The Value of Spatial Information in
Evaluating Pollution Control Policies in Agriculture

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Abstract

Water quality and the need for pollution control in agriculture are well-established concerns in the United States. This paper addresses the effectiveness of using site-specific or spatial information to predict farm responses to a practice-standard NPS pollution control policy and the associated compliance costs. In this study a phosphorous-based nutrient management plan was used to evaluate four scenarios which make use of different amounts of information about farm characteristics. Results indicate more accurate predictions can be made using spatial information but there exists a need for further research.

Keywords

spatial information, heterogeneity, compliance costs, gross margins, typical farms

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INTRODUCTION

Water quality and the need for pollution control in agriculture are well-established concerns in the United States. In 1983 the states surrounding the Chesapeake Bay, along with the District of Columbia, the Chesapeake Bay Commission, and the Environmental Protection Agency agreed to protect and restore the Bay, which was affected, in particular, by nutrient pollution. In 1987 the parties agreed to reduce controllable nitrogen and phosphorous entering the Bay by 40 percent. Because agriculture contributes 39 percent of the nitrogen and 49 percent of the phosphorous that enters the Bay, farms throughout the Chesapeake Watershed were targeted for control (Chesapeake Bay Program). In 1992 parties adopted “tributary strategies” which target nutrient problems within each river basin (Chesapeake Bay Program).

This paper addresses the information used to design and evaluate non-point source (NPS) pollution control policies. Specifically, it is concerned with the value of site-specific or spatial information about farm characteristics which affect NPS pollution control costs. Previous works have addressed this issue in other contexts.

In 1993 Feuz and Skold showed that spatial information could allow for the use of a typical farm rather than a representative farm. In the context of production practices they found that using a typical farm, or subset of typical farms, reduces or eliminates bias in aggregation. They also found that many practices appear profitable from a single enterprise perspective but are less attractive when considered as part of a whole-farm system. Because averaging data implicitly assumes that surplus resources on one farm are available for use on another farm for which those resources are limiting, using averages can overstate production and/or production possibilities. To alleviate this problem they suggest developing a set of typical farms that include similar proportions of resource endowments, yields, and technologies.

In 1995 Wu and Segerson showed that spatial data could reduce or eliminate the biases of incorrectly estimating pollution per acre, and the number of polluting acres. Their research on groundwater contamination is rooted in the fact that site-specific characteristics affect production decisions and the transport processes of nutrients. They showed that if (1) the relationship between site characteristics and water quality is highly non-linear, or (2) the site characteristics determining crop choices are correlated with factors determining vulnerability to water contamination, then the use of aggregate data would lead to bias.

Preckle and Senatre analyzed farm commodity program participation, supply responses, and budgetary outlays. They evaluated a policy that would affect 1,427 farms by running a model on (1) each of the farms in the population, (2) a subset of 10 generated farms maintaining heterogeneity, and (3) the conventional method treating all the farms as homogenous.
They showed that the model based on heterogeneous farm responses would predict more subtle changes in farm responses than the single aggregate model. They stated that farm-policy analysis based on the behavior of a representative farm implicitly assumes that the farmers in the region are homogenously endowed.

In 1998 Carpentier, Bosch and Batie showed that spatial information could allow for the targeting of farms with lower costs of complying with a nitrogen runoff control policy. The policy used in the analysis was to reduce nitrogen loadings from an area by 40 percent. They showed that using spatial information to target specific farms reduced control costs by 75 percent and transaction costs by 80 percent over a uniform implementation of the policy. Savings are made, in addition to the lower compliance costs, because fewer farms were required to participate, which lowered contracting and enforcement costs, and because some farms had very high costs of achieving the 40 percent reduction under the uniform policy.

The objective of this paper is to evaluate the effectiveness of using site-specific or spatial information to predict farm responses to a practice-standard NPS pollution control policy and the associated compliance costs. The area of study is the Muddy Creek Watershed in Rockingham County, Virginia. Nearly two-thirds of the area is occupied by livestock intensive farms raising dairy and beef cows and poultry. Because of the large amounts of feed imports to the area, nutrients in livestock and poultry manure exceed recommended crop applications. Because the ratio of nitrogen to phosphorous in manure is less than the ratio of nitrogen to phosphorous requirements for crops, current practices involve spreading poultry litter to meet crop nitrogen requirements. This, however, causes the farmers to exceed phosphorous requirements. A phosphorous-based nutrient management policy (P-standard), which is evaluated in this study, limits the spreading of poultry litter and livestock manure to amounts needed to meet crop phosphorous requirements. The affects of the policy will be twofold. The first is that the demand for poultry litter will decrease, pushing its price down. This will lower the revenues of poultry growers. The second affect is that farmers will have to purchase nitrogen fertilizer to compensate for the shortfall from reduced manure and litter applications. Manufactured fertilizer is more costly than litter from nearby farms so these farmers will realize an increase in costs.

METHODS

Farms

The Muddy Creek watershed contains 121 farms with a combined area of 13,100 acres. The farms range in size from eight to 430 acres and average 108 acres. There are five types of farms with production for market consisting primarily of dairy, poultry and beef products, with poultry litter and crops also serving as revenue sources for some farms. Farms with dairy operations represent 52 percent of the total population and those with poultry operations represent 35 percent.

The farms were analyzed under four scenarios. The first was the case of perfect information where the management behavior and gross margins were analyzed for all 121 farms. The critical data for the farms were provided by the Virginia Department of Conservation and Recreation (VA-DCR) in the form of geographic information systems (GIS) data layers containing land use, the distribution of soil types, and field boundaries. Farm boundaries and types were defined based on expert opinion of their number and distribution and a geometric procedure called the Thiessen Polygon method (Heatwole). Farm-generation points were determined from the set of farmsteads and poultry houses designated in the land use coverage while the farm types were randomly assigned based on the estimated distribution provided. The Thiessen Polygon method involved surrounding each farm generation point with an area that would provide the required fields to support the designated farm type with sufficient forage for beef and dairy animals. Farms in the area usually import grain for some dairy and all poultry feed. Animal numbers were assigned to the dairies and beef cattle farms based on the farm area. The estimated distribution of farms, based on interviews with experts familiar with the region, indicated that 57 percent of poultry operations raise turkeys and 43 percent raise broilers, therefore each poultry house was randomly assigned either 25,000 broilers or 7,000 turkeys to fit the distribution. The resulting polygon matrix data layer of farm types and boundaries was added to the GIS layer containing soil types and printed as a large-scale map. The map was reviewed by a conservationist for the National Resource Conservation Service of the USDA who verified or revised farm types and boundaries. The conservationist, who is familiar with the watershed, also provided information about the area and the practices of the beef cattle and dairy farms. The GIS data layers were then revised to the form which was used for this study.

Soils were grouped into six categories, soil resource groups (SRG), according to crop yield potential based on the Virginia Agronomic Land Use Evaluation System, VALUES (Donohue et. al.). These were used to determine the productivity of each farm and their crop rotation.

The second scenario considered the watershed represented by one farm, which was described using only the original soil-type data layer and the estimate of the farm-type distribution. To assign land to the representative farm, the total area of each SRG was divided by the estimated number of farms – for this study the actual number of farms, 121, was used. Since farms with dairy operations represent 52 percent of the total population, and those with poultry operations represent 35 percent, the representative farm was selected as a dairy/poultry farm with capacity for 80 cows and one broiler house.

The third scenario used the spatial data described in the perfect information scenario to define ten farms typical of each farm type and size. Each was defined using the average number of acres of each SRG and the corresponding number of animals.

The fourth scenario analyzed the watershed as one "mega farm." In this case the original soil-type data layer was used and the farm was given the capacity to produce all animal types from the distribution. This differs from the representative farm which was only given the capacity to produce dairy cows and broilers.

Table 1: Characteristics of Farms: By farm Type and Information Scenario

Farm Type	Number Of	Land Area (acres)	Corn Yield (bushels/acre)	Dairy Cows	Beef Cows	Poultry Houses
Scenario One--Perfect Information						
Small Dairy	20	1,327	114	1,200	-	-
Medium Dairy	21	3,506	116	2,100	-	-
Small Dairy/Poultry	9	623	126	540	-	18
Medium Dairy/Poultry	8	1,295	115	800	-	16
Medium Beef	18	1,278	121	-	1,260	-
Large Beef	17	2,446	119	-	2,550	-
Small Beef/Poultry	8	393	115	-	320	16
Medium Beef/Poultry	8	767	119	-	560	16
Large Beef/Poultry	8	1,161	120	-	1,200	16
Poultry Only	4	303	110	-	-	12
Total	*121*	*13,100*		*4,640*	*5,890*	*94*
Scenario Two--Single Representative Farm						
Dairy/Poultry	1	108	118	80	-	1
Scenario Three--Typical Farms						
Small Dairy	1	66	114	60	-	-
Medium Dairy	1	167	116	100	-	-
Small Dairy/Poultry	1	69	126	60	-	2
Medium Dairy/Poultry	1	162	115	100	-	2
Medium Beef	1	71	121	-	70	-
Large Beef	1	144	119	-	150	-
Small Beef/Poultry	1	49	115	-	40	2
Medium Beef/Poultry	1	96	119	-	70	2
Large Beef/Poultry	1	145	120	-	150	2
Poultry Only	1	76	110	-	-	3
Scenario Four--Mega Farm						
Mega Farm	1	13,100	118	4,640	5,890	94

Policy

The baseline for which each of the farm scenarios was analyzed contains no environmental constraints. Each farm under each scenario is free to maximize profits given only endogenous resource constraints and exogenous prices. The policy to be implemented is one that requires a phosphorous-based nutrient management plan. The constraint is that farmers must comply with the P-standard and can only apply the quantity of phosphorous required to meet crop needs. Currently farmers apply low cost poultry litter to meet crop nitrogen requirements. In doing this, however, phosphorous levels are often exceeded. It is expected that the constraint will have two affects. The first is that it will create a surplus of poultry litter that will drive its price down and reduce the revenues of poultry producers. The second is that it will force farmers who apply litter and manure to purchase commercial fertilizers to make up the difference in nitrogen caused by the reduced applications. These farmers will realize an increase in marginal costs. The price of cow manure is assumed to be negative under the baseline scenario and to decrease after the P-standard is applied. The price for poultry litter is assumed to be positive under the baseline scenario and zero after the policy is implemented.

ECONPLAN

ECONPLAN, a linear programming farm model written in GAMS, was used to estimate management decisions and compliance costs. The assumed objective function is maximization of farm profits. The model obtains inputs describing the resources of each farm, costs and technical requirements, per unit costs of crop and livestock enterprises, and policy constraints and incentives. Resource constraints are of three types: physical, policy, and technical. Physical constraints include available crop and pastureland, livestock facilities, and farmer labor by season. Policy constraints relate to the best management practices, which in this study is a mandatory phosphorous-based nutrient management planning. Technical constraints include livestock ration requirements, crop nutrient requirements, a requirement to produce all crops and livestock products marketed, and the disposition of animal manure. ECONPLAN determines the set of activities that maximize the objective function which. Crop activities require the allocation of limited acreage resources to crop rotation, tillage, and nutrient application alternatives. Livestock activities include the selection of livestock feed rations and levels of livestock production. Farm-level outputs of ECONPLAN include quantities of livestock and crop production, acreages of crops/pasture and associated tillage and nutrient applications, variable costs, levels of best management practices adopted, variable costs of production, net farm revenue above cash costs, and shadow prices of land, livestock facilities, and manure storage.

ECONPLAN was run eight times, once for each set of farms under the baseline and policy scenarios. The cost of complying with the phosphorous policy was calculated as the difference between gross margins under the baseline and P-standard.

RESULTS

As mentioned above, it was expected that the P-standard constraint would cause gross margins to decrease as a result of lower prices for poultry litter and cow manure, and the limit on their applications. Table 2 provides the animal units produced and the gross margins for each information scenario under the baseline and P-standard. The outcome of the represented farm was multiplied by 121 to aggregate it to the size of the watershed. The typical farms were similarly summed based on the total acreage of each type to maintain their proportions, and then the categories were summed to derive a total for the watershed.

Table 2: Animal Units Produced and Gross Margins, Aggregated for all of Muddy Creek Watershed

Baseline	**Population**	**Representative**	**Typical Farms**	**Mega Farm**
Crops (acres)	13,100	13,100	13,094	13,100
Cows Milked	3,699	9,291	4,640	4,640
Beef (head)	7,685	-	8,046	-
Poultry (houses)	94	116	94	94
Total Gross Margins	$8,819,286	$11,115,234	$9,797,542	$9,818,838
P-Standard	**Population**	**Representative**	**Typical Farms**	**Mega Farm**
Crops (acres)	13,100	13,100	13,094	13,100
Cows Milked	3,790	9,291	4,640	4,640
Beef (head)	7,853	-	8,046	-
Poultry (houses)	94	116	94	94
Total Gross Margins	$8,648,726	$10,904,448	$9,488,981	$9,542,356
Net Cost	$170,560	$210,786	$308,561	$276,482

As Table 2 indicates, the only difference in production units is under the population, or perfect information scenario, which had small increases in the number of both dairy and beef cattle. The P-standard had no other affect on output decisions. The mega farm did not select beef in either scenario. This is probably because the returns to dairy and poultry are higher. Gross margins under each scenario fell as expected. Each of the limited information scenarios overstated gross margins under the baseline and P-standard, and the compliance cost of the policy. The set of typical farms provided the best estimates of gross margins followed closely by the mega farm. Contrary to this result is that the single representative farm provided a more accurate estimate of the compliance cost of the policy.

The more accurate prediction of compliance costs by the representative farm can be explained by Table 3 which shows that the representative farm had offsetting errors in predicting the lost revenue from lower poultry litter prices, the cost savings of these lower prices to their consumers, and to the increase in the quantity of commercial fertilizers purchased. Table 3 also shows that the representative and mega farms did not select poultry litter as feed or crop nutrients, whereas the population and typical farms did. The decrease in the purchase price of litter for nutrient application, which is assumed to be positive in both cases, but lower under the P-standard, results in a decrease in costs under the population and typical farm scenarios. Furthermore, the representative and mega farms predicted a decrease in the quantity of commercial fertilizers purchased while the population and typical farms predicted an increase. This difference in predictions effectively moves gross margins in opposite directions.

Table 3: Costs of P-Standard for Various Spatial Representations of Muddy Creek Watershed

Baseline	**Population**	**Representative**	**Typical Farms**	**Mega Farm**
Litter Sales				
Quantity	39,030	23,111	42,223	37,831
Revenue	$250,849	$173,158	$267,974	$246,077
Litter Purchases (Nutrients)				
Quantity	1,979	-	1,370	-
Cost	$17,797	-	$12,259	-
Litter Purchased (Feed)				
Quantity	1,212	-	1,285	-
Cost	$17,000	-	$17,789	-
Fertilizer Purchased				
Quantity	33,933	38,673	36,341	43,157
Cost	$274,145	$309,734	$292,908	$345,618
P-Standard				
Litter Sales				
Quantity	39,164	17,420	42,046	33,587
Revenue	-	-	-	-
Litter Purchases (Nutrients)				
Quantity	2,341	-	1,734	-
Cost	$14,038	-	$10,474	-
Litter Purchased (Feed)				
Quantity	1,238	-	1,285	-
Cost	$17,371	-	$17,789	
Fertilizer Purchased				
Quantity	35,765	34,841	36,848	39,768
Cost	$293,059	$285,578	$300,624	$294,509

There are also explanations as to the small differences in the predictions made by the typical set of farms and the representative farm. As mentioned above, Table 2 shows that the output decisions under the population scenario varied only slightly between the baseline and the P-standard cases. This implies that there were few affects to be modeled. The results also indicate that the farms individually and in aggregate were maximizing their resources in the baseline case and under the P-standard; therefore there were no resources for the representative farm to assume transferable – which is a primary argument Prekle and Senatre make. Furthermore, the endowments of the farms are relatively homogenous. Table 1 highlights the fact that the crop yield of the various farm types are relatively equal. This implies that what is optimal for one farm is generally optimal for another. Finally, the added net costs of the P-standard simply were not enough to significantly alter behavior under any of the information scenarios.

Table 2 reflects a problem with the representative farm when aggregating to the watershed level. Poultry operations are prevalent in the region and will be impacted by the policy, so they should be represented. The representative farm, a dairy/poultry farm, was given the capacity to operate one poultry house, a reasonable and necessary resource allocation. When the production decisions were aggregated however, the number of poultry houses exceeded what is actually in the watershed. This explains a large portion of the overstated gross margins.

CONCLUSIONS

Although progress has been made in the abatement of water pollution in the state of Virginia and its partners in the Chesapeake Bay Program, significant reductions in pollutants from agricultural sources have not been realized. The objective of this paper was to evaluate the effectiveness of spatial information about farms and watersheds, in predicting farm management decisions and profits under a practice-standard NPS pollution control policy. The analysis was conducted using a perfect information scenario in which all farm characteristics of the Muddy Creek Watershed were included, and three scenarios of lesser information: a representative farm, a set of typical farms, and a mega farm. Each of these scenarios was evaluated under a baseline scenario with no policy constraint and a scenario in which a restriction on phosphorous applications was imposed. The study indicated that more accurate predictions of gross margins can be made using a model based on site-specific spatial information. The differences in predicted costs were not large due to the similarities among farms and crop productivity.

Although this study does not provide conclusive evidence that the use of spatial data will significantly improve predictions, it does suggest distinctions for further research. The fact that production decisions between the baseline and P-standard varied only slightly in the perfect information scenario suggests that that there was very little behavior to be ignored by the representative farm and gained by the typical farms. The generally homogenous nature of the farm endowments indicate that resources that are average for the watershed are also average for each individual farm. Since there is clear evidence that the use of spatial data can lead to more accurate predictions of behavior and profits, further research should evaluate watersheds with more diversity in farm types and soil resources.

Another limitation of this study was that only one policy instrument was evaluated, the P-standard. Further research is needed to evaluate management decisions under policies such as restricted cropping practices, buffers, and manure treatment. Furthermore, a performance-based standard, which limits nutrient losses, would allow more flexibility in farm responses made to comply with the standard. It is possible that better information about farm characteristics would be more important in predicting farm costs and production responses made to meet such a standard compared to a less flexible practice standard.

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