area planted to the rotation chosen under the base and shifts it to idle land. With current effective prices, there is a gradual shift with an increase in N price from the corn-soy rotation (2) to rotation 7 which uses the least amount of N among the rotations considered.

Performance Based Instruments

Restricting the level of nitrate emissions directly, forces the risk neutral producer to gradually shift to rotation 7 which has the lowest level of excess N of any rotation. At an average NO_3^- standard for the farm, maximum profits are earned under risk neutrality from growing 56% of the available land area to rotation 2 (corn-soy) and the remainder to rotation 7 (corn-soy-wheat-soy) regardless of the price scenario (Table 4). Reducing the NO_3^- standard further to 7.5 mg L^{-1} ha^{-1} changes the land mix to 28% rotation 2 and 72% rotation 7. For a given price scenario, risk aversion results in a management choice with less excess N and thus a more stringent NO_3^- standard is required before changes from the optimal base rotations are prompted.

Taxing the nitrate emissions at \$200 mg L^{-1} results in the corn-soy rotation being chosen for all price scenarios under risk neutrality. This is a change from the base for only the average GRIP price scenario. Raising the tax to \$400 mg L^{-1} causes all land to be planted to rotation 7 with the two average price scenarios. No effect on rotational choice is brought about with the increased tax under 1993 effective prices regardless of the risk aversion level.

Comparison of On-Farm Abatement Costs

Reductions in farm profits associated with the alternative instruments are summarized in Table 5. On-farm abatement costs per hectare are those associated with reducing the average nitrate level in the groundwater to 10 $mgNL^{-1}$ which is the drinking water quality standard in Ontario. The results highlight several points raised in theoretical model section.

First, on-farm abatement costs are similar for design or performance based standards. The result is due to the direct linear relationship between management choices and emissions levels. Second, tax instruments on design or performance reduce farm profits more than direct regulations of those bases by the extent of the tax burden. Third, the total tax paid per hectare is greater for a tax on N applied (design-base) than for a tax on actual excess N (performance-base). The required N tax is approximately 4 times the price implying that the instrument is a politically infeasible means to achieve the environmental quality objective. Fourth, risk aversion reduces on-farm abatement costs. The risk premium for the rotation with the lowest excess N level (rotation 7) is lower than that for rotations 1 and 2 because the absolute variance of revenues is lower for wheat than corn. Fifth, government programs have ambiguous effects on abatement costs. Under risk neutrality, abatement costs with average GRIP prices are lower than with average market prices because average wheat price is increased by 26% with GRIP as opposed to the 18% increase for corn which is more N-intensive. The result is reversed under risk aversion. Consideration of the risk premium together with the lower absolute returns causes some of the land to be idled and the remaining land planted to rotation 2 with the average market price scenario. The resulting N leaching is below the standard so no changes in practices and thereby profits result. However, the standard does restrict choices under average GRIP prices with risk aversion so there are associated abatement costs. Finally, on-farm abatement costs differ significantly depending upon the price scenario. Reduction in farm profits per hectare to achieve the desired water quality range from $1,444 to $2,031 for the standards and from $14,282 to $18,277 for the N tax under risk neutrality. With risk aversion, the ranges increase to $0-$1,053 for the standards and to $0-$11,522 for the N tax. The nature of the management choices to reduce groundwater NO_3^- levels implies that on-farm abatement costs can range from nothing to a significant amount depending upon relative crop prices.

Conclusions

Potential leaching losses of nitrogen depend in large part on the crops grown. Since crop selection is a major means of abatement for nitrates in groundwater, it follows that the compliance costs to producers for reducing excess nitrogen is influenced by crop prices. This paper has demonstrated the role that crop prices play in determining the level of on-farm abatement costs and even the necessity for regulatory policies to deal with the nitrate problem. These abatement costs are also affected by risk but the direction and magnitude depends upon the relative level of return variance between rotations that differ by the amount of nitrogen required. Tax instruments are particularly sensitive to changes in the risk premium. The paper has also shown that such taxes on nitrogen will likely have to be very large in order to achieve the desired environmental objectives, which is consistent with other studies, but also that a similar percentage change in output price will have a much larger impact on rotational choice and subsequently leaching losses. While the paper has not examined problems in the design of environmental regulatory policies such as informational asymmetries, it has highlighted the previously ignored influence of crop prices. Changes in the mean and variance of relative output prices can significantly alter on-farm abatement costs associated with alternative environmental control instruments which in turn affects policy design through issues such as political feasibility and equity considerations.

References

Addiscott, T.M., A.P. Whitmore and D.S. Powlson. 1991. *Farming, Fertilizers, and the Nitrate Problem.* Wallingford:C-A-B International.

Babcock, B.A. 1992. "The Effects of Uncertainty on Optimal Nitrogen Applications." *Review of Agricultural Economics.* 14(2):271-280.

Barry, D.A.J., D. Goorahoo and M.J. Goss. 1993. "Estimation of Nitrate Concentrations in Groundwater using a Whole Farm Nitrogen Budget." *Journal of Environmental Quality.* 22(4):767-775.

Bosch, D.J., Z.L. Cook and K.O. Fuglie. 1995. "Voluntary versus Mandatory Agricultural Policies to Protect Water Quality: Adoption of Nitrogen Testing in Nebraska." *Review of Agricultural Economics.* 17(1):13-24.

Braden, J.B., and K. Segerson. 1993. "Information Problems in the Design of Nonpoint Source Pollution Policy." in *Theory, Modelling and Experience in the Management of Nonpoint Source Pollution.* C.S. Russel and J.F. Shogren (eds.) Boston:Kluwer Academic Publishers.

Choi, E.K., and E. Feinerman. 1995. "Regulation of Nitrogen Pollution: Taxes versus Quotas." *Journal of Agricultural and Resource Economics.* 20(1):122-134.

Dosi, C., and T. Tomasi. 1994. *Nonpoint Source Pollution Regulation: Issues and Analysis.* Boston:Kluwer Academic Publishers.

Giraldez, C. and G. Fox. 1995. "" *Canadian Journal of Agricultural Economics.* (4):.

Griffin, R.C., and D.W. Bromley. 1982. "Agricultural Runoff as a Nonpoint Externality: A Theoretical Development." *American Journal of Agricultural Economics.* 64(3):547-552.

Hanley, N. 1990. "The Economics of Nitrate Pollution." *European Review of Agricultural Economics.* 17(2):129-151.

Heatwole, C.D., P.L. Diebel and J.M. Halstead. 1990. "Management and Policy Effects on Potential Groundwater Contamination from Dairy Waste." *Water Resources Bulletin.* 26(1):25-34.

Helfand, G.E., and B.W. House. 1995. "Regulating Nonpoint Source Pollution Under Heterogeneous Conditions." *American Journal of Agricultural Economics.* 77(5):1024-1032.

Huang, W., and R. Latin. 1993. "A Comparison of Farmers' Compliance Costs to Reduce Excess Use Under Alternative Policy Options." *Review of Agricultural Economics.* 15(1):51-62.

Huang, W., and M. LeBlanc. 1994. "Market-Based Incentives for Addressing Non-Point Water Quality Problems: A Residual Nitrogen Tax Approach." *Review of Agricultural Economics.* 16(2):427-440.

Johnson, S.L., R.M. Adams and G.M. Perry. 1991. "The On-Farm Costs of Reducing Groundwater Pollution." *American Journal of Agricultural Economics*. 73(4):1063-1073.

Just, R., and J. Antle. 1990. "Interactions Betwee Agricultural and Environmental Policies: A Conceptual Framework." *American Economic Review*. 80(2):197-202.

McSweeny, W.T., and J.S. Shortle. 1989. "Reducing Nutrient Application in Intensive Livestock Area: Policy Implications of Alternative Producer Behavior." *Northeastern Journal of Agricultural and Resource Economics*. 18(1):1-11.

Mapp, H.P., D.J. Bernardo, G.S. Sabbagh, S. Gelata, and K.B. Watkins. 1994. "Economic and Environmental Impacts of Limiting Nitrogen Use to Protect Water Quality: A Stochastic Regional Analysis." *American Journal of Agricultural Economics*. 76(4):889-903.

Moxey, A., and B. White. 1994. "Efficient Compliance with Agricultural Nitrate Pollution Standards." *Journal of Agricultural Economics*. 45(1):27-37.

Musser, W.N., J.S. Shortle, K. Kreahling, B. Roach, W.C. Huang, D.B. Beegle and R.N. Fox. 1995. "An Economic Analysis of the Pre-Sidedress Nitrogen Test for Pennsylvania corn Production." *Review of Agricultural Economics*. 17(1):25-36.

Ontario Ministry of Agriculture and Food. various issues. *Agricultural Statistics for Ontario: Publication 20*. Toronto:Queen's Printer for Ontario.

______. 1994a. *1993-1994 Field Crop Recommendations: Publication 296*. Toronto:Queen's Printer for Ontario.

______. 1994b. *Best Management Practices: Nutrient Management*. Toronto:Queen's Printer for Ontario.

Organization for Economic Cooperation and Development. 1989. *Economic Instruments for Environmental Protection*. Paris:Organization for Economic Cooperation and Development.

Pan, J.H., and I. Hodge. 1994. "Land Use Permits as an Alternative to Fertiliser and Leaching Taxes for the Control of Nitrate Pollution." *Journal of Agricultural Economics*. 45(1):102-112.

Ribaudo, M., and D. Woo. 1991. Summary of State Water Quality Laws Affecting Agriculture. Agricultural Resources - Cropland, Water, and Conservation - Situation and Outlook Report. USDA/ERS/RTD AR-23.

Rudolph, D., M. Goss, A. Graham, G. Kachanoski, M. Scafe, D. Aspinall, R. VandenBroek, S. Clegg, D. Barry, and J. Stimson. 1992. *Ontario Farm Groundwater Quality Survey, Winter 1991/92*. Report prepared for Agriculture Canada, September.

______. 1993. *Ontario Farm Groundwater Quality Survey, Summer 1992*. Report prepared for Agriculture Canada, June.

Russel, C.S., and J.F. Shogren. 1993. *Theory, Modelling and Experience in the Management of Nonpoint Source Pollution.* Boston:Kluwer Academic Publishers.

Schnitkey, G.D., and M.J. Miranda. 1993. "The Impacts of Pollution Controls on Livestock-Crop Producers." *Journal of Agricultural and Resource Economics.* 18(1):25-36.

Shortle, J.S., and J.W. Dunn. 1986. "The Relative Efficiency of Agricultural Source Water Pollution Control Policies." *American Journal of Agricultural Economics.* 68(3):668-677.

Swinton, S.M., and D.S. Clark. 1994. "Farm-Level Evaluation of Alternative Policy Approaches to Reduce Nitrate Leaching from Midwest Agriculture." *Agricultural and Resource Economics Review.* 23(1):66-74.

Taylor, M.L., R.M. Adams and S.F. Miller. 1992. "Farm-Level Response to Agricultural Effluent Control Strategies: The Case of the Williamette Valley." *Journal of Agricultural and Resource Economics.* 17(1):173-185.

Teague, M.L., D.J. Bernardo and H.P. Mapp. 1995. "Farm-Level Economic Analysis Incorporating Stochastic Environmental Risk Assessment." *American Journal of Agricultural Economics.* 77(1):8-19.

Wossink, G.A.A., T.J. de Koeijer and J.A. Renkema. 1992. "Environmental-Economic Policy Assessment: A Farm Economic Approach." *Agricultural Systems.* 39(4):421-438.

Wu, J., and K. Segerson. 1995. "The Impact of Policies and Land Characteristics on Potential Groundwater Pollution in Wisconsin." *American Journal of Agricultural Economics.* 77(5):1033-1047.

Table 1. Gross Revenues, Variable Costs, and Estimated Nitrogen Leaching Coefficients for Various Rotations of Corn, Soybeans, and Wheat (1993 dollars)

Crop Rotation	Revenue ($/tonne)			Variable Cost ($ ha^{-1}) [b]	Excess Nitrogen (kgNha^{-1}yr^{-1})
	Average Market	Average GRIP	Effective 1993		
(1) Continuous Corn	902.53 (18.43)[a]	961.13 (7.72)	854.55	369.38	79
(2) Corn-Soy	829.30 (17.89)	859.32 (5.70)	778.87	318.71	14
(3) Corn-Wheat	766.27 (18.38)	835.74 (8.28)	709.44	287.53	57
(4) Corn-Soy-Wheat	762.87 (17.99)	809.68 (6.70)	707.37	281.03	19
(5) Corn-Soy-Wheat/Clover	762.87 (17.99)	809.68 (6.70)	707.37	292.95	41
(6) Corn-Corn-Soy-Wheat/Clover	797.78 (17.80)	847.53 (6.93)	744.15	312.06	47
(7) Corn-Soy-Wheat-Soy	761.17 (18.15)	796.63 (5.96)	706.31	277.79	5

[a] - coefficient of variation in parentheses

[b] - does not include the cost of nitrogen fertilizer applied

Table 2. Crop Mix, Net Revenue and Excess Nitrate Leached under Alternative Prices and Risk Aversion

Pricing Scenario		Risk Aversion Coefficient (λ) 0.0000	0.0002	0.0004	0.0006
	Crop Mix (ha)				
Average Market	Corn	81.0	29.9	14.9	10.0
	Soy	81.0	59.7	29.9	19.9
	Wheat	0.0	29.9	14.9	10.0
	Idle Land	0.0	42.6	102.3	122.1
	Net Revenue ($)	79,102	54,448	27,224	18,149
	Leachate	14	3.7	1.8	1.3
	Crop Mix (ha)				
Average GRIP	Corn	162.0	81.0	81.0	81.0
	Soy	0.0	81.0	81.0	81.0
	Wheat	0.0	0.0	0.0	0.0
	Idle Land	0.0	0.0	0.0	0.0
	Net Revenue ($)	82,944	81,966	81,966	81,966
	Leachate	79	14	14	14
	Crop Mix (ha)				
Effective 1993	Corn	81.0	40.5	40.5	40.5
	Soy	81.0	81	81	81
	Wheat	0.0	0.0	0.0	0.0
	Idle Land	0.0	0.0	0.0	0.0
	Net Revenue ($)	68,933	66,416	51,105	34,070
	Leachate	14	8.3	3.9	2.6

Table 3. Effects of Design Instruments on Management Choices and Excess Nitrogen

Pricing Scenario	Risk Aversion		Base	N Restrictions (kg)			N Tax Rate[a]	
				10,000	8,000	6,000	25%	50%
Average Market	Risk Neutral	Corn (ha)	81.0	77.0	40.0	30.0	81.0	81.0
		Soy (ha)	81.0	81.0	80.0	60.0	81.0	81.0
		Wheat (ha)	0.0	4.0	40.0	30.0	0.0	0.0
		Idle Land (ha)	0.0	0.0	2.0	42.0	0.0	0.0
		N Applied	10,206	10,000	8,000	6,000	10,206	10,206
		Leachate	14	13.1	4.9	3.7	14	14
		Net Revenue ($)	77,102	76,784	72.941	54,706	75,699	74,296
	λ=.0002	Corn	29.9	29.9	29.9	29.9	29.4	29.0
		Soy	59.7	59.7	59.7	59.7	58.8	57.9
		Wheat	29.9	29.9	29.9	29.9	29.4	29.0
		Idle Land	42.6	42.6	42.6	42.6	44.4	46.1
		N Applied	5,972	5,972	5,972	5,972	5,877	5,792
		Leachate	3.7	3.7	3.7	3.7	3.6	3.6
		Net Revenue ($)	54,448	54,448	54,448	54,448	52,818	51,213
Average GRIP	Risk Neutral	Corn	162.0	77.0	40.0	30.0	81.0	81.0
		Soy	0.0	81.0	80.0	60.0	81.0	81.0
		Wheat	0.0	4.0	40.0	30.0	0.0	0.0
		Idle Land	0.0	0.0	2.0	42.0	0.0	0.0
		N Applied	23,490	10,000	8,000	6,000	10,206	10,206
		Leachate	79	13.1	4.9	3.7	14	14
		Net Revenue ($)	82,944	81,734	78,614	58,961	80,333	79,159
	λ=.0002	Corn	81.0	77.0	40.0	30.0	81.0	81.0
		Soy	81.0	81.0	80.0	60.0	81.0	81.0
		Wheat	0.0	4.0	40.0	30.0	0.0	0.0
		Idle Land	0.0	0.0	2.0	42.0	0.0	0.0
		N Applied	10,206	10,000	8,000	6,000	10,206	10,206
		Leachate	14	13.1	4.9	3.7	14	14
		Net Revenue ($)	81,966	81,734	78,614	58,961	80,562	79,159
Effective 1993	Risk Neutral	Corn	81.0	77.0	40.0	30.0	81.0	81.0
		Soy	81.0	81.0	80.0	60.0	81.0	81.0
		Wheat	0.0	4.0	40.0	30.0	0.0	0.0
		Idle Land	0.0	0.0	2.0	42.0	0.0	0.0
		N Applied	10,206	10,000	8,000	6,000	10,206	10,206
		Leachate	14	13.1	4.9	3.7	14	14
		Net Revenue ($)	68,933	68,545	64,163	48,122	67,530	66,126
	λ=.0002	Corn	55.3	55.3	40.0	30.0	45.7	40.5
		Soy	81.0	81.0	80.0	60.0	81.0	81.0
		Wheat	25.7	25.7	40.0	30.0	35.3	40.5
		Idle Land	0.0	0.0	2.0	42.0	0.0	0.0
		N Applied	8,870	8,870	8,000	6,000	8,369	8,100
		Leachate	8.3	8.3	4.9	3.7	6.2	5.0
		Net Revenue ($)	66,416	66,416	64,163	48,122	64,325	62,738

[a] Percentage increase in price of nitrogen ($0.55 kg^{-1})

Table 4. Effects of Performance Instruments on Management Choices and Excess Nitrogen

Pricing	Risk			NO3 Restrictions ($mg\ L^{-1}\ ha^{-1}$)			NO3 Tax Rate ($\$\ mgL^{-1}\ ha^{-1}$)	
Scenario	Aversion		Base	12.5	10.0	7.5	$200	$400
Average Market	Risk Neutral	Corn (ha)	81.0	74.2	63.0	51.8	81.0	40.5
		Soy (ha)	81.0	81.0	81.0	81.0	81.0	81.0
		Wheat (ha)	0.0	6.8	18	29.2	0.0	40.5
		Idle Land (ha)	0.0	0.0	0.0	0.0	0.0	0.0
		N Applied	10,206	9,855	9,270	8,685	10,206	8,100
		Leachate	14	12.5	10	7.5	14	5
		Net Revenue ($)	77,102	76,561	75,658	74,755	74,302	71,853
	λ=.0002	Corn	29.9	29.9	29.9	29.9	29.5	29.1
		Soy	59.7	59.7	59.7	59.7	58.9	58.1
		Wheat	29.9	29.9	29.9	29.9	29.5	29.1
		Idle Land	42.6	42.6	42.6	42.6	44.1	45.7
		N Applied	5,972	5,972	5,972	5,972	5,891	5,810
		Leachate	3.7	3.7	3.7	3.7	3.6	3.5
		Net Revenue ($)	54,448	54,448	54,448	54,448	52,983	51,539
Average GRIP	Risk Neutral	Corn	162.0	74.3	63.0	51.8	81.0	40.5
		Soy	0.0	81.0	81.0	81.0	81.0	81.0
		Wheat	0.0	6.7	18.0	29.3	0.0	40.5
		Idle Land	0.0	0.0	0.0	0.0	0.0	0.0
		N Applied	23,490	9,855	9,270	8,685	10,206	8,100
		Leachate	79	12.5	10.0	7.5	14	5
		Net Revenue ($)	82,944	81,571	80,913	80,255	79,166	77,597
	λ=.0002	Corn	81.0	74.3	63.0	51.8	81.0	40.5
		Soy	81.0	81.0	81.0	81.0	81.0	81.0
		Wheat	0.0	6.7	18.0	29.3	0.0	40.5
		Idle Land	0.0	0.0	0.0	0.0	0.0	0.0
		N Applied	10,206	9,855	9,270	8,685	10,206	8,100
		Leachate	14	12.5	10.0	7.5	14	5
		Net Revenue ($)	81,966	81,571	80,913	80,255	79,166	77,597
Effective 1993	Risk Neutral	Corn	81.0	74.3	63.0	51.8	81.0	81.0
		Soy	81.0	81.0	81.0	81.0	81.0	81.0
		Wheat	0.0	6.7	18.0	29.3	0.0	0.0
		Idle Land	0.0	0.0	0.0	0.0	0.0	0.0
		N Applied	10,206	9,855	9,270	8,685	10,206	10,206
		Leachate	14	12.5	10.0	7.5	14	14
		Net Revenue ($)	68,933	68,271	67,169	66,067	66,133	63,333
	λ=.0002	Corn	55.3	55.3	55.3	51.8	40.5	40.5
		Soy	81.0	81.0	81.0	81.0	81.0	81.0
		Wheat	25.7	25.7	25.7	29.3	40.5	40.5
		Idle Land	0.0	0.0	0.0	0.0	0.0	0.0
		N Applied	8,870	8,870	8,870	8,685	8,100	8,100
		Leachate	8.3	8.3	8.3	7.5	5	5
		Net Revenue ($)	66,416	66,416	66,416	66,067	63,965	62,965

Table 5. On-Farm-Abatement Costs of Policy Instruments Under Alternative Price and Risk Scenarios to Achieve Average Groundwater Nitrate Level of 10 mg L^{-1} (\$ ha^{-1})

Pricing Scenario	Risk Aversion	Design Instruments		Performance Instruments	
		Standards	Taxes	Standards	Taxes
Average Market	Neutral	1,444	15,713 (2.04)[a]	1,444	5,052 (361.1)
	λ=.0002	0	0	0	0
Average GRIP	Neutral	2,031	14,282 (1.19)	2,031	4,659 (263)
	λ=.0002	1,053	11,522 (1.89)	1,053	3,267 (221.4)
Effective 1993	Neutral	1,764	18,277 (2.44)	1,764	6,172 (440.8)
	λ=.0002	0	0	0	0

[a] - Tax rates are in parenthesis