Targeting Environmental Protection in Agriculture: IPM and BMPs as Environmental Performance Indicators

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Selected paper for 1999 AAEA meetings.

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Abstract, not more than 50 words.

Nonparametric technical efficiency estimates of potentially polluting input use in soybean and wheat indicate substantial heterogeneity across farms. This implies large costs would be associated with uniform standards or incentives to regulate these inputs. While technical efficiency is not observable, indicators of environmentally beneficial practices are found useful predictors.

Abstract (Extended)

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Two observations motivate this paper. First, traditional Pigouvian strategies (e.g. taxes or standards) have had limited application to management of the environmental impacts of agriculture. Elasticities of use of polluting inputs with respect to their price appear to be small suggesting that substantial tax rates would be required to induce necessary changes in use, see e.g. Carpentier and Weaver (AJAE,1997). Also, the impact of changes in use on environmental pollution is estimated to be small, see Weaver et al.(J. of Envir. Man., 1996). Use of standards and incentives are inefficient when the regulated population is heterogeneous. Carpentier and Weaver (AJAE, 1997) have shown heterogeneity is substantial and important to consider in estimation of the productivity of polluting inputs such as pesticides. Nonparametric results further extend evidence of this heterogeneity to technical efficiency in use of polluting inputs, see Fernandez-Cornejo (AJAE, 1994) or Piot-Lepetit, et al. (J. of Ag. Econ. 1997). In both cases, substantial and heterogeneous inefficiency in the use of polluting inputs such as pesticides and fertilizers were reported. Second, at least two previous studies have considered the technical efficiency of potentially polluting input use in agriculture. Piot-Lepetit et al. (Applied Economics, 1997) estimated both radial and nonradial technical efficiency of aggregates of polluting inputs (fertilizers and pesticides) in French cereal production. Their results found substantial opportunities for reduction in use of these inputs would be associated with improved efficiency. The opportunity for this type of free lunch adjustment in the use of these inputs suggest a second basis of inefficiency in traditional Pigouvian approaches.

In this paper, we re-examine two hypotheses relevant to the selection of policy approaches to managing pollution from agricultue. First, we examine the hypothesis that substantial reduction in use of polluting inputs can be achieved through improvement in the technical efficiency of their use. Second, we reexamine the extent of heterogeneity in the efficiency of use of potentially polluting inputs in agriculture. We find both a high level of heterogeneity and significant opportunity for improvement in efficiency in input use. Based on these results we extend past work by evaluating the usefulness of information describing current use of specific IPM practices or other environmentally beneficial BMPs to classify farm-level environmental performance as measured by technical efficiency in polluting input use.

High quality survey data for Pennsylvania subsamples of soybean and wheat producers are analyzed. In both cases, the survey data allow disaggregation of polluting inputs and of environmentally beneficial practices. Fertilizers are disaggregated to nitrogen, potassium, phoshorous, and lime. Pesticides are disaggregated to insecticides, herbicides, and fungicides. While Fernandez-Cornejo were limited to use of a simple binary indicator of any IPM use, here we use a set of binary, polychotomous, and continuous indicators of specific environmentally beneficial practices (e.g. use of nitrogen tests, use of variety selection, use of scouting, extent of scouting, specific land

use practices, tillage practices). Nonparametric estimates are implemented under nonincreasing returns to scale and strong disposability.

First, the distribution of efficiency estimates is reported and characterized nonparametrically. Our results indicate considerable heterogeneity even after the distribution is conditioned by measures of farm attributes such as scale and farm operator characteristics. These results suggest that uniform Pigouvian standards would result in substantial variation in shadow costs of the standard across producers. Results are reported indicating the potential for reduction of inefficiency depending on crop and polluting input and conditional upon farm attributes. Results confirm heterogeneity is substantial suggesting the benefits of targeting are also large. Potential for targeting based on current use of environmentally beneficial practices is confirmed and indicators of potential for improvement of technical efficiency in use of polluting inputs are evaluated.

Background

Traditional Pigouvian strategies (e.g. taxes or standards) have not been applied to manage the environmental impacts of agriculture. First, elasticities of use of polluting inputs with respect to their price appear to be small suggesting that substantial tax rates would be required to induce necessary changes in use, see e.g. Carpentier and Weaver (1997). Second, the impact of changes in use on environmental pollution is also estimated to be small, see Weaver et al.(1996). Use of standards side steps these problems, however, they are most attractive when the regulated population is homogeneous. Carpentier and Weaver (1997) have shown heterogeneity across farm producers can be substantial and important to consider in estimation of the productivity of polluting inputs such as pesticides. Nonparametric results further extend evidence of this heterogeneity to technical efficiency in use of polluting inputs, see Fernandez-Cornejo (1994) or Piot-Lepetit, et al. (1997). In both cases, substantial and heterogeneous inefficiency in the use of polluting inputs such as pesticides and fertilizers were reported.

Within this context, use of incentive-based contracts becomes attractive, however, their design and effectiveness also depends upon the extent and nature of heterogeneity across the regulated population. Extensive use of this approach has been made in both the U.S. and E.U. to induce discrete changes in practices (e.g. IPM or BMPs). However, their application has been compromised by an absence of indicators of environmental performance that could be used to target qualification for incentives to change particular practices.

Only two previous studies have considered the technical efficiency of polluting input use in agriculture. Piot-Lepetit et al. (1997) estimated both radial and nonradial technical efficiency of aggregates of polluting inputs (fertilizers and pesticides) in French cereal production. Their results found an opportunity for between 12-18% reduction in these inputs. In a study of a sample of Florida vegetable farms, Fernandez-Cornejo (1994) estimated opportunity for radial and nonradial adjustment of aggregates of polluting input use (fertilizer and pesticides) to improve efficiency. Their results confirmed that substantial opportunity (e.g. reductions on average of 50%) exists for adjustment of polluting input use. They further considered how estimated input use efficiency is related to farm attributes. Their results indicate a strong positive relationship between efficiency and scale measured by land, form of business organization, and location, and a negative relationship with off-farm labor supply by the operator and use of unpaid family labor. Further, they found a strong though nonlinear relationship between use of IPM and efficiency. Farms up to 120 acres were found to be substantially less efficiency if they used IPM, while larger farms were found to be more efficient in use of polluting inputs if they used IPM.

In this paper, we re-examine the hypothesis that substantial reduction in use of polluting inputs can be achieved through improvement in the technical efficiency of their use. Further, we extend past work by evaluating the usefulness of information describing current use of specific IPM practices or other environmentally beneficial BMPs to classify farm-level environmental performance as measured by technical efficiency in polluting input use.

Approach

Nonparametric estimation of technical efficiency based on DEA has been recognised as an important tool for the development of recommendations for adjustment of factors of production (Brauer, 1990). Past studies have established the usefulness of this approach to evaluation of potential adjustment in inputs and outputs for cases where all products are variable, some factors are quasi-fixed, or some outputs are undesirable. Of interest in this paper is estimation of persistent technical inefficiency in the use of potentially polluting inputs. Clearly, persistent technical inefficiency in use of inputs that generate environmental impacts is of policy interest if it can be related to a control which may be influenced by policy.

Farrell measures of technical efficiency provide insights for total factor employment and propose equiproportional reduction of all factors necessary to attain technical efficiency (Farrell, 1957). While this type of measure of technical efficiency may be useful for some questions, the differential impacts of agricultural inputs on the environment would seem to beg for a measure of input specific potential for adjustment of input use. In the measurement of adjustment necessary to attain a technically efficient input bundle, the path between a technically inefficient point and an efficient one must be limited to economically efficient points. That is, only economically efficient adjustment is of interest. When technologies are homothetic, expansion paths are rays from the origin and recommendations for radial adjustments for technical efficiency are consistent with achieving economic efficiency under the given price structure. In this case, measures of radial technical efficiency (RTE) would be of interest to managers because they provide recommendations that are consistent with economic efficiency. This correspondence between radial technical adjustment and economic efficiency dissolves when technology is nonhomothetic. Figure 1 illustrates this point. Where technology is homothetic, a firm operating at A would be inefficient with respect to the isoquant BE.

To achieve technical efficiency, the firm would follow the ray AA* to point A*. In contrast, where technology is nonhomothetic, economically efficient adjustment would require the firm to adjust along a nonlinear expansion path, e.g. AA** to point A**. In this case, the radial adjustment AA* would provide a biased estimate of the economically efficient adjustment AA**. Importantly, the measurement of the adjustment required in the two inputswould necessarily be different. For the homothetic case, adjustment would be a equiproportional reduction in both inputs, while for the nonhomothetic case adjustment would be differing proportions.

The implications of this problem for the measurement of technical efficiency were recognised by Farrell (1957) though he maintained a focus on radial technical adjustment. The input based measures of Farrell and of Russell efficiency can be defined following these studies for a set of *J* firms indexed *j= 1,...,J*, each with access to the same technology that transforms a vector of inputs $x_j \in R_+^N$ into a vector of outputs $y_j \in R_+^M$. More generally, for the set of firms, we can define a $(J \times N)$ input matrix *X* and a $(J \times M)$ output matrix *Y*. The elements of *X* are assumed to be variable inputs. Suppose the technology satisfies the augmented regularity conditions adopted by Banker, Charnes, and Cooper (1984). The production possibilities set can be written as the following piece-wise linear technology:

$$P=\left\{(y,x^{v}):x^{v}\geq \lambda X^{v},\ y\leq \lambda Y,\sum_{j=1}^{J}\lambda_{j}=1,\lambda\in R_{+}^{J}\ \right\}$$

$$=\left\{(y,x^{v}):x^{v}\geq \sum_{j=1}^{J}\lambda_{j}x_{j}^{v},\ y\leq \sum_{j=1}^{J}\lambda_{j}y_{j},\sum_{j=1}^{J}\lambda_{j}=1,\lambda\in R_{+}^{J}\ \right\}(1)$$

where $\lambda=(\lambda_{1},\lambda_{2},\ldots,\lambda_{J})$ is the intensity vector with elements indicate the intensity with which each firm's production plan is taken into account in the construction of the technology frontier. By equation (1), the *jth* firm's production plan (y_{j},x_{j}^{v}) belongs to the production possibilities set, if, and only if, $(y_{j},x_{j}^{v})\in P$. Input based radial technical efficiency (RTE) is for the firm "0" as follows:

Measure	***Definition***	***Linear Program***
Radial	$R_{0}(y_{0},x_{0})=\min\{h:hx_{0}\in I(y_{0})\}$ where *h is scalar*	*$Min_{\lambda,z}\ \lambda$* *$\sum_{j=1}^{J} z_j x_{jn} \leq \lambda\ x_{0n}$, n=1,2,……,IT, ;* *Continuous variable inputs.* *$y_{0m} \leq \sum_{j=1}^{J} z_j y_{jm}$ m=1,2,..YT,Outputs.* *$\lambda_j \leq 1$;For N.S. $\sum_{j=1}^{J} z_j \leq 1$.*
Nonradial	$NR_{0}(y_{0},x_{0})=\min\{\hat{h}:\hat{h}x_{0}\in I(y_{0})\}$ where $\hat{h}$ *is* $1xN$	*$Min_{\lambda,z} \sum_{n\in\{i\vert x_{ji}\neq 0\}} \lambda_n / IT$* *$\sum_{j=1}^{J} z_j x_{jn} \leq \lambda_n x_{jn}$, n=1,2,……,IT, ;* *Continuous variable inputs.* *$y_{jm} \leq \sum_{j=1}^{J} z_j y_{jm}$ m=1,2,..YT,Outputs.* *$\sum_{n=1}^{IT} \lambda_n \leq IT$;For N.S. $\sum_{j=1}^{J} z_j \leq 1$.* *IT=# nonzero inputs*

Data Description

Estimates are based on data collected in the Pennsylvania implementation of the Agricultural Resource Management Study surveys of Soybean and Wheat Production

Practices for 1997. This survey was designed by the NASS, USDA and implemented with professionally trained enumerators. Extensive data on production practices were collected on selected fields across a sample of 400 producers selected as representative based on acreage planted. Data included farm level data describing acreage and production systems, as well as field specific data including seeding, fertilization, land use, pest management, field operation, and harvest practices. While the initial sample included 400 respondents due to the detailed nature of the survey, many questions were not appropriate for particular respondents. Based on the variables of interest to this study, we were able to analyze 108 observations for soybeans and 118 for wheat.

In both cases, the survey data allow disaggregation of polluting inputs and of environmentally beneficial practices. Fertilizers are disaggregated to nitrogen, potassium, phosphorous, and lime. Pesticides are disaggregated to insecticides, herbicides, and fungicides. Finally, while Fernandez-Cornejo were limited to use of a simple binary indicator of any IPM use, we use a set of binary, polychotomous, and continuous indicators of specific environmentally beneficial practices (e.g. use of nitrogen tests, use of variety selection, use of scouting, extent of scouting, specific land use practices, tillage practices).

Table 1 summarizes the characteristics of the data set. For soybeans, we view yield per acre and yield loss due to pests as outputs. Acres planted, seeding rate, applications of lime, nitrogen, phosphate, and potash, pesticide applied per acre, and acres treated with pesticide are specified as inputs. For the sample analyzed for soybeans, yields varied from 11.6 bushels/acre to 80.0 compared to a statewide average of 39, while yield loss due to pests ranged from 0 to 40.0. Mean acres planted for the sample was just under 100 acres. For each of the inputs, corner solutions of zero use were found across the firms as indicated by the percentage of zero responses. For the sample analyzed for wheat, yield varied from 17.0 to 100.0 bushels/acre compared to the state average of 52 with yield loss due to pests ranging from 0 to 20.0 bushels per acre.

Results

Initial estimates of efficiency for the samples of soybeans and wheat exhibited a high degree of heterogeneity suggestive of a two distinct subsamples of producers. One class of producers (Case 1) were found to face an efficient isoquant that allowed them to produce outputs without using particular inputs. A second set of firms (Case 2) were found to face an isoquant requiring use of all inputs. Figure 2 illustrates these cases. To proceed within the space constraint of this paper, we report only results for Case 2 firms. First, the distribution of efficiency estimates reported in Table 2 clarifies the existence of a high degree of heterogeneity in technical efficiency. Radial efficiency estimates range from .3880 to unity, while nonradial (the average of input specific estimates) estimates range from .2337 to unity. For specific inputs, efficiency scores indicated as zero occur when the use of the respective input was zero. To examine the relevance of the nonradial specification, we tested the hypothesis that the radial and nonradial average efficiency scores are equivalently distributed. Based on Kendall's τ test reported in Table 3 we can conclude the two indexes provide different rankings of the firms.

Our results indicate considerable heterogeneity even after the distribution is conditioned by measures of farm attributes such as scale of acreage harvested. Results of estimation of double limited Tobit models of the efficiency scores are reported in Table 4. Estimated parameters indicate that efficiency is conditional upon particular farm practices. Results reported indicate that efficiency is conditional upon how timing decisions for pre- and post-emergent herbicide application are made. They are also conditional upon whether the individual producer practices no-till planting.

Conclusions

This paper focused on evaluation of the extent of heterogeneity across farm level use of potentially polluting inputs. Fertilizers and pesticides were considered. For samples of Pennsylvania soybean and wheat producers, farm level data was used to estimate nonparametric measures of the technical efficiency with which these farms utilize these inputs. Substantial heterogeneity was found in technical efficiency. Secondly, substantial opportunity was found for improving the efficiency through reduction in the use of these inputs on many farms. Both the observed heterogeneity across the farm population and the inefficiency in current use implies that traditional uniform Pigouvian approaches to public management of the use of these inputs would be inefficient. Potential for targeting of farm specific instruments is affirmed by evidence that farm characteristics can be used to predict difficult to observe technical efficiency levels.

Figure 1 : Alternative Measures of Technical Efficiency

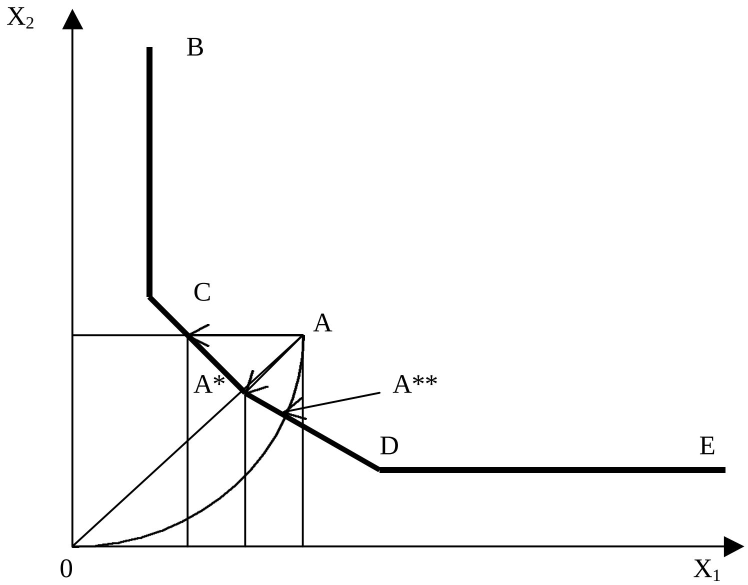

Figure 2: Alternative Efficiency Frontiers

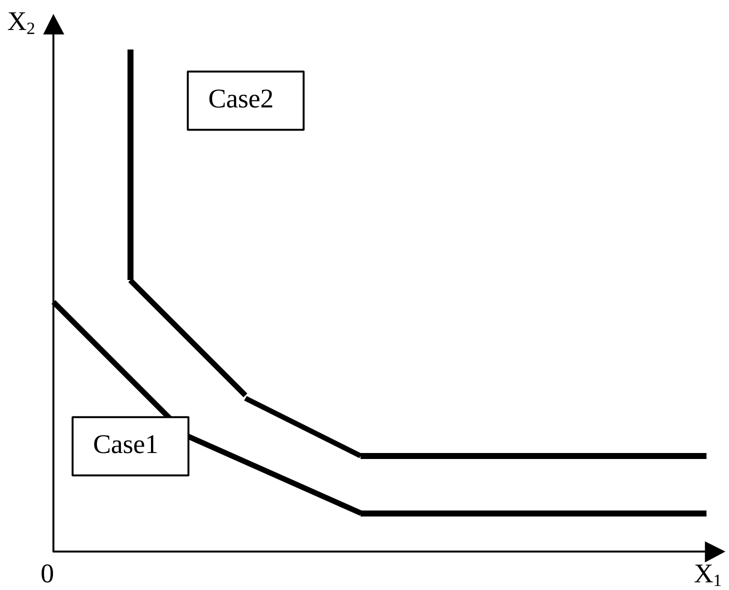

Table 1. Data Summary

Soybeans					
Variable	N	Min	Max	Mean	Standard Deviation
Acres planted	66	3	1400	88.7121	206.9623
Seed rate (lbs.)	66	330	3000	1002.4697	494.8098
Lime applied (tons)	66	0	300	113.7879	94.1605
Nitrogen applied (lbs.)	66	0	6300	347.8333	916.5920
Phosphate applied (lbs.)	66	0	4000	171.1061	568.8477
Potash applied (lbs.)	66	0	8000	295.4848	1000.7274
Pesticide applied /acre (lbs.)	66	0	2.89	0.3489	0.6307
Acres treated (Pesticide)	66	0	40	6.1697	8.1457
Yield/acres (bushel)	66	116	800	417.8636	120.3109
Yield loss due to pest (bushel)	66	0	400	39.6970	79.7876
Wheat					
Variable	N	Min	Max	Mean	Standard Deviation
Acres planted	44	3	200	29.4773	37.1230
Seed rate (lbs.)	44	600	1800	1342.5000	297.0954
Lime applied (tons)	44	0	300	104.7727	97.4378
Nitrogen applied (lbs.)	44	0	1400	106.8409	254.1839
Phosphate applied (lbs.)	44	0	1750	233.9773	409.0069
Potash applied (lbs.)	44	0	1225	93.0000	217.6112
Acres treated (Fertilizer)	44	0	35	6.0568	7.0341
Yield/acre (bushel)	44	170	1000	612.7273	170.9803
Yield loss due to pest (bushel)	44	0	200	12.0455	36.5729

Table 2. Summary of DEA Results
Soybeans

	N	# of efficient farms	Min	Max	Mean	Standard Deviation
Radial	66	38	0.1657	1.0000	0.8566	0.2019
Non-radial	66	38	0.0730	1.0000	0.7355	0.3277
Acres planted	66	40	0.0241	1.0000	0.7856	0.3043
Seed rate (lbs.)	66	44	0.2160	1.0000	0.8610	0.2308
Lime applied (tons)	66	27	0.0000	1.0000	0.5588	0.4423
Nitrogen applied (lbs.)	66	23	0.0000	1.0000	0.4079	0.4528
Phosphate applied (lbs.)	66	24	0.0000	1.0000	0.4497	0.4493
Potash applied (lbs.)	66	21	0.0000	1.0000	0.3865	0.4434
Pesticide applied /acre (lbs.)	66	23	0.0000	1.0000	0.3909	0.4717
Acres treated (Pesticide)	66	25	0.0000	1.0000	0.4346	0.4719

Wheat

	N	# of efficient farms	Min	Max	Mean	Standard Deviation
Radial	44	19	0.3115	1.0000	0.8293	0.1965
Non-radial	44	19	0.1552	1.0000	0.6855	0.3071
Acres planted	44	23	0.0873	1.0000	0.7666	0.2963
Seed rate (lbs.)	44	21	0.0000	1.0000	0.8019	0.2552
Lime applied (tons)	44	10	0.0000	1.0000	0.4092	0.4020
Nitrogen applied (lbs.)	44	8	0.0000	1.0000	0.1879	0.3887
Phosphate applied (lbs.)	44	12	0.0000	1.0000	0.2828	0.4463
Potash applied (lbs.)	44	7	0.0000	1.0000	0.1652	0.3688
Acres treated (Fertilizer)	44	18	0.0000	1.0000	0.5245	0.4376

Table 3. Kendall's τ test

	Soybean		Wheat	
Model	Radial	Non-radial	Radial	Non-radial
Mean	0.8566	0.7355	0.8293	0.6855
Tau	0.8689		0.7902	
Z	10.315		7.561	
Sig.	0.0000		0.0000	
Result	Reject H_0		Reject H_0	

Table 4. Double limit Tobit results

Soybeans

	Radial	Non-radial	Nitrogen
Use of no-till	0.7989**	0.8135**	0.9353*
	(0.027)	(0.033)	(0.061)
Soil-test	-0.0263	0.0188	-0.8741
	(0.946)	(0.964)	(0.155)
Pre-emergence routine treatment	0.9287***	0.9397***	0.6251*
	(0.000)	(0.001)	(0.086)
Pre-emergence recommendation	-0.2339	-0.2629	0.2485
	(0.518)	(0.494)	(0.626)
Post-emergence routine treatment	0.1595	0.0068	-0.5175
	(0.643)	(0.985)	(0.334)
Acres harvested	-0.0485***	0.0384**	-0.0037
	(0.003)	(0.025)	(0.808)
Intercept	0.9131***	0.9820***	1.3147***
	(0.000)	(0.000)	(0.000)
-2 Log-likelihood function	-61.9968	-64.9998	-65.1881

Wheat

	Radial	Non-radial	Fertilizer applied	Lime applied
Land use practice: strip cropping	0.4788**	0.5638**	0.4672	-0.6917**
	(0.033)	(0.020)	(0.344)	(0.050)
Soil test	0.6622***	0.6020***	0.3843	0.0475
	(0.000)	(0.000)	(0.253)	(0.835)
Land use practice: contour	0.4475**	0.3187	-0.0486	0.5001*
	(0.015)	(0.111)	(0.910)	(0.075)
Land use practice: water way	0.0191	0.0826	0.7320	0.1648
	(0.934)	(0.739)	(0.175)	(0.634)
Acres harvested	0.0373***	0.0246**	0.0192	0.0384**
	(0.002)	(0.053)	(0.488)	(0.041)
Intercept	0.5206***	0.5752***	1.1856***	0.8074***
	(0.000)	(0.000)	(0.000)	(0.000)
-2 Log-likelihood function	-31.9288	-35.8610	-46.2223	-42.8376

*. Significant at the 10% level. **. Significant at the 5% level. ***. Significant at the 1% level.

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