THE ECONOMICS OF GREEN PAYMENTS FOR REDUCING AGRICULTURAL NONPOINT SOURCE POLLUTION IN THE CORN BELT

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Introduction

The traditional approach to improving the environmental performance of U.S. agriculture has been to develop voluntary participation programs that pay farmers to undertake actions that are believed to improve the environment (e.g., Conservation Reserve Program [CRP] and Water Quality Incentives Program [WQIP], the Environmental Quality Incentives Program [EQIP], and the new Conservation Security Program [CSP]; see Claassen et al. 2002). Such *green payments* are of interest because they have the potential to provide environmental benefits as well as an alternative source of producer income relative to traditional commodity programs.

Despite these efforts, agriculture remains the largest single contributor of nonpoint pollution (especially the nutrients nitrogen and phosphorous) and the leading source of U.S. riverine and lake impairments (U.S. EPA 2000). It may be possible to improve the cost-effectiveness of these programs in achieving nonpoint pollution reductions by focusing on specific environmental goals and addressing other critical design issues related to nonpoint pollution control.

To be cost-effective, programs targeted at non-point pollution must address a number of complex features that are characteristic of non-point problems: unobservable and stochastic emissions, stochastic fate and transport, and heterogeneity that can affect producer responses to policy and the environmental consequences of those responses (Horan and Shortle 2001). Economic studies increasingly incorporate one or more of these features when analyzing agricultural pollution control instruments (see Horan and Shortle 2001, Table 2.2), but few studies incorporate all these features and there is still much to learn about how these features affect policy design and associated environmental outcomes. This is particularly true for the use of 'second-best' instruments – policy instruments that cannot be first-best due to practical limitations on how they can be designed and/or implemented (e.g., a uniform abatement subsidy or a subsidy based on a limited number of production practices) (Helfand and House 1995; Shortle et al. 1998). Other important features that are often not considered are the implications of managing multiple watersheds and the role of endogenous price effects. Most economic studies of agricultural pollution control instruments focus on the responses by a particular farm, or by farms in a small region such as a single watershed. Few studies incorporate multiple watersheds over a large production region and/or endogenous prices (see Claassen and Horan 2001). But these features are important considerations for developing a large-scale subsidy program, particularly one that adopts a watershed-based approach to management and that strives to target payments to the least-cost providers of water quality improvements.

In this paper, we develop a watershed-based model of green payments and apply it to agricultural production in the Corn Belt region of the U.S. This region is an important source of nutrients that are believed to be leading to serious environmental problems (e.g., hypoxia) in the Gulf of Mexico. We use this model to examine how payments applied to different environmental performance measures compare on the basis of economic efficiency, equity, and environmental outcomes, and how economic and watershed characteristics and the specification of water quality goals (e.g., TMDLs) affect program performance.

A Model of Production and Nonpoint Pollution in the Corn Belt

We develop a model of corn production and associated nonpoint pollution for that part of the central U.S. (often referred to as the Corn Belt) that is a major contributor of nutrient loads to the Gulf of Mexico. Specifically, we select the portion of the ERS farm resource region known as the 'Heartland' that coincides with USGS water resource regions 05, 07, and 10, each of which feeds into the Gulf. The Heartland region contains Iowa, Illinois, Indiana, large portions of Missouri, Minnesota, and Ohio, and smaller portions of Kentucky, Nebraska, and South Dakota (see *Farm Resource Regions*, Economic Research Service, USDA, www.ers.usda.gov/publications/aib760). USGS water resource regions (or 2-digit hydrologic cataloging units or HUCs) 05, 07, and 10 cover much of the north central U.S., including much of the Heartland or Corn Belt regions and the northern plains. More than half of region 07, about half of region 05, and a small portion of region 10 are included in the study area. The water resource regions are further divided into 8-digit HUCs, which form the basic geographic area for the environmental model. The study region includes 191 of the national total (48 states) of 2150 8-digit HUCs. (*see http://wy.water.usgs.gov/ projects/watershed/htms/whatrhucs.htm*).

The Heartland region accounts for a large share of U.S. corn production and for most of the nitrogen that flows into the Gulf of Mexico through the Mississippi River, which is believed to contribute to a large zone of hypoxic waters off the Gulf Coast (CAST, 1999). Developing the model along HUC boundaries facilitates the analysis of nutrient runoff and transport, particularly long-range transport that is typical of nitrogen.

Within each of the three USGS water resources regions in our study area, we define four classes of land, based on soil productivity and erodibility, for a total of twelve production regions. Productivity is defined as corn yield potential, calculated using a productivity index (Pierce, *et al.*1983) and county average corn yields available from NASS-USDA (see Claassen, *et al.* 2002 for more details). Productivity is considered high when the expected corn yield is 120 bushels per acre or higher. Erodibility is measured by the erodibility index, which is a measure of the soil's inherent propensity to erode, given local climatic conditions, relative to the soil's natural ability to withstand erosion without long-term productivity damage. Land is considered highly erodible or HEL, when the erodibility index is 8 or larger. Because runoff and erosion are closely related, the erodibility index also serves as a reasonable (and available) proxy for runoff of nutrients in solution and attached to the soil. Within each 2-digit HUC there are therefore four land quality (LQ) types: 1. highly productive land (HPL)/non-highly erodible (non-HEL) land, 2. HPL/HEL, 3. non-HPL /non-HEL, and 4. non-HP/HEL. Table 1 shows the land quality distribution of the 100 million acres of cropland in the study area.

Our model of corn production is similar to those of Claassen and Horan (2001) and Shortle et al. (1998). Without loss of generality, we consider aggregate production by groups of producers or farms, defined by watershed and land quality type as described above. The model therefore captures production over a range of climate, soil, and hydrologic conditions. Denote farm *i*'s production by the concave function $f_i(x_i)$, where x_i is an (*m* x 1) vector of inputs (*j*th element x_{ij}). The price of corn is *p*, with inverse demand $p(\sum_i f_i)$

($p'(\sum_i f_i) < 0$). Define x_{i1} to be farm *i*'s allocation of land, supplied according to a regional inverse supply $w_{i1}(x_{i1})$ ($w'_{i1}(x_{i1}) > 0$). All other inputs *j*≠1 are supplied according to an aggregate inverse supply $w_j(\sum_i x_{ij})$ ($w'_j > 0$).

Each farm *i* is a price-taker operating in competitive input and output markets, with profits $p_i = p_i \; f_i \; (x_i) - \sum_j w_j x_{ij}$. Assuming income and substitution effects are small, net private surplus is the sum of consumer surplus, firm-quasi rents, and the economic surplus to factors of production not supplied at a constant cost to the industry (Just et al. 1982)

$$V = \int_0^{\sum_i f_i} p(v)dv - \sum_i \int_o^{x_{i1}} w_{i1}(v)dv - \sum_{j\neq 1} \int_0^{\sum_i x_{ij}} w_j(v)dv \tag{1}$$

To calibrate this part of the model, we take production to be a two-level, constant elasticity of substitution (CES) technology (Sato 1967) that exhibits constant returns to scale. Following prior work based on the two-level CES approach (Abler and Shortle 1992; Claassen and Horan 2001; Kawagoe *et al*. 1985; Hayami and Ruttan 1985; Thirtle 1985; Binswanger 1974), production is a function of a composite biological input (produced using land and nutrients) and a composite mechanical input (produced using capital and labor). Nitrogen is more or less a fixed proportion of nutrient applications, and so we refer to nutrients as nitrogen.

Demand for corn is a first order approximation of actual demand, as described in Claassen and Horan (2001). Factor supplies take a constant elasticity form. As described above, land supply is specified at the (aggregate) farm level, while other factors are freely allocated through region-wide markets, given the long-run nature of the model. The economic model is developed using data from the USDA Agricultural Resource Management Study (ARMS) and the USDA National Resource Inventory (NRI).

Now consider the environmental side of the model. Corn production creates external social costs through the unintended generation of nonpoint source nutrient emissions or loads. These loads are increasing in nitrogen use and decreasing in cropland (i.e., applying the same total amount of nitrogen over a larger land base reduces loads). Nonpoint loads are also stochastic due to the effects of precipitation. Specifically, the nitrogen load from region *i* is defined as the amount of nitrogen leaving the region and is denoted by $r_i\,(x_{iN}\,, x_{i1}\,, P_i)$, where x_{iN} is nitrogen use, x_{il} is land use, and P_i is precipitation ($\partial r_i / \partial x_{iN} > 0, \partial r_i / \partial\, x_{i1} < 0, \partial r_i / \partial P_i > 0$). Precipitation is stochastic in our simulation, and hence so is the load.

The load from each farm is transported to the Gulf of Mexico, which is the chief area of concern for policy purposes. The proportion of loads that is delivered is modeled as a constant delivery coefficient, T_i, so that total delivered loads are $a = \sum_i T_i r_i$. This relation represents a first-order approximation to the actual transport process, which is thought to be reasonable in many cases (Roth and Jury 1993). Transport from each farm is given by a stochastic transport coefficient, although as we describe below our focus is on mean delivered loads so only the mean coefficient matters. The environmental component is developed using USDA-NRI data and results from the USGS SPARROW model (Smith et al. 1997), along with precipitation data from NOAA. This data is statistically aggregated for each land quality type over the 8-digit HUCs to provide loading functions and delivery coefficients for each aggregate farm. A more complete description of the model is available in a technical appendix available from the authors.

We define a first-best allocation of pollution control efforts as one that maximizes V subject to the following environmental constraint

(2) $E\{a\} \leq T$

where T is a target level of delivered loads and E is the expectations operator over all uncertain variables.[1] In each of the simulations below, we take T to be a 20 percent reduction from the unregulated baseline nitrogen loads at the Gulf Coast.

We consider four policy options for achieving the goal defined by (2). The first option is a subsidy on reductions in estimated loads, $s_i(r_{i0} - E\{r_i\})$, where s_i is the farm-specific subsidy rate, and r_{i0} is farm i's estimated baseline loads from which the subsidy is calculated. This targeted subsidy can be first-best within the context of the current model provided the subsidy rates are optimally differentiated to reflect each farm's delivery of nitrogen loads (Baumol and Oates 1988).

There may be practical limitations to the implementation of a first-best system, however, for at least two reasons. First, the subsidies are based on estimated as opposed to actual emissions (which are unobservable given their nonpoint nature). This means that a model of pollution loads must be developed and provided to both farmers and the regulatory agency so that they each know how farmers' production and pollution control actions affect their subsidy. A second potential barrier to implementation is that it may be difficult, for either administrative or political reasons, to differentiate the subsidy rates across producers. These issues lead us to consider three second-best subsidies: (1) a targeted nutrient management subsidy (actually, nutrient use reduction), $s_{iN}(x_{iN0} - x_{iN})$, where s_{iN} is farm i's subsidy rate and x_{iN0} is the farm's initial level of nitrogen use, (2) a non-targeted (uniformly applied) subsidy on reductions in estimated loads, and (3) a non-targeted nutrient management subsidy. The targeted nutrient subsidy is second-best because it only targets one input affecting emissions; if all inputs affecting emissions were targeted with farm-specific rates then a first-best outcome would be possible. The non-targeted subsidy approaches cannot be first-best because they fail to take into account the unique marginal environmental impacts of each farm's loads. But although these final three policy options cannot be first-best, they might be preferred over the first-best approach if they result in sufficiently lower transactions costs (Helfand and House 1995; Shortle et al. 1998).

Handling uncertainty in the simulation experiment

The components of the model are calibrated using available data and parameters as described in the technical appendix. By calibration, we mean that some parameters are specified *a priori*, while others are adjusted so that the model replicates available data for the unregulated baseline scenario. For the most part, the specified parameters are drawn from a literature that reports a range of values. This parameter uncertainty is dealt with through an *ex post* Monte Carlo analysis (Abler and Shortle 1995; Davis and Espinoza 1997; Claassen and Horan 2001). The Monte Carlo analysis is essentially a sophisticated sensitivity analysis that enables us to determine the robustness of model results for a range of parameter values.

For a particular policy scenario, the Monte Carlo analysis proceeds by solving the model K times to produce K simulations or samples. For each sample, we randomly draw a set of values for the specified parameters and then calibrate and solve the model. Each sample essentially represents a different possible state of the Corn Belt – and hence a distinct watershed in terms of economic and environmental conditions. The K samples therefore produce a distribution of results. For instance, sample expected net benefits are $\sum_{k=1}^{K}(\text{Max}\quad\{V_k \mid E\{a\} \leq T\})/K$, where the subscript k denotes the kth sample. The parameters and their distributions, as well as the choice of our sample size of K=1000, are described in the technical appendix.

Results

Simulation results for the four policy options are presented in Table 2, with reported welfare measures representing reductions from the unregulated baseline scenario. We begin by considering the impacts of the two targeted subsidies. Subsidies to reduce estimated runoff (performance-based subsidies) are first-best in this model, although targeted nutrient management subsidies produce almost equivalent results to net private surplus, consumer surplus, and returns to non-land factors. Because performance-based subsidies indirectly target both land and fertilizer (the only two inputs affecting runoff in this model), this result suggests that altering nitrogen use is by far the most efficient approach for reducing nutrient loads, whereas altering land use to confront the problem would be a comparatively costly measure. Indeed, differences in returns to landowners under the two approaches are not great as farmers exhibit only a slightly larger demand for land under the first-best approach. Although the efficiency of these two approaches is almost equivalent, there are important differences in the amounts farmers receive. Specifically, the total subsidy payment is considerably larger under the nutrient management scenario ($87 million vs. $27.7 million) –

not because the nutrient management subsidy pays for more controls but rather because it effectively pays a higher price per unit of control. Accordingly, farmers will generally prefer targeted nutrient management subsidies to targeted performance subsidies.

The non-targeted subsidies are less efficient than the targeted subsidies, as theory suggests. Without the ability to target the subsidies in accordance with a farmer's marginal control costs and marginal environmental impacts, the environmental goal *T* will be achieved by having farmers with high (low) marginal control costs and/or small (large) marginal environmental impacts facing inefficiently high (low) subsidy rates. The additional loss to net private surplus under a non-targeted, performance-based approach is small, however, because such incentives still encourage farmers to consider the environmental impacts of their actions. In contrast the loss to net private surplus under a non-targeted nutrient management subsidy is almost three times larger than under a targeted subsidy because a non-targeted nutrient management subsidy increases the opportunity cost of nutrient use in a way that may have little correlation to the associated environmental impacts. For many farms the opportunity cost of nutrient use will be so inefficiently high that significant output effects will result. This is the reason for greater loss to consumers and all factors of production under the non-targeted nutrient management subsidies relative to the non-targeted performance subsidies. But the output effects are not bad for everyone, as they result in larger subsidy payments and higher output prices that drive producer returns up even as land utilization declines. While these profits are attributed to producers in our comparative static analysis, some portion of these gains would likely be capitalized into land values. The result is that farmers in aggregate prefer non-targeted nutrient subsidies over all of the more efficient policy approaches.

Now consider how farmers operating on different land quality types in different watersheds fare under the various subsidy approaches. The net gains to producers (i.e., post-subsidy profits plus returns to landowners) relative to the unregulated baseline are reported in Table 3. There are wide variations in impacts to producers across watershed/land type. But for each policy, the rankings of gains across producers is consistent, with producers in HUC 07 who operate on HP/non-HEL land receiving the most gains, producers in HUC 05 who operate on HP/non-HEL land receiving the next highest gains, and so on.

These rankings are perfectly correlated with production shares by region. Consider the targeted policies, the outcomes of which optimally emphasize proportionately greater (fewer) pollution controls for producers with low (high) marginal profits and high (low) marginal environmental impacts. If we take a producer's production share to be an index of marginal profits and divide through by the producer's delivery coefficient, the resulting index is an inverse measure of control. This index is almost perfectly correlated to production shares and hence producer net gains in the current model, implying that producers facing the least stringent controls gain the most. This makes sense if we consider output effects. Producers who face incentives to undertake significant pollution controls will end up reducing output, resulting in an increased corn price. Producers facing less stringent control incentives benefit from this increased price. Moreover, they must be paid a greater subsidy to overcome these output price effects. The result is that they gain the most from the subsidy programs.

Similar results arise for the non-targeted subsidy programs, although the divergence in producer net gains is increased relative to the targeted case. In the non-targeted case, producers with a low control index (i.e., high marginal profit/low marginal impact producers) face inefficiently high incentives for pollution control while producers with a high control index face inefficiently low incentives. Although low control index producers undertake greater controls, they gain even more than in the targeted case because they now face a larger subsidy and overall there are more output effects that further increase the corn price. High control index producers also generally gain under a non-targeted policy, but their net gain is comparatively small because they still bear the bulk of pollution control costs.

Subsidy rates for the various programs are reported in Table 4. For the targeted performance-based policies, these rates are perfectly correlated to delivery coefficients: smallest rates go to producers having the smallest delivery coefficients and largest rates go to producers having the largest delivery coefficients. When producers evaluate their marginal profits relative to the subsidy (marginal opportunity cost) the result is a pattern of control efforts consistent with the control index described above. For nutrient-based policies, the pattern of targeted subsidies is only moderately correlated to either the delivery coefficients or the control index. The reason is that these subsidies must also account for the marginal impact of nitrogen on estimated runoff levels. But when producers evaluate their marginal incentives the pattern of control efforts will be consistent with the control index.

A number of results so far have been driven by output price effects. We now examine the role of price effects in more detail by considering subsidy levels and net gains to farmers for the case in which the corn price was fixed. Table 5 reports mean subsidy rates and producer net gains for this situation. Two results are worth mentioning. First, the subsidy rates are all smaller than when output price is fixed. This is consistent with the statements we made above that the subsidies must be increased when output price is variable in order to offset the price effects associated with the policy. This issue is described in greater detail in Claassen and Horan (2001). The second result is that producer net gains are considerably smaller when output price is fixed. Surprisingly, the net gains are negative under a uniform nutrient policy whereas they are the largest under this policy when output price is variable. This means that most of the income transfers realized in Tables 2 and 3 are a direct result of changes in price and the associated impacts on profits, and also an indirect result of the larger subsidy rate needed to offset the price effects. These results also suggest that the degree of price effects have an important role in determining which subsidy policy producers prefer, as targeted nutrient management subsidies provide greater net gains when price effects are unimportant.

Finally, we consider the impact of targeting when it comes to policy goals. Specifically, consider a policy goal to reduce runoff by 20 percent from each region, so that the environmental goal *T* is achieved without any regard to delivery coefficients. In this case, for example, the first-best outcome would result in an expected private net surplus reduction of $101.4 million, compared to $38.5 million as reported in Table 2. The difference would be greater for the less efficient policies. Clearly, it is important to take pollution delivery into account when designing agricultural pollution control programs.

Conclusion

We considered four policies designed to reduce nitrogen loading to the Gulf of Mexico from the Corn Belt. We incorporated heterogeneity in the underlying land base, production technology, and the watershed itself in term of propensity toward nitrogen runoff and transport to the Gulf of Mexico. Finally, unlike many models of non-point pollution policy, we incorporate input and output markets to study the role of price effects in determining optimal subsidy rates, the social cost of reducing nitrogen runoff, and the distribution of these costs among farmers and consumers.

Several results are worth highlighting. First, targeting is critical in practice-based policies. While targeting makes little difference when applied to the expected runoff-based subsidy payments, the cost to the economy of the targeted nutrient management policy is only one-third the cost of the non-targeted nutrient management policy.

Second, output effects and output price changes play a large role in determining program performance. Higher prices and higher subsidy rates mean that the cost of nutrient loadings is higher for both consumers and taxpayers than would be apparent when price effects are not considered. Farmers and landowners, on the other hand, benefit significantly from these output price increases.

Finally, results suggest that returns to farmers and landowners vary significantly across regions and land types for both targeted and non-targeted policies. Non-targeted policies are sometimes viewed as more equitable, because all producers face the same subsidy rate. In a heterogeneous setting, however, the effect of a uniformly applied subsidy rate will be different for different producers on different type of land. Output price effects tend to exacerbate these differences. Ultimately, we find very little difference in distributional outcomes to producers between uniformly and non-uniformly applied (targeted) policies. Thus, we find no reason to believe that uniformly applied policies produce a more uniform distribution of returns to producers.

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Table1. Distribution of Land by Quality Class (million acres)[1]

	non-HEL	HEL
high productivity (HP)	58.20	10.39
low productivity (LP)	21.74	10.33

[1] Total cropland is roughly 100 million Acres

Source: ERS analysis of National Resources Inventory (NRI) data.

Table 2. Aggregate welfare impacts (difference from baseline) of various green payment programs (in millions $)

Welfare Measure	Payments to reduce estimated runoff		Nutrient management payments	
	Targeted	Non-targeted	Targeted	Non-targeted
Net private surplus	-38.4[a]	-42.3	-38.4	-118.3
	(5.9)[b]	(6.7)	(6.0)	(39.0)
Consumer surplus	-369.0	-411.5	-371.4	-707.3
	(72.4)	(85.4)	(73.1)	(283.8)
Post-subsidy profits	302.6	336.8	369.9	458.8
	(52.2)	(52.2)	(55.2)	(58.2)
Return to landowners	86.2	94.6	80.7	-6.6
	(52.3)	(58.8)	(52.5)	(270.5)
Net gain to farmers	388.9	431.4	450.7	452.2
(profits + landowner returns)	(70.8)	(84.0)	(77.8)	(285.4)
Return to fertilizer	-24.3	-27.3	-24.3	-61.0
	(2.3)	(3.2)	(2.3)	(6.8)
Return to capital	-2.4	-2.6	-2.4	-4.9
	(1.3)	(1.5)	(1.3)	(3.0)
Return to labor	-3.8	-4.1	-3.8	-5.5
	(2.0)	(2.2)	(2.0)	(4.5)

[a] Sample mean. [b] Sample standard deviation.

Table 3. Distributional impacts (difference from baseline) to farmers of various green payment programs, by land-type and watershed (in millions $)

Policy scenario	Watershed	Land type			
	(2-digit HUC)	HP / non-HEL	HP / HEL	LP / non-HEL	LP / HEL
Targeted payments to reduce estimated runoff	05	56.2[a]	4.1	15.0	1.6
		(10.1)[b]	(0.9)	(2.6)	(1.4)
	07	181.5	23.4	18.3	10.9
		(32.5)	(4.7)	(3.8)	(3.1)
	10	41.6	9.1	17.9	9.3
		(7.4)	(1.7)	(3.2)	(1.8)
Non-targeted payments to reduce estimated runoff	05	62.9	4.9	17.0	2.1
		(12.1)	(1.0)	(3.2)	(0.7)
	07	202.2	26.5	20.3	12.4
		(38.4)	(5.8)	(5.0)	(3.7)
	10	45.2	9.5	18.6	9.7
		(8.6)	(2.2)	(3.8)	(2.3)
Targeted nutrient management payments	05	56.5	7.3	16.5	5.8
		(10.1)	(1.6)	(3.1)	(2.1)
	07	183.7	35.5	29.9	27.2
		(33.2)	(6.6)	(5.3)	(4.8)
	10	42.6	12.5	20.2	12.9
		(7.7)	(2.3)	(3.7)	(2.4)
Non-targeted nutrient management payments	05	120.5	10.6	33.5	5.2
		(45.9)	(4.1)	(12.6)	(2.4)
	07	389.8	56.9	47.2	29.8
		(152.3)	(23.0)	(17.3)	(12.3)
	10	90.0	21.9	40.7	22.5
		(34.3)	(8.7)	(15.1)	(8.5)

[a] Sample mean. [b] Sample standard deviation.

Table 4. Subsidy rates from various green payment programs, by land-type and watershed[a]

Policy scenario	Watershed	Land type			
	(2-digit HUC)	HP / non-HEL	HP / HEL	LP / non-HEL	LP / HEL
Targeted payments to reduce estimated runoff	05	0.34[b]	0.46	0.39	0.40
		(0.09)[c]	(0.12)	(0.1)	(0.1)
	07	0.25	0.32	0.30	0.35
		(0.06)	(0.09)	(0.08)	(0.1)
	10	0.16	0.23	0.18	0.23
		(0.04)	(0.06)	(0.05)	(0.06)
Non-targeted payments to reduce estimated runoff	05				0.34
	07				(0.09)
	10				
Targeted nutrient management payments	05	0.07	0.41	0.16	0.79
		(0.08)	(0.08)	(0.07)	(0.15)
	07	0.07	0.35	0.36	0.61
		(0.05)	(0.06)	(0.06)	(0.11)
	10	0.09	0.29	0.17	0.30
		(0.03)	(0.05)	(0.03)	(0.05)
Non-targeted nutrient management payments	05				0.34
	07				(0.04)
	10				

[a] Estimated runoff subsidies expressed in absolute terms. Nutrient management subsidies expressed relative to the initial fertilizer price.

[b] Sample mean. [c] Sample standard deviation.

Table 5. Mean subsidy rates and aggregate impacts on net gains to farmers (difference from baseline) of various green payment programs when output price is fixed (in millions $)

Welfare Measure	Payments to reduce estimated runoff		Nutrient management payments	
	Targeted	Non-targeted	Targeted	Non-targeted
Mean subsidy rates (across regions)	0.25[a]	0.28	0.25	0.26
	(0.04)[b]	(0.07)	(0.03)	(0.03)
Net gain to farmers	41.4	43.6	91.5	-164.7
	(3.6)	(4.7)	(9.3)	(85.7)

[a] Sample mean. [b] Sample standard deviation.

Endnotes

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[1] There are many ways to define environmental goals. The ideal goal from an economic standpoint would be to limit the expected economic damages from pollution, for only in this case will the allocation that achieves the goal at least cost also be the allocation that achieves the goal with maximum net economic surplus (Shortle 1990). However, economic damages are not known and so we have opted for an alternative specification for the goal.