EFFICIENCY AND INNOVATION OFFSETS IN NONPOINT- SOURCE POLLUTION CONTROL AND THE ROLE OF EDUCATION

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Abstract

This paper discusses and empirically analyses the implications of efficiency and innovation offsets for the management of non-point source pollution from agriculture. If efficiency improvements and green innovation indeed combine environmental advantages with economic advantages, these offsets would offer a free lunch adjustment to environmental regulations. A theoretical model of the farm is developed where pollution is a joint output of production, where inefficiency in production prevails and environmental innovations are available. We discuss whether education about environmentally friendlier farming practices is effective in such a context. The empirical analysis addresses pesticide use in conventional and genetically modified cotton production in North Carolina, USA. The conceptual model was implemented by means of the non-parametric directional distance function approach (Data Envelopment Analysis, DEA).

Keywords: non-point source pollution, agricultural extension, Porter hypothesis, environmental indicator, pesticides, genetically modified cotton, directional distance function, DEA

1. Introduction

Agricultural nonpoint-source pollution of U.S. surface and ground waters is a major societal concern (USEPA [1]). As public awareness is growing on environmental problems in the food production chain, governments are faced with the challenge of designing policies aimed at re-directing farming practices, particularly in the use of environmentally detrimental inputs. One of the major concerns is with pesticide application in agricultural production.

Correcting pollution problems requires changing the production behaviour of those who contribute to pollution. Traditionally, U.S. policy makers have addressed agricultural non-point source pollution using educational programmes to encourage producers to adopt more environmentally friendly (or 'best') farming practices (BMPs). In order to understand the functioning of such voluntary programmes it is helpful to consider farm level transition to environmentally sound production practices as a process of three stages that overlap in time: efficiency, substitution and redesign (Hill et al. [2]). In the efficiency stage, conventional production systems are altered to reduce the input of resources and environmental impacts while maintaining production levels. In the substitution stage, inputs that are more environmentally benign replace environmental disruptive inputs. Efficiency and substitution imply a change in input levels and in input mixes, respectively. Finally in the redesign stage the emphasis is on retrofitting and technical environmental innovations, *i.e.* on direct outlays of capital cost and operating expenditures for environmental purposes.

Obviously, each of the three stages (efficiency, substitution and redesign) offers different possibilities to reduce the environmental impacts of agricultural production. Abatement costs studies generally focus on the latter two stages, *i.e.* on the cost associated with reducing output or with direct outlays of capital and operating expenditures for additive technology. Traditional neo-classical abatement cost analysis does not account for the possibilities that firms can reduce emissions in the shorts term by either efficiency improvements or by substitution for ecologically harmful inputs (Rennings [3]). In practice producers confronted with an environmental regulation, will first try to reduce pollution at source by either efficiency improvement of input use or by substitution of productive inputs or production processes.

The objective of this paper is twofold. Firstly, we intend to develop a theoretical model of the farm where pollution is a joint output of production. In this model, inefficiency in production prevails and environmental innovations are available. It is discussed whether educational assistance to farmers is effective in the context of environmental inefficiency and technical environmental innovation.

The second objective of this paper is to present empirical analysis of the existence of efficiency and innovation offsets for the case of the use of pesticides in conventional and genetically modified cotton. This case was selected because of the controversy surrounding the potential environmental benefits of the cultivation of transgenic cotton. High quality survey data for a sample of 275 North Carolina cotton producers were used for the case study assessment. The conceptual model was implemented by means of the non-parametric directional distance function approach (Data Envelopment Analysis, DEA).

The plan of the paper is as follows. The next two sections provide a theoretical discussion of the agricultural non-point source problem and efficiency and innovation offsets. Next we present the empirical analysis. The results suggest that there is considerable room for improving environmental quality of agricultural production without conflicts between economic and environmental goals. We conclude with a discussion of the main findings and their implications.

2. Environmental-economic production possibility frontier [4]

Agricultural production generates outputs that can be distinguished in two major subsets: food and fibres, and environmental and health effects. Production externalities (*viz.* pollution or resistance) most often result from specific inputs that have the characteristics of joint inputs, as any quantity simultaneously produces the intended agricultural output and the unintended externality. The combination in which these marketable outputs and bad side effects are generated however is not fixed but rather depends on the production method chosen. Generally, several production methods are available that vary both in their costs and in their environmental impacts. In the case of the use of pesticides, a few specific alternatives include changing the usage operation so that less chemical is required (pest control by band spraying versus full field treatment) or substitution (mechanical weed control versus herbicide use, or a switch to a less environmentally harmful type of herbicide). Figure 1 depicts the relationship between agricultural production and environmental impacts for pesticide use on an individual farm in a given natural production environment as defined by climate/weather and soil type and for a given variety of production methods.

The economic relationship between pesticide use and the producer's profit is illustrated in quadrant I. Every point on the function T shows the maximum amount of profit that can be achieved with a given level of pesticide use. Alternately, considered from an input orientation, the function describes the minimum amount of pesticide input required to achieve the given profit level. Without loss of generality, the profit axis could be thought of as the expected utility of profits for risk-adverse producers when there is production uncertainty (Ribaudo and Horan [5, p. 334]).

The relationship between pesticide use and expected environmental quality for the individual farm is represented in quadrant II. Ecosystem health, which is adversely affected by pesticide use, is represented by function R. The s-shape of this function is derived from the dose response relationship in toxicology [6]. Quadrant III transposes ecosystem health into quadrant IV. Finally, the relationship between ecosystem health and profit is depicted in quadrant IV. This is a production possibility frontier (PPF) that depicts the feasible set of economic performance and ecosystem quality levels.

The shape of the PPF expresses the extent to which economic and environmental performances are compatible. Profits and expected ecosystem health are complements over the increasing range of the frontier and substitutes over the decreasing range. Where markets for environmental services are missing, the larger part of the production possibility frontier is steeply downward sloping as with the PPF in Figure 1 (*cf.* Aldy, Hrubovcak and Vasavada [7]). Without any regulation, the economic optimal point is at S_1, with profits T_1 and environmental quality R_1. Obviously, it would be costly to improve the environmental quality of agricultural production to a level beyond R_1.

The presentation in Figure 1 assumes optimal, profit maximizing behaviour of agricultural producers and a given technological state of the art. In practice there will be inefficiency in production and progress in production technology through innovations. The next section analyses the impacts of inefficiency and innovations on environmental improvements and the associated costs.

3. Efficiency and innovation offsets and education

Firms are considered inefficient in production if the quantity and/or quality of output per unit of input is less than what is technically and economically feasible. Similarly, firms can be considered environmentally inefficient if pollution per unit of input is more than the ideal minimum. Efficiency is therefore determined by the (outermost) production possibility frontier, which is determined by the state of technology. Inefficient farms operate somewhere in the interior of this PPF. While privately owned farms are likely to be efficient with regard to conventional input/output productivity there are several reasons why there would be inefficiencies in environmental performance (Altman [8]). For example, an internal lack of economic incentive and information, bounded rationality, and an absence of external competitive pressure applying to environmental performance. For a given production technology, lack of information about the production frontier may lead producers to use inputs inefficiently. Producers may also have limited knowledge of the set of alternative production technologies that are available and their economic and environmental characteristics, as well as a lack of information about how their actions affect environmental quality (Ribaudo and Horan [5]).

The importance of inefficiencies is illustrated by farm A_1 in Figure 2. The technology available to producer A_1 is represented by PPF, which is a stylized version of the downward sloping part of S in Figure 1. Profit P_1 and environmental quality W_1 represent the skill with which producer A_1 is currently using the technology. Efficiency offsets available to farm A_1 are along the portion BK of PPF. Points along the lower part of PPF do not provide offsets because profit would decrease. Farms like A_2, which utilizes available production technologies efficiently, will likely be close to the Y-axis.

Suppose that the socially desired level of expected environmental quality is at W_s. By educating farmer A_1 about the frontier where profits are higher for each level of input use, the producer could be encouraged to use existing management practices more efficiently or to adopt alternative ones. Once on the frontier, the producer could operate according to the Best Management Practice (point C) which would the environmental quality goal and at the same time increases profits. However, without any regulation, competition will drive the producer to operate on CI. The expected environmental quality levels that correspond to the production possibilities to the right of K would be an improvement over the initial situation with production at A_1 but does not meet the standard. The environmental quality levels associated with the production possibilities on the portion IK of PPF would even be less than in the original situation. This makes it possible that education about production practices might even reduce environmental quality. Thus, educational assistance and technical innovation alone are not necessarily sufficient to ensure that environmental quality goals are met.

Now assume that a regulation is implemented that specifies the maximum amount of pollution at W_s. Efficiency offsets available to Farm A_1, given a standard of W_s, are now along the portion BC of the PPF. For Farm 1 the regulation would entail no compliance cost, since this farm can meet the standard by using its efficiency offsets. Efficiency offsets are not available for (the already efficient) farm A_2 and it will encounter compliance cost of P_2-P_C. However, economic theory predicts that farm A_2 will modify its use of pesticides in order to minimize costs given that it must meet a new environmental standard. Hick's induced innovation hypothesis says producers will seek out technologies that lower the compliance costs of the regulation and improve environmental quality. In addition, the Porter hypothesis suggests that environmental regulation by means of the use of standards can trigger innovation that may partially or more than fully offset the costs of complying with them (Porter and van der Linde [9, p. 98]. Assume new technologies become available after some time and expand the production opportunities to a new frontier. Farm A_2 will shift out to this new frontier PPF^{new} and depending on the shape of this new frontier, the innovations will partially offset the environmental compliance costs. If farm A_2 positions itself at H on PPF^{new} it will reduce the cost of complying with the new standard from P_2-P_C to P_2-P_G. For farm A_1 innovation offsets expand the already existing efficiency offsets from BC to DG.

In summary, whether environmental quality and costs competitiveness are mutually consistent hinges upon whether or not producers are typically efficient in production and whether environmental regulation induces technical change. More specifically, the opportunity of the "free lunch" adjustment offered by efficiency and innovation offsets depends on: (1) the positioning of a farm with respect to PPF^{new}, (2) the shape of PPF^{new}, and (3) the level at which the environmental standard is set.

4. Empirical assessment of potential efficiency and innovation offsets in cotton production

4.1 Background

The goal of pest control is to prevent crop loss up to the level of economic yield. Control inputs used to this end are pesticides (chemical compounds that reduce pest levels or reduce pest damage), resistant crop varieties, natural enemies and all types of cultural practices such as rotation, tillage and planting date (Wossink and Rossing [10]). Historically, most pest control efforts in cotton production have sought to find single, simple, direct interventions that quickly reduce the pest population(s) below an acceptable level by means of conventional prophylactic, calendar-based use of broad-spectrum pesticides. Educational programmes on Integrated Pest Management (IPM) in cotton aim at improving the accuracy and timing with which pesticides are applied and promote benign substitutes such as less harmful pesticides, biological controls and changes in planting date, rotation and conservation tillage (Yee and and Ferguson [11]). The planting date influences insect control, plant growth, and defoliant strategies indirectly. Crop rotation aids in the control of soil-borne pest and diseases and additionally can be a significant component of weed management. Conservation tillage, specifically no-till systems can save time, allowing growers to plant closer to the optimum planting dates.

Recently, biotechnology has further enlarged the spectrum of pest controls by introducing new methods of production. Transgenic insect-resistant and herbicide tolerant cotton varieties have been developed that enable growers to use in-plant protection methods that replace insecticide and herbicide applications (e.g. Hubbell et al. [12]).

In summary, cotton producers can alter externality levels of pest control by varying input levels, input mixes or methods of production. Producers' efficiency in applying the control methods further affects costs and environmental impacts.

Based on the theoretical model in section 3, two hypotheses were derived for the situation outlined above. First, we expect to find offsets offered by improvements in efficiency and by innovation. Second, we expect the environmental improvements offered by the offsets to be rather unutilised because of a lack of regulation.

4.2 Empirical method

The literature on the measurement of efficiency is still mainly based on physical and monetary inputs and outputs. Färe *et al.* [13] introduced negative environmental effects in the output distance function of the economic efficiency literature. This approach considers emissions as undesirable outputs or by-products that are a direct function of the producing firm's output. In other words, a certain percentage reduction in emission can only be achieved by the same percentage reduction output, which by definition makes pollution abatement costly. Recent applied work on environmental efficiency has taken another perspective in which emissions are modelled as freely disposable, which means that reduction of their use, can be achieved at no private costs (Boyd et al. [14]). The latter implies that environmental improvement can be achieved by fine-tuning input levels and input mixes and this does not have to lead to lower levels of the good output.

Data Envelopment Analysis (DEA) was employed to quantify the offsets and the extent to which an individual farmer employs these. The DEA constructs a frontier representing the latest technology and simultaneously calculates the distance to that frontier for the individual observations. The frontier is piecewise linear and is formed by tightly enveloping the data points of the observed 'best practice' activities in the observations, that is the most efficient and innovative farms in the sample. So it is assumed that the performance of the best farmers can be used to assess a benchmark for the state of the art PPF^{new}.

DEA uses the distance to the frontier as a measure of efficiency. In Figure 2, farm A_1 is compared to point F on the frontier PPF^{new} to calculate the total of innovation and efficiency offsets available to this specific farm. The comparison results in an efficiency measure of OF/OA_1. Differences in the distance to the frontier provide a score for each farm greater or equal to 1, where 1 stand for best performance. A high score indicates considerable unused offsets for the specific farm whereas a score of 1 indicates that the farm is located on the frontier [15]. The efficiency measure visualized in Figure 2 is known as the directional output distance function efficiency (Boyd et al. [14]).

In addition to the calculation of the efficiency, the DEA method was employed to calculate several other efficiency measures for each farm in the sample. Traditionally, efficiency analysis has focused on marketable output relative to paid inputs. Hence, most frequently DEA is used to assess the technical efficiency of input use. In the case of two input variables, x_1 and x_2, assessing the output per unit of input provides a plot where the co-ordinates (y/x_1 and y/x_2) indicate the efficiency of the used inputs. The deviation from the efficiency frontier is considered to be associated with technical inefficiency of the farms involved.

We also calculated the relative cost efficiency by comparing realized cost per lbs. of cotton among growers. See the Appendix for a discussion of the mathematics of the various efficiency measures.

4.3 Data

A total of 275 North Carolina cotton producers were interviewed as part of the 2000 USDA Upland Cotton Production Practices Survey. After removing incomplete questionnaires, 202 remained for analysis. The data used are from an entire growing season. Table 1 presents summary statistic of the variables used in the analysis. Three technologies were distinguished: herbicide tolerant, stacked gene (herbicide tolerant and insect resistant) and conventional.

The data set includes one desirable output (cotton yield in lbs of lint per acre) and one non-desirable output. The non-desirable output, i.e. the external effects of pesticide use, is quantified by means of the use of the pesticide leaching potential. Most active ingredients of pesticide leach into the surface water and the pesticide leaching potential (PLP) can be described as the relative potential that residues of this pesticide reach the surface water. The PLP is an indicator to describe the relative chance of leaching compared to the chance of leaching of other pesticides. Pesticides have several properties that affect their ability to leach to ground water that are combined in the following equation to estimate their impact on leaching potential: PLP value $=(T_{1/2} \times R \times F)/K_{oc}$. Where $T_{1/2}$ = Persistence of the pesticide, measured as half-life in days; R = Rate of application (pounds of active ingredient per acre); F = Fraction of pesticide reaching the soil during application; K_{oc} = Affinity for soil organic matter, the soil organic carbon binding value (McLaughlin *et al*., [16]). The PLP index range from 0 to 100, where 0 = no leaching potential and 100 = very high leaching potential. The PLP values of the various pesticides applied by a grower per acre of cotton production are totaled and used as the bad output in the efficiency calculations.

The data set includes eight variable inputs (five groups of pesticides and three non-environmental detrimental inputs for pest control) and the cost of pest control. These variable inputs are all aggregated measures. Chemical pest control is represented by the use of herbicides, insecticides, fungicides, growth regulators and defoliants and is measured in dollars per acre. Regarding the no-detrimental inputs, we discussed in section 4.1 that management decisions regarding planting date, rotation and conservation tillage and many other field operations also contribute to pest control. However, these cultivation decisions interact in complex ways. We solved this problem by identifying and quantifying the non-detrimental inputs of pest management through a factor analysis of the 89 variables under the heading ‘field characteristics’ in the Upland Cotton Production Practices Report survey. Among the 13 main composite factors with an eigenvalue greater than 1, we determined three composite factors related to pest control: "Formal plans for pest, nutrient and conservation management"; "Crops planted on specific field in previous years", and "Timing of planting and harvesting".

Inputs and outputs values used in a DEA model need to be strictly positive whereas the factor scores for the non-detrimental inputs of pest management included negative estimates. Following Adler and Golany [17] we subtracted the minimum observed factor score from the value of each observation to assure positive values. The resulting translated factor scores were used as DEA input values for the non-environmental detrimental inputs.

Cost of pest control is composed of the cost for the five categories of pesticides and a technology fee if genetically modified cottonseed is used. For the calculation of the technology fee we used the survey information on the variety used and the seed drop rate combined with external information on the technology fee per 50-lbs. bag of each specific variety in 2000 [18].

5. Results

The efficiency measures were estimated in OnFront (Färe and Grosskopf [19]). Efficiency scores were computed for all 202 observations. Table 2 presents the sample mean, the standard deviation of the cost efficiency, technical efficiency and the directional distance function efficiency. The efficiency scores were calculated twice. First we used the growers with the same technology as the reference base and then all growers.

The overall output-oriented technical efficiency for pesticide use ranged from 1.26 to 1.64 depending on the scale assumption (CRS, NIRS or VRS). The associated standard deviations were considerable (0.28 to 0.48). This means that, assuming VRS technology, for example herbicide tolerant growers on average could improve the efficiency of pest control inputs by 34%. For growers of conventional cotton this would be 33%. Overall technical inefficiency of pest control under constant returns to scale (CRS) was higher for growers of herbicide tolerant than for growers of stacked gene cotton and conventional cotton (1.64 versus 1.44 and 1.63). By comparing Technical Efficiency CRS to Technical Efficiency NIRS, we can determine whether production is characterized by decreasing or increasing returns to scale. If TECRS>1 and TECRS = TENIRS, inefficiency is because of increasing returns to scale, i.e. the grower is producing at an inefficiently low output level. For TECRS>1 and TENIRS<TECRS inefficiency is caused by operating at an inefficiently high output level, i.e. in the region of decreasing returns to scale. Thus, for our case study, it can be concluded that overall technical inefficiency is due to the fact that on average cotton growers are operating in the region of decreasing returns to scale. The results for technical efficiency by seed type also show that growers of conventional cotton make better use of the technical potential of their technology than do growers of herbicide tolerant and cotton conventional cotton.

The distance function efficiency scores indicate the percentage reduction in environmental impact per unit output (lbs of cotton) by reducing herbicide use or by substituting herbicides with a lower PLP score while increasing productivity by the same percentage. Assuming VRS technology, for example the environmental impact of herbicide tolerant, stacked gene and conventional cotton could be reduced 7 %, 4% and 3% when compared by seed type. When comparing among all 202 growers the reduction could be 13%, 6 % and 9 %, respectively. Growers of stacked gene cotton have the best overall distance function efficiency. Next, the Mann-Whitney U-Test (two-sided) was used to test whether these differences in overall distance function efficiency between seed types were significant. The difference between herbicide tolerant and stacked gene cotton was significant at 1%; for stacked gene and conventional cotton the difference was significant at 10 %. There was no significant difference between herbicide tolerant and conventional cotton in overall distance function efficiency. For the distance function efficiency by seed type all differences were significant at 5% level.

Finally, we assessed the cost efficiency. Overall cost inefficiency was high at 3.52, 4.11 and 3.62 for herbicide tolerant, stacked gene and conventional cotton, respectively. Employing again the Mann-Whitney U-Test, we found that there were significant differences in cost efficiency between herbicide tolerant and stacked-gene, and between conventional and stacked-gene cotton at the 5% significance level. However, there was no statistical difference in cost efficiency between herbicide tolerant cotton and conventional cotton. This implies that conventional and herbicide tolerant cotton were the more cost efficient technologies under North Carolina conditions in 2000.

Next, the information provided by the DEA-based measures was used to identify management strategies to combine profit objectives with environmental quality. Table 3 presents the rank correlation between the efficiency measures. Spearman rank correlations between efficiency measures were calculated under the three different scale assumptions

(CRS, NIRS and VRS). Regardless of these scale assumptions, the rank correlations between efficiency measured produced very similar results. The results in Table 3 are under VRS technology. There was a significant positive correlation between the technical efficiency and the cost efficiency for both herbicide tolerant and stacked gene cotton. The correlations between cost efficiency and distance function efficiency were significant only for stacked gene cotton.

6. Conclusions and implication

The objective of this paper was to discuss and empirically analyse the implications of efficiency and innovation offsets for the management of non-point source pollution from agriculture. Based on the theoretical economic model two hypotheses were derived and tested for the case of pesticide use in cotton production. First, we expected to find efficiency and innovation offsets. Second, we expected the environmental improvements offered by the offsets to be relatively unutilized because of a lack of environmental regulation.

Based on the overall distance function inefficiency, the average farmer in our sample could simultaneously improve productivity and reduce the environmental impact from pesticide use by 16 percent. These results confirm the existence of efficiency offsets. When evaluated by seed type, stacked gene cotton had a significantly better overall distance function efficiency which confirms the existence of innovation offsets.

A significant positive rank correlation was found between the scores for overall technical efficiency and for overall distance function efficiency. These results suggest that farmers who focus on optimizing technical efficiency follow a good strategy to achieve environmental efficiency. The estimates of technical efficiency for different scale assumptions suggested that on average the cotton growers were producing at an inefficiently high output level.

We found a significant positive correlation of distance function efficiency and cost efficiency for stacked gene cotton. These positive correlations suggest that there is room for controlling the non-point source pollution from pesticides in cotton production without conflicts between economic and environmental goals.

The average overall distance function inefficiency for stacked gene cotton (ranging from 6 to 11 percent depending on CRS, NIRS or VRS technology) shows that improvements offered by innovation and efficiency offsets are only partially utilised by the average grower of stacked gene cotton. The outcomes demonstrate the complexity of factors affecting farmers' pest control decisions. More specifically they demonstrate the interaction of actual, *i.e.* non-optimal, producer behaviour, agricultural innovation and extension programmes.

Appendix

The DEA model for each specific production unit is formulated as a fractional programming problem. For example, the formulation for the output oriented *Technical Efficiency* of farm *j* is:

$$\text{Maximize} \quad TE_j \qquad (1a)$$

$$\text{subject to} \quad TE_j y_j \le Yv_j \qquad (1b)$$

$$Xv_j \le x_j \qquad (1c)$$

$$v_j \ge 0 \qquad (1d)$$

where TE_j is the measure of technical efficiency of the *j*-th farm; Y is a $p \times n$ matrix of p outputs produced by the n farms; v_j is the intensity vector of the weights attached to the n farms for the construction of the virtual comparison unit for farm *j*; y_j is a $p \times 1$ vector of quantities of output produced by farm *j; X* is a $m \times n$ matrix of m inputs used by the n farms, and b_j is the vector of these inputs for farm *j*. The efficiency of the n farms is assessed by solving n LP models, in which the vectors y_j and x_j are adapted each time for the farm *j* considered.

The model to calculate the *Directional Distance function Efficiency* with free disposability of bads for farm *j* is formulated as:

$$\text{Maximize} \quad DDE_j \qquad (2a)$$

$$\text{subject to} \quad Yv_j \ge \left(1 + DDE_j\right) \cdot y_j \qquad (2b)$$

$$Zv_j \geq \left(1 - DDE_j\right) \cdot z_j \qquad (2c)$$

$$Xv_j \leq x_j \qquad (2d)$$

$$v_j \geq 0 \qquad (2e)$$

where DDE_j measures the extent in which the good output can be increased and the bad output can be decreased for farm j, Z is a $r \times n$ matrix of r environmental impacts generated by the n farms and X and v_j are defined as before.

Let W be the cost of pest control per lbs. of cotton lint produced. The *cost efficiency CE* of the production for farm j can then be calculated as:

$$CE_j = \frac{\mathrm{W_j}}{\mathrm{Min(W_n)}} \qquad (3)$$

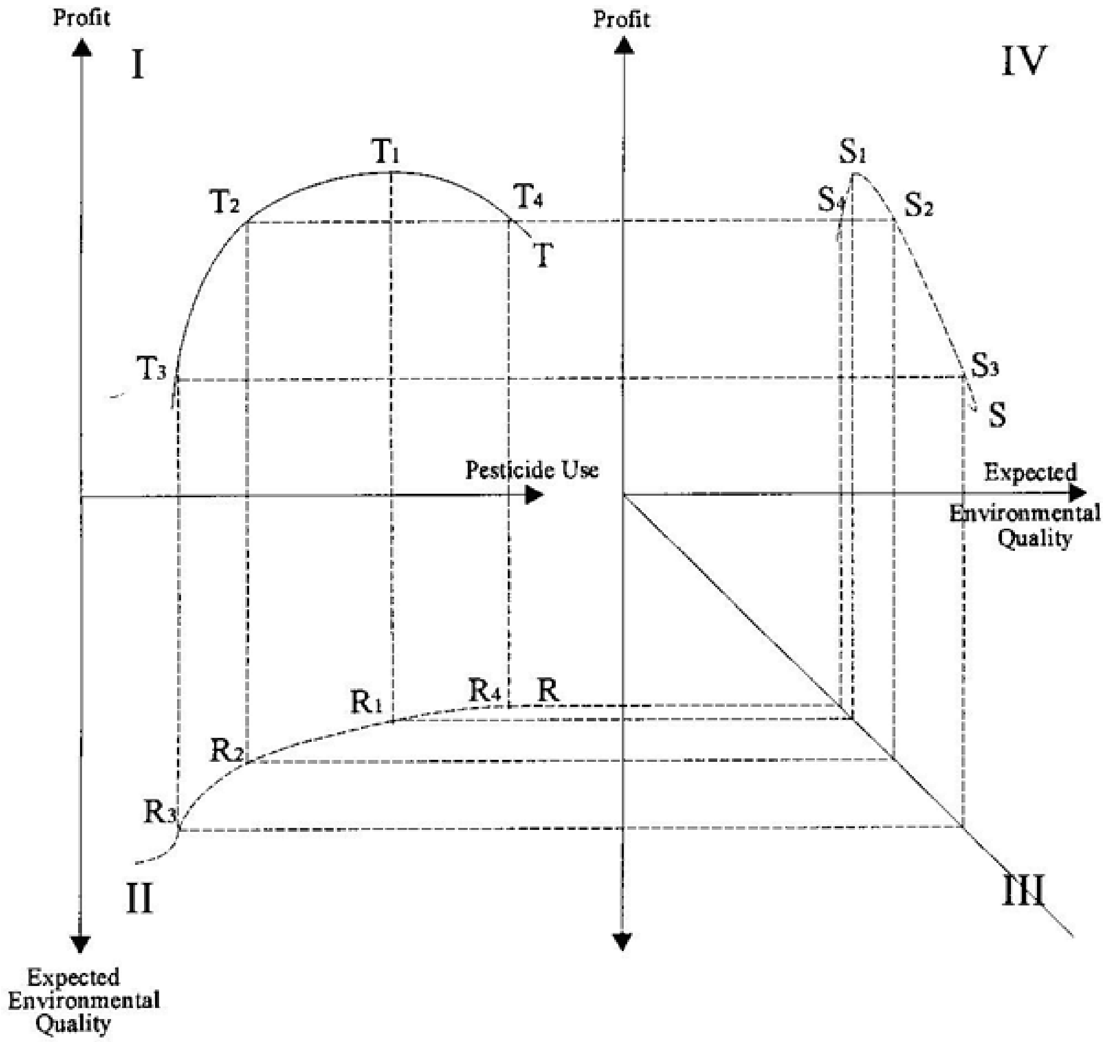

Figure 1. Producer pesticide use decisions and their effect on expected environmental quality

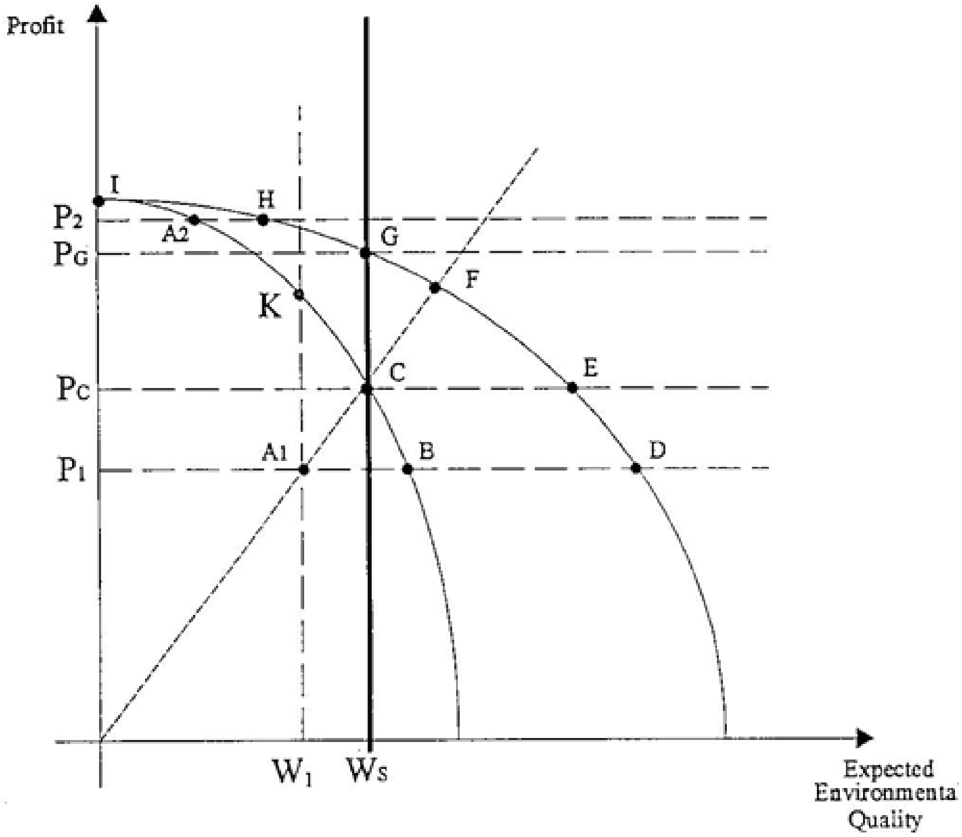

Figure 2. Efficiency and innovation offsets

Table 1 Summary statistics of the date used

Variable	*Units*	*Seed type*					
		Herbicide tolerant		Stacked-gene		Conventional	
		mean	s.d.	mean	s.d.	mean	s.d.
Output:							
Yield of Cotton Lint	Lbs./acre	785.53	142.12	792.34	142.38	813.13	151.34
Inputs: “Pesticide use”							
• Insecticides	$/acre	19.58	9.89	17.80	19.32	20.91	15.22
• Herbicides		16.49	9.99	12.80	11.73	22.28	13.34
• Fungicides		0.20	1.41	0.64	2.85	0.41	1.94
• Growth reg.		15.91	9.81	15.08	11.07	18.06	9.13
• Defoliants		4.63	6.46	4.81	6.27	4.59	9.92
Other inputs for pest control:							
• "Formal plans for pest, nutrient and conservation management"	Factor scores	1.22	1.15	1.22	0.93	1.22	0.93
• "Crops planted on specific field in previous years"		3.51	1.16	3.57	0.93	3.57	0.93
• "Timing of planting and harvesting"		4.95	0.94	4.62	0.91	4.62	0.91
Env. detrimental effects of pest control: Total for insecticides, herbicides, fungicides, growth regulators and defoliants	PLP*/ acre	154.01	72.93	139.04	75.07	180.04	67.04
Costs of pest control							
• Costs of pesticides	$/acre	64.4	22.44	75.17	35.52	66.76	26.50
Technology fee		7.59	3.76	24.02	9.64	0	0
Observation	**N=202**	**74**		**79**		**49**	

* PLP = Pesticide leaching potential is an environmental indicator based on the relative potential that residues of a pesticide reach the surface water.

Table 2 Mean[1] scores[2] for technical efficiency, directional distance function efficiency and cost efficiency of herbicide tolerant, stacked gene and conventional cotton production of North Carolina cotton producers in 2000

Performance measure by technology	**Technical Efficiency of pest control**			**Directional Distance Function[5] Efficiency of pest control**			**Cost Efficiency of pest control**
	CRS	NIRS	VRS	CRS	NIRS	VRS	
Herbicide tolerant							
By seed type[3]	1.38(0.34)	1.28(0.26)	1.26(0.25)	1.11(0.16)	1.07(0.12)	1.07(0.12)	3.50(1.22)
Overall[4]	1.64(0.44)	1.35(0.28)	1.34(0.27)	1.21(0.25)	1.13(0.17)	1.13(0.17)	3.52(1.22)
Stacked gene							
by seed type	1.35(0.40)	1.20(0.29)	1.19(0.29)	1.07(0.14)	1.04(0.10)	1.04(0.10)	2.47(1.07)
Overall	1.44(0.45)	1.27(0.33)	1.26(0.33)	1.11(0.17)	1.06(1.10)	1.06(1.10)	4.11(1.78)
Conventional							
By seed type	1.22(0.32)	1.12(0.22)	1.12(0.22)	1.05(0.18)	1.03(0.12)	1.03(0.12)	3.62(1.45)
Overall	1.63(0.48)	1.34(0.32)	1.33(0.32)	1.16(0.29)	1.09(0.17)	1.09(0.17)	3.62(1.45)

[1] Standard deviations are in parentheses.

[2] The table reports output oriented efficiency scores. For example the cost efficiency of 3.50 for herbicide tolerant by seed type means that the cost of pest control per lbs of cotton of the average producer is 3.5 times the cost of the most efficient producers.

[3] Using growers with the seed type as the reference base.

[4] Using all growers as the reference base.

[5] The directional distance function efficiency measures the extent in which good output can be increased and bad output (pollution) can be decreased at the same time. We assumed free disposability of the bad output in the calculation.

Table 3 Spearman rank correlation between efficiency measures under VRS technology

Rank correlation between and	Herbicide tolerant	Stacked gene	Conventional
CE TE	0.20***	0.42**	-0.007
DDE TE	0.68**	0.61**	0.49**
DDE CE	0.11	0.23*	0.09

CE = overall cost efficiency; TE = overall technical efficiency; DDE = overall directional distance function efficiency.

*, **, ***: significant at 5%, 1%, and 10%, respectively.

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References and Notes

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