A Logit Analysis of Precision Farming Technology Adoption in Tennessee

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Abstract

Data from a survey of County Agricultural Extension Agents and the Census of Agriculture were use to develop logit regression models to estimate the probabilities of farmers adopting four precision farming technologies in Tennessee counties. County characteristics associated with adoption were owned versus rented land, land in large farms relative to total land in farms, the value of crop sales per acre, total cropland, numbers of full- and part-owner farmers, and cropland relative to total land in farms. Agribusiness firms could use the estimated probabilities to identify counties with favorable characteristics for adoption of their precision farming services.

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Farm fields have numerous areas that differ from one another with respect to soil type, topography, microclimate, and other factors that influence crop yields (Carr et al.; Hannah, Harlan, and Lewis; Hibbard et al.; Malzer et al.; Sawyer; Spratt and McIver). The concept of precision farming employs information about the heterogeneous makeup of farm fields for making management choices. Precision farming does not use a single technology to generate information for decision making but a whole set of information technologies (Swinton and Lowenber-DeBoer). These technologies include: (*a*) diagnostic and data management technologies which generate and organize data that describe field variability, (*b*) technologies capable of attaching spatial coordinates to the data, and (*c*) variable rate application equipment that allows farmers to apply inputs using the information about field variability (Nowak; Khanna, Epouhe, and Hornbaker). More precise placement of inputs with precision farming may increase farm profits and may reduce adverse environmental consequences of crop production (Kitchen et al.; Koo and Williams; Sawyer; Watkins, Lu, and Huang). However, the key to farmer adoption of site-specific farming is the profitability of the technology (Daberkow; Reetz, and Fixen; Roberts, English, and Mahajanashetti; Sawyer).

Available information on where precision farming practices have been adopted is primarily for a few higher value crops such as sugar beets and for several crops grown in the Midwestern United States (Daberkow and McBride; Khanna, Epouhe, and Hornbaker; Franzen; Surjandari and Batte). Little information currently exists on where precision farming practices have been adopted in the Southern United States. Crops in the Southern United States are generally produced in fields known to have a high degree of variability in soil type, topography, soil moisture and other factors affecting crop production. In addition, high value crops specific to the region such as cotton, rice, tobacco, and peanuts require extensive use of chemicals such as fertilizers, insecticides, herbicides, and defoliants. Precision farming technologies hold great promise for these high-value, high-input southern crops.

A March 1999 survey of Tennessee Agricultural Extension Agents identified 284 producers using some form of precision farming technology in 38 of Tennessee's 95 counties (English, Roberts, and Sleigh). Yield monitors were used in 34 counties; grid soil sampling was practiced in 28 counties; and variable rate application of fertilizer and/or lime was practiced in 18 counties. An April-May 1999 survey of firms providing precision farming services to Tennessee farmers found that 170 farmers received grid soil sampling services and 88 producers received variable rate application of fertilizer and/or lime services from the 23 responding firms (Roberts, English, and Sleigh). The number of Tennessee producers using grid soil sampling and variable rate fertilizer and/or lime application was less than 0.5% of the total number of farms harvesting crop acreage and less than 1% of the number of farms with sales over $10,000 in Tennessee (U.S. Department of Agriculture). Even though the number of farms using precision farming technology in Tennessee was low relative to other areas, firms supplying these services expected the demand for precision farming services to grow rapidly over the next 5 years. Because of anticipated growth in demand, firms providing precision farming services are interested in knowing where in Tennessee to offer these services with the largest likelihood of finding new clients. The objective of this research was to identify factors that influence the geographic location of precision farming technology adoption in Tennessee.

Methods

Analytical Framework

The location of precision farming technology adoption can be analyzed in the same way as other technology investment decisions. A farmer's decision to investment in precision farming technology is related to maximization of expected net farm income over time, which depends on factors influencing costs and revenues in a geographic area. Assume the probability of precision farming technology adoption by farmers in a geographic area depends on a set of locational characteristics that affect costs and revenues over time according to a cumulative logistics probability function as follows (Pindyck and Rubinfeld):

$$(1) \qquad P(D = 1| X) = \frac{\exp(\sum bX)}{[1 + \exp(\sum bX)]},$$

where $P(D = 1{*}X)$ is the probability that precision farming technology will be adopted within an area, given X; D is a qualitative variable that indexes the adoption of precision farming technology with D =1 indicating that precision farming technology has been adopted within the area and D = 0 indicating nonadoption; X is a set of K explanatory variables that influence the location of precision farming technology adoption; exp(3$X) denotes e raised to the (3$X) power; and $ is a set of K parameters to be estimated.

The parameters can be estimated using a dichotomus dependent-variable logit model as follows:

(2) $\ln\{P(D = 1) / [1-P(D = 1)]\} = \$X + u$,

where the left-hand side is the natural logarithm of the odds of precision farming technology adoption in an area; u is a random error term; and other symbols are defined in equation 1.

After substituting the parameter estimates from equation 2 into equation 1, the probability of adoption within a given area is estimated by substituting the characteristics of the particular area into equation 1. Mean adoption probabilities are calculated by substituting the means of X into equation 1.

The ability of a particular locational characteristic to influence precision farming technology adoption is measured by the change in probability, or the change in P resulting from a one unit change in X_k. This change in probability is calculated as follows (Pindyck and Rubinfeld):

(3)) $P = \$_k P(1 - P)$,

where) P is the change in the probability of adoption resulting from a one unit change in X_k, and all other symbols are defined in equation 1. Equation 3 is typically calculated for the overall means of the area data. These changes in probabilities are interpreted as follows: If area characteristic, X_k, is one unit different in one area than another, the estimated probability of adoption will be) P different in the one area that the other, holding other explanatory variables constant between the two areas.

Empirical Framework

Five logit models were estimated, each with a binary dependent variable indicating whether a Tennessee county had at least one farmer using a yield monitor with GPS (YMW), a yield monitor without GPS (YMO), grid soil sampling (GSS), variable rate fertilizer and/or lime application (VRT), and any precision farming technology (APF). Data required to form the dependent variables were obtained from a March 1999 telephone survey of Agricultural Extension Agents in Tennessee's 95 counties (English, Roberts, and Sleigh). Two weeks prior to the survey Extension Agents were informed by mail of the survey and the questions that would be asked. They were also informed of Extension Administration support for the survey. The following percentages of Tennessee counties had farmers using these technologies (Table 1): YMW, 22%; YMO, 25%; GSS, 29%; VRT, 19%; and APF, 39%.

Explanatory variables used in the analysis are reported in Table 1 with their hypothesized signs, county means, standard deviations, and Gibson and Knox County levels. County differences in soil type, topography, soil moisture, and other factors affecting crop growth may influence productivity and the likelihood of precision farming technology adoption. Areas with larger farm units are more likely to adopt new technology (Rahm and Huffman; Putler and Zilberman; Zepeda). Precision farming technology requires a large capital investment which may be more feasible when the cost is spread over a larger farm unit. Moreover, bigger farms typically have larger fields that may facilitate the application of precision farming technologies. Larger field sizes have higher within-field yield variability because of a less uniform distribution of soil properties or because of a variable response to uniformly applied inputs

(Babcock and Pautsch). Input quality such as soil endowment is of major importance in the adoption of new technologies (Caswell and Zilberman; Dinar and Yaron). The intensity of agricultural production within a county reflects the ability of farmers to compete with farmers in other areas because of lower costs made possible by a more favorable resource endowment. For example, farmer adoption of variable rate application technology has been relatively high for some high value crops such as sugar beets in areas where they are produced (Franzen). Counties that rely heavily on agricultural production, and more specifically on crop production, especially high value crop production, would be more likely to have farmers using precision farming technologies because these technologies are typically used to manage crops, whereas counties that rely heavily on livestock production would be less likely to have farmers using these technologies.

Six variables were included in the logit models to capture differences in resource endowments among counties and, hence, the relative potential for farmers to earn higher net farm income from adopting precision farming technology (Table 1). The percentage of county land in farms (LANDP), which attempted to capture the general importance of agriculture within a county, was hypothesized to positively influence the likelihood of adoption. Total cropland (TCL) was hypothesized to be positively related to the odds of precision farming technologies being adopted in a county, while the value of sales of livestock, poultry, and their products (LSAL) was hypothesized to be negatively related to precision farming technology adoption. Cropland as a percentage of total land in farms (PCIF) was hypothesized to be positively related to precision farming technology adoption. The percentage of farmland in farms of 260 acres or more (PALF) was hypothesized to be positively related to adoption because larger farmers are more likely to have the resources to cost effectively use these technologies and are more likely to be in a position to bear the risk. Finally, the value of crop sales per harvested acre (CSPA) was hypothesized to positively influence adoption.

Land ownership plays a role in the adoption of technology (Lee and Stewart). Farmers who rent a large portion of their crop acreage may not be as willing to make the investment in precision farming technology. Renters may be interested in short-term profit at the expense of longer-term profits. Four tenure variables were hypothesized to influence the location of precision farming technology adoption. Adoption of precision farming technologies was viewed more likely on owned cropland than on rented cropland. Therefore, the number of farmers harvesting crops who fully owned their land (FOCF) was hypothesized to positively influence precision farming technology adoption in a county, while the numbers of farmers who were part owners (POCF) and tenants (TCF) were hypothesized to negatively influence adoption. Finally, part-owner farmers renting smaller amounts of land compared to the amounts of land owned were considered more likely to adopt precision farming technologies. Therefore, the number of owned acres in part-owner farms minus the number of acres rented (LOMR) was hypothesized to be positively related to adoption.

Results

Logit regression results are presented in Table 2. All regressions had highly significant log likelihood scores and percentages of concordant predictions were all greater than 91%. The logit models had from two to six significant explanatory variables. Only one variable (CSPA) had significant coefficients with signs contrary to expectations. From a theoretical standpoint, the production of higher (lower) valued crops cannot be said to discourage (encourage) the adoption of precision farming technologies (Swinton and Lowenberg-DeBoer), but from a practical standpoint one can conclude that the production of higher (lower) valued crops in Tennessee counties was significantly associated with lower (higher) odds of precision farming technology adoption. Higher valued crops such as tobacco, nursery crops, fruits and vegetables are typically produced on small fields relative to row crops and/or in

Tennessee counties where row crops are relatively unimportant. The technologies evaluated were not typically used on the smaller fields, nor in the counties where these higher valued crops are produced.

All technologies evaluated were more likely to be adopted in counties where part-owner farmers owned more land compared to the amount they rented (LOMR) and, except for yield monitors without GPS, where the percentage of cropland compared to total land in farms was higher (PCIF). In addition to those variables, several other variables significantly affected the adoption of individual technologies. Yield monitors with GPS (YMW) were more likely to be adopted in counties with more cropland, more full-owner farmers harvesting crops, and fewer part-owner farmers harvesting crops. Adoption of yield monitors without GPS was more likely in counties with more acreage in large farms. Grid soil sampling (GSS) was more likely in counties with lower-valued crop production, more cropland, and fewer part-owner farmers harvesting crops. Variable rate fertilizer and/or lime application (VRT) was more likely to be adopted by farmers in counties with more acreage in large farms and more full-owner farmers harvesting crops. Finally, adoption of at least one precision farming technology (APF) was more likely in counties with more acreage in large farms, lower-valued crop production, more full-owner farmers harvesting crops, and fewer part-owner farmers harvesting crops.

The one technology that clearly stood apart in terms of significant variables was yield monitors without GPS (YMO). This technology was the only one evaluated that does not rely on GPS. YMO had only two significant explanatory variables; owned versus rented land in part-owner farms (LOMR) and land in large farms as a percentage of total land in farms(PALF). These results suggest that farmers who were using this technology resided in counties with larger farms and with more owned relative to rented land. Other variables were less relevant because farmers who purchased yield monitors without GPS were probably those who had farms large enough to warrant purchasing new combines when prices were high in 1995-97 (Tennessee Department of Agriculture). Many of these combines included yield monitors in the total package at very little additional cost. Thus, farm size probably played a major role in the adoption of this technology.

Estimates of the probabilities of adopting each of these precision farming technologies, evaluated at the means of the county data and for Gibson and Knox Counties, are presented in Table 3. These probabilities were calculated for the levels of the variables given in Table 1. When evaluated at the means of the county data, probabilities of farmers in the average Tennessee county adopting these technologies ranged from 9.27% for yield monitors without GPS (YMO) to 43.08% for any precision farming technology (APF).

The estimated probabilities for Gibson county, where all technologies except variable rate application of fertilizer and/or lime (VRT) were use (Table 1), ranged from 70.29% for VRT to 99.92% for grid soil sampling (GSS). Knox county, on the other hand, had very low estimated probabilities of adoption, ranging from 0.01% for yield monitors without GPS (YMO) to 1.52% for yield monitors with GPS (YMW). The comparison of estimated probabilities for Gibson and Knox Counties generally followed expected patterns. For example, Gibson County had higher PALF, TCL, and PCIF and lower POCF which increased the probability of adoption in Gibson County compared to Knox County. Exceptions to expected patterns occurred with regard to LOMR and FOCF, which decrease the probability of adoption in Gibson County compared to Knox County because these variables were lower for Gibson County than for Knox County. Obviously, the effects of the variables that indicated Gibson County would have a higher probability of adoption greatly outweighed the effects of those that reduced its adoption probabilities relative to Knox County.

Estimated changes in probabilities for significant variables are presented in Table 4. Numbers in the body of the table are estimates of changes in adoption probabilities for the average Tennessee county if the explanatory variable changed by one unit (See Table 1 for units.). For example, Table 3 indicates that the mean probability of adopting yield monitors with GPS (YMW) was 15.53%. Table 4 indicates that this probability would increase by 0.55% to 16.08% if the total cropland mean (TCL) increased by 1,000 acres from 74.42 to 75.42 thousand acres, holding other variables constant.

The probability of farmers adopting any precision farming technology (APF) increased by 2.79% for a 1,000-acre increase in the difference between owned and rented land in part-owner farms (LOMR), 4.38% for a 1% increase in land in farms of more than 259 acres as a percentage of total land in farms (PALF), 0.39% for an increase of one full-owner farmer (FOCF), and 4.58% for a 1% increase in cropland as a percentage of total land in farms (PCIF).

Changes in probabilities for significant variables ranged widely among the technologies. For a one unit change in the difference between owned and rented land in part-owner farms (LOMR), they ranged from 1.07% for YMO to 3.67% for GSS, and for the percentage of farmland in large farms (PALF) they ranged from 2.09% for VRT to 4.38% for APF. They ranged from -9.86% for GSS to -14.75% for APF given a $100 change in the value of crop sales per harvested acre (CSPA). Changes in probabilities varied from 0.55% for YMW to 1.61% for GSS given a 1,000-acre change in total cropland, while adding one full-owner farmer (FOCF) increased the probabilities of adopting precision farming technologies between 0.15% for VRT and 0.39% for APF. Alternatively, an increase of one part-owner farmer decreased the probability of adoption between 0.64% for YMW and 0.76% for GSS. Finally, a 1% increase in cropland as a percentage of total land in farms (PCIF) increased the probability of adoption between 1.83% for VRT and 5.84% for GSS.

The map presented in Figure 1 provides a visual representation of where in Tennessee adoption of precision farming technologies (APF) was predicted to be more or less likely. Counties with high estimated probabilities of adoption (greater than 50%) were located mostly in the western and, to a lesser extent, in the central portions of the state. Precision farming technology adoption was estimated to be less likely in the more mountainous eastern portion of the state, although a few counties in that area had high estimated adoption probabilities.

Firms providing precision farming services may want to target their services toward counties with estimated adoption probabilities greater than 50%, where they would most likely find clients. Also, farmers in those counties may want to consider evaluating the use of these technologies on their farms as they see more and more of their neighbors experimenting with them. Counties with estimated adoption probabilities of less than 25% would not likely be fruitful areas to target in the near future. Those counties with estimated probabilities between 25 and 50% may be fruitful for precision farming technology adoption now or in the not too distant future. In fact, a small number of those counties already had farmers using precision farming technologies as implied by the third column of Table 5 and by the 1 in Figure 1 for APF in Perry County (west-central Tennessee).

Between 11 and 18 counties with estimated adoption probabilities greater than 50% did not have farmers using precision farming technologies (Table 5 and Figure 1). The high estimated probabilities of adoption in these counties, coupled with the apparent unavailability of firms providing precision farming services or farmers using their own equipment, suggest that these counties may be fruitful areas for expansion of precision farming services.

Conclusions

Data from a March 1999 survey of County Agricultural Extension Agents and the 1997 Census of Agriculture were use to develop five logit regression models to estimate the probabilities of Tennessee counties having farmers adopting various precision farming technologies. Probabilities estimated from these models can help agribusiness firms identify the regions of the state where favorable factors associated with the adoption of precision farming technologies exist. Firms contemplating providing precision farming services in Tennessee could use these estimated adoption probabilities to decide where to target their services. According to model predictions, the counties targeted would be those where favorable conditions exist for adoption; for example, counties with sufficient crop acreage, land in large farms, and farmers who are potential adopters. Additional logit analyses are planned to determine the factors that influence an individual farmer residing within a high-adoption-probability county to adopt precision farming technologies.

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Table 1. Variable Definitions, Means and Standard Deviations, and Levels of Variables for Gibson and Knox Counties

Variable	Definition	Hypo-thesis	Mean	St. Dev.	Gibson County	Knox County
YMW	1 if at least one farmer in county used yield monitor with GPS; 0 otherwise		0.22	0.42	1	0
YMO	1 if at least one farmer in county used yield monitor without GPS; 0 otherwise		0.25	0.44	1	0
GSS	1 if at least one farmer in county used grid soil sampling; 0 otherwise		0.29	0.46	1	0
VRT	1 if at least one farmer in county used variable rate fertilizer or lime; 0 otherwise		0.19	0.39	0	0
APF	1 if at least one farmer in county used any precision farming technology; 0 otherwise		0.39	0.49	1	0
LANP	Land in farms as a percentage of county land area (%)	%	42.57	19.20	72.10	27.00
TCL	Total cropland (1000 acres)	%	74.42	53.11	249.10	53.03
LSAL	Sales of livestock, poultry, and their products ($1,000,000)	!	10.71	11.52	8.92	6.57
PCIF	Cropland as a percentage of total land in farms (%)	%	60.04	11.94	89.58	60.39
PALF	Land in farms of more than 259 acres as a percentage of total land in farms (%)	%	49.72	18.21	83.30	24.48
CSPA	Value of crop sales per harvested acre ($100)	%	2.52	1.81	2.78	3.90
FOCF	Number of farmers harvesting cropland who are full owners (farmers)	%	382.18	270.05	321.00	546.00
POCF	Number of farmers harvesting cropland who are part owners (farmers)	!	173.46	103.11	232.00	258.00
TCF	Number of farmers harvesting cropland who are tenants (farmers)	!	34.00	24.42	57.00	40.00
LOMR	Acres in part-owner farms that are owned minus acres rented (1000 acres)	%	1.73	17.51	-57.88	1.81

Table 2. Logit Regressions for the Location of Precision Farming Technology Adoption in Tennessee

Explanatory Variable[a]	Dependant Variable[a]				
	YMW	YMO	GSS	VRT	APF
Intercept	-16.025[b] (0.00)[c]	-21.443[b] (0.00)	-17.738[b] (0.00)	-21.991[b] (0.00)	-19.207[b] (0.00)
LANP	-0.037 (0.26)	-0.015 (0.67)	-0.052 (0.15)	0.046 (0.20)	-0.051 (0.14)
TCL	0.042[b] (0.03)	-0.001 (0.95)	0.069[b] (0.00)	0.004 (0.85)	0.020 (0.39)
LSAL	-0.010 (0.75)	0.011 (0.74)	-0.056 (0.14)	-0.064 (0.20)	-0.035 (0.27)
PCIF	0.221[b] (0.00)	0.072 (0.33)	0.248[b] (0.00)	0.162[b] (0.03)	0.187[b] (0.01)
PALF	0.036 (0.46)	0.286[b] (0.00)	0.058 (0.30)	0.185[b] (0.01)	0.179[b] (0.01)
CSPA	-0.102 (0.61)	-0.842 (0.15)	-0.419[b] (0.09)	-0.454 (0.14)	-0.602[b] (0.05)
FOCF	0.019[b] (0.02)	0.006 (0.43)	0.009 (0.22)	0.013[b] (0.10)	0.016[b] (0.02)
POCF	-0.049[b] (0.01)	0.002 (0.90)	-0.032[b] (0.06)	-0.029 (0.11)	-0.030[b] (0.05)
TCF	-0.023 (0.45)	0.017 (0.62)	0.004 (0.92)	0.017 (0.62)	0.010 (0.79)
LOMR	0.082[b] (0.06)	0.127[b] (0.02)	0.156[b] (0.01)	0.137[b] (0.01)	0.114[b] (0.03)
Likelihood Ratio	42.087[b] (0.00)	52.953[b] (0.00)	64.021[b] (0.00)	38.562[b] (0.00)	64.299[b] (0.00)
Concordant (%)	91.4	92.8	94.8	91.2	92.7
Discordant (%)	8.6	7.2	5.0	8.7	7.2
Tied (%)	0.0	0.0	0.2	0.1	0.1

[a] Variables are defined in Table 1.

[b] Significantly different from zero (" = 10%).

[c] Probability of Chi Square greater than estimated Chi Square.

Table 3. Estimated Adoption Probabilities for Alternative Precision Farming Technologies at the Means of the County Data and for Gibson and Knox Counties

	Precision Farming Technology[a]				
Estimated for	YMW	YMO	GSS	VRT	APF
	Estimated probability of technology being adopted (percent)				
County mean	15.53	9.27	37.98	13.98	43.08
Gibson County	94.98	76.30	99.92	70.29	97.86
Knox County	1.52	0.01	1.24	0.04	0.75

[a] Variables are defined in Table 1.

Table 4. Changes in Adoption Probabilities for Alternative Precision Farming Technologies and Explanatory Variables Evaluated at the Means of the County Data

Explanatory Variable[a]	Precision Farming Technology[a]				
	YMW	YMO	GSS	VRT	APF
	Change in probability for a one unit change in the explanatory variable				
LANP					
TCL	0.55		1.61		
LSAL					
PCIF	2.90		5.84	1.83	4.58
PALF		2.41		2.09	4.38
CSPA			-9.86		-14.75
FOCF	0.24			0.15	0.39
POCF	-0.64		-0.76		-0.73
TCF					
LOMR	1.08	1.07	3.67	1.55	2.79

[a] See Table 1 for variable names and units.

Table 5. Categorization of Estimated Adoption Probabilities Compared to Survey Results

Precision Farming Technology Variable[a]	Estimated Adoption Probability > 50% and Technology Variable = 0	Estimated Adoption Probability < 50% and Technology Variable = 1
	Number of counties in each category	
YMW	11	3
YMO	16	2
GSS	14	3
VRT	18	4
APF	15	2

[a] Variables are defined in Table 1. County lists in each category are available upon request.

Figure 1. Categorization by Estimated Adoption Probability Quartile of Counties with Farmers Adopting Any Precision Farming Technology