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Factors Affecting Perceived Improvements in Environmental Quality from Precision Farming

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This study identified the factors that influenced whether farmers in the Southeastern United States perceived an improvement in environmental quality from adopting precision farming technologies (PFTs). Farmers with larger farms or higher yields were more likely to believe that they observed positive externalities associated with PFTs. Farmers who found PFTs profitable or who believed input reduction was important had higher probabilities whereas those with higher incomes or who were more dependent on farm income were less likely to perceive such benefits. Interestingly, the importance of environmental quality and length of time using PFTs were not found to affect the probability of perceiving an improvement in environmental quality.

Key Words: precision agriculture, site-specific farming, variable rate application

JEL Classifications: C25, Q12, Q24.

Precision farming (also known as precision agriculture) entails the assessment of site-specific land and crop needs to develop management practices that are calibrated to the needs of each site within a field. The adoption of precision farming as a management practice thus involves both the identification of temporal and spatial variation and the subsequent use of the site-specific information to apply inputs at variable rates across a field. The suite of available precision farming technologies (PFTs) has the potential to increase profits, especially for the production of input-intensive crops (Roberts et al. 2004). The profitability of many of these technologies, especially in regard to their use for different crops and in different combinations, has not been categorically proven (Griffin et al.; Lambert and Lowenberg-DeBoer; Swinton and Lowenberg-DeBoer 2001). However, profitability may not be the sole motivation for PFT adoption. Farm managers and society may realize environ-

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mental benefits following the adoption of PFT-based crop production. For example, a recent study found that farmers were willing to forsake higher yields (by reducing input use) to avoid the risk of moderate environmental damage (Lohr, Parker, and Higley).

If an improvement in environmental quality from the adoption of precision farming technologies also benefits society and not just the farmer adopting the new production practices, we might expect a suboptimal PFT adoption rate. The adoption (or lack of adoption) of PFT may produce a positive (negative) externality. For example, a farmer who uses excess inputs might have a field with excessive runoff that could contribute to water pollution and impose a cost on society from increased human health problems or increased water treatment costs. Resources used in the production of such crops are being allocated inefficiently; the resulting market failure is causing negative environmental externalities.

What can be done to address these types of externalities? The value of the externality needs to be captured and internalized into the production process. If the use of traditional production practices is considered to cause a negative externality, the "polluter pays principle" supports a tax-based solution. Under this principle, the government sets emission standards that, when exceeded, result in a tax payment by the farmer. If the use of PFTs is considered to produce a positive externality, a subsidy program could be used to increase usage of these technologies, and thus improve environmental quality. If PFTs are not profitable, or the costs to impose the tax and monitor the standard exceed the expected benefits, the latter approach is necessary to solve the market failure problem.

As for the role of policy in this case, if precision farming practices produce socially desirable benefits (as opposed to private benefits) in the form of a cleaner environment (i.e., a positive externality) then policy makers could implement programs to subsidize the use of PFTs or establish credible market-based incentives. The Environmental Quality Incentives Program, the Conservation Security Program, and the National Organic Program are examples of federal efforts to promote these types of practices in the United States. In Australia, a process-based rating system has been proposed that would offer progressive tax rebates on land that is managed using the Environmental Management System (EMS), which involves land stewardship using best management practices (BMPs) such as PFTs; the proposed rating system follows the successful use of the EMS for urban fringe areas (Gunningham; Nind).

The alternative approach assumes that farmers are polluters who should pay for the harm they cause by using existing production practices and dictates the restriction, taxation, or fining of traditional practices. Examples of such regulation in the United States include the imposition of civil penalties for violating confined animal feeding operation requirements, mandated BMPs, and pollution limits. Although this approach may be less politically feasible, such regulations may be easier to implement especially given the precedents that have been established. The effectiveness of either approach, however, requires specific information about the quantity and value of potential damage occurring from the use of traditional agronomic methods and the benefits of using PFTs (Zilberman and Marra).

Although farmers have shown considerable interest in PFTs, reliable information about the degree to which farmers have adopted such practices and whether such adoption has been profitable is just becoming available. Several recent studies have examined the factors that explain adoption rates (e.g., Batte and Arnholt; Daberkow, Fernandez-Cornejo, and Padgitt; Daberkow and McBride; Griffin et al.; Fernandez-Cornejo, Daberkow, and McBride; Khanna; McBride and Daberkow; Napier, Robinson, and Tucker; Roberts et al. 2004; Swinton and Lowenberg-DeBoer 2001). Other published studies have examined directly the relative profitability of alternative production methods, including PFT-based methods (e.g., Lambert and Lowenberg-DeBoer; Swinton and Lowenberg-DeBoer 1998; Wang et al.). In general, the published studies have concluded that high-value high-input crops such as cotton, tobacco and sugar beets have potential for profitable precision farming; the relatively higher profitability of such crops increases the chance of PFT adoption and, thus, the observance of positive environmental effects (Swinton and Lowenberg-DeBoer 1998).

Studies concerned with environmental impacts have focused on reduced input use and input losses to the environment from adoption of variable rate technologies (e.g., Larson et al.; Norton and Swinton; Roberts et al. 2002; Wang et al.; Watkins, Lu, and Huang). The implicit assumption has been that reduced input use and input losses translate into improved environmental quality. Although this is likely to be true, it can be difficult or impossible to quantify the linkages and assess whether they are meaningful (especially in the short run). The absence of such information can preclude the establishment of effective environmental quality standards or educational programs designed to promote "green" production practices.

Our objective was twofold. First, we sought to determine the extent to which PFT-adopters believe that their practices have improved the quality of the environment. Such perceptions are important to understanding the degree to which farmers may directly benefit from PFT adoption. The larger the number of farmers who experience private benefits associated with supplying a cleaner environment (public good), the lower would be the associated free rider problem. Of course, this issue would be mute if PFTs were profitable. Unfortunately, studies to date have shown that profitability is not universal.

The second objective was to determine the factors that influence whether farmers perceived there to be an improvement in environmental quality following PFT adoption. Identifying these factors could help identify where to initiate educational and or regulatory efforts designed to increase the use of environmentally-friendly production practices. Such programs may be necessary to improve the quality of the environment that is affected by crop production.

Theoretical Model

First consider an agricultural household production model to frame the discussion and illustrate the set of factors that may influence perceived environmental improvement from adoption of precision farming technology. The farmer-observed, or perceived, change in the level of environmental factors drives the choice, not necessarily the actual change. The perceived change may deviate from the actual change, but it is the decision-maker's perception that is important in this case. Assume that a household utility function is defined over consumption goods (c) and nonmarket goods (y), which are broadly defined here as environmental factors. Perceived environmental factors are defined as y^o and are assumed to change with the choice of acres on which the new technology is employed, A_T. The utility function is given by $U(c, y^o(A_T)|\Omega_H)$, where Ω_H denotes a set of household characteristics. Characteristics included in Ω_H could be household income, age and education level of the decision maker, environmental attitudes, and so forth.

Production of the final output is given by $f(A, z|\Omega_F)$ where A denotes crop acres, assumed to be fixed in the short run, and z is a vector of other inputs determined in part by farm characteristics, Ω_F. Characteristics included in Ω_F could be location of the farm, farm size, crop mix, production techniques, yields, and so forth.

The farm's household choice problem every period after initial adoption (assuming no saving or borrowing for simplicity) is:

$$(1) \quad \max_{c, A_T, z} U[c, y^o(A_T)|\Omega_H]$$

subject to the net value of final output equalling the value of consumption goods:

$$(2) \quad p_f f(A, z|\Omega_F) - rA - wz = p_c c$$

where p_f and p_c are the prices of the final output and consumption goods, respectively; r and w are the land rental rate and a vector of input prices, respectively; A_0 represents the crop acres on which the technology is not employed, and $A_0 + A_T = A$.

Because the change in the level of perceived environmental factors (∂y^o) is determined by changes in A_T, and A_T^* is jointly determined with z^* and c^* in the optimization problem, ∂y^o is related to household and farm characteristics, as well as to prices. With this model, we define a relationship that characterizes the unobservable process for the ith PFT-adopting farmer as

$$(3) \quad y_i^* = \beta' x_{ik} + \varepsilon_i \qquad (i = 1, \ldots, N;\ k = 1, \ldots, K)$$

where y_i^* is the latent variable (i.e., some empirical level of improved environmental quality perceived after adoption of PFTs, y^o), x_{ik} is a vector of k exogenous variables (i.e., factors affecting the probability that a farmer perceived some net environmental benefits from PFT adoption, Ω_H and Ω_F), β is a vector of unknown coefficients corresponding to the k exogenous variables, and ε_i is the error term.

The direct quantitative measurement of improved environmental quality incurred by farmers after adoption of PFTs is not possible through survey techniques. What is observable through surveying is whether a PFT-adopting farmer has perceived there to be any improvements in environmental quality through the use of PFTs. Because this is a "yes" or "no" question, a binary indicator variable, y, takes on the value one if the answer is "yes" or zero if the answer is "no". A farmer either perceives some environmental benefits or not:

$$(4) \quad y_i = \begin{cases} 1 & \text{if } y_i^* > 0 \\ 0 & \text{if } y_i^* \le 0. \end{cases}$$

With this dichotomous qualitative response model, the observable dependent indicator variable y_i takes on the value of 1 with probability π_i and the value 0 with probability $1 - \pi_i$. Observed values of y_i are realizations of a binomial process with probabilities that change from observation to observation because of changes in x_{ik}. Thus, the probability that a farmer perceives an improvement in environmental quality after adoption of PFTs can be represented as

$$(5) \quad \Pr(y_i = 1 \mid x_{ik}) = \Pr(\varepsilon_i > -\beta' x_{ik}) = \pi_i = 1 - F(-\beta' x_{ik})$$

where F is the cumulative distribution function for the random error ε, where ε has a distribution with a mean equal to zero, $E[\varepsilon_i \mid x] = 0$, and a variance equal to $\mathrm{Var}(\varepsilon_i \mid x) = \pi_i(1 - \pi_i)$. Thus, there is a constraint on the response, $0 \le E[\beta' x_{ik}] = \pi_i \le 1$, and the conditional distribution of the response variable is binomial.

Although many distribution functions can be considered for the analysis of a dichotomous response variable, the logistic has many advantages (Cox and Snell). Assuming the error term has a standard logistic distribution:

$$(6) \quad 1 - F(-\beta' x_{ik}) = \frac{\exp(\beta' x_{ik})}{1 + \exp(\beta' x_{ik})}.$$

One of the advantages to assuming a logistic distribution is that F is represented as a closed-form expression that can be used to easily evaluate the likelihood function, which can be defined in terms of the individual probabilities associated with each farmer's perception of an improved environmental quality:

$$(7) \quad \ell(\beta \mid y, x) = \prod_{y_i=0} (1 - \pi_i) \prod_{y_i=1} \pi_i.$$

The parameters are incorporated into the likelihood equation using the relationship in Equation (5):

$$(8) \quad \ell(\beta \mid y, x) = \prod_{y_i=0} F(-\beta' x_{ik}) \times \prod_{y_i=1} [1 - F(-\beta' x_{ik})].$$

Taking logarithms, the log likelihood equation is specified as

$$(9) \quad L(\beta \mid y, x) = \ln \ell(\beta \mid y, x) = \sum_{y_i=0} \ln F(-\beta' x_{ik}) + \sum_{y_i=1} \ln[1 - F(-\beta' x_{ik})].$$

Coefficient estimates are found by maximizing the value of the log likelihood equation using the method of maximum likelihood. Once coefficient estimates are found, the probability that a specific type of farmer and/or farm would observe environmental benefits can be predicted. The significance and magnitude of the parameter estimates also help to identify factors that may influence a farmer's perception of environmental improvements resulting from the adoption of PFTs.

Data

The sample frame for this mail survey included all cotton farmers in Alabama, Florida, Georgia, Mississippi, North Carolina, and Tennessee. The geographic focus was the Southeastern United States because empirical work on precision farming in this region was sparse. Cotton was the focus crop because it is important in the South and, at the time of the survey in 2001, PFTs were becoming more prevalent for this crop than others in the region.

Using standard procedures for a mail survey, including the sending of two questionnaires and a reminder postcard, a total of 1,131 responses (19% of the total) were received from a stratified random sampling approach (Roberts et al. 2004).[1] The survey instrument asked questions about 21 PFTs for each of the seven primary crops grown in the Southeast United States (i.e., cotton, tobacco, peanuts, soybeans, corn, wheat, and rice). This data set was previously used to estimate the probabilities of farmers adopting specific PFTs for cotton (Roberts et al. 2004). In this study, we are interested in the subgroup of respondents who adopted PFTs for use on any of the seven crops.

The 21 PFTs fell into two distinct categories. The first category contained the technologies used to obtain the prerequisite background information on site variability, including: yield monitoring (3 technologies), soil sampling (2 technologies), tissue testing (1 technology), mapping (2 technologies), and sensing (3 technologies). All respondents in the subgroups used at least one of these information-gathering technologies. The second category contained information on experience with the variable rate application of inputs. In this study, variable rate application of the following inputs (on any of the seven crops) was considered: nitrogen, phosphorous and potassium, lime, seed, growth regulator, defoliant, fungicide, herbicide, insecticide, and irrigation. Because we are interested in environmental benefits from using precision farming technologies, the information on variable input application rates (second category) is especially relevant for this study.

The questionnaire asked those farmers who indicated they had adopted PFTs whether they had experienced any subsequent improvements in environmental quality in their fields. The number of PFT adopters responding appropriately to this question was 197 (3.3% of cotton producers in 2000).[2] This number is

[1] This response rate is considered acceptable because of the uncertain feasibility of several PFTs at the time of the survey (e.g., Swinton and Lowenberg-DeBoer, 1998) and the broad scope of the survey, which included six states, seven crops, and 21 PFTs. Cost constraints prohibited the examination of non-response bias through a stratified follow-up survey. As an alternative, comparisons at the state level revealed a distribution of responses to farm characteristics (e.g., average farm size, crop acreage, and yields) and farmer demographics (e.g., age, education, and farm experience) that corresponded to available point estimates. The one notable difference is that mean cotton yields were slightly higher among respondents than reported by the National Agricultural Statistics Service.

[2] Respondents were asked "Have you experienced any improvements in environmental quality through the use of precision farming technologies?" An open-ended follow-up question was asked to ascertain how each respondent may have interpreted the question ("If you answered yes, please list the improvements you have observed"). Space was provided for up to four responses. If none of the write-in responses pertained to land or air quality, then a yes response to the initial question was changed to no. Although there was a concern that responses to questions about the possible positive environmental effects of PFTs would be subject to strategic bias, the response rate regarding whether environmental benefits were very important to their PFT adoption decision (*ENVIRON* variable) and to whether they experienced any environmental improvements were relatively small (21% and 38%, respectively), which suggests no such bias. In addition, environmental questions concerned only three of over 600 variables in the questionnaire so they were not the focus of the survey.

slightly higher than the 153 adopters of PFTs for cotton examined in Roberts et al. (2004). For comparison, 3.1% of cotton acres were soil-mapped by 1998 and by 2000 approximately 1% of acres planted to cotton were harvested by equipment with yield monitors (Griffin et al.). This incidence of PFT adoption is lower than the 4% national rate at the time of the survey, likely because early adoption has been by large producers of other crops (Cowan). Of the 197 adopters of PFTs for use on any of the seven Southeastern crops by cotton farmers, 38.2% indicated they had perceived an improvement in environmental quality from using PFTs.

Empirical Model

Whether farmers reported observing an improvement in environmental quality from the use of precision farming technologies (*IMPROVE*) was used as the dependent variable in the binomial logit model. The farm and household explanatory variables utilized in the empirical model and their hypothesized signs are presented in Table 1.

The characteristics of the farm included location, farm size, and land quality. Location was captured with five dummy variables (i.e., *AL, FL, GA, MS,* and *NC*) to test whether PFT-adopting farmers in Alabama, Florida, Georgia, Mississippi, and North Carolina had higher or lower probabilities of perceiving environmental quality improvements relative to farmers located in Tennessee. No *a priori* hypotheses were specified regarding the sign on these variables, although state-level differences are anticipated because of spatial heterogeneity in environmental quality, available technologies, and agronomic behavior (Hatfield).

Acres planted (*PLANTED*) is the total acres planted in all seven crops. This variable, a proxy for farm size, was expected to positively affect the probability that a farmer would perceive an improvement in environmental quality following the use of PFTs. A larger farm size has been associated with in-

Table 1. Definitions of Variables and Hypotheses of Effects on Perceived Environmental Improvements (IMPROVE)

Variable	Variable Description	H_0
IMPROVE	Perceived environmental improvements from PFT (yes = 1; no = 0)	
AL	Farm located in Alabama (yes = 1; no = 0)	+−
FL	Farm located in Florida (yes = 1; no = 0)	+−
GA	Farm located in Georgia (yes = 1; no = 0)	+−
MS	Farm located in Mississippi (yes = 1; no = 0)	+−
NC	Farm located in North Carolina (yes = 1; no = 0)	+−
TN	Farm located in Tennessee (yes = 1; no = 0)	+−
PLANTED[a]	Total acres planted in seven crops in 2000 (1,000 acres)	+
YIELD	Average cotton yield in 2000 (1,000 lbs. acre)	+−
USE_VRT[b]	Used variable rate technologies for at least 5 years (yes = 1; no = 0)	+
COMPUTER	Uses a computer for farm management (yes = 1; no = 0)	+
ENVIRON	Believes environmental benefits are very important (yes = 1; no = 0)	+
REDUCE	Believes reducing input use is very important (yes = 1; no = 0)	+
PROFIT	Has found PFTs to be profitable (yes = 1; no = 0)	+
HIGH_INC	Household income in 2000 was at least $50,000 (yes = 1; no = 0)	+−
PI_FARM	Percentage income from farming (%)	+−
OVER50	Over 50 years old (yes = 1; no = 0)	−
COLLEGE	Attended college (yes = 1; no = 0)	+

[a] The crops included cotton, corn, soybeans, peanuts, wheat, tobacco, and rice.

[b] Including the variable rate application of nitrogen, phosphorous and potassium, lime, seed, growth regulatory, defoliant, fungicide, herbicide, insecticide, or irrigation.

creased adoption rates for certain crops (Cowan) and allows for more opportunity to observe environmental changes.[3] A measure of production yield was included to capture differences in land quality. Cotton yields were selected because all respondents in this sample farmed cotton. Higher average land quality as reflected by high average yields (*YIELD*) may indicate greater opportunities for spatial yield response variability (Roberts et al. 2004). Higher input levels (which are likely to produce higher yields) may, however, create greater potential for run-off problems.[4] Thus, an *a priori* expectation regarding the sign on *YIELD* is indeterminate.

Two types of production practices were included to explain the perception of improvements in environmental quality from PFT adoption: the variable application of inputs and computer usage. If a farmer has been using variable rate technologies (VRTs) for at least five years (*USE_VRT*), a greater probability of perceiving improvements was expected. Also, if they used a computer for farm management (*COMPUTER*), operators would more likely be educated about and better able to use information regarding the effects of precision farming, and thus would be more likely to have perceived an improved environmental quality.[5]

Three additional types of farm attributes were initially slated for inclusion in the empirical model: information on use of specific PFTs, crop mix, and yield variability. The first could identify the relative environmental impact of alternative PFTs. The second could capture differences in the production of high-input crops. The latter could capture differences in the potential for environmental quality improvements from the adoption of PFTs. None could be included because of lack of sufficient data. All respondents were PFT-adopters, which means that they used at least one of the 11 information-gathering technologies. Attempts to include more refined information were unsuccessful, usually because of perfect or near-perfect correlation with other variables. The percentage of planted land in high-input crops (cotton and peanuts) was highly correlated with total planted acreage (*PLANTED*). The survey asked for the average yield and the yields on the most and least productive one third of farmers' acreage for each crop. The incidence of reporting on the extremes was low and inconsistent across crops.

In terms of farmer attitudes, two variables were included. The first indicated whether environmental benefits were "very important" to their decision to practice precision farming (*ENVIRON*). The second indicated whether reducing input use was "very important" to their decision to practice precision farming (*REDUCE*). Both variables were intended to capture potential "feel-good" responses and, thus, were expected to have a positive effect on perceived environmental quality improvements.

Three questions addressed characteristics related to income and profitability. Whether or not the use of PFTs had been profitable to date (*PROFIT*) was expected to affect whether environmental quality improvements had been perceived. Higher profit could indicate more intensive use of cost-saving VRTs, resulting in larger environmental quality improvements. The other two variables were intended to capture different aspects of income, namely total household income (*HIGH_INC*) and the percentage of household income from farming (*PI_FARM*). A high absolute income level could indicate the financial ability to consider environmental consequences, especially if use of some of the PFTs considered was not profitable at the time of the survey. A greater reliance on farm income could indicate a higher importance placed on environmental quality, which is generally assumed to be a normal (or perhaps superior) good.

[3] *PLANTED* was highly correlated with the number of acres owned in this sample and, although ownership is a better proxy for land tenure issues, *PLANTED* was used because of the higher incidence of reporting.

[4] Detailed information on input levels were not obtained in the survey, and thus could not be included directly.

[5] Managing the site-specific data necessary to use PFTs requires the use of a computer; however, farmers are able to obtain some support from local extension agents or hire these services through local agribusiness firms or farmers' cooperatives (Roberts et al.).

Two farmer characteristics were hypothesized to affect the probability that a farmer perceived environmental quality improvements following PFT adoption. Because the use of PFTs requires considerable analytical ability, farmers who attended college (*COLLEGE*) may be more likely to possess the human capital to understand and perceive such improvements. In general, older farmers have shorter planning horizons, diminished incentives to change, and less exposure to the technologies required for precision farming than younger farmers (Roberts et al. 2004); thus, a farmer over 50 years old (*OVER50*) was hypothesized to be less likely to have attributed any perceived improvement in environmental quality to the use of PFTs.

Results

The unknown parameters (β) were estimated using the LIMDEP software package. There was a total of 141 observations.[6] Summary statistics of the data and the empirical binomial logit model are presented in Table 2. The marginal effects are the marginal effects of changes in the variables on $\Pr[y = 1]$. Marginal effects for the continuous variables were calculated by differentiating the probabilities with respect to the explanatory variables and standard errors were computed using the delta method. Marginal effects of dummy variables were computed as $\Pr[y = 1 | d = 1] - \Pr[y = 1 | d = 0]$, where d is the dummy variable under consideration.

Our study found 36.2% of adopters perceived environmental improvements following the use of PFTs. Given the sample size, the 95% confidence interval has a 7.9% margin of error. From 28.3% to 44.1% of Southeast cotton farmers believed that they observed an improvement in environmental quality. This provides some information regarding the potential for visible improvements to induce greater or sustained use of PFTs.

The likelihood-ratio test statistic of 54.8 was statistically significant at the 99% level (16 d.f.), which indicates that the model explained a significant portion of the variance in

[6] Approximately 28% of observations were lost because of missing data on certain variables, including *COMPUTER* and *COLLEGE*.

Table 2. Variable Statistics and Model Estimation Results ($N = 141$)

Variable	Mean	SD	Coefficient Estimate[a]	Coefficient SE	Marginal Effect[b] Estimate[a]	Marginal Effect[b] SE
CONSTANT	N/A	N/A	−2.735*	1.251	N/A	N/A
AL	0.135	0.343	0.813	0.938	0.184	0.225
FL	0.036	0.186	3.271*	1.480	0.639**	0.136
GA	0.163	0.371	0.094	0.812	0.020	0.171
MS	0.241	0.429	0.047	0.836	0.010	0.174
NC	0.298	0.459	0.450	0.765	0.096	0.168
PLANTED	1.744	1.744	0.325*	0.142	0.067*	0.029
YIELD	0.660	0.282	2.095*	1.056	0.431*	0.212
USE_VRT	0.234	0.425	0.233	0.538	0.049	0.116
COMPUTER	0.773	0.420	1.394*	0.617	0.237**	0.083
ENVIRON	0.206	0.406	0.517	0.587	0.113	0.134
REDUCE	0.397	0.491	1.014*	0.482	0.215*	0.102
PROFIT	0.674	0.470	2.104**	0.625	0.358**	0.079
HIGH_INC	0.808	0.395	−1.258*	0.639	−0.287	0.151
PLFARM	0.720	0.283	−2.786**	0.885	−0.573**	0.181
OVER50	0.319	0.468	0.640	0.530	0.137	0.118
COLLEGE	0.851	0.355	−0.867	0.664	−0.200	0.158

[a] ** and * indicate statistical significance at the 99% and 95% levels, respectively.
[b] N/A indicates the value is not applicable for this variable.

the perception of improved environmental quality by PFT-adopting Southeastern cotton farmers. The percentage of concordant and discordant pairs of observations with different responses from the model was 83.5% and 16.5%, respectively, with no ties. Because a concordant (discordant) pair is one where the higher ordered value ($y_i = 1$ response) had the higher (lower) predicted probability, the concordant rate indicates an acceptable prediction rate. The associated Somers' D of 0.67 indicates a moderately high strength of agreement of the pairs. The model correctly predicted 71.6% of farmers' responses overall (43.1% and 87.8% for those reporting improvements or not, respectively) using the cutoff probability associated with rate of observed environmental quality improvements (i.e., 36%), which is more conservative.

Multicollinearity was not considered a factor because the Pearson Correlation coefficients and the condition indices were low (Kennedy). The only correlation coefficients in excess of 0.75 were associated with *PLANTED* and *PROFIT*, both of which were statistically significant at the 5% level. The remaining correlation coefficients ranged from 0.33 to 0.31. The highest condition index was 15.16, but was associated with the location dummy variables. The remaining condition indices were below 9.5.

Most of the statistically significant effects had their hypothesized signs. Total acres planted (*PLANTED*), computer use for farm management (*COMPUTER*), farmer perceptions about the importance of reducing input usage (*REDUCE*) and the profitability of precision farming on their farm (*PROFIT*) all positively affected the probability that a farmer in the sample perceived environmental improvements after the adoption of PFTs.

For each additional 1,000 acres of all crops planted in 2000, the probability of a farmer perceiving an improvement in environmental quality increased by 6.7%, holding all other variables at their means. Similarly, an additional 100 pounds of cotton produced per acre increased the probability of improvement perception by 4.3%, holding all other variables at their means. Farmers who used computers were 24% more likely to perceive environmental quality improvements following the adoption of PFTs. Farmers who indicated that it was very important to reduce input usage were 22% more likely to perceive improvements. Farmers who believed implementing PFT was profitable were 36% more likely to perceive improvements in environmental quality after adoption.

The *YIELD* variable was statistically significant and positive, indicating that the land quality effect outweighed the input level effect as described earlier. Thus, farms reporting higher average cotton yields during the previous season, which are often associated with higher spatial variability, were more likely to report having perceived an improvement in environmental quality.

The coefficients of two variables had signs different from their hypothesized values. Household income greater than $50,000 (*HIGH_INC*) and higher levels of percentage income from farming (*PI_FARM*) negatively affected the probability that a cotton farmer perceived environmental improvements after the adoption of PFTs. High-income farmers (those who made more than $50,000 in 2000) were 29% less likely to perceive environmental quality improvements than farmers from households with lower incomes. For each 10% increase in the contribution of farm income to total income, farmers were 5.7% less likely to perceive environmental quality improvements. Perhaps the most successful farmers (as reflected by the higher income) or those most financially dependent on farming had less capacity for recent environmental improvement because they were good stewards prior to implementing PFTs.

Figure 1 shows the probability of perceived improvements in environmental quality from farm size (*PLANTED*) and dependence on farm income (*PI_FARM*), holding other variables at their means. The probability of perceiving an improvement was greater than 50% for farmers planting more than about 4,000 acres and for farmers with less than about 40% of household income from farming.

Personal characteristics of the farmer (i.e., whether the farmer was over 50 years old

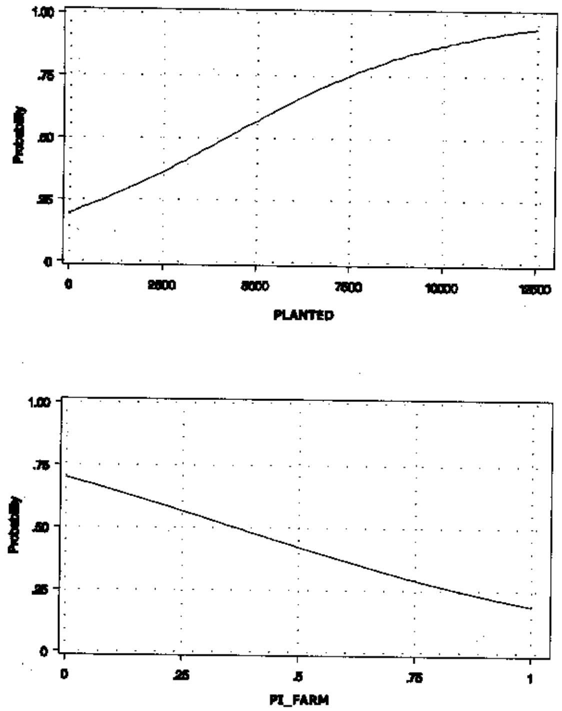

Figure 1. The Probability of Perceiving and Improvement in Environmental Quality Following PFT Adoption by Total Acres Planted in 2000 (*PLANTED*) and the Percentage of Income from Farming (*PI_FARM*)

[*OVER50*] and had attended college [*COLLEGE*]) were not statistically significant. Interestingly, two of the variables that might be expected to be most significant were not: whether VRTs have been used for at least five years (*USE_VRT*) and whether environmental benefits were very important (*ENVIRON*). If using VRTs for at least five years does not affect the probability that a farmer perceives any positive environmental effects, then the duration of time between adoption and observance of environmental quality improvements could be different or irrelevant. If the importance of environmental benefits does not affect the probability that a farmer perceives any positive environmental effects, then concern over strategic bias is lessened.

On average, farmers from Florida were 64% more likely to observe an improvement in environmental quality from precision farming than similar farmers located in Tennessee.[7] This finding could indicate that lands in Florida are more resilient, that farmers in Florida used agronomic behaviors following PFT adoption that were more effective, and/or that PFT technologies (including the availability of custom hired services) were more available in Florida as compared to Tennessee at the time of the survey.

Summary and Discussion

Southeastern cotton farmers who have adopted precision farming technologies (PFTs) were asked if they perceived environmental quality improvements from their technology decision. Approximately one third indicated that they had. Although this share was lower than expected because of the nature of the question, and positive responses are not indicative of the extent of actual improvements, the share does provide a proxy for the extent to which farmers have an incentive to supply a cleaner environment. If the adoption of PFTs provides continuous improvements in environmental quality, and a cleaner environment has value, the incidence of perceived improvements in environmental quality results in a suboptimal provision of the public good. In situations where PFTs may not be profitable, especially soon after adoption, continued use of the environmentally-friendly production practices may depend in part on the degree to which farmers perceive there to be visible improvements in environmental quality.

In this study, the probability that a farmer perceived any improvements in environmental quality following the adoption of PFTs was higher if the farm was larger, was located in Florida, or had higher yields. The direct relationship between farm size and the observance of environmental quality improvements may support findings of a threshold effect with regard to actual improvements following PFT

[7] Using a different state for the base, or omitting the constant and including all states as regressors, did not alter the results that Florida farmers were more likely to observe environmental improvements from using VRTs.

adoption. To the extent that perceived and actual environmental benefits are correlated, the finding also suggests that larger farms may be good for the environment. Different perceptions between farmers in Florida and Tennessee support geographic differences in available information, agronomic practices, and land characteristics. From a social perspective, encouraging larger farms and those with the greatest potential for increased yields to adopt PFTs may have the highest potential to improve environmental quality.

PFT-adopters who personally used computers for farm management were more likely to perceive an improvement in environmental quality, perhaps because they are more aware of the magnitude of changes in input use following PFT adoption. This supports the finding of a higher probability among those who felt that reducing inputs was very important. Although both findings could reflect bias, this study also found that those who indicated that environmental benefits were very important to their decision to adopt PFTs were not more likely to have perceived an improvement in environmental quality. Either there was no visible improvement by the time of the survey, or their environmental views did not affect the probability of observing an improvement in environmental quality.

This study hypothesized that an environmental improvement might not be perceived until five years after a farmer began using VRTs; however, this hypothesis was not supported by the data. The probability of perceiving an improvement in environmental quality following the adoption of PFTs was also unaffected by a farmer's age and education level. These findings contrast with those from the same survey that examined adoption decisions (Roberts et al. 2004). Thus, the factors that drive PFT adoption may not be the same as those that drive perceptions of environmental benefits.

Overall, there appears to be a potential for the extension service to deliver targeted farm-level decision support services with regard to environmental benefits of precision farming. Educating farmers on visible improvements in land quality can be a valuable tool in promoting future adoption of environmentally-friendly production practices, such as PFTs. In addition, it can provide landowners with information that could increase land values, particularly for conservation easements where landowners may be required to maintain the quality of land. The establishment of PFTs and corresponding BMPs could provide a system that includes monitoring of practices and changes in environmental quality that could prevent the need for uniform regulatory measures (Cowan).

The results from this study are based on the population of cotton farmers in the six Southeastern states that responded to a 2001 mail survey. Although the survey captured state-level differences and key characteristics of farms and farmers, the analysis was unable to capture potential differences related to crop mix decisions and input use. Surveys designed to capture such information on various crops, and the proximity to the nearest watershed, would strengthen a subsequent analysis. Also, the valuation of environmental quality improvements would be useful for policy makers charged with developing cost-effective solutions to the environmental concerns of modern crop production.

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