Motivation for Technology Adoption and Its Impact on Abandonment: A Case Study of U.S. Cotton Farmers

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Abstract

We estimate a bivariate probit model with sample selection to identify factors affecting adoption and abandonment of precision farming technologies for cotton farmers, using the 2009 Southern Cotton Precision Farming Survey conducted in 12 Southern states in the United States. Farmers for whom being at the forefront of agricultural technology is not an important reason for adoption are more likely to abandon precision farming technologies. This study identified various factors associated with adoption and retention of precision farming technologies. Findings from this study offer significant information to policy-makers for a better formulation of agri-environmental programs that encourage farmers to adopt environmentally benign farming practices including precision farming technologies.

Keywords: Technology Abandonment, Technology Adoption, Bivariate Probit with Sample Selection, Multinomial Logit, Precision Farming Technologies

JEL Codes: Q10, Q12, Q16

I. Introduction

Technology adoption is one of the most extensively studied topics in agricultural economics, including literature investigating factors affecting adoption and diffusion of agricultural technology. On one end of the spectrum, a wide range of socio-economic and environmental factors have been identified to influence farmers' adoption behavior. At the other end of the spectrum, receiving much less attention in the empirical literature is post-adoption behavior of farmers; agricultural economists know far less about factors influencing technology retention or abandonment, compared to the one-time discrete decision of whether or not to adopt a technology.

The primary objective of this study is to enhance our limited understanding about agricultural producers' decision-making following technology adoption. The specific context of the study is adoption and abandonment of precision farming technologies by cotton farmers, using the 2009 Southern Cotton Precision Farming Survey. We aim to contribute to the literature in technology abandonment in two ways. First, we estimate the relationship between motivation for adopting precision farming and post-adoption behavior, using a sequential decision-making model with sample selection. We make use of three variables that represent farmers' motivation for technology adoption: profit, environmental benefits, and being at the forefront of agricultural technology. Second, to examine if factors affecting non-adoption are associated with those for abandonment, we estimate a multinomial logit model to directly compare non-adopters and abandoners of precision farming technology, which the sequential model cannot accomplish,.

The rest of the paper is organized as follows. In Section II, we review a limited number of empirical studies on technology abandonment in agricultural economics. Section III and IV presents conceptual and empirical models, respectively. Section V discusses data, followed by econometric results in Section VI. The final section offers concluding remarks.

II. Literature Review

In contrast to the vast amount of empirical studies on technology adoption, there exists a little empirical evidence on post-adoption behavior of farmers who have previously adopted a new technology. The paucity of such studies could perhaps be attributed to data requirements; to analyze the decision to retain or abandon previously adopted technologies, researchers need information not only on whether or not to adopt the technology but also on whether the adopters choose to retain or abandon the technology. *Ex post* information of technology adoption such as actual profitability of the technology and its suitability to the existing farming practice can also be important determinants of continued use of the technology as well.

The simplest approach to model the sequential decision-making of technology adoption and abandonment is to estimate the two discrete decisions (e.g., probit models) separately as in An (2009), who studied adoption and abandonment of Bovine Somatotropin by dairy farmers in the United States. A restrictive assumption, however, is required for this simple approach. Because the decision to retain or abandon technology in place is only relevant to those who have previously adopted the technology, it is necessary to assume that the error terms in two probit models are uncorrelated, assuming away the sample selection issue. Although the assumption of no correlation between the error terms is a statistically testable hypothesis, a more popular approach is to employ bivariate probit model that accounts for the sequential nature of decision-making and the possibility of sample selection (Heckman, 1976, Khanna, 2001). The bivariate probit model with sample selection in the context of technology adoption and disadoption were employed by Neill and Lee (2001), Amsalu and de Graaff (2007), and Walton, et al. (2008). While the first two studies are conducted in developing countries, Walton, et al. (2008) is more relevant to the current study as it studied use of precision farming technologies by cotton farmers in the United States.

Neill and Lee (2001) investigated reasons for the high disadoption rate of a conservation practice for maize production called "maize-*mucuna*" which was considered labor-saving, yield increasing, and risk reducing for rural households in Honduras. While farmers with higher dependence on and longer experience with maize production are likely to retain maize-*mucuna*, the economic factors surrounding the adopters of the technology were also important. Off-farm income and opportunity cost of land (in terms of distance to a main road) were found to be positively associated with abandonment.

Amsalu and de Graaff (2007) analyzed the relationship between adoption and continued use of stone terrace, a conservation practice to curtail soil erosion, in Ethiopia. Factors relevant to suitability of stone terrace, such as soil fertility and slope of land, were found important in both adoption and abandonment decisions. Perceived profitability and actual profitability positively influenced adoption and abandonment decisions, respectively. As in Neill and Lee (2001), off-farm income was correlated with abandonment. The authors concluded that factors influencing adoption and abandonment are not similar to each other.

Walton et al. (2008) identified factors affecting adoption and abandonment of soil sampling technologies by U.S. cotton farmers. Factors positively associated with technology retention were age, longer experience with soil sampling technology, and the use of variable-rate input application. Farms with large cotton acres were more likely to adopt the technology but such farms were also found more likely to abandon the technology, contrary to their expectation. They argued that large-scale farms might place a higher level of scrutiny on the adopted technology in terms of profit and thus such farms were more likely to abandon the technology. Note that this unexpected result can be seen as an omitted variable problem, which the current study will overcome. Walton et al. (2008) did not control for the motives for technology adoption as a factor in adoption model. Hence, faced with an unexpected result, the authors attributed the effect of profit motivation on technology abandonment to total cotton acres. By specifically including the three variables representing motivation for technology adoption including profit, our econometric model is able to separate the effect of profit motivation from the effect of total cotton acres in explaining reasons for technology abandonment.

In the three studies reviewed above, the correlation between the two error terms were found statistically significant, validating the use of the bivariate probit model with sample selection. Although this model seems to be the appropriate way to incorporate the sequential nature of the two decisions, i.e., adoption and abandonment, it does not allow us to directly compare non-adopters against abandoners. Another modeling approach to technology adoption and abandonment amenable to this issue is a multinomial logit model, in which the dependent variable classifies observations into three categories: non-adopters, retainers who adopted and maintained the technology and abandoners who adopted but later abandoned the technology (Foltz and Chang, 2002).

Barham, et al. (2004a) and Barham, et al. (2004b) employed this approach to identify factors associated with adoption and abandonment of the Recombinant Bovine Somatotropin technology for U.S. dairy farmers. Barham et al. (2004a) observed that significant differences were present between non-adopters and adopters; more educated or younger farmers were associated with adoption of the technology. In Barham et al. (2004b), higher education, keeping record of farming operation and herd size were positively correlated with adoption but only education was also positively correlated with retention, while herd size was positively correlated with abandonment. In both studies, the authors found significant differences between adopters and non-adopters, but little difference between retainers and abandoners. Foltz and Chang (2002) also supported this finding.

Although the multinomial logit model allows us to directly compare three groups of farmers, a caveat to this model is that it cannot utilize any information that are only available after adoption of technology because such information are unavailable to non-adopters. As the review of the literature above reveals, there are two popular approaches to modeling technology adoption and abandonment, with each having an advantage over the other. In this paper, we primarily rely on the bivariate probit model with sample selection but we estimate the multinomial logit model as a follow-up to test if any additional insight can be gleaned.

III. Conceptual Model

Existing studies (Amsalu and de Graaff, 2007, Khanna, 2001, Neill and Lee, 2001, Roberts, et al., 2004) typically consider a rational farm agent who faces two sequential decisions regarding technology: whether to adopt a technology or not and whether to retain or abandon the technology, once adopted. It is obvious that the second decision is only relevant to those farmers who have previously adopted the technology. Thus, the two decisions are correlated with each other because the probability of technology retention (or abandonment) is contingent upon the probability of technology adoption.

Following Walton et al. (2008), we incorporate the sequential decisions into the expected utility framework. Let U_1^* be the farmer's expected utility from technology adoption:

$$U_1^* = E[U_{AD}] - E[U_{NA}], \tag{1}$$

where U_{AD} and U_{NA} are the utilities from adoption and non-adoption. U_1^* is a latent variable that is unobservable to researchers but assumed to be a function of exogenous variables so that

$$U_1^* = X'\beta + \varepsilon_1, \tag{2}$$

where X is a vector of exogenous variables, β is a vector of unknown parameters to be estimated, ε_1 is the error term assumed to have a normal distribution with zero mean. The decision of whether or not to adopt is observed by a discrete variable, y_1:

$$y_1 \begin{cases} = 1 \text{ if } U_1^* > 0 \\ = 0 \text{ otherwise} \end{cases}. \tag{3}$$

Likewise, let U_2^* represent the farmer's utility from technology retention:

$$U_2^* = (U_{AD}|U_1^* > 0) - E[U_{AD}|U_1^* > 0] \tag{4}$$

The first term on the right hand side of equation (4) represents the actual realization of utility from adoption while the second term is the *ex ante* expectation of utility from adoption. U_2^* is also unobservable, but assumed to be a function of observable variables such that

$$U_2^* = Z'\gamma + \varepsilon_2, \tag{5}$$

where Z is a vector of exogenous variables, γ is a vector of unknown parameters to be estimated, and ε_2 is the error term also assumed to be normally distributed with zero mean. The decision of whether to retain or abandon the technology is also observed by a discrete variable, which we denote as y_2:

$$y_2 \begin{cases} = 1 \text{ if } U_2^* > 0 \\ = 0 \text{ otherwise} \end{cases}. \quad (6)$$

Substituting equation (2) into equation (3) and equation (5) into equation (6), the probability that the farmer retains the previously adopted technology is represented by

$$Pr[y_1 = 1, y_2 = 1] = Pr[U_1^* > 0, U_2^* > 0]$$

$$= Pr[\varepsilon_1 > -X'\beta, \varepsilon_2 > -Z'\gamma]$$

$$= Pr[\varepsilon_1 < X'\beta, \varepsilon_2 < Z'\gamma]$$

$$Pr[y_1 = 1, y_2 = 1] = \Phi_2(X'\beta, Z'\gamma, \rho), \quad (7)$$

where Φ_2 is the bivariate standard normal distribution and ρ is the correlation coefficient between the error terms ε_1 and ε_2. Equation (7) reduces to a product of two univariate standard normal distributions of ε_1 and ε_2 when $\rho = 0$ or the two decisions farmers face are independent of each other.

Because the probability of technology abandonment is the difference of the probability of adoption and the probability of retention, it can be obtained by subtracting the right hand side of equation (7) from the univariate probability distribution of technology adoption, denoted as $\Phi(X'\beta)$:

$$Pr[y_1 = 1, y_2 = 0] = \Phi(X'\beta) - \Phi_2(X'\beta, Z'\gamma, \rho) \quad (8)$$

Since there are only three possible states of the world, retention, abandonment and non-adoption, the probability of non-adoption can be obtained by using equations (7) and (8):

$$Pr[y_1 = 0] = 1 - \Phi_2(X'\beta, Z'\gamma, \rho) - [\Phi(\mathrm{X}'\beta) - \Phi_2(X'\beta, Z'\gamma, \rho)]$$

$$Pr[y_1 = 0] = 1 - \Phi(\mathrm{X}'\beta) \tag{9}$$

The objective of the econometric analysis is to maximize the likelihood function of the three different states of the world given as follows:

$$L = \prod_{y_1=1, y_2=1} \Phi_2(X'\beta, Z'\gamma, \rho) \times \prod_{y_1=1, y_2=0} \Phi(\mathrm{X}'\beta) - \Phi_2(X'\beta, Z'\gamma, \rho) \times \prod_{y_1=0} 1 - \Phi(\mathrm{X}'\beta) \tag{10}$$

The log-likelihood function is given as:

$$\ln L = \sum_{y_1=1, y_2=1} \Phi_2(X'\beta, Z'\gamma, \rho) + \sum_{y_1=1, y_2=0} \Phi(\mathrm{X}'\beta) - \Phi_2(X'\beta, Z'\gamma, \rho) + \sum_{y_1=0} 1 - \Phi(\mathrm{X}'\beta) \tag{11}$$

We obtain maximum likelihood estimates by simultaneously equating the first derivatives of equation (11).

IV. Empirical Model

Our empirical model consists of two equations, one for adoption decision equivalent to equation (2) and the other for retention/abandonment decision equivalent to equation (5). Thus, specification of the empirical model requires identification of exogenous variables that influence technology adoption and abandonment. In the context of the conceptual model introduced above, we specify the two vectors of exogenous variables, X and Z, in equations (2) and (4), respectively.

The observable dependent variables, y_1, in equations (3) takes a value of 1 if the farmer adopts at least one precision farming technology. The other dependent variable, y_2, in equations (6) takes a value of 0 if the farmers abandoned at least one of the previously adopted precision farming technologies. Due to the aggregate nature of the dependent variable it is possible that some farmers abandon some technologies but retain others. Thus, $y_2 = 1$ indicates that the farmer has retained all precision farming technologies adopted.

1) Factors Affecting Adoption of Precision Farming Technologies

The vector of exogenous variables, X, in equation (2) consists of factors affecting adoption of precision farming technologies. Following the literature, it includes variables representing the characteristics of the operator and the farm. Operator variables include: perception about the future profitability of precision farming, years of formal education, age, number of information sources consulted about precision farming technologies. Farm variables include time horizon, use of computer for farm management, total cotton acres, share of other crop acres, share of dry cotton field, yield variability of cotton, livestock operation, dummy variables for full owners and tenants, household income, percentage of farm income in total household income and regional dummy variables representing USDA production regions (USDA, 2008). See Table 1 for the complete list of variables used in this study and their definitions.

We expect that a more educated or younger farmer who perceives that precision farming technologies will be profitable in the future is more likely to adopt precision farming technologies. While the number of information sources consulted in making the adoption decision can be important, its effect is unclear as some farmers may decide not to adopt after carefully reviewing many sources of information. We hypothesize that farms that plans further into the future, or farms using computer for farm management are more likely to adopt precision farming technologies. A higher yield variability of cotton should also be positively correlated with adoption of precision farming technologies (Paxton, et al., 2011). We have no *a priori* expectation about the impact of dry and irrigated cotton fields on adoption decision.

Full owners and tenants may be less likely than part owners to adopt precision farming technologies, as part owners tend to operate larger scale farms. Farms with higher dependence on off-farm income or livestock operation may rely less on grain production and thus less likely to adopt precision farming technologies. However, Walton et al. (2008) unexpectedly reached a seemingly contradictory finding that both total cotton acres and share of other crop acres were positively correlated with adoption and abandonment of precision farming technologies. We expect these two variables to be positively correlated with both adoption and retention of precision farming technologies as in Walton et al. (2008). Precision farming technologies may help farmers to exploit economies of scale in cotton production and economies of scope in production of multiple crops.

Although Roberts et al. (2004) found significant effects of regional variables on adoption of precision farming technologies, no such effects were found in Walton et al. (2008). Roberts et al. (2004) used the 2001 Southern Precision Farming Survey conducted in six states (Alabama, Florida, Georgia, Mississippi, North Carolina and Tennessee), while Walton et al. (2008) employed the 2005 version of the same survey conducted in 11 states (Arkansas, Louisiana, Missouri, South Carolina, and Virginia, in addition to the six states in the 2001 version). The 2009 version of the survey used in this study includes Texas in addition to 11 states in the 2005 version. Although it is not *a priori* clear as to how regional differences will be affected as more states are included in the survey, our intention is to capture an aggregate effect of otherwise uncontrolled factors such as environmental and climatic conditions (Khanna, 2001, Larson, et al., 2002, Roberts, et al., 2004)

2) Factors Affecting Retention or Abandonment of Precision Farming Technology

The vector of exogenous variables, Z, in equation (5) consists of factors affecting retention and abandonment of previously adopted precision farming technologies. Variables included in **Z** but not in **X** are only observable from those who have adopted precision farming technologies. They are motivation for adoption (profit, environmental benefits, and being at the forefront of agricultural technology) measured on a 5-point Likert scale and perceived changes in environmental quality and cotton quality after the adoption. We hypothesize that profit-motivated adopters may be more myopic and likely to abandon precision farming technologies once they turn out to be unprofitable, while the opposite is expected for the other two; farmers who adopt precision farming technologies for environmental benefits or to be up to date with the latest agricultural technologies may be more patient with the technologies even if they turn out to be unprofitable. Perceived improvements in environmental and cotton quality should motivate the farmer to retain technology. See Table 1 for variable definitions and Table 2 for summary statistics by non-adopters, abandoners, and retainers.

V. Data

The 2009 Southern Cotton Precision Farming Survey is used in this study. The survey collected data from cotton producers in 11 Southern states: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, and Virginia in 2009. It is the third in a series of cotton precision farming surveys and developed to collect information about cotton producers' attitudes toward and use of precision farming technologies in 2007 and 2008. The survey questionnaire, a postage-paid return envelope, and a cover letter to explain the survey purpose were sent to each producer in February and March 2009, following the mail survey procedures outlined in Dillman (1978). A total of 1,692 surveys were received with a response rate of 12.5%. After deleting observations with missing values, 779 observations are used in the bivariate probit model with sample selection. See Mooney, et al. (2010) for more detail on the 2009 Southern Cotton Precision Farming Survey.

VI. Results

Bivariate Probit Model with Sample Selection

Econometric results from the bivariate probit model with sample selection are presented in Table 3. The table presents parameter estimates for both adoption/non-adoption and retention/abandonment equations as well as two marginal effects estimates: marginal effects on the probability of adoption, $Pr(y_1 = 0)$, for the adoption/non-adoption equation and marginal effects on the probability of retention, $Pr(y_1 = 1,\ y_2 = 1)$, for the retention/abandonment equation. The Wald Chi-square test of independent equations examines the null hypothesis that the error terms in the two equations are uncorrelated.

The correlation coefficient estimate of $\rho = 0.579$ and the p-value $= 0.085$ suggests that the two error terms are positively and statistically significant. This justifies the use of bivariate probit model with sample selection, instead of two separate probit models.

1) Factors Affecting Adoption of Precision Farming Technologies

The positive and significant coefficient of future profitability indicates that farmers who believe that precision farming will be profitable in the future are more likely to adopt the technology. Results suggest that positive perception about the future profitability of precision farming increases the probability of adoption by 11 percent. Findings here are consistent with previous studies (Roberts, et al., 2004, Walton, et al., 2008). As expected, age has a negative and significant effect on adoption of precision farming technologies (Roberts, et al., 2004). A one year increase in the farmer's age decreases the probability of adoption by 0.3%. The number of information sources consulted upon adoption encourages adoption; as the farmer consults an additional source of information about precision farming technology, the probability of adoption increases by 5%.

Farmers who plan further into the future or use computers for farm management are both more likely to adopt precision farming technologies. The longer time horizon increases the net present value of future profits from precision farming technologies and makes it easier to justify initial investments required to adopt precision farming technologies. An additional year of planning into the future increases the probability of adoption by 2%. The positive and significant coefficient on computer use may indicate that using computer for farm management and being proficient in computer use – some of which can be human capital intensive – may reduce learning costs of adopting precision farming technologies. Farmers who use computer for farm management are 6% more likely to adopt precision farming technologies, compared to their counterpart. While total cotton acres has a positive and significant coefficient, share of other crop acres is not a significant factor to explain adoption of precision farming technologies. This is partially inconsistent with Walton et al. (2008) who found both variables to have a positive impact on adoption of precision farming technologies. We discuss the effect of total cotton acres on adoption and retention in more detail below. A negative and significant coefficient on share of dry cotton field suggests that a higher share of acres in dry cotton field relative to irrigated cotton field is negatively correlated with adoption of precision farming technologies. The marginal effect is economically very significant. Specifically, a one percent increase in the share of dry cotton field relative to irrigated cotton field decreases the probability of adoption by 12%. All the regional variables except for **Corn Belt** have obtained a positive and significant effect on adoption of precision farming technologies. Cotton farmers in Delta, Appalachia, and Southeast regions are 41%, 38%, and 22% more likely to adopt precision farming technologies, respectively, relative to cotton farmers in Texas.

2) Factors Affecting Retention or Abandonment of Precision Farming Technology

Our expectation was that profit-motivated adopters would be more myopic and thus more likely to abandon the technology once it turned out to be unprofitable. On the other hand, farmers adopting the technology for environmental benefits would be more likely to retain it even if it turned out to be unprofitable. The coefficients of profit and environment both obtain the expected signs, but they are not statistically significant. One possible reason for the expected but insignificant estimates is the fact that we have a small number of observations on abandoners (only 21 observations out of 779 or 2.7% of the entire sample). Although the small number of observations could have masked the true relationship between the variables in the population of our interest, this is also an indication that precision farming technologies are utility-increasing to many cotton farmers, as the majority of farmers who adopted precision farming technologies retain them.

Consistent with our expectation, the effect of technology are positive and significant, indicating that those farmers who cited "*being at the forefront of agricultural technology*" as an important reason for adoption are more likely to retain precision farming technologies. An increase in the importance of "*being at the forefront of agricultural technology*" by one unit on the 5-point Likert scale leads to a 12% increase in the probability of retaining precision farming technologies. However, a close look at the descriptive statistics gives us more insight. Of those 21 farmers who have abandoned at least one precision farming technology, 13 of them cited "*being at the forefront of agricultural technology*" as "not important" (or a score of 1 on the 5-point Likert scale). Thus, it is more accurate to say that farmers for whom being at the forefront of agricultural technology is not important are more likely to abandon precision farming technologies instead of a positive correlation between technology and retention.

Parameter estimates for most operator and farm variables obtain the same sign in both equations even though some variable have statistically insignificant coefficients in the retention/abandon equation. As in the adoption/non-adoption equation, use of computer for farm management has a positive impact on retention of precision farming technologies. Share of dry cotton field has a very large negative effect on technology retention. A one percent increase in the share of dry cotton field decreases the probability of retaining precision farming technologies by 18%. Combined with its negative effect on technology adoption, the result suggests that cotton farmers prefer to adopt and retain precision farming technologies in irrigated field rather than in dry field.

The coefficient of total cotton acres in the retention/abandon equation is very close to zero and the estimate is statistically insignificant, even thought it has a positive impact on technology adoption. The result here is inconsistent with Walton et al. (2008) who found a positive impact of total cotton acres on adoption but a negative impact on retention. As discussed earlier in Section II, the negative impact of total cotton acres in Walton et al. (2008) could be because they did not control for profit motivation. Thus, the insignificant impact of total cotton acres on retention or abandonment of precision farming technologies is expected, once we control for profit motivation.

Share of other crop acres and yield variability yield a significant coefficient in the retention/abandonment equation but not in the adoption/non-adoption equation. The share of other crop acres is an important factor for technology retention; a one percent increase in the share of other crop acres increases the probability of retaining precision farming technologies by 51%. This result is consistent with our expectation but contradicts with the finding in Walton et al. (2008) who unexpectedly found the opposite effect of the same variable. The result here lends supports to our expectation that there may be economies of scope in precision farming technology; precision farming technologies may be more profit-increasing when used for other crop enterprises in combination with cotton as the benefits of the technology can be spilled over to other crop enterprises.

A positive effect of yield variability indicates that farmers experiencing a large gap in cotton yield between the most and the least productive fields are more likely to retain precision farming technologies. Since the variability in cotton yield is based on farmers' perception, it may be the case that farmers obtain a more accurate estimate of the yield variability once they adopt precision farming technologies than they did before the adoption.

Multinomial Logit Model

In order to reinforce our understanding of retention and abandonment of precision farming technologies, we estimated a multinomial logit model to directly compare three types of farmers: non-adopters, retainers and abandoners. Econometric results from the multinomial logit model are presented in Table 4. Walton et al. (2008) found that total cotton acres positively influenced both adoption and retention. Our bivariate probit model found that total cotton acres positively affects adoption, but not retention. We compare results from the multinomial logit model in order to further investigate its impact on adoption and retention of precision farming technologies. The results in Table 4 suggest that, although farms with larger cotton acres are more likely to be adopters (both abandoners and retainers) and such farmers are also likely to abandon precision farming technologies. The negative coefficient of total cotton acres on "Retainers" relative to "Abandoners" (the right most column, Table 4) indicate that farms with larger cotton acres are more likely to abandon precision farming technologies, the same result unexpectedly obtained by Walton et al. (2008). Note, however, that the multinomial logit model estimated here does not account for post adoption variables including three types of motivation for adoption, as it was the case for Walton et al. (2008). Therefore, we conjecture that the negative effect of the total cotton acres on technology retention in the multinomial logit model and in Walton et al. (2008) is due to the omitted variable problem, as hypothesized earlier in this paper. Once we control for motivation for adoption, the total cotton acres no longer exhibit a negative effect on technology retention, as we observed in the bivariate probit model with sample selection.

Overall, the multinomial logit model obtained only a few significant coefficients when comparing retainers to abandoners, suggesting that the two groups of farmers share similar characteristics (Foltz and Chang, 2002, Barham, et al. 2004a, 2004b). Comparison of non-adopters against either retainers or abandoners obtained mostly significant coefficients, confirming that remarkable differences exist between adopters and non-adopters of technology (Foltz and Chang, 2002, Barham, et al. 2004a, 2004b). Again, an important caveat is that the multinomial logit model cannot utilize post adoption information that is only available to adopters and thus results may be subject to bias. However, it is also important to note that the multinomial model had 110 more observations than the bivariate probit model with sample selection in this study. The additional data requirements for the bivariate probit model may also induce the sample selection issue of its own to the extent that the error term in the retention/abandonment equation and reasons for missing values are correlated. Therefore, even the bivariate probit model with sample selection is not completely free from sample selection. As each of the two modeling approaches used in this study has advantages to each other, researchers should, to the extent possible, esimate the two models and compare their results to examine if there are any marked differences attributable to different modeling approaches.

VII. Conclusion

The objective of this study was to estimate the impact of motivation for technology adoption on technology retention or abandonment. The specific context of the study was use of precision farming technologies for cotton farmers, using the 2009 Southern Cotton Precision Farming Survey conducted in 12 Southern states in the United States. We employed two econometric models that were popular in the limited empirical literature on technology adoption and abandonment. Our bivariate probit model with sample selection observed that farmers who cite "being forefront of agricultural technology" as not important are more likely to abandon precison farming technologies. The effects of profit and environmental benefits as motivation for adoption on technology retention or abandonment were statistically insignificant, even though they obtained expected signs. Although the small number of farmers who abandoned precision farming technologies could have caused some estimates to be statistically insignificant, the low abandonment rate was a manifestation that use of precision farming technologies were utility-increasing to a wide spectrum of cotton farmers in the Untied States.

One important difference in this study compared to Walton et al. (2008) was the effects of the total cotton acres on adoption and retention of precision farming technologies. Our results indicated that the total cotton acres had a positive impact on adoption but no significant impact on retention or abandonment. We believe that we could refine findings in Walton et al. (2008) thanks to the three variables representing motivation for adoption, which was not available in the previous versions of the Southern Cotton Precision Farming Survey. The results from our second model, the multinomial logit model, which did not make use of the three variables, lend support to our proposition. For this reason, we recommend that researchers interested in technology adoption and retention estimate both the bivariate probit model with sample selection and the multinomial logit model to examine if there are any marked differences attributable to different modeling approaches.

Finally, this study identified factors associated with adoption and retention of precision farming technologies. Findings from this study offer significant information to policy-makers for a better formulation of agri-environmental programs that encourage farmers to adopt environmentally benign farming practices including precision farming technologies.

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Table 1: Variable Definitions

Variable Name	Definition
Dependent Variables	
Adoption	=1 if farm adopts at least one precision farming technology, 0 otherwise
Retain	=1 if farm maintains all precision farming technologies adopted, 0 if farm abandons at least one previously adopted precision farming technology
Adopt + Retain	= 2 if farm maintains all precision farming technologies adopted = 1 if farm abandons at least one precision farming technologies adopted = 0 if farm does not adopt any precision farming technologies
Motivations for Adoption (measured on a 5-point Likert scale)	
Profit	= 5 if profit is very important; =1 if not important
Environment	= 5 if environmental benefit is very important, =1 if not important
Forefront	= 5 if being at the forefront of agricultural technology is very important, =1 if not important
Perceptions about Precision Farming Technologies	
Environmental quality	Experienced improvements in environmental quality through the use of precision farming technologies = 1 if Yes; = 0 if do not know; = -1 if No
Cotton quality	Experienced improvements in cotton quality through the use of precision farming technologies = 1 if Yes; = 0 if do not know; = -1 if No
Operator Variables	
Future Profitability	Precision farming technologies will be profitable in the future = 1 if Yes; = 0 if do not know; = -1 if No
Education	Operator's formal education in years
Age	= Operator's age
Information	Number of sources that farms use to collect information about precision farming. Sources are 1. farm dealers, 2. crop consultants, 3. university extension, 4. university publications, 5. university events, 6. other farmers, 7. trade shows, 8. Internet and 9. news/media)
Farm Variables	
Time horizon	Years into future farms plans its farming enterprise =1 if 1 year; =2 if 2 years; =3 if 3 years; =4 if 4 year;, =5 if 5 or more years
Computer	=1 if use computer for farm management, 0 otherwise
Total cotton acres	= dry cotton field + irrigated cotton field (average of 2007 and 2008)
Share of other crop acres	= other crop acres/total operated acres (average of 2007 and 2008)

Share of dry cotton field	= dry cotton acres/ total cotton acres (average of 2007 and 2008)
Yield Variability	= The difference in cotton yield (lbs. lit/acre) in the most productive 1/3 of land and the least productive 1/3 of land (weighted average of dry and irrigated cotton field)
Livestock	= 1 if farm has livestock operation, 0 otherwise
Full Owner	= 1 if farm is a full owner
Part Owner	=1 if farm is a part owner
Tenant	= 1 if farm is a tenant
Household Income	= 1 if Annual household income is > $100, 000, 0 otherwise
Farm Income Percentage	= (Farm Income/Total Household Income) × 100
Regional Dummy Variables	
Delta	=1 if farm is located in Delta region (Louisiana, Arkansas, Mississippi), 0 otherwise
Corn Belt	=1 if farm is located in Corn belt region (Missouri), 0 otherwise
Appalachia	= 1 if farm is located in Appalachia region (Tennessee, North Carolina, Virginia), 0 otherwise
Southeast	= 1 if farm is located in Southeast region (South Carolina, Alabama, Georgia, Florida), 0 otherwise
Southern Plains	= 1 if farm is located in Southeast region (Texas), 0 otherwise

Source: The 2009 Southern Cotton Precision Farming Survey

Table 2: Summary Statistics by categories

Variables	Means			
	Entire Sample	Non-Adopters	Abandoners	Retainers
Dependent Variables				
Adoption	0.24	0.00	1.00	1.00
Retain			0.00	1.00
Adoption + Retain				
Motivations for Adoption				
Profit	4.44	4.23	4.76	4.63
Environment	3.35	3.15	3.33	3.57
Forefront	2.65	2.60	1.81	2.82
Perceptions about Precision Farming Technologies				
Environmental Quality			0.19	0.23
Cotton Quality			-0.19	0.04
Operator Variables				
Future Profitability	0.50	0.39	0.71	0.86
Education	14.53	14.39	14.90	14.99
Age	53.99	55.52	48.71	49.31
Information	3.77	3.30	5.29	5.20
Farm Variables				
Time Horizon	3.75	3.64	4.29	4.05
Computer	0.58	0.51	0.76	0.81
Total Cotton Acres	839.98	788.42	1546.50	931.90
Share of Other Crop Acres	0.19	0.18	0.09	0.27
Share of Dry Cotton Field	0.70	0.72	0.64	0.67
Yield Variability	481.35	467.66	485.95	528.50
Livestock	0.35	0.35	0.33	0.36
Full Owner	0.13	0.15	0.10	0.08
Part Owner	0.60	0.60	0.57	0.60
Tenant	0.27	0.25	0.33	0.32
Household Income	3.02	3.03	2.86	2.98
Farm Income Percentage	74.17	73.18	77.29	77.24
Regional Dummy Variables				
Delta	0.13	0.09	0.29	0.24
Corn Belt	0.02	0.02	0.05	0.02
Appalachia	0.19	0.16	0.29	0.29
Southeast	0.18	0.17	0.14	0.22
Southern Plains	0.47	0.56	0.24	0.22
Number of Observations	779	589	169	21

Table 3: Bivariate probit model with sample selection

Variables	Retention/Abandonment		Adoption/Non-Adoption	
	Coefficient	Probability of Retention[1]	Coefficient	Probability of Adoption[2]
Intercept	-1.62		-2.59	
Motivations for Adoption				
Profit	-0.10	-0.03		
Environment	0.05	0.02		
Forefront	0.36***	0.12***		
Perceptions about Precision Farming Technologies				
Environmental Quality	-0.05	-0.02		
Cotton Quality	0.13	0.04		
Operator Variables				
Future Profitability	0.28	0.09	0.49***	0.11***
Education	0.06	0.02	0.01	0.00
Age	0.01	0.002	-0.01**	-0.003**
Information	-0.04	-0.01	0.19***	0.05***
Farm Variables				
Time Horizon			0.09**	0.02**
Computer	0.53*	0.18	0.26*	0.06*
Total Cotton Acres	-0.0001	-0.0001	0.0002**	0.00003**
Share of other crop acres	1.54**	0.51**	0.22	0.05
Share of dry cotton field	-0.55*	-0.18*	-0.51**	-0.12**
Yield Variability	0.0008*	0.0002	0.0002	0.00005
Livestock	0.11	0.04	0.31**	0.08**
Tenant			0.17	-0.04
Full Owner			-0.20	0.04
Household Income	-0.37	-0.12	-0.17	-0.04
Farm Income Percentage	0.0002	0.0001	0.001	0.0003
Regional Dummy Variables				
Delta			1.26***	0.41***
Corn Belt			0.65	0.20
Appalachia			1.23***	0.38***
Southeast			0.76***	0.22***
Number of Observations	589		190	

Log Pseudo Likelihood = -350.96
Wald Chi-square statistic = 50.47 (d.f.=17)
P-value = 0.000

ρ=0.579
Wald Chi-square statistic of independent equations ($\rho = 0$) = 2.95 (d.f.=1)
P-value = 0.085

***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively.
[1] Marginal effect of regressors on the probability of retention: $Pr(y_1 = 1,\ y_2 = 1)$
[2] Marginal effect of regressors on the probability of adoption: $Pr(y_1 = 0)$
For continuous variables, marginal effects are calculated at the means of regressors.
For discrete variables, marginal effects are calculated based on a discrete change from 0 to 1.

Table 4: Multinomial Logit Model

Variable	Base Group			
	Non-Adopters		Abandoners	
	Comparison Group			
	Abandoners	Retainers	Non-Adopters	Retainers
Intercept	-5.96**	-3.84***	5.96**	2.12
Operator Variables				
Future Profitability	0.40	0.29**	-0.40	-0.11
Education	0.08	0.08**	-0.08	-0.01
Age	-0.01	-0.02**	0.01	0.00
Information	0.32***	0.25***	-0.32***	-0.07
Farm Variables				
Time Horizon	0.08	0.12**	-0.08	0.04
Computer	0.26	0.07	-0.26	-0.19
Total Cotton Acres	0.0006***	0.0002**	-0.0006***	-0.0004**
Share of other crop acres	-2.20*	0.66**	2.20*	2.86***
Share of dry cotton field	-1.11	-0.73	1.11	0.38
Yield Variability	-0.0008	0.0003	0.0008	0.0011
Livestock	0.45	0.24	-0.45	-0.21
Tenant	0.15	0.22	-0.15	0.07
Full Owner	-0.08	-0.26	0.08	-0.18
Household Income	-0.24	-0.03	0.24	0.21
Farm Income Percentage	0.01	0.00	-0.01	0.00
Regional Dummy Variables				
Delta	1.98***	1.85***	-1.98***	-0.13
Corn Belt	1.44	0.99*	-1.44	-0.45
Appalachia	2.03***	1.71***	-2.03***	-0.32
Southeast	1.22*	1.29***	-1.22*	0.07
Number of Observations	889			

***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively.