Uncertainty and the Regulation of Nitrate Pollution from Agriculture

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Abstract

A simulation of U.S. corn production compares four environmental policies for controlling agricultural nitrate pollution. Public uncertainty about key economic parameters are considered. Results indicate that policy choice is sensitive to commodity programs and the public information structure. Agricultural research benefits are also sensitive to agricultural environmental policy choices.

Keywords: *environmental policy, nonpoint pollution, uncertainty, value of information*

Introduction

There is currently much interest in reducing nitrate pollution from agriculture. This interest is motivated by concerns for the health impacts of nitrate contamination of drinking water and the ecological damages of increased nutrient levels in water bodies. Economists have long advocated the use of emission taxes and other emission-based economic instruments for efficient control of environmental externalities (e.g. Bohm and Russell, 1985). However, such instruments are of limited utility for the control of nitrate pollution from agriculture because monitoring emissions by source is impractical. Alternatives that have received attention in the literature include taxes and standards on excess nitrogen (defined as the difference between total nitrogen applied in fertilizer and manure, plus nitrogen carry over, less the nitrogen taken up by the crop), ambient nitrate concentrations in water resources, and nitrogen fertilizer purchases or applications (e.g., Griffin and Bromley, 1982; Huang and LeBlanc, 1994; Shortle and Dunn, 1986; Shortle and Abler, 1994; Segerson, 1988; Stevens, 1988). There is, however, little empirical analysis of the implications of public uncertainty about benefits and costs for the choice of instruments. Yet, it is clear from the work of Weitzman (1974) and others (e.g Stavins, 1996) that uncertainty is a critical factor in policy choices. Instruments that can be designed to perform with equal efficiency with perfect information (e.g., emissions taxes and standards), will in general perform unequally when designed with imperfect information.

In this paper, we compare the performance of taxes and standards under public uncertainty about the costs and benefits of nitrate pollution control in the production of corn using a simulation model of aggregate U.S. corn production. Public uncertainty is modeled here as uncertainty by environmental regulators about such economic parameters as demand and input substitution elasticities, and the environmental costs of nitrate pollution, and also uncertainty about environmental parameters, such as nitrate losses and delivery. In addition, we explore the impacts of learning on policy choices and performance. All of these issues are considered with and without traditional commodity programs.

Simulation Model

As in Weitzman's and much of the subsequent work on policy choices under uncertainty, the optimal form of a particular instrument, such as a linear tax on nitrate fertilizer, maximizes the expected net benefits (producers' plus consumer surplus from commodity production and consumption less environmental damage costs) to society given the existing market structure and government programs. Transactions costs and distributional impacts aside, one instruments is considered to be economically superior to another if the expected net benefit from its optimized form exceeds the expected net benefit from the optimized form of the alternative. Accordingly, for this analysis, we must determine the fertilizer and excess nitrogen taxes and standards that maximize expected net benefits. In order to calculate the effect of information on policy choice, we must also compute expected net benefits of information.

A partial market equilibrium model of the U.S. corn market is used to compute equilibrium market prices and quantities. Farmers are assumed to be price takers, but commodity and input markets are distorted by deficiency payments and the acreage reduction program. The complete set of equations that make up the model include first-order conditions for profit maximization, consumer demand for output, input supply, and constraints implied by market clearing conditions.

Production is modeled as a two-level nested CES production function (Sato, 1967). The key parameters of this functional form are the share parameters and elasticities of substitution between inputs. Following Abler and Shortle (1992), output is modeled as a function of a composite mechanical input, *M*, and a composite biological input, *B*. The mechanical input provides power for planting and weeding while the biological input provides the nutrients and environment for plant growth (Abler and Shortle, 1992). The lower level production function generates the composite inputs. Inputs included are land (x_L), fertilizer (x_F), capital and labor. The mechanical input is a function of capital and labor. However prices of these inputs are fixed implying there is no change in the relative price within the nest and as such it has no effect on the analysis. The inputs are therefore aggregated into a single input, x_K. The production function is therefore given as $Q = A\left(s_B B^{\rho_T} + s_K x_K^{\rho_T}\right)^{\frac{1}{\rho_T}}$, where $\rho_T = \frac{\sigma_T - 1}{\sigma_T}$, $0 < s_B, s_M < 1$ are share parameters, σ_T is the elasticity of substitution between the mechanical and biological inputs, and *A* is a scaling constant. The biological input is a function of land (x_L) and fertilizer (x_F), $B = K\left(s_L x_L^{\rho_B} + s_F x_F^{\rho_B}\right)^{\frac{1}{\rho_B}}$, where $\rho_B = \frac{\sigma_B - 1}{\sigma_B}$, $0 < s_L, s_F < 1$ are the share parameters, σ_B the elasticity of substitution between land and fertilizer, and *K* is a scaling constant. The elasticity of substitution between land and fertilizer and other parameters (output demand elasticity, land supply elasticity and a runoff coefficient) introduced below are assumed to be unknown by policy makers prior to the decision making process although their distributions are known.

All inputs except land are assumed to be supplied perfectly elastically. In the short run, supply responses are not perfectly elastic, but over time labor and resources used in capital and chemical production can be withdrawn at relatively low cost to non-agricultural use (Gardner, 1987). However, even if the long run supply responses are not perfectly elastic, they can be treated as such because in the long run the elasticities are very large. For simplicity, output demand is represented by a linear inverse demand function with intercept α_1 and slope α_2. This specification of the demand function can be viewed as a linear Taylor series approximation for the true demand function in the neighborhood of the expansion point.

Land supply is specified as a constant elasticity function of the rental rate of land, with ϵ as the land supply elasticity. The effect of participation in the ARP is a shift in the supply of land (Gardner, 1992). If L is total land supply, x_L land in use, and ϕ the proportion of land idled in the ARP, then total land supply is given as $L = x_L + \phi L$. The land supply equation with the ARP is, $\frac{x_L}{1-\phi} = \rho\,\omega_L^{\epsilon}$. Following Shortle and Laughland (1995), deficiency payment is modeled as a per unit subsidy (s) on output. Producer price is thus equal to consumer price plus the subsidy.

Environmental damages (D) are represented as a function of excess nitrogen and are specified as $D = \delta(r)^{\tau}$. If γ is the proportion of nitrogen removed per bushel of corn, and β represents the proportion of excess nitrogen in runoff, then runoff is given as $r = \beta(x_F - \gamma Q)$ (Roth and Jury, 1993).

Net benefit is consumer plus producer surplus less government transfers and environmental damages (Freeman, 1993; Just et al., 1992). Produces surplus in this model is equal to land rents. The opportunity cost of land is calculated using the inverse land supply function adjusted for the ARP. Government transfers is the net of tax receipts and subsidy payments.

Because the net benefit function is highly nonlinear, its expected value cannot be derived analytically as a function of the policy and exogenous parameters. A numerical procedure is therefore used to solve for the endogenous variables for any given set of policy and exogenous parameter values. This procedure involves approximating parameter distributions with discrete points (θ_i) and associated probability values (p_i) - that is, a discrete distribution - using the Guassian Quadrature approach to numerical integration.

Several steps are used to derive optimal instrument values. (1) determine the points and probabilities that approximate the random parameters, (2) combine the parameter points into parameter sets to create a joint distribution, (3) solve the market model for each parameter set of the joint distribution for given tax rates and standards and commodity program structure, (4) calculate net benefit for each parameter set, (5) construct a probability weighted average of outcomes for each tax rate and standard, and (6) conduct a search for the tax rate or standard that gives the highest expected net benefit. This is *ex ante,* policy that maximizes expected net benefits.

The value of perfect information contingent on the use of a particular instrument is the difference between the expected net benefits when instrument is optimized with perfect information, and the expected net benefits when the instrument is optimized with imperfect information. Or in other words, it is the difference between the expected net bebefit of the *ex ante* and *ex post* optimal forms of the instrument. In addition to the results outlined above, computation of the value of perfect information requires (1) determining the optimal policy for every possible realization of the unknown parameters, and (2) computing the expected net benefits when policies are optimized with perfect information. Steps (1) - (4) outlined above are repeated, then a search procedure is used to find the instrument setting that gives the highest net benefit for a given parameter set. This is the setting that maximizes *ex post*, net benefit for a given parameter set. Repeating this for each parameter set generates a distribution of maximized net benefits. A probability weighted average is used to calculate expected net benefit *ex post*. In addition to the value of perfect information, we also consider the consequences of perfect information about subsets of parameters in order to gain insight about their relative importance.

Approximating the Probability Distributions

Calculating the expected value for a continuous variable involves evaluating the integral of a function over a given range, but with no closed form solutions to the system of equations that characterize the equilibrium, the net benefit function also has no closed form solution and therefore the integral (expected net benefits) cannot be evaluated. If the probability density functions of the random variables $(f(\theta))$ can be represented by a set of values, θ_i and probabilities, p_i, then the integral can be approximated by a probability weighted sum of net benefits evaluated at the various values of θ_i (Miller and Rice, 1983). The accuracy of such a discrete approximation to a continuous distribution obviously depends on it's ability to preserve as many moments of the original distribution as possible.

Three methods have been used in the economic literature on choice under uncertainty for determining discrete approximations. Direct Expected-Utility Maximization Program (Lambert and McCarl, 1985), Direct Expected-Utility Maximization Using Quadrature (Kaylen et al., 1987) , and Gaussian Quadrature (Preckel and DeVuyst, 1992). Preckel and DeVuyst show that the Gaussian Quadrature procedure condenses the approximation to only a few points compared to the other approaches while preserving the moments of the distribution. The Gaussian Quadrature method is used in this study.

Points and probabilities for standardized distributions can be found in Stroud and Secrest

(1966). Values for similar distributions with different means and standard deviations can be obtained by performing the same affine transformations needed to transform the standard distribution to the desired distribution. The probability values remain the same. Like Abler (1994) two distributions, the uniform and normal are assumed for the random variables. The uniform distribution reflects ignorance about the parameter values within the bounded interval, the distribution is diffuse and not centered. The normal distribution is used because is a centered distribution, not bounded and as such provides a contrast to the uniform distribution. It can also be justified by reference to the central limit theorem. The Guassian Quadrature approximations for the random variables in this model are presented in Table 1.

Results - Commodity programs

In Table 2 and 3 we present the results for our simulations. With traditional commodity programs in place, the expected net benefit from the *ex ante* optimal tax instruments are slightly greater than the expected net benefits from the *ex ante* quantity instruments for both the normal and uniform distributions, with the expected net benefit from the fertilizer tax being slightly greater than that of the excess nitrogen tax. Similarly, the fertilizer standard gives a higher expected net benefits than the excess nitrogen standard. The *ex post* efficiency of the optimized tax and quantity instruments for each base are virtually the same. However, the fertilizer instruments remain more efficient than the excess nitrogen based instruments. In fact, of the 625 parameter sets in the perfect information case, net benefits from fertilizer tax was greater or equal to expected net benefits from excess nitrogen tax in all but one case for both the uniform and normal distributions.

The *ex ante* optimal excess nitrogen tax rate is lower than the optimal fertilizer tax for both the normal and uniform distributions. Similarly, the shadow price of the *ex ante* optimal fertilizer standard is higher than the shadow price of the excess nitrogen standard. These results hold for the perfect information case as well. However, with perfect information, the expected tax rates (shadow prices) are higher than the *ex ante* optimal tax rates and shadow prices. Accordingly, in this case, uncertainty results in less restrictive policies.

In general, the value of perfect information on all the uncertain parameters for quantity instruments is about twice that for the tax instruments. This reflects the fact that the tax instruments are significantly more efficient than the quantity instruments *ex ante* but not *ex post*. Comparing either tax instruments or quotas, the value of perfect information is slightly greater with the fertilizer based instruments. The value of perfect information is slightly higher with the uniform approximation than with the normal. As stated earlier, the uniform distribution is diffuse and is used to represent greater ignorance about the parameter within a bounded interval. The normal distribution on the other hand is more centered. In effect some information is available in the normal distribution which could account for the lower value of improved information.

With perfect information on individual parameters, the results indicate that the elasticity of substitution between fertilizer and land is the most important parameter for the design of nonpoint pollution policy. This result is consistent with Hrubovak, LeBlanc and Miranowski (1990) and Laughland (1995). Information on the runoff parameter is more valuable if the instrument is based on excess nitrogen. In this model, emissions are directly proportional to excess nitrogen. Therefore, a better understanding of this parameter should lead to greater efficiency in the design of excess nitrogen based instruments. Output demand elasticity is more important for the design of fertilizer based instruments. The least important parameter is land supply elasticity. With an inelastic land supply, the change in land supply on an aggregate level is not significant. It is possible however that this parameter could become more important with disaggregation.

Results - Without Commodity Programs

Other things equal, eliminating deficiency payments and land set-asides decreases output and input use. The cost of the nitrogen pollution falls. The expected net benefits from the environmental policies are much more without the commodity programs than with the commodity programs in place. Very little increase in expected net benefits is attained with the price instruments over the competitive equilibrium, while the quantity instruments give essentially no improvement at all. The tax rates without the commodity programs are lower than the rates with commodity programs.

An interesting result is that, without the commodity programs, the excess nitrogen tax is more efficient than the fertilizer tax both *ex ante* and *ex post*. This too reflects the effects of commodity programs. Because the programs encourage excess production, a benefit of the environmental policies is to reduce the social costs of the excess production. In the absence of the commodity programs, the benefits of the environmental policies are limited to the reduction in the external costs of nitrate pollution. We do not report the results here, but the fertilizer tax has a larger negative impact on production than the excess nitrogen tax. This is a positive dimension of the tax when there is excess production under the commodity programs but a negative dimension when these programs are removed. This difference in the performance of environmental policies with and without the commodity is consistent with the theory of second best.

The results for the value of information on all uncertain parameters are similar to those from the case with commodity programs. The value of perfect information is higher with the quantity instruments, the elasticity of substitution between land and fertilizer is the most important parameter in policy design, and land supply elasticity is the least important. While there is no value to additional information on all other parameters with respect to quotas, additional information on output demand is more valuable for fertilizer taxes. On the other hand, improved information on land supply elasticity and the runoff coefficient is more valuable in the formulation of excess nitrogen taxes.

Conclusion

The research indicates that economically efficient nitrate policy choices are sensitive to commodity programs and uncertainty. With the commodity programs, the most efficient instrument is a fertilizer tax. Without the commodity programs, the preferred policy is an excess nitrogen tax. With uncertainty, the taxes on fertilizer or excess nitrogen are more efficient than quantity controls, but with perfect information the quantity instruments are as efficient as the tax instruments. Finally, our analysis suggests that the value of agricultural research is influenced by the environmental policy choices. For example, the elasticity of substitution between land and fertilizer is more important in the design of fertilizer based instruments while the runoff coefficient is more important in the design of excess nitrogen instruments.

Table 1: Gaussian Quadrature Approximations for Parameters of the Model

UNIFORM					NORMAL				
Elasticity of Substitution $(\sigma_B)^a$	Output Demand Elasticity	Land Supply Elasticity	Runoff Coefficient	Probabilities	Elasticity of Substitution	Output Demand Elasticity	Land Supply Elasticity	Runoff Coefficient	Probabilities
0.09	-0.31	0.11	0.42	0.118	0.04	-0.21	0.04	0.27	0.011
0.34	-0.38	0.15	0.49	0.239	0.17	-0.33	0.12	0.44	0.222
0.69*	-0.50*	0.20*	0.60*	0.284	0.69*	-0.50*	0.20*	0.60*	0.533
1.04	-0.66	0.25	0.71	0.239	1.21	-0.75	0.28	0.76	0.222
1.29	-0.80	0.29	0.78	0.118	1.78	-1.17	0.36	0.93	0.011

* variable mean; [a] $\sigma_B = s_B\sigma_{LF} + (1-s_B)\sigma_T$ where σ_{LF} is the Allen Elasticity of Substitution

Parameter Distribution: $\sigma_{LF} \sim (1,1)$; $\log(\varepsilon_d) \sim (-0.7, 0.3)$; $\epsilon \sim (0.2, 0.057)$; $\theta \sim (0.6, 0.115)$

Other Parameter Values: $\sigma_T = 0.5$; $s = 0.21$; $\phi = 0.01$; $\gamma = 0.66$; $\tau = 1.5$

Table 2: Optimal Tax Rates and Shadow Prices of Standards

	Uniform Approximation				Normal Approximation			
	Fertlizer Tax	Fertlizer Standard	Excess Nitrogen Tax	Excess Nitrogen Stanfard	Fertlizer Tax	Fertlizer Standard	Excess Nitrogen Tax	Excess Nitrogen Stanfard
With Commodity Programs								
Imperfect Information	0.33	0.28	0.29	0.20	0.35	0.28	0.30	0.22
Perfect Information	0.36	0.36	0.31	0.36	0.36	0.36	0.32	0.36
Without Commodity Programs								
Imperfect Information	0.06	0.00	0.03	0.00	0.08	0.00	0.05	0.00
Perfect Information	0.12	0.12	0.10	0.10	0.13	0.13	0.11	0.11

Table 3: Expected Net Benefits and Value of Perfect Information for Different Environmental Policies

		Uniform Approximation				Normal Approximation			
		Fertilizer Tax	Excess Nitrogen Tax	Fertlizer Standard	Excess Nitrogen Standard	Fertilizer Tax	Excess Nitrogen Tax	Fertlizer Standard	Excess Nitrogen Standard
With Commodity Programs									
Expected Net Benefit ($ billion)	With Uncertainty	16.61	16.56	16.56	16.51	16.70	16.66	16.65	16.60
	With Perfect Information	16.68	16.63	16.68	16.63	16.77	16.72	16.77	16.72
Value of Perfect Information ($ billion)	All Parameters	0.076	0.072	0.124	0.120	0.067	0.066	0.123	0.120
	Elasticity of Substitution	0.064	0.061	0.104	0.104	0.057	0.056	0.105	0.106
	Output Demand Elasticity	0.0091	0.0085	0.020	0.014	0.0089	0.0082	0.019	0.013
	Land Supply Elasticity	0.00004	0.00004	0.0001	0.0001	0.00002	0.00003	0.0001	0.0001
	Runoff Parameter	0.0042	0.0055	0.0050	0.0061	0.0043	0.0057	0.0053	0.0066
Without Commodity Programs									
Expected Net Benefit ($ billion)	With Uncertainty	17.2111	17.2180	17.2043	17.2043	17.3072	17.3092	17.2989	17.2989
	With Perfect Information	17.2460	17.2513	17.2460	17.2513	17.3394	17.3431	17.3394	17.3431
Value of Perfect Information ($ billion)	All Parameters	0.0349	0.0333	0.0417	0.0470	0.0322	0.0339	0.0405	0.0442
	Elasticity of Substitution	0.0319	0.0254	0.0403	0.0314	0.0240	0.0222	0.0436	0.0335
	Output Demand Elasticity	0.0026	0.0020	0.0000	0.0000	0.0026	0.0022	0.0000	0.0000
	Land Supply Elasticity	0.00009	0.00011	0.00	0.00	0.00006	0.00008	0.00	0.00
	Runoff Parameter	0.00547	0.00552	0.00	0.00	0.0058	0.0063	0.00	0.00

REFERENCES

Abler, David G. *A Comparison of the Performance of Alternative Agricultural Nonpoint Pollution Controls.* Paper Presented at Annual Meeting of American Association of Environmental Economists, San Diego, August 1994.

Abler, David G. and James S. Shortle. "Environmental and Farm Commodity Policy Linkages in the U.S. and the E.C. *European Review of Agricultural Economics.* 19(1992):197-217.

Bohm, P and C.S. Russell. "Comparative Analysis of Alternative Policy Instruments." in *Handbook of Natural Resource and Energy Economics.* Vol. i. Knesse, A.V. and J.L. Sweeny, editors, New York: Elsevier Publishing Company, 1985.

Freeman, A. Myrick III. *The Measurement of Environmental and Resource Values.* Washington, D.C: Resources for the Future, 1993.

Gardner, Bruce L. *The Economics of Agricultural Policies*. New York, N.Y.: McGraw Hill, 1987.

Gardner, Bruce L. "Changing Economic Perspectives on the Farm Problem." *Journal of Economic Literature.* 30(1992):62-101.

Griffin, R. and D. Bromley. "Agricultural Runoff as A Nonpoint Externality." *American Journal of Agricultural Economics.* 64(August, 1982):547-52.

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

Hrubovcak, James, Michael LeBlanc and John Miranowski. "Limitations in Evaluating Environmental and Agricultural policy Coordination Benefits." *American Economic Review*. 80(1990):208-212.

Just, Richard E., Daniel L. Heuth and Andrew Schmitz. *Applied Welfare Economics and Public Policy*. Englewood Cliffs, New Jersey: Prentice Hall, 1992.

Kaylen, M.S., P.V. Preckel and E.T. Loehman. "Risk Modeling via Direct Utility Maximization using Numerical Quadrature." *American Journal of Agricultural Economics.* 69(1987):701-706.

Lambert, D.K. and B.A. McCarl. " Risk Modeling Using Direct Solution of Nonlinear Approximations of the Utility Function." *American Journal of Agricultural Economics*. 67(1985):846-852.

Laughland, Andrew S. *Multiple Instruments in the Regulation of Nonpoint Source Pollution*. Unpublished Ph.D. Dissertation, Pennsylvania State University, 1994.

Miller, A.C. and T.R. Rice. "Discrete Approximations of Probability Distributions." *Management Science*. 29(1983):352-362.

Preckel, Paul V and Eric DeVuyst. "Efficient handling of Probability Information for Decision Analysis under Risk." *American Journal of Agricultural Economics*. 72(1992):655-662.

Roth, K., and W.A. Jury. "Modeling the Transport of Solutes to ground Water Using Transfer Functions." *Journal of Environmental Quality*. 22(1993):487-493.

Sato, K. "A Two-Level Constant-Elasticity-of Substitution Production Function." *Review of Economic Studies*. 34(1967):201-218.

Segerson, K. "Uncertainty and Incentives for Nonpoint Pollution Control." *Journal of Environmental and Economic Management.* 15(1988):87-98.

Shortle, J. and D. Abler. "Incentives for Agricultural Nonpoint Pollution Control." in *Nonpoint Source Pollution Regulation: Issues and Analysis.* Cesare Dosi and Theodore Tomasi, editors. Dordrecht: Kluwer Academic Publishers, 1994.

Shortle, James S. and James W. Dunn. "The Relative Efficiency of Agricultural Source Water Pollution Control Policies." *American Journal of Agricultural Economics.* 68(August, 1986):668-77.

Shortle, James S. and Andrew Laughland. "Impacts of Taxes to Reduce Agrichemical Use when Farm Policy is Endogenous." *Journal of Agricultural Economics.* 45(1994):3-14.

Stavins, Robert N. "Correlated Uncertainty and Policy Instrument Choice." *Journal of Environmental Economics and Management.* 30(1996):218-232.

Stevens, Brandt K. "Fiscal Implications of Effluent Charges and Input Taxes." *Journal of Environmental Economics and Management.* 15(1988):285-296.

Stroud, A.H. and Secrest, D., *Gaussian Quadrature Formulas*, Prentice-Hall, Englewood Cliffs, N.J., 1966.

Wietzman, Martin L. "Prices and Quantities". *Review of Economic Studies.* 41(1974):477-491.