Adoption and Abandonment of Precision Soil Sampling in Cotton Production

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Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Orlando, FL, July 27-29, 2008

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Abstract

Technology adoption in precision agriculture has received considerable attention, while abandonment has received little. Our objective was to identify factors motivating adoption and abandonment of precision soil sampling in cotton. Results indicate younger producers who farmed more cotton area, owned more of their cropland, planted more non-cotton area, used a computer, or used a Personal Digital Assistant (PDA) were more likely to adopt precision soil sampling. Those with more cotton area or who owned livestock were more likely to abandon, while those who used precision soil sampling longer, used a PDA, or used variable-rate fertilizer application were less likely to abandon.

Introduction

Precision farming technologies include information technologies and variable-rate application technologies. Factors affecting adoption and abandonment may change as new technologies are developed, and research is needed to understand and keep pace with this evolution. Producers adopt new agricultural technologies based on the expected economic benefits gained from the technology. An extensive body of research explains which farm and farmer characteristics are associated with the adoption of agronomic decision-making technologies (e.g., Feder and Slade 1984; Putler and Zilberman 1988; Batte, Jones, and Schnitkey 1990; Amponsah 1995; Daberkow and McBride 2003). Yet, reasons producers abandon such technologies have received less attention. Once a technology is adopted, the producer may abandon the technology if the benefits produced by the technology are perceived to be less than the costs of adoption. Rogers (1983) refers to this type of technology abandonment as “disenchantment discontinuance.” Like other agricultural technologies, some precision agriculture technologies are discarded in favor of newer, more efficient technologies. Rogers (1983) categorizes these decisions as “replacement discontinuance.”

Previous research (e.g., Khanna 2001; Roberts et al. 2004) examined the relationship between site-specific information gathered using soil testing technology and adoption of variable-rate application of inputs in agriculture. The relationship between the information gathered and other precision farming activities, such as variable-rate application, makes information technology a logical starting point for examining technology adoption and abandonment. Barham et al. (2004) and Carletto, de Janvry, and Sadoulet (1996) looked at adoption and subsequent abandonment of hormone use in dairy cattle and export crops, respectively. Their research provides an opening for analyzing why some precision agriculture technologies are abandoned. Foltz and Chang (2002) and Barham et al. (2004) studied the adoption of recombinant bovine somatotropin (rBST), and examined the characteristics of farmers who abandoned that technology. Barham et al. (2004) found that abandonment decisions were moderated in cases where adoption of a given technology involved significant sunk costs. The results of the rBST adoption study found no differences between the characteristics of adopters and those who stopped using the technology. An important parallel between rBST and soil sampling technologies is that they both have low sunk costs associated with adoption. Grid and management zone soil sampling only have variable costs that depend on the acres sampled and sampling intensity (Swinton and Jones 1998).

Precision agricultural technologies are typically more profitable with high valued crops, such as cotton (Swinton and Lowenberg-Deboer 1998). The typical entry point for grain producers interested in precision farming technology has been through the installation of electronic yield monitors on harvesting equipment (Lowenberg-DeBoer 1999). Farmers typically use monitors to observe yield differences in fields and follow-up with other information technologies such as precision soil sampling. Cotton growers are just as passionate about yields as grain farmers are, but the adoption sequence of precision farming technology in cotton production has differed because of the lack of reliable yield monitoring technologies. Reliable yield monitors for cotton were not available until 2000 while monitors for grains and oilseeds have been on the market since the early 1990s (Perry et al. 2001). Thus, the typical entry point into precision farming for cotton producers has been through the adoption of grid or management zone soil sampling (precision soil sampling), not yield monitoring. A 2001 survey of cotton producers in six southern states indicated that only 3% of 1,373 survey respondents used cotton yield monitors compared with 41% using precision soil sampling (Roberts et al. 2002). Users of grid soil sampling at the time of the 2001 survey had an average of 8.4 years of experience with the technology (Roberts et al. 2002). Thus, precision soil sampling is a relatively widely adopted and mature precision farming technology for which cotton farmers have had sufficient time to evaluate its benefits and costs.

The objective of this research was to determine the farm and farmer characteristics that affect the adoption and subsequent abandonment of precision soil sampling in cotton production. This research focuses on the adoption and subsequent abandonment of precision soil sampling by cotton producers in 11 Southeastern states (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, and Virginia). Current use of precision soil sampling in these states provides a usable pool of data to study abandonment of the technology. This article seeks to fill part of the void in the literature on the abandonment of precision farming technologies in crop production. Identification of the factors influencing farmers who choose to either continue use or abandon precision soil sampling can provide insight into why certain agricultural technologies succeed or fail in the marketplace. Knowledge of the characteristics associated with abandonment provides greater insight into the adoption process. This information could assist agribusiness with the development and upgrading of technologies to better suit the needs of end-users. In addition, an understanding of why farmers abandon such practices might provide Extension insight with respect to training or other kinds of information dissemination to encourage producers to continue using these practices in environmentally sensitive habitats (Lambert et al. 2007).

Conceptual model for adoption and abandonment

Assume that cotton producers are rational agents that face a discrete choice to adopt precision soil sampling. The producer maximizes expected benefits from cotton, grain crops, and/or livestock production over a time horizon, and therefore must weigh the costs of incorporating a new technology into their management portfolio. Let U_{AD} (U_{NA}) be the expected utility of a producer following the adoption (rejection) of precision soil sampling technology, and let $U_{K|AD}$ ($U_{AB|AD}$) be the expected utility of keeping (abandoning) this technology following its adoption. Defining $U^*_{AD} = U_{AD} - U_{NA}$ and $U^*_{AB} = U_{AB|AD} - U_{K|AD}$, the utility-maximizing producer will choose to adopt precision soil sampling when $U^*_{AD} > 0$ and abandon precision soil sampling when $U^*_{AB} > 0$.

By choosing to adopt precision soil sampling, the producer self-selects into the sample of farmers who discontinue precision soil sampling or continue to gather information collected from precision soil sampling. This sequence suggests the use of econometric methods that attend to sample-selection bias (Heckman 1976; Khanna 2001; Roberts et al. 2004). The unobservable latent variables U^*_{AD} and U^*_{AB} are hypothesized to be random functions of observable exogenous variables Z_{AD} and Z_{AB} such that

(1a) $U^*_{AD} = Z_{AD}A + e_{AD}$ and

(1b) $U^*_{AB} = Z_{AB}B + e_{AB}$

where A and B are vectors of unknown parameters and e_{AD} and e_{AB} are random disturbance terms. The latent variables are not directly observable but dichotomous variables measure the producer's decisions as follows: $I_{AD} = 1$ if $U^*_{AD} > 0$ (0 otherwise) and $I_{AB} = 1$ if $U^*_{AB} \cap U^*_{AD} > 0$ (0 otherwise). Because multiplication of the unobserved variables U^*_{AD} or U^*_{AB} by any positive constant does not change the interpretation of I_{AD} or I_{AB}, it is common to assume that the variance of the error terms equals one as implied by the standard normal distribution.

With these assumptions, the indicator variables I_{AD} and I_{AB} measure the probabilities (Pr) associated with the decisions characterized by equations (1a) and (1b). First, the probability of abandoning following adoption is as follows:

(2) $\Pr(I_{AB} = 1, I_{AD} = 1) = \Pr(I_{AB} = 1|I_{AD} = 1)\cdot\Pr(I_{AD} = 1)$

$= \Phi_2(Z_{AD}A, Z_{AB}B, \rho)$

where Φ_2 is the cumulative distribution function of the standard bivariate normal distribution. Second, the probability of continued use following adoption is:

(3) $\Pr(I_{AB} = 0, I_{AD} = 1) = \Phi(Z_{AD}A) - \Pr(I_{AB} = 1, I_{AD} = 1)$

$= \Phi_2(Z_{AD}A, -Z_{AB}B, -\rho)$

where Φ is the cumulative distribution function of the standard normal distribution. Lastly, the probability of not adopting the technology is:

(4) $\Pr(I_{AD} = 0) = 1 - \Phi(Z_{AD}A) = \Phi(-Z_{AD}A)$.

The resulting sample log likelihood objective function for this system is (Greene 2000):

$$(5) \qquad \max_{A,B,\rho} \ln L = \sum\nolimits_{AB\in 1, AD\in 1} \ln \Phi_2 \left(Z_{AD} A, Z_{AB} B, \rho \right) + \sum\nolimits_{AB\in 0, AD\in 1} \ln \Phi_2 \left(Z_{AD} A, -Z_{AB} B, -\rho \right) +$$

$$\sum\nolimits_{AD\in 0} \Phi\left(-Z_{AD} A \right).$$

When there is no sample selection bias (e.g., $\rho = 0$), the adoption and abandonment models can be estimated as separate probit regressions, noting that the group discontinuing the use of the technology is a subset of the adoption group.

To facilitate the interpretation of results, the marginal effects for the adoption part of the system are determined as follows: $\partial \Pr(I_{AD} = 1)/\partial x$. The marginal effects for abandonment, conditioned on adoption of the technology, are estimated as $\partial \Pr(I_{AB} = 1 | I_{AD} = 1)/\partial x$. Standard errors of the marginal effects are estimated using the delta method (Greene 2000).

Survey Data

The data were collected from a survey of cotton producers in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, and Virginia (Roberts et al. 2006). The survey questionnaires were mailed on January 28, 2005. Reminders and follow-up mailings were sent on February 4, 2005 and February 23, 2005, respectively. Of the 12,243 surveys mailed, 200 were returned either undeliverable or by farmers indicating they were no longer cotton producers. A total of 12,043 cotton farmers remained in the sample after these exclusions. The response rate was 10% (1,216 cotton producers).

Producers answered questions about the extent to which precision agricultural technologies were used on their farms as well as information on the general structure and characteristics of their farming operations. They were also asked about their profitability of precision agriculture as well as their perceptions of the future prospects of precision agriculture. A total of 827 farms indicated whether they had adopted precision soil sampling. A total of 335 had adopted precision soil sampling (40.5%) and among those, 56 (16.7%) had subsequently abandoned the use of precision soil sampling.

In order to determine how well the respondents to this study represent the population of cotton farmers in the Southeastern U.S., these data are compared with data from the 2002 Agricultural Census (U.S, Department of Agriculture 2004). The average age of the respondents (50 years) was slightly less than the average age of cotton farmers (52 years) reported in the census for the 11 states. The average cotton enterprise size calculated from the census was 635 acres for the 11 states while the average size was 815 acres for survey respondents.

The difference between the survey respondents and the census data is explained, in part, by protocols used in recording census data. In particular, there is a need to prevent identification of farms in the larger census categories. Information on relatively larger farms is included because this study only reports statistics on aggregated data. Also, planted cotton area decreased in the 11 states by 650,000 acres between 2002 and 2004 (U.S. Department of Agriculture, 2004). Thus, the survey data used in this study is representative of larger farms relative to census figures. Given that larger farms have been found to have higher adoption rates for certain precision farming technologies (Daberkow and McBride 2003), the data in this study is well-suited to analyzing the population of farmers more likely to be affected by factors associated with adoption and abandonment of precision soil sampling.

Empirical Models

The empirical models for precision soil sampling adoption and abandonment were specified as:

(6a) $ADOPT_i = Z'_{AD,i} A + e_i$,

(6b) $ABANDON_{j \in i=1} = Z'_{AB, j \in i=1} B + e_{j \in i=1}$,

where *ADOPT* equals one if farmer *i* adopted precision soil sampling (zero otherwise) and *ABANDON* equals one if the farmer $j \in i$ abandoned precision soil sampling (zero otherwise). Descriptive statistics and definitions of producer characteristics and farm attributes (Z_{AD} and Z_{AB}) along with their expected relationships with adoption and discontinuance are in Tables 1 and 2.

When $\rho = 0$, there is no selectivity bias and (6a, 6b) can be estimated as separate probit regressions; equation 6a would be estimated using probit regression using the full sample, and equation 6b would be estimated using probit regression with the sub-sample of adopters. If $\rho \neq 0$, a full information maximum likelihood (FIML) procedure would be used to maximize the log likelihood function of the system (Eq. 5), and standard errors would be estimated with a heteroskedastic robust covariance estimator (Greene 2000).

Multicollinearity

Mutlicollinearity can affect the inferential power of tests by inflating the variance of estimates. Variance inflation factors were used to determine whether standard errors were inflated (Chatterjee and Price 1991). Variance inflation factors greater than 10 suggest that standard errors may be inflated by collinearity.

Exogeneity Tests

A common problem encountered in survey analysis is that certain attributes or characteristics of a respondent may be codetermined with the response variable. For example, use of a computer may be part of a precision technology package adopted by the producer. Yield variability may be lower for producers who use precision soil sampling because it enables them to target inputs site-specifically. Farm household income may be higher from more efficient farm management, which may be due to the technology in question. Complementary relationships between technologies and practices may also affect farmer perceptions of the expected value of a decision (Barham et al. 2004). One approach to attend to this issue is to model the variables hypothesized to be endogenous as a system of equations with instrumental variables. A data-driven approach includes forming hypotheses about the exogeneity of the variables in question, and then statistically testing these hypotheses. We take the second approach in this study, noting that rejection of the exogeneity hypotheses suggests a more complicated two-stage instrumental variable model. In both cases, the reliability of answers to questions about the exogeneity of certain variables is constrained by the number of instrumental variables available for these tests or for a complete two-stage system.

Variables in the adoption equation hypothesized to be potentially endogenous include cotton acreage (ACRES), percentage of total cropped acreage devoted to other crops (OCROPS), yield variability (YVAR), computer use in farm management (COM), and household income above $150,000 (INCOME). Variables in the abandonment equation where exogeneity is suspect include cotton acreage (ACRES), percentage of total cropped acreage devoted to cotton (OCROPS), yield variability (YVAR), the number of years precision soil sampling had been used (YRADOPT), computer use in farm management (COM), household income above $150,000 (INCOME), and the use of variable-rate application of phosphorus, potassium, and lime (VRPKL). The use of precision soil sampling could enable more efficient management of larger operations, increase managerial efficiency, or decrease yield variability. Managing data generated by precision soil sampling is likely accomplished using computer-based technology. Uncertainty regarding the issue of whether computers were used previously to make management decisions or if their use was a result of adopting an array of precision agriculture technologies is difficult to untangle. The use of precision soil sampling data has the potential to increase managerial efficiency, thereby potentially increasing profit and income reported by the producer. The decision to continue the use of precision soil sampling is also related with the number of years it was used. And finally, the use of variable-rate application may require information from precision soil sampling.

The Rivers and Vuong's (1988) procedure was used to test the assumption that these variables were exogenous. Each variable whose exogeneity was questionable was regressed against all other exogenous variables, and an additional set of instrumental variables. The residuals from these regressions were then included as additional explanatory variables in a separate estimation of the adoption-abandonment system. For the binary variables hypothesized to be exogenous, the score vector proxies the residuals (Vella 1992). The joint significance of the coefficients associated with the residual terms was tested using a Wald test (Wooldridge 2002). Failure to reject the null hypothesis is evidence that the variables are exogenous. The instruments included all exogenous variables in the adoption equation along with additional instruments. Instrumental variables used in the Rivers-Vuong test included annual precipitation, July humidity, and January sunlight hours, all from the Area Resource Files (2005, www.arfsys.com). Additional instrumental variables included a population interaction index (a rurality measure, www.ers.usda.gov/Data/PopulationInteractionZones), and variables indicating whether the county the respondent lived in was classified as a manufacturing-dependent county, low employment county, or low education county in 2003 (www.ers.usda.gov/Data/TypologyCodes). These instruments were selected because they are determined outside the producers' immediate decision making nexus for farm management activities (e.g., they are exogenous), but are correlated with the model *explanans* (e.g., farm location, climate patterns influencing production, access to agricultural support service [as physical or human capital], off-farm work opportunities, etc.).

Comparison of characteristics between adopters (n = 335) and non-adopters (n = 492), and producers who abandoned (n = 56) and who continued (n = 279) soil sampling were made to provide further insight into the factors motivating adoption and abandonment. Hartely's F-max test (Lentner and Bishop 1993) was used to determine if the variances of the characteristic variables from each subset were significantly different. When the null hypothesis of equal variance between the groups was rejected, degrees of freedom for the sample t tests were adjusted using Satterthwaite's procedure (Lentner and Bishop 1993). Farmer characteristics and farm attributes were compared at the 5% level.

Hypotheses

Six farmer characteristics were hypothesized to influence the adoption and abandonment of precision sampling (Table 1). Farmer age (AGE) was expected to be negatively associated with adoption of soil sampling and positively associated with discontinuance. As age increases, the individuals' the planning horizon decreases and limits the time period when farmers perceive they can make changes and offset learning costs (Batte, Jones, and Schnitkey 1990; Roberts et al. 2004). The quadratic age coefficient (QUADAGE) captures elements of experience. Adoption of precision soil sampling is expected to increase with age for younger farmers as familiarity and experience with precision agricultural technologies grow, but declines after a certain age as the planning horizon shortens (Putler and Zilberman 1988; Alexander and Van Mellor 2005). The number of years of formal education (EDUC) is expected to positively influence adoption and negatively influence abandonment of precision soil sampling. Higher levels of formal education may increase the analytical ability of operators managing the voluminous amount of data generated by precision agriculture (Batte, Jones, and Schnitkey 1990). In the same way, computer use in farm management (COM) should relate positively with adoption but negatively with abandonment of soil sampling. Because computer technology is either integrated into precision agricultural technology or used to transfer and manage precision farming data, computer use for farm management is likely tied to adoption and abandonment decisions. Higher income levels from farming (INCOME) should be positively associated with adoption and negatively related with discontinuance. In this study, high income households are those reporting annual income from farm and off-farm sources greater than $150,000. Higher income could facilitate investment in precision farming technologies while lack of resources may increase the likelihood of abandoning soil sampling due to an inability to obtain other complementary technologies or consultation (Rogers 1983). Farmers who responded that Extension services were useful in making precision farming decisions (EXTEN) were expected to more likely use precision soil sampling. These same attitudes are expected to negatively correlate with soil sampling abandonment. Therefore, the ability of Extension to provide useful information to farmers could reduce disenchantment discontinuance. Positive perceptions about the future profitability of precision agriculture (PROFIT) are expected to be positively related with adoption and negatively associated with abandonment. Farmers may be more willing to adopt and keep using precision soil sampling when they perceive future payoffs to be greater than the costs.

Seven farm characteristics were hypothesized to correlate with adoption and/or abandonment of precision soil sampling (Table 1). The number of cotton acres planted (ACRES) measures enterprise size, and is hypothesized to be positively related with adoption but negatively correlated with abandonment of the technology. Farmers who operate relatively more cotton acres are expected to more likely use precision soil sampling by virtue of scale economies. The percentage of total farm acres planted with other crops (OCROPS) is expected to be positively correlated with adoption but negatively related with abandonment of soil sampling. Farmers who place greater emphasis on grain and oilseed crops may apply information produced by soil sampling used to manage production of other crops to cotton. Enterprise diversification is measured by livestock ownership (LIVEST) and is expected to be negatively correlated with adoption but positively associated with discontinuance. Fernandez-Cornejo, Beach, and Huang (1994) found that livestock production had a negative impact on the adoption of integrated pest management. Management of an enterprise not directly related to precision soil sampling may reduce the time available to effectively apply soil test information. The percentage of total acres owned (LANDTEN) is hypothesized to positively correlate with adoption but negatively with abandonment. Farmers likely pay more managerial attention to land owned than rented because owned land may be passed to subsequent generations. Yield variability (YVAR) is hypothesized to be positively related with adoption and negatively related with abandonment. Technologies increasing management and input application efficiency can increase profitability (Larson and Roberts 2004). The ability to manage inputs more effectively may decrease yield variability. The number of years precision soil sampling had been used (YRADOPT) is hypothesized to be negatively correlated with abandonment. Continued use of a technology is evidence that the technology provided some benefit to the adopter greater than the cost of its adoption. Variable-rate application of phosphorus, potassium, and lime is hypothesized to be negatively related with abandonment of soil sampling. The use of variable-rate application of inputs (VRPKL) may suggest that benefits from the adoption of precision soil sampling outweigh its costs by providing information about optimal input placement.

The USDA Economic Research Service farm resource regions were included in the soil sampling adoption and abandonment models (Table 1, U. S. Department of Agriculture-Farm Resource Regions 2007). These regional variables control for differences in land prices, access to farm services, climate, and growing seasons (Khanna 2001). The Southern Seaboard (ERS6) region was chosen as the reference region because it had the modal number of survey responses. The hypotheses tested are therefore whether cotton producers in the Heartland (ERS1), Eastern Uplands (ERS5), Fruitful Rim (ERS7), and Mississippi Portal (ERS9) regions were more likely to adopt or abandon precision soil sampling than cotton producers in the Southern Seaboard region.

Results and Discussion

Univariate Comparison of Adopters with Nonadopters

Cotton producers who adopted precision soil sampling were younger and more educated, reported higher household income, and used computers more frequently to manage their farms (Table 3). On average, precision soil sampling adopters had about one year more of formal education than nonadopters, and were (on average) about 3 years younger than producers who had not adopted the technology. About 67% percent of the producers who adopted soil sampling technology used computers as a farm management decision aid compared to nonadopters (57%). Adopters were more sanguine about the future profitability of precision agriculture (66%) than producers who had not adopted the technology (46%). Adopters also, on average, farmed more cotton acres (1,020) compared to 650 acres to nonadopters, which is consistent with the notion of scale economies, and the ability spread the cost of soil sampling over more acres. Cotton producers adopting soil sampling devoted a smaller percentage of the total crop acres operated to cotton production (74%) than nonadopters (78%), suggesting that information obtained from soil sampling was likely used in tandem with production of other crops. Likewise, producers who adopted soil sampling were more likely to apply phosphorous (P), potassium (K), or lime using variable-rate technology (40%) as opposed to cotton producers who had not adopted the technology (7%). Producers who adopted precision soil sampling also reported greater yield variability compared to their counterparts, suggesting that adopters may use soil sampling as a tool to reduce the risks associated with yield variability. There were no differences between adopters and nonadopters of precision soil sampling with respect to livestock production, land ownership, or views and opinions expressed about Extension services.

Univariate Comparison Adopters and Abandoners

There were more similarities than differences between cotton producers who abandoned precision soil sampling and those that continued to use the technology. Surprisingly, cotton producers who discontinued the use of soil sampling expressed that they were optimistic about the profitability of precision agriculture in the future. About 80% of the producers who discontinued precision soil sampling ($n = 44$) were optimistic about the future of precision agriculture. First, this question focused on precision agriculture in general, and not specifically precision soil sampling. Respondents optimistic about the future of precision agriculture could be satisfied with other precision technologies they use, may know others who have profited from adoption of precision agriculture packages, or have confidence in research and development of precision agriculture systems. It is worth noting that variable-rate P, K or lime application, yield variability, and computer use—all factors related to other precision agriculture devices—were not different between users and abandoners. Relatively high fertilizer costs may have mandated variable rates by some method, and computer use to some degree is probably standard for any farm or business operation today. Among producers who abandoned precision soil sampling (53%), the sum of farm and off-farm income was (on average) more than $150 thousand per year, compared to producers who continued to use the technology (35%). As expected, the longer cotton producers used precision soil sampling, the more likely they were to continue using the technology. On average, producers who reported continued use of precision soil sampling had used the technology for about 12 years (compared to 3.7 years for abandoners). Operator age, sentiments about Extension services, land tenure, cotton acres operated, crop diversity, and livestock production were not different between adopters and abandoners at the 5% level.

Model Estimation and Specification

The joint null hypotheses $\beta_k = 0 \;\forall\; k$ and $\alpha_l = 0 \;\forall\; l$ was rejected at 5% (Wald test = 73, df = 37, Table 5). The correlation between the adoption and abandonment decisions was strong and significant (ρ = 0.997, Wald test = 21, df = 1, Table 5). Khanna (2001) investigated the sequential adoption of site-specific management tools and identified strong sample selection bias. The high correlation between the selection and outcome equations is not surprising given the nature of the type of data used in the research and the research objectives. For example, producers who abandoned soil sampling must have adopted it at some point, or producers who used soil sampling are likely to use that information to apply inputs site-specifically. In many empirical situations, the selection and outcome equations are highly collinear (usually by construction). As a result, the correlation between the disturbance terms of the equations is typically strong. Consequently, the signs, magnitude, and significance of regressors shared between the equations may in fact be an artifact of the highly nonlinear procedures used to estimate the system, rather than an attribute of the sample. Puhani (2000) studied the collinear effects arising from FIML estimation of the Heckman probit selection model using Monte Carlo experiments. Nawata (1992) studied the effects of collinearity between the selection and outcome equations estimated using Heckman's (1979) procedure using Monte Carlo experiments. Both studies found that when correlation between the outcome and selection equations was highly collinear, the effects typically expected from collinearity (sign switching, changes in coefficient magnitude, and inflated standard errors) were more likely. As a sensitivity analysis, the adoption and abandonment equations were estimated separately using probit regression (Table 6). The results of the selection model estimated with FIML appear to be robust with respect to collinearity between the adoption and abandonment sequences. The signs, magnitudes, and significance of the marginal effects estimated using FIML and the separate probit regressions were also similar, and conclusions drawn from inference of the marginal effects are identical.

The null hypotheses of the exogeneity test could not be rejected in the ADOPTION (Wald test = 6.50, df = 5, P = 0.26) or the ABANDON equations (Wald test = 8.22, df = 7, P = 0.31). Therefore, insufficient evidence exists to reject the null hypothesis that cotton acres, crop diversity, yield variability, computer use, and income were exogenous in the adoption equation; and that cotton acres, crop diversity, yield variability, computer use, income, variable-rate P, K, or lime, or the number of years soil sampling had been used were exogenous in the abandonment equation. The same results were obtained when the adoption and abandonment equations were estimated as separate probit regressions.

With the exception of AGE and QUADAGE, variance inflation factors were less than 2 for all variables. The collinearity between AGE and QUADAGE was expected given the construction of these variables. Nonetheless, the high variance inflation factors of these variables suggest that failure to reject the null hypothesis that AGE and QUADAGE had no relationship with the decision variables should be interpreted carefully. A sensitivity omitting the quadratic age term in the model is reported below.

Precision Soil Sampling Adoption

Cotton acreage (ACRES), perceptions about the future profitability of precision agriculture (PROFIT), the number of years of education (EDUC), and the use of a computer in farm management (COM) were positively correlated with the adoption of precision soil sampling, holding other factors constant (Table 5). The percentage of total acres used to produce crops other than cotton (OCROPS) was positively related with the adoption of precision soil sampling, suggesting some knowledge spillover advantage from using the technology on multiple crops. Enterprise diversification (LIVEST), land tenure (LANDTEN), yield variability (YVAR), farmer age (AGE), farmer age squared (QUADAGE), pre-tax household income (INCOME), and perceptions about the usefulness of extension (EXTEN) were not related with the decision to adopt precision soil sampling. The probability of adoption in other ERS Farm Resource Regions was not significantly different from adoption in the Southern Seaboard region.

These results suggest that farmers who had more years of formal education, farmed more cotton acres, used computers in farm management, were optimistic about the future of precision agriculture, and allocated relatively more acres to crops other than cotton were more likely to adopt precision soil sampling for cotton production. These findings are consistent with the existing body of literature on adoption of various precision agriculture technologies in general (e.g., Khanna 2001; Daberkow and McBride 2003; Roberts et al. 2004). Surprisingly, though, age does not appear associated with the adoption decision. We surmised this might be due to collinearity between AGE and its square. As a sensitivity check, AGE was significant after eliminating the quadratic term. This check had no effect on the other coefficients with respect to direction and significance.

Precision Soil Sampling Abandonment

Cotton acres (ACRES), the percentage of acres devoted to other crops (OCROPS), farmer age (AGE), farmer age squared (QUADAGE), number of years precision soil sampling had been used (YRADOPT), and variable-rate application of P, K, or lime (VRPKL) were all found to have a statistically significant correlation with abandoning precision soil sampling, all else equal (Table 5). The signs of these variables were consistent with a priori expectations, with the exception of cotton acres (ACRES). Cotton acreage (ACRES) was positively associated with the probability of abandoning soil sampling. An alternative explanation concerning this variable is that larger cotton operations may have received increased managerial attention than smaller operations, and therefore the profitability of an investment in precision agriculture may be subject to a higher level of scrutiny. Or, larger operations do not have managerial time required to do (or perceive any value in) precision soil sampling. Higher levels of scrutiny may increase the likelihood of abandonment at even smaller margins below profit. Variables not correlated with discontinuance of precision soil sampling were enterprise diversification (LIVEST), perceptions about the future profitability of precision agriculture (PROFIT), land tenure (LANDTEN), yield variability (YVAR), number of years of formal education (EDUC), pre-tax household income (INCOME), and perceptions about the usefulness of Extension (EXTEN). The probability of abandoning soil sampling was significantly lower in the Eastern Uplands region than in the Southern Seaboard region. The adoption rate for soil sampling by farmers in other ERS Farm Resource regions was not significantly different than in the Southern Seaboard region.

That acres allocated to cotton production were positively correlated with discontinuance of precision soil sampling is consistent with Foltz and Chang (2002) and Barham et al. (2004). These studies report that adopters and abandoners share many of the same characteristics. The univariate comparisons of adopters and abandoners shows that producers discontinuing soil sampling planted (at least numerically) more acres to cotton than producers who continued using the technology. Those who adopted precision soil sampling planted an average of 1020 acres of cotton while those who abandoned precision soil sampling planted an average of 1390 acres. This lends support to the earlier stated alternative hypothesis that larger acres receive increased managerial attention and therefore the performance of a technology is subject to a higher level of scrutiny. An increased level of attention paid to the performance of precision soil sampling could foster abandonment decisions when even moderately poor performance is observed.

The positive coefficient associated with non-cotton acreage as a percentage of total cropped acres is consistent with the previous hypothesis for this variable. As the percentage of total acreage devoted to cotton increased, the likelihood of abandoning soil sampling decreased. This finding suggests that crop enterprise diversification increases the probability of abandonment of cotton precision soil sampling. It is possible that while some farmers may use crop diversification as a risk managing strategy, others may use information from soil sampling, and allied site-specific technologies, to manage risk.

Age was positively related with soil sampling discontinuance, which is consistent with hypotheses concerning the effects of shortened planning horizons of decision making. The square of age was negatively associated with discontinuance, suggesting that with experience comes understanding of how to successfully apply information from soil testing. Younger, less experienced farmers appear more likely to abandon soil sampling, perhaps out of frustration. But with age come experience, and the likelihood of abandoning soil sampling decreases. Beyond a certain age, the effect of experience decreases and the role of a shortened planning horizon takes affect, increasing the likelihood of abandonment.

Negative coefficients for the number of years adopted and for the use of variable-rate application of inputs are consistent with earlier stated hypotheses. Continuing the use of precision soil sampling in subsequent years after adoption demonstrates perceived benefits were greater that associated costs. Using data obtained from an information gathering technology, such as precision soil sampling, for variable-rate application of inputs is also evidence the value obtained from adoption is greater than the associated costs.

Summary and Conclusion

Farmer decisions regarding the adoption and abandonment of precision soil sampling were analyzed as a function of observable farm and farmer characteristics. Because adoption is a prerequisite to abandonment, equations were estimated sequentially to provide a basis for comparison of the farmer and farmer characteristics affecting adoption and abandonment.

The results from a sequential adoption-abandonment model suggest that younger farmers, those with larger cotton acreages who had positive perceptions about the future profitability of precision agriculture, or those who used a computer in farm management were more likely to adopt precision soil sampling. Results showed that farmers who devoted larger percentages of their acreage to the production of other crops were more likely to adopt precision soil sampling for cotton production. Thus, evidence exists that farmers transferred technology familiarity and use from other crops to cotton. Of those who adopted, younger farmers in the Eastern Uplands region, those who used precision soil sampling technology a greater number of years, or those that utilized variable-rate application of inputs were less likely to abandon. Results also showed that adopters with larger cotton acreages were more likely to abandon. This result suggests that farmers operating larger acreages of cotton applied greater scrutiny to management practices, or that larger operations have less time to manage detailed soil sample information. In addition, producers may not perceive any value in precise measurement of soil characteristics in a field sampled over several seasons since this information is generally applicable for several years.

The marketing efforts of agribusiness firms could benefit from tailoring efforts towards younger farmers or farms with larger cotton acreages as they attempt to promote precision soil sampling services. An important conclusion drawn from this research is that agribusiness firms wishing to maintain the use of precision soil sampling technology could benefit from promoting other technologies and practices that make use of the site-specific data obtained from soil sampling. Extension personnel could create educational programs that would emphasize the application of precision soil sampling data in production. Expanding adoption/abandonment analyses could also be important for understanding the use and discontinuance of other precision farming methods, including aerial imagery and other remote sensing technologies, controlled drainage systems, and yield monitoring. Similar patterns of adoption and abandonment may imply that producers may perceive the benefits of precision agriculture technologies to be initially high, but after repeated use over time, these technologies become routine, with less immediate value attributed to them.

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Table 1. Variable Definitions, Hypothesized Signs, and Means in the Precision Soil Sampling Adoption and Abandonment Equations

Variable	Definition	Hypothesized sign: Adopt	Hypothesized sign: Abandon	Mean
Farmer Characteristics				
AGE	Age in years of the primary decision maker	−	+	49.98
QUADAGE	Age in years squared	+	−	2576.31
EDUC	Number of years of formal education	+	−	14.29
COM	Equals one if the farmer uses a computer for farm management and zero otherwise	+	−	0.58
EXTEN	Equals one if the farmer perceived extension services helpful in implementing precision farming practices and zero otherwise	+	−	0.84
PROFIT	Equals one if the farmer thought that it would be profitable to use precision agricultural technologies in the future and zero otherwise	+	−	0.54
Farm Characteristics				
ACRES	Average cotton acreage grown in 2003 and 2004	+	−	800.34
OCROPS	Percentage of non-cotton acreage to total cropped acreage	+	−	23.54
LIVEST	Equals one if the farming operation includes livestock and zero otherwise	−	+	0.27
LANDTEN	Percentage of owned land to total land farmed	+	−	31.17

Table 1. Continued

Variable	Definition	Hypothesized sign Adopt	Abandon	Mean
YVAR	Difference between the farmer's estimates of average yields for the most productive 1/3 of and the least productive 1/3 of a typical field	+	−	522.33
INCOME	Equals one if pre-tax household income is greater than $150,000 and zero otherwise	+	−	0.33
YRSADOPT	Number of years precision soil sampling was used		+	4.12
VRPKL	Equals one if variable-rate application of P, K, or L was used and zero otherwise		−	0.2
Location Variables				
ERS1	Heartland	+ −	+ −	0.035
ERS5	Eastern Uplands	+ −	+ −	0.052
ERS7	Fruitful Rim	+ −	+ −	0.045
ERS9	Mississippi Portal	+ −	+ −	0.365
ERS6[a]	Southern Seaboard	+ −	+ −	0.503

[a]Reference region

Table 2. Comparison of Characteristics between Adopters and Non-Adopters of Precision Soil Sampling

Variable[a]	Adopter Mean	Non-Adopter Mean	T-value[bc]
LIVEST	0.27	0.27	0.01
PROFIT	0.66	0.46	5.81**†
ACRES	1020	650	4.97**†
OCROPS	0.26	0.22	–2.28**†
LANDTEN	31.88	30.60	0.58
YVAR	545.61	506.73	2.16**†
AGE	47.87	50.59	–3.46**†
EDUC	14.73	13.99	4.80**
COM	0.67	0.51	5.12**
INCOME	0.38	0.30	2.41**†
EXTEN	0.59	0.54	1.52†
YRADOPT	10.19	0.00	16.97**†
VRPKL	0.40	0.07	11.35**†
n	335	492	

[a] Variables are defined in Table 1.
[b] ** significance at the 5%.
[c] T-test calculated assuming unequal variance denoted by †.

Table 3. Comparison of Characteristics of Producers Who Abandoned and Producers Who Continued the Use of Precision Soil Sampling

Variables[a]	Abandon Mean	Continue Mean	T-value[bc]
LIVEST	0.30	0.27	0.53
PROFIT	0.79	0.64	2.37**†
ACRES	1394.00	943.00	1.64†
OCROPS	0.31	0.25	–1.72†
LANDTEN	33.19	31.61	0.33
YVAR	548.66	545.00	0.09
AGE	48.32	47.78	0.38†
EDUC	14.39	14.80	–1.93†
COM	0.75	0.67	1.18†
INCOME	0.52	0.35	2.30**
EXTEN	0.88	0.86	0.22
YRADOPT	3.70	11.70	–7.48**†
VRPKL	0.39	0.40	–0.17
n	56	279	

[a] Variables are defined in Table 1.
[b] ** significance at the 5%.
[c] T-test calculated assuming unequal variance denoted by †.

Table 4. Results from Heckman Full Information Maximum Likelihood Estimation of Adoption and Abandonment Equations.

	Dependent Variable[a]			
	ADOPT		ABANDON	
Independent Variable[b]	Probit Coefficient	Marginal Effect	Probit Coefficient	Marginal Effect
Constant	-1.968**		-4.822**	
LIVEST	0.076	0.030	0.121	0.028
PROFIT	0.321**	0.123**	0.454**	0.095*
ACRES	0.216**	0.083**	0.232**	0.041**
CROPS	0.281*	0.108*	0.667**	0.173**
LANDTEN	0.002	0.001	0.002	0.000
YVAR	0.000	0.000	0.000	0.000
AGE	0.019	0.007	0.128*	0.039*
QUADAGE	-0.0003	-0.0001	-0.001*	-0.0004*
EDUC	0.058**	0.022**	-0.006	-0.012
COM	0.181*	0.069*	0.279	0.061
INCOME	0.158	0.061	0.268*	0.065
EXTEN	-0.027	-0.010	-0.010	0.001
YRADOPT			-0.062**	-0.021**
VRPKL			-0.317**	-0.091**
ERS1	0.330	0.130	0.352	0.069
ERS5	0.303	0.120	-0.847*	-0.167*
ERS7	-0.013	-0.005	0.053	0.021
ERS9	0.132	0.051	-0.197	-0.082
ρ		0.997**		
N	827		335	
Log-likelihood		-630		
Wald statistic[d] (H_0: $\boldsymbol{\beta} = \mathbf{0}$)		73.07		
Wald statistic[e] (H_0: $\rho = 0$)		20.86		

[a] ADOPT equals one if the farmer adopted precision soil sampling and zero otherwise, ABANDON equals one if the farmer abandoned precision soil sampling and zero otherwise.

[b] Independent variables are defined in Table 1.

[c] Significance at the 5% and 10% levels denoted by **, and * respectively.

[d] df = 37, critical value = 52 at 5%.

[e] df = 1, critical value = 3.84 at 5%.

Table 5. Results from Estimation of Adoption and Abandonment Equations.

	Dependent Variable[a]			
	ADOPT		ABANDON	
Independent Variable[b]	Probit Coefficient	Marginal Effect	Probit Coefficient	Marginal Effect
Constant	–1.932**	–0.746**	–4.258**	–0.703**
LIVEST	0.073	0.028	0.118	0.020
PROFIT	0.321**	0.123**	0.378	0.058*
ACRES	0.213**	0.082**	0.200**	0.032**
OCROPS	0.303*	0.117*	0.650*	0.108*
LANDTEN	0.002	0.001	0.000	0.000
YVAR	0.000	0.000	0.000	0.000
AGE	0.017	0.007	0.169**	0.026**
QUADAGE	0.000	0.000	–0.002**	-0.000**
EDUC	0.057**	0.022**	–0.030	–0.008
COM	0.183*	0.070*	0.265	0.038
INCOME	0.153	0.059	0.283	0.045
EXTEN	–0.028	–0.011	0.002	0.000
YRADOPT			–0.073**	–0.012**
VRPKL			–0.387*	–0.064**
ERS1	0.291	0.115	0.305	0.060
ERS5	0.303	0.120	–1.136**	–0.095**
ERS7	–0.033	–0.126	0.197	0.037
ERS9	0.135	0.052	–0.353	–0.056
N	827		335	
Log-likelihood	–512.881		–117.736	
Correctly predicted	539 (65%)		285 (85%)	
Wald statistic[d] (H_0: $\boldsymbol{\beta} = \mathbf{0}$)	22.362**		27.587**	

[a] ADOPT equals one if the farmer adopted precision soil sampling and zero otherwise, ABANDON equals one if the farmer abandoned precision soil sampling and zero otherwise.

[b] Independent variables are defined in Table 1.

[c] Significance at the 5% and 10% levels denoted by **, and * respectively.

[d] Degrees of freedom for the ADOPT and ABANDON models were 13 and 17 respectively.