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Precision Farming Information Sources Used by Cotton Farmers

Amanda Renee Jenkins
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Amanda Renee Jenkins entitled "Precision Farming Information Sources Used by Cotton Farmers." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Economics.

Margarita Velandia, Major Professor

We have read this thesis and recommend its acceptance:

Roland Roberts, Dayton Lambert, James Larson, Steven Yen

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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PRECISION FARMING INFORMATION SOURCES USED BY COTTON FARMERS

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Amanda Jenkins
December 2009

Abstract

Precision farming entails production decisions that are made by obtaining data about soil and field traits. Information about yield and soil characteristics at different locations is collected and management strategies consistent with this information are designed. Information providers play a major role in helping farmers incorporate precision farming information into their decision-making processes. The main goal of this research is to add to the understanding of preferences of information sources in the context of precision farming. Data from cotton farmers in 11 Southeastern states were used to achieve this goal. Results from this study can be utilized by precision farming information providers to more effectively target their clientele.

This thesis examines two related research topics. The first essay focuses on the use of Extension as a source of precision farming information and the factors that determine preferences for this information source. The second essay examines farm business attributes, farmer characteristics and regional factors affecting cotton farmers' use of various precision farming information sources.

Farmers' preferences for precision farming education programming from Extension were described and analyzed using a basic statistical analysis. Results indicate that farmers tend to use various information sources simultaneously with Extension to make decisions about precision farming technology. An independent samples t-test showed that the means for age, education, income, farm size, and land tenure were statically significantly different between Extension users and non-users when other factors that may influence the use of precision farming information sources were not controlled.

A multivariate probit model was used in the second essay to determine the farm business, farmer, and regional characteristics affecting the use of different precision farming information sources. The multivariate approach accounts for correlation among the different information sources. Results suggest that the decision to use a precision farming information source may be correlated with the decision to use other information sources. When controlling for other factors that may influence the use of precision farming information sources age, education, farm size, and income were found to significantly affect the decision to use information sources.

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Part 1: Introduction

Introduction

Precision farming is the use of different site-specific technologies to obtain information that could potentially help farmers in the establishment of more efficient crop management strategies using variable rate technology which considers the heterogeneity among different locations within a field. Precision farming entails production decisions that are made by obtaining data about soil and field traits. Information about yield and soil characteristics at different locations is collected and management strategies consistent with this information are designed. More efficient crop management plans based on site specific information may provide farmers the ability to decrease costs, increase profits, and mitigate hazards to the environment (Swinton and Lowenberg-DeBoer, 1998).

The demand for information has been increasing along with the complexity of agricultural technologies (Schnitkey et al., 1992; Ortmann et al., 1993). Precision farming has the potential to improve efficiency but also adds complexity to the decision making processes because of the large amount of information to be processed. Thus, the large amount of information available to farmers through different technologies may require guidance on how to incorporate this information into an actual management plan (Griffin and Lambert, 2005). Hence, information providers may play an important role in farmers' decisions about precision farming technologies. The need for precision farming information by farmers has been met by various private and public sources including crop consultants, farm input dealerships, Extension, and mass media outlets (McBride and Daberkow, 2003).

Previous studies have focused on determining the factors affecting awareness, importance-perception, adoption, and abandonment of precision farming technologies (McBride and Daberkow, 2003; Daberkow and McBride, 2003; Roberts et al., 2004; Torbett et al., 2007;

Banerjee et al., 2008; Walton et al., 2008). However, only a few studies have concentrated on factors affecting producers' preferences of information sources in the context of precision farming including McBride and Daberkow (2003) and Larson et al. (2008).

Banerjee et al. (2008) analyzed factors affecting cotton producers' adoption of GPS guidance systems. Using a logit model they identified farm size, age, computer use ability, and income level as factors significantly affecting the adoption decision. Torbett et al. (2007) used an ordered logit model to evaluate factors affecting producer's perceptions about the importance of precision farming technologies in improving the efficiency of phosphorus and potassium use in cotton production. They found that land tenure, age, and computer use ability had a significant impact on farmers' perceptions of the importance of precision farming technologies (Torbett et al., 2007). Roberts et al. (2004) utilized a bivariate probit approach to determine farm and farmer characteristics influencing site-specific information and variable rate technology adoption among Southeastern cotton farmers. They found that farm size, education, and age affect site-specific information and variable rate technology adoption decisions. Similarly, McBride and Daberkow (2003) used a Heckman's multistage logit approach to evaluate factors affecting precision farming information-use and adoption of precision agriculture technologies. They identified farm size, full-time farming, computer literacy, crops grown on the farm other than cotton, and location as key factors affecting the adoption of precision farming technologies. Daberkow and McBride (2003) analyzed farm and operator characteristics affecting the awareness of precision farming technologies' existence and adoption of these technologies in the United States. Using a bivariate logistical specification, they found farm size, farm size squared, age, education, occupation, computer use, production of other crops, and location to be significant for awareness. They found size, occupation, and production of other crops to significantly affect adoption. Walton et al. (2008) evaluated factors affecting the adoption and abandonment of precision soil sampling in cotton production. Using a probit regression model, they found perceptions about the future profitability of precision agriculture, number cotton acres, percentage of total acres used to produce other crops, years of education, and use of computers for management decisions to significantly affect the adoption decision. They found factors that influenced the abandonment decision included perception about the future profitability of precision agriculture, number of cotton acres, percentage of total acres used to produce crops other than cotton, age, number of years precision soil sampling has been used, variable-rate application of P, K, or lime, and location.

Although various studies have examined factors affecting producers' preferences for information sources when making production, marketing and financial decisions (Schnitkey et al., 1992; Ortmann et al., 1993; Just et al., 2002, 2006), literature that explicitly addressed factors affecting preferences for information sources in the context of precision farming is limited (McBride and Daberkow, 2003). Schnitkey et al. (1992) studied farmers' use and usefulness-perception of information sources in the context of production, marketing and financial decisions. Media sources and Extension ranked among the most useful of information sources for production and marketing decisions. Information sources found to be beneficial when making financial decisions included financial specialists, media sources, and Extension. Using a multinomial logit model, they found that information preferences under various decision making scenarios were affected by farm size, farm type, farmer's age, and ability to use computers.

Ortmann et al. (1993) studied the use of consultants as a source of information among large cornbelt farmers. General information about information preferences was identified for various production, marketing, and financial decisions. They found that farm records, the farm's work force, consultants, and University specialists were the most useful information sources for production decisions. Computerized information sources and consultants were ranked as the top sources in terms of usefulness when making marketing decisions. Finally, financial specialists were found to be the most useful aid in making financial decisions (Ortmann et al., 1993). In general, they found that private consultants had the most influential role in providing information to support various decision making processes. Using a simple regression analysis they determined factors affecting the use of private consultants. They identified farm size, gross farm sales, education and age as significant factors affecting the decision to use private consultants.

Longo (1990) analyzed the relationship between information-source use and the adoption of crop and animal husbandry innovations. Using regression analysis, they found that both mass media and interpersonal communication played a significant role in explaining adoption of new crop production technologies. Even though neither source significantly explained the adoption of animal husbandry innovations, results showed that the first source a farmer was exposed to about an innovation was important in the adoption of animal husbandry innovations. The most widely used sources of information in this study were publications, other farmers, and family. Overall, their results indicated that use of interpersonal communication was more important for awareness of an innovation, while mass media was the best predictor of whether or not a farmer would adopt.

Ford and Babb (1989) evaluated farmers' use of private and public information sources. Descriptive statistics were used to summarize preferences toward information sources and the value placed on the information received from these sources. They observed that farmers prefer personal, service-oriented information providers over written material. Bankers and relatives were important information sources for financial decisions, while private firms, cooperatives, family, and friends were beneficial for production decisions. Overall, the main sources of information used by farmers were farm magazines, other farmers, and family and friends.

McBride and Daberkow (2003) studied how information sources impact the awareness about precision farming technologies' existence and adoption of these technologies in the United States. They identified farmer use of mass media as a major factor affecting awareness of precision farming technologies. Additionally, they found information sources allowing for interpersonal communication, such as crop consultants, have a significant role in the decision to adopt precision farming technologies.

Larson et al. (2008) examined factors affecting farmer adoption of remotely sensed imagery for precision management in cotton production. They found crop consultants and Extension to positively affect the adoption of remotely sensed imagery for precision management in cotton production. In light of the sparse literature, the current study advances in the literature of farmers' as information consumers in the context of precision farming technologies.

This study focuses on the factors affecting farmers' use of private sources (crop consultants and farm input dealerships), Extension services, and mass media sources (internet and news media) to obtain precision farming information. Identifying producers' preferences for these information sources in the context of precision farming, and determining factors affecting these preferences may help information suppliers to better tailor their services to clientele. Better targeting of information delivery efforts could help farmers improve their management skills, and this could have a positive impact on their success when making decisions in the context of precision farming technologies.

Objectives

The objectives of this research are: 1) to identify farmers' preferences towards information sources in obtaining precision farming information, and 2) to determine the farm business attributes, farmer characteristics, and regional factors influencing cotton farmers' preferences for precision farming information sources.

Thesis outline

This thesis examines two related research topics related to factors affecting preference for information sources in the context of precision farming. The first essay looks at how farmers use Extension education programming related to precision farming. Differences between Extension users and non-users are then evaluated. Using a multivariate probit model, the second essay identifies the factors affecting information-source-use decisions.

Given the two essay approach outlined above, this thesis is organized as follows. Part two presents methods, main results, summary and conclusion for the first essay. Part three presents conceptual framework, description of the data, results, discussion, and conclusion for the second essay. Note that in parts two and three a general introduction to the problem is provided and specific objectives for each essay are differentiated. Finally, in part four contributions of the two essays are summarized and concluding comments are provided.

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Part 2: Precision Farming Information Sources Used by Cotton Farmers, and Implications for Extension

Abstract

Cotton farmers in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North and South Carolina, Tennessee, and Virginia were asked where they obtained information about precision farming. Farmers use Extension as a source of precision farming information, but in combination with other information sources, including media, crop consultants, farm dealers, and other farmers. Farmers using Extension as a source of information tend to be younger, with more education and higher incomes compared to producers not seeking information about precision farming from Extension. Understanding the profiles of producers using Extension resources for precision farming information may help Extension design programs to improve information delivery to fulfill clientele demand.

Introduction

Farmers using precision agriculture technologies may decrease variable costs, increase profits, and moderate environmental risks by not applying more inputs than needed (Bullock, Lowenberg-DeBoer, and Swinton, 2002; Bongiovanni and Lowenberg-DeBoer, 2004; Roberts, English, & Larson, 2002; Watson et al., 2005; Torbett et al., 2007). Precision farming entails production decisions that are made by obtaining data about soil and field traits. Information about yield and soil characteristics at different locations is collected and management strategies consistent with this information are designed. Given the potential economic and environmental benefits from some precision farming practices, effective dissemination of precision agriculture information by Extension appears justified. Extension plays an important role in the diffusion of information to help individuals make informed decisions that influence profitability (Hall et al., 2003). Therefore, Extension is positioned to provide information to farmers about the costs, benefits, and use of precision agriculture technologies, and how these practices can be integrated into whole farm management plans.

Demand for information about technologies to manage agricultural production systems increased with the advent of yield monitors and global positioning systems, and improvements in computing power and data management (Schnitkey et al., 1992; Swinton and Lowenberg-DeBoer, 1998; Griffin et al., 2004). However, with the decline in Extension resources over recent years (Smith and Swisher, 1986; Diem, 2002; Aguilar and Thornsbury, 2005), other information providers such as crop consultants, farm input dealerships, media, and other farmers are important complements for Extension and its ability to meet farmer demand for precision farming information (Schnitkey et al., 1992; Just et al., 2002). Farmers may choose to use a single information source. More likely, producers will combine various sources of information to make farm business decisions.

This study examines which sources of information farmers use to obtain precision farming information and evaluates how they make decisions about the use of each source of information. The focus of the analysis is on the complementary use of Extension and other information sources, comparing the profiles of farmers using Extension as a single source of precision agriculture information, or in combination with other information sources, including private consultants or farm input dealerships, news media, the internet or other farmers. Understanding the farm business and operator characteristics of precision farming information consumers, and the sources of information they use to learn about precision agriculture can provide Extension with more accurate knowledge about clientele demand for precision agriculture information. Such knowledge may motivate innovative approaches to effectively coordinate, package and deliver precision agriculture information through a variety of channels.

Methods

A survey was mailed in January, 2005, to 12,243 cotton farmers in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North and South Carolina, Tennessee, and Virginia. Of the questionnaires mailed, 200 were returned undeliverable or by farmers no longer producing cotton. In total, 1,214 surveys were suitable for analysis (10% response rate).

The survey captured general demographic characteristics including year born, highest level of education completed, number of years spent in farming, percentage of income derived from agriculture, number of acres farmed (owned versus rented), and percentage of taxable household income derived from farming. The survey requested information about use, profitability, and perceived benefits from precision farming technologies. Additionally, the questionnaire asked farmers about the precision farming technologies used on their farms, and the resources used to obtain precision farming information. Additional details of the survey are found in Roberts, English, and Larson (2002) and Walton et al. (2008).

An assessment of how well the sample represented the population of cotton farmers in the Southeastern United States (2005) was made by comparing the sample data with data from the 2002 Agriculture Census [U.S. Department of Agriculture/National Agricultural Statistics Service (USDA/NASS), 2004]. Frequency histograms tabulating farm size and age were compared for the sample and the Census population data. The farm size and age distribution from the sample data are similar to the distributions from the Census for the 11 states included in this study (see Appendix in Part 3, Figures 1 and 2). Albeit this result, it is important to notice that the sample data showed a smaller percentage of cotton producers whose farm size was less than 220 acres (14%) when compared with the census data (22%). Additionally, the sample data included a smaller percentage of farmers older than 64 years old (10%) when compared with the census data (18%). The sample data are representative of larger farms and younger farmers relative to the census figures. Given that larger farmers are more likely to consider the adoption of certain precision farming technologies (Daberkow and McBride, 2003), the survey data used in this study are representative of farmers who are more likely to be interested in precision farming technologies (Walton et al., 2008).

For this analysis, the information sources were divided into four categories: private (crop consultants and farm input dealerships), Extension, other farmers, and media. Frequencies of information sources used by respondents were enumerated based on whether the respondent reported using Extension, other farmers, crop consultants or farm input dealerships, media, or combinations of these sources of information about precision agriculture. Of particular interest were (1) producers who used Extension alone or in combination with other information sources ('Extension Users'), and (2) respondents who did not use Extension, but used one or a combination of other information sources ('Non-Users'). For both groups, there were 8 possible combinations of information sources (Table 1). The farm business and operator characteristics of Extension users and non-users were compared using an independent samples t-test.

Results

About 66% of the producers used Extension either solely or in combination with other information sources. Only 2.6% of the farmers surveyed used Extension as the only source of precision farming information. About 75% of the Extension users combined information from Extension with media sources, crop consultants, farm dealers, and other farmers.

Table 2 compared the farm business and operator characteristics of Extension users and non-Extension users. Respondents using Extension, individually or in combination with other sources, were typically younger than farmers not using Extension. Producers who used

Extension tended to report higher levels of educational attainment than those who did not use Extension. A larger percentage of farmers who used Extension earned more than $150,000 in 2004 than those who did not use Extension (35.82% and 30.45%, respectively).

The average farm size varied between the two groups, with Extension users operating larger farms than non-users. Additionally, Extension users rented a larger percentage of the land they farm than non-users, as evidenced by the own-to-total operated acres percentage (31.80% and 35.43%, respectively).

Summary and Discussion

Producers learning about precision farming tend to use multiple sources of information to increase their knowledge about precision agriculture. Extension is one of the main sources of information, but it appears that farmers combine Extension with other information sources. About 66% of producers used Extension, and about 75% of these users combined Extension with all the other information sources, including crop consultants and farm input dealerships, media, and other farmers.

Users of Extension tended to be younger, have larger farms, and rented a larger percentage of land than non-users of Extension. A higher percentage of Extension users have earned an Associate's, Bachelor's or Graduate degree, and earned higher incomes than non-users. This profile is consistent with the demographic profile of producers who typically adopt precision agriculture technologies (Roberts, English, and Larson, 2002; Walton, et al., 2008).

Information suppliers (crop consultants, farm input dealerships, Extension educators and media information providers) may be able to tailor their services to clientele. For example, because farmers tend to use Extension and private information sources simultaneously, Extension educators can tailor a more comprehensive training/outreach program for this target population in conjunction with crop consultants and/or farm input dealerships. This information might help to develop precision farming Extension programs that combine efforts with other information suppliers to provide more effective precision farming information to consumers.

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Appendix

Table 1. Survey Question: Where did you get your precision farming information? (Circle each source that you have used to get information)

Information Source Combinations	Number of Farmers	Percentage
(1) Only Extension sources	31	2.55
(2) Private and Extension sources	37	3.05
(3) Extension and other farmer sources	17	1.40
(4) Extension and media sources	17	1.40
(5) Private, Extension, and other farmer sources	57	4.70
(6) Private, Extension, and media sources	25	2.06
(7) Extension, other farmer, and media sources	18	1.48
(8) Extension, other farmer, media and private sources	596	49.09
TOTAL EXTENSION USERS	798	65.73
(9) None of the sources considered in the survey	203	16.72
(10) Only private sources	43	3.54
(11) Only other farmer sources	29	2.39
(12) Only media sources	48	3.95
(13) Private and other farmer sources	21	1.73
(14) Private and media sources	33	2.72
(15) Other farmer and media sources	15	1.24
(16) Private, other farmer, and media sources	24	1.98
TOTAL NON-EXTENSION USERS	416	34.27

Table 2. Variable Means for Users and Non users of Extension

Variable	Extension Users	Non-Extension Users
Average Age of producers as of 2004 (in years)***	48.57	53.28
Proportion of farmers with a High School Degree or less (%) **	42	50
Proportion of farmers with an Associate Degree (%) *	12	9
Proportion of farmers with a Bachelor's Degree (%) ***	33	23
Proportion of farmers with a Graduate Degree (%) **	9	5
Proportion of farmers with Income higher than $150,000 (%)*	36	30
Average percent of income from farming (%)	73	71
Average Farm size (in acres)***	1469.10	1151.67
Land Tenure (Owned acres divided by owned acres plus rented acres %) *	32	35

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

Part 3: Factors Influencing Selection of Precision Farming Information Sources by Cotton Producers

Abstract

Information plays an important role in the adoption of precision farming technologies. Farmer demand for precision farming information has been met by various suppliers in the past, including crop consultants, farm input dealerships, Extension, and various media sources. Factors associated with the use of different information sources are analyzed using a multivariate probit regression accounting for correlation among the different information-source-use decisions. Empirical findings suggest that decisions to use crop consultants and/or farm input dealerships, Extension, and media as precision farming information sources are correlated with each other. Factors influencing the use of precision farming information sources are age, education, farm size, and income.

Introduction

Farmers face uncertainty when making production decisions. Information about field production characteristics, weather, new technologies, and prices help reduce producer's uncertainty (Stigler, 1961; Gould, 1974; Clemen and Winkler, 1985; Bullock, Lowenberg-DeBoer, and Swinton, 2002). Information plays a very important role in precision farming technologies which can be used to reduce uncertainty about spatial variability in farm fields. The concept of precision farming uses site-specific information to improve the management of production factors used in farm fields (Hurley, Oishi and Malzer, 2005). Farmer demand for precision farming information has been met by various suppliers; including private and public sources such as crop consultants, farm input dealerships, Extension, and mass media sources (McBride and Daberkow, 2003).

Producers' demand for information about agricultural technologies has increased with the increased complexity of production technologies (Schnitkey et al., 1992; Ortmann et al., 1993).

Precision farming technology has the potential to improve production efficiency but adds complexity to the decision making processes because of the large amount of information to be processed. Thus, the large amount of information available to farmers through different precision farming technologies may require guidance on how this information is incorporated into actual management plans (Griffin and Lambert, 2005). Therefore, information providers have an important role in guiding farmers on the use of precision farming information.

Previous studies have focused on determining the factors affecting awareness, importance-perception, adoption, and abandonment of precision farming technologies (McBride and Daberkow, 2003; Roberts et al., 2004; Torbett et al., 2007; Banerjee et al., 2008; Walton et al., 2008). However, only a few studies have focused on factors affecting producers' preferences for information sources in the context of precision farming including McBride and Daberkow (2003) and Larson et al. (2008).

In the general context of farm business decision-making (marketing, production, and financial decisions) several researchers have focused on the effect of farmer/farm business characteristics on preferences for information sources (Schnitkey et al., 1992; Ortmann et al., 1993; Just et al., 2002, 2006). Producers commonly utilize multiple information sources to gain knowledge about precision agriculture technologies. Yet studies on the factors influencing the use of agricultural information sources have not typically analyzed the simultaneous use of multiple information sources. Previous research has implicitly assumed that decisions to use different information sources are mutually exclusive ignoring the possibility of simultaneous use and the potential correlation of information-source-use decisions. Schnitkey et al. (1992) studied the factors influencing farmers' use and information usefulness-perception in the context of production, marketing, and financial decisions. The multinomial logit regression used in their study implicitly assumes independence between information-source-use decisions. Ortmann et al. (1993) studied the factors influencing the use of a single information source (consultants) among large cornbelt farmers, but ignored the potential influence of other information sources on the use of consultants. One exception is the study by Just et al. (2006) who analyzed information-source use, acknowledging the possibility of substitute and complementary relationships between sources, suggesting that information-source-use decisions may be correlated. However, their study estimated individual probit models to determine demand for information sources, making it difficult to model the potential correlation between use decisions.

The objective of this research is to examine factors influencing cotton farmers' choices of precision farming information sources while taking into account the possibility of simultaneous use of information sources and the potential correlation between these decisions. In particular, factors are examined that may influence farmers' use of crop consultants, farm input dealerships, Extension, and mass media sources using a multivariate probit approach. Data from cotton farmers in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North and South Carolina, Tennessee, and Virginia are used in the analysis. The results of this study contribute to the understanding of farmer preferences for precision farming information sources. These findings should be valuable to precision farming information providers. For example, identifying the characteristics of producers who are more likely to use crop consultants may help companies offering these services to better target their clientele. Hence, different information providers may be able to better tailor their precision farming information dissemination tools to the needs of their target clientele. More efficient delivery of information may help farmers improve their management skills and production efficiency. In turn with better information, farmers can increase the likelihood of successful outcomes resulting from their decision to use precision farming technologies.

Conceptual Framework

A random utility model was developed to analyze the factors influencing information source use by cotton farmers. Cotton producers are assumed to be rational decision makers who maximize the discounted expected benefits from farming. Producers make decisions about the sources of precision farming information that they perceive as useful in crop management and are willing to spend time and money to collect information about a specific technology if an economic return is anticipated (Feder and Slade, 1984; Strickland, Ess, and Parsons, 1998; Plant, 2001).

Farmers' consumption of information and input allocation decisions can be modeled in three stages (Just et al., 2002). In the first stage, the producer decides how much information from each source (supplier) is needed to manage inputs, subject to a resource availability constraint. Producers face uncertainty associated with unobserved information benefits that are only realized in the second stage where input management production decisions are made. In the second stage, producers use information acquired in the first stage to make input management decisions. Profits are realized in the third stage.

Optimal information-source-choice decisions made in the stages described above can be determined through backward induction as in dynamic programming. To determine choice decisions faced by the farmer in stage 1, the second stage must first be considered. Define $\boldsymbol{I}$ as a vector of j information sources ($\boldsymbol{I_1, I_2, I_3, \ldots, I_j}$) available to producers for decisions about precision farming. In the second stage, the producer faces the following problem:

(1) $$\underset{x}{Max}\ EU(\pi(x) \mid \mathbf{I}, \mathbf{Z}),$$

where $EU(\cdot)$ is expected utility, π is the quasi-rent with respect to information (Just et al., 2002), $\mathbf{x}$ is a vector of production inputs, ***I*** is a vector of information obtained from different information sources, and ***Z*** is a vector of observed farmer/farm business characteristics and regional variables. Given ***I***, a farmer chooses an expected utility ($EU(\cdot)$) maximizing combination of inputs $\mathbf{x}^*$. Therefore, the optimal solution to the problem defined in (1) can be represented as $\pi^*(\mathbf{I,Z}) = \pi(\mathbf{x}^* | \mathbf{I,Z})$.

Assumptions about the uniqueness of an optimal expected utility for each possible choice of any information source allows us to identify the problem faced by a producer in stage one (Just et al. 2002). In stage one, a producer faces the following problem:

(2) $$\underset{I}{Max}\ EU(\pi^*(\mathbf{I}) - \mathrm{p}'\mathbf{I} \mid \mathbf{Z}),$$

where ***p*** is a vector of the costs of obtaining information from different sources. A producer chooses an optimal combination of information from different sources (***I***) with prices (***p***). The random variable defining returns from information ($\pi^*(I)$) is defined in stage 2 as described above.

The first order conditions for equation (2) are:

(3) $$\frac{\partial EU(\pi^*(\mathbf{I}) \mid \mathbf{Z})}{\partial I_j} - p_j = 0 \qquad \text{for } j=1,2,\ldots,k.$$

The solution to the system is found by choosing an optimal vector of information input levels (I^*), which reduce to demand functions for information sources *j*=1,2,3,…,*k*: $I_j^*(p,Z)$.

Defining $U_{I_j}^*$ as

(4) $$U_{I_j}^* = EU(\pi * (\mathbf{I}) - p'\mathbf{I} \mid \mathbf{Z}) - EU(\pi * (\mathbf{I}_{-\mathbf{j}} - p'\mathbf{I}_{-\mathbf{j}} \mid \mathbf{Z}))$$

where $\mathbf{I}_{-\mathbf{j}}$ is a vector of information sources excluding information obtained from information source *j*, the utility maximizing producer chooses information source *j* if $U^*_{I_j} > 0$. Note that the difference $U^*_{I_j}$ is an unobserved latent variable, but the decision to use an information source (y_j) is observable such that:

(5) $$y_j = \begin{cases} 1 & \text{if } U^*_{I_j} > 0 \\ 0 & \text{if } U^*_{I_j} \leq 0 \end{cases},$$

where y_j = 1 if the producer decides to use information source j and y_j = 0, otherwise. This identity provides an empirically tractable approach to estimate the factors influencing the selection of precision farming information sources. Information source choices *j* and *k* are not mutually exclusive for $j \neq k$. Thus, the decision to consume information from one source may be correlated with other information-source decisions. For example, a producer may use Extension education programming in combination with crop consultants to acquire precision farming information.

Empirical Model

The empirical models for information source use are specified as:

(6a) $$\mathbf{y}_{PR} = \boldsymbol{\beta}'_{PR}\,\mathbf{Z} + \mathbf{e}_{PR},$$

(6b) $$\mathbf{y}_{EX} = \boldsymbol{\beta}'_{EX}\,\mathbf{Z} + \mathbf{e}_{EX},$$

(6c) $$\mathbf{y}_{MM} = \boldsymbol{\beta}'_{MM}\,\mathbf{Z} + \mathbf{e}_{MM},$$

where $\mathbf{y}_{PR} = 1$ if a producer uses crop consultants and/or farm input dealerships as a source of precision farming information (0 otherwise), $\mathbf{y}_{EX} = 1$ if a producer uses University Extension (0 otherwise), and $\mathbf{y}_{MM} = 1$ if a producer uses media sources (0 otherwise); $\boldsymbol{\beta}_{PR}, \boldsymbol{\beta}_{EX}$, and $\boldsymbol{\beta}_{MM}$ are vectors of unknown parameters associated to each information-source-use decision, $\mathbf{e}_{PR}, \mathbf{e}_{EX}$, and $\mathbf{e}_{MM}$ are random disturbance terms for each information-source-use decisions; $\mathbf{Z}$ is a matrix of observed farmer/farm business characteristics and regional variables described in (1). It is expected that different individual, farm, and local/regional characteristics (Z) should result in different access to information sources, abilities to process information from those sources, and therefore different information-source consumption patterns (Just et al., 2002, 2006). Descriptions of dependent and explanatory variables are presented in Table 3.

Hypothesis

Farmer characteristics hypothesized to affect the use of precision farming information sources included age, education, income, and percentage of income coming from farming. As a farmer's age (AGE) increases the planning horizon decreases. Older farmers may be less likely to invest resources in obtaining precision farming information without the certainty of receiving returns on their investment in the short run (McNamara, Wetzstein, and Douce, 1991; Daberkow and McBride, 1998; Arnholt, Batte, and Prochaska, 2001; Banerjee et al., 2008). Additionally, since age seems to be correlated with experience (Schnitkey et al., 1992), older farmers may prefer their own experience as the main source of information over all other sources available. In turn, age is hypothesized to negatively influence all information-source-use decisions.

Higher educational levels (AS, BS, GD) give farmers higher analytical ability to use information and translate it into a useful input for their decision-making processes (Just et al., 2002). Therefore, more educated farmers may be more likely to use media sources because information from these sources is relatively unprocessed, and require higher analytical skills to translate this information into useful input for management. As a result, education is expected to have a positive effect on the decision to use media sources. The use of crop consultants and farm input dealerships as information sources not only implies time but also monetary costs. Accessing information provided by these private sources may require a preliminary evaluation before making the decision to use their services; this evaluation may demand a certain level of analytical skills. Therefore, it is expected that crop consultants and/or farm input dealerships are more likely to be used by farmers with higher levels of education. Less educated farmers (HS) may be more likely to use sources that customize, target, and reformate information to make it useful for their specific decision-making context such as Extension (Just et al., 2006). In turn, education is hypothesized to have a negative relationship with the decision to use Extension as a source of precision farming information.

Income level (INC150) is expected to be positively associated with the use of information sources that may require not only a search and processing implicit cost (e.g. time), but also a monetary cost (e.g. crop consultants and farm dealers). In this study, farmers reporting household incomes greater than $150,000 were considered high-income farmers. High income may facilitate access to consulting services complementing new technologies (Rogers, 1983). Crop consultants and farm input dealerships may specialize in services complementing precision farming technologies, while Extension may focus on the general needs of a particular region. Specific information about precision farming provided by crop consultants may be more complete given the level of specialization of the professional providing these services but may also come at a higher cost. Therefore, farmers with high incomes are hypothesized to be more likely to use crop consultants and/or farm input dealerships, while lower income farmers may be more likely to use Extension as a source of precision farming information.

In this study, the percentage of income from farming activities (INCFP) is used to measure the importance of farming as an income source. Producers relying on farming as their primary source of income are hypothesized to be more likely to use all information sources available because of income dependence on farming performance. Resource investment on new management strategies may imply a large increase in income levels for farmers highly dependent on farm income. A farmer receiving a lower percentage of income from farming may spend less time managing the farm; therefore, farmers reporting lower percentages of income coming from farming may tend to prefer sources providing customized and action-oriented information that requires less time to be acquired and processed and already adjusted to their specific farm operation (e.g. Extension). Media sources providing information that needs further processing and therefore time to be used in supporting any decision-making process may be less preferred by farmers reporting less income from farming. Part-time farmers may require customized and action-oriented information already adjusted to their specific decision-making context because a large portion of their time is dedicated to off-farm responsibilities (Salin et al., 1998; Solano et al., 2003). On the other hand, farmers whose income is highly dependent on farming activities are more likely to use sources that provide action-oriented information even if that implies that more resources need to be invested (e.g. crop consultants and/or farm input dealerships).

Along with farmer characteristics, farm attributes, including farm size and land tenure, are hypothesized to impact information-source-use decisions. Farm size (FARMSIZE) is hypothesized to be positively correlated with the use of all information sources. Larger farms are able to spread information costs over more production acres (Feder and Slade, 1984; Ortmann et al., 1993; Solano et al., 2003).

The percentage of total acres owned (TENURE) is hypothesized to be positively correlated with the use of all information sources. Planning horizon seems to be larger for land owners relative to land renters (Soule, Tegene, and Wiebe, 2000) because land may be passed to subsequent generations. Therefore, the search for information about technologies providing economic and environmental benefits may be overall more complete for land owners than for land renters, obtaining information from all information sources available.

Location and regional variables were included to control for factors outside the farmer's management-decision context that possibly affect information-source-use decisions. Dummy variables for the state where the respondent's farm is located were hypothesized to control for general state differences, from climate to farmers' idiosyncrasies. Tennessee was chosen as the reference state. The hypotheses tested were whether cotton producers in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North and South Carolina, and Virginia had different preferences for precision farming information sources when compared with cotton farmers in Tennessee. Variables representing the number of merchant wholesalers, plus farm supply merchants and wholesalers in the county were hypothesized to control for differences in access to agricultural services. It is expected that the likelihood of using farm input dealerships as a source of precision farming information might be higher in a county where there are more establishments of that nature. Distance to a metro county from a county centroid was hypothesized to control for access to information technologies (internet), and general access to information services that might be more likely to be found in metropolitan counties. Variables measuring January sunshine hours and July humidity were hypothesized to control for growing season conditions affecting differences in information requirements. Variables measuring percentage change in agricultural sales between 1997 and 2002 and percentage change in land in farms between 1997 and 2002 were hypothesized to control for differences in level of agricultural activity between counties. Finally, a variable representing farm density (number of farms per acre) in the county was included to control for differences in farm distribution; for instance we might expect that counties with a high farm density may represent a farm distribution structure where distance between farms is small and therefore farmers may be more likely to rely on other farmers to obtain precision farming information. Farm density may also account for differences in average farm size; a county with a high farm density, may have a smaller average farm size than a county with a low farm density.

Data

A survey was mailed on January, 2005 to 12,243 cotton farmers in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North and South Carolina, Tennessee, and Virginia. The list of cotton farmers was obtained from the Cotton Board in Memphis, Tennessee. Out of 12,243 questionnaires mailed, 200 were returned either undeliverable or by farmers no longer producing cotton. Of the remaining mailed questionnaires 1214 surveys were returned completed, for a response rate of 10%.

The survey requested information about use, profitability, and perceived benefits from precision farming technologies and general farm business and farmer characteristics. A question about sources of information used to obtain precision farming information was asked. Answers about crop consultants, farm input dealerships, University Extension, Internet, and news media use were grouped into three categories based on characteristics of information and service provided. Crop consultants and farm input dealerships were classified as private sources. Information from media and Internet were classified as media sources. A third category included Extension University sources of precision farming information.

After eliminating observations with missing data, there were 989 responses available for analysis (see Table 3). An assessment of how well the sample represented the population of cotton farmers in the Southeastern United States (2005) was made by comparing the sample data with data from the 2002 Agriculture Census [U.S. Department of Agriculture/National Agricultural Statistics Service (USDA/NASS), 2004]. Frequency histograms tabulating farm size and age were compared for the sample and the Census population data. The farm size and age distribution from the sample data are similar to the distributions from the Census for the 11 states included in this study (Figure 1 and 2). Albeit this result, it is important to notice that the sample data showed a smaller percentage of cotton producers whose farm size was less than 220 acres (14%) when compared with the census data (22%). Additionally, the sample data included a smaller percentage of farmers older than 64 years old (10%) when compared with the census data (18%). The sample data are representative of larger farms and younger farmers relative to the census figures. Given that larger farmers are more likely to consider the adoption of certain precision farming technologies (Daberkow and McBride, 2003), the survey data used in this study are representative of farmers who are more likely to be interested in precision farming technologies (Walton et al., 2008).

Secondary data about farm density, percentage change in agricultural sales between 1997 and 2002, and percentage change in land in farms between 1997 and 2002 were collected from the 2002 Agriculture Census [U.S. Department of Agriculture/National Agricultural Statistics Service (USDA/NASS), 2004]. County agriculture-related business information patterns (number of merchant wholesalers, plus farm input supply merchants and wholesalers, distance to a metro county from county centroid) were gathered from the 2002 County Business Pattern (U.S. Census Bureau, CBP). January sunshine hours, and July humidity information was collected from the USDA/ERS natural amenities scale data set (USDA/ERS).

Estimation Methods

The decision to pursue various sources of information is hypothesized to be a function of observable exogenous variables such that:

(7) $$\mathbf{y}_j = \boldsymbol{\beta}'_j\,\mathbf{Z} + \varepsilon_j\text{, for } j = 1,2,...,k$$

where **Z** is a vector of observed farmer/farm business characteristics and regional variables, $\boldsymbol{\beta}_{\mathrm{j}}$ is a vector of unknown parameters to be estimated, and $\boldsymbol{\varepsilon}_{\mathrm{j}}$ is a random disturbance term.

Choice decisions over multiple alternatives can be framed in the context of a multinomial probit (logit) model. A very restrictive assumption of these models is Independence from Irrelevant Alternatives (IIA), which generally assumes that the error terms of the choice equations are independent and homoscedastic (Greene, 2003). This assumption does not allow for the possibility of unobserved factors shared by different choices (McFadden, 1984). On the other hand, a plausible assumption in the context of precision farming is that information sources may share similar attributes because they provide complementary services (Just et al., 2006). These conditions may potentially cause correlation between the random components of decision-making processes. Also, the multinomial model implies that choices are mutually exclusive. Under the analytical framework described above, the assumption of non-exclusive choices of information sources seems more plausible. Therefore, a multinomial approach may not be appropriate for investigating the use of precision farming information sources.

Given that precision farming information sources are not likely to be mutually exclusive and that the decisions to use these sources may be correlated, multivariate probit regression was used to model the correlated decision-making process between information sources. Assuming a multivariate normal distribution, the unknown parameters in (7) were estimated using maximum likelihood (ML). The probabilities entering the likelihood function, as well as the derivatives needed for the ML procedure, were computed using the Geweke-Hajivassiliou-Keane (GHK) simulation procedure (Geweke, 1989; Hajivassiliou, 1991; Keane, 1994), which produced approximations to the *m*-fold multivariate normal integrals:

(8) $$\int_{-\infty}^{z_1'\beta_1} \dots \int_{-\infty}^{z_m'\beta_m} \phi(s_1, \dots, s_m) ds_1 \dots ds_m$$

where $\phi(\cdot)$ is the *m*-variate normal density of a random variable ***s*** with mean vector equal to zero and $m \times m$ positive definite covariance matrix. The log-likelihood for the model was then calculated as the sum of the logs of the probabilities of the observed outcomes defined as:

(9) $$\text{Prob}\,(y_1, \dots, y_m | z_1, \dots, z_m) = \text{MVN}(\mathbf{T}W, \mathbf{TRT}')$$

where *W* is a vector defined from $W_m = Z_m^{'}\beta_m$, **R** is the correlation matrix, **T** is a diagonal matrix with $t_{mm} = 2y_m - 1$, and MVN refers to the multivariate normal density (Greene, 2007). Pairwise correlation of the error terms associated with each information source was computed and its significance was tested.

Marginal effects can be computed given the multivariate nature of the model (Greene, 2003). The approach taken here was to first obtain the expected value of a use-decision for a particular information source (say, y_1=1), conditional on all other information sources also being used (y_2,..., y_m =1):

(10) $$E(y_1 | y_2, \dots, y_m) = \frac{\text{Prob}(y_1 = 1, \dots, y_m = 1)}{\text{Prob}(y_2 = 1, \dots, y_m = 1)} = \frac{P_{1\dots m}}{P_{2\dots m}} = E_1 \,.$$

Then, to get the marginal effects, the derivative of (10) was taken with respect to the explanatory variables of interest:

(11) $$\frac{\partial E_1}{\partial Z} = \sum_{j=1}^{m}\left[\frac{1}{P_{2\ldots m}}\frac{\partial P_{1\ldots m}}{\partial w_m}\right]\gamma_m - E_1\sum_{j=2}^{m}\left[\frac{1}{P_{2\ldots m}}\frac{\partial P_{2\ldots m}}{\partial w_m}\right]\gamma_m,$$

where **Z** is the union of all regressors that appear in the model and γ_m is defined such that $w_m = Z'\gamma_m = \beta_m' Z_m$. The terms on the right hand side of equation (11) suggest that the parameter signs estimated in (9) are not necessarily the same as the signs of their respective marginal effects.

Multicollinearity Tests

Multicollinearity can compromise inferences by inflating variances estimates (Greene, 2003; Judge et al., 1988). The condition index was used to detect collinear relationships (Belsley, Kuh, and Welsch, 1980). Condition indexes between 30 and 100 have moderate to strong relations. A condition index that is accompanied by a proportion of variation above 0.5 indicates a potential collinearity problem (Belsley, Kuh, and Welsch, 1980).

Exogeneity Tests

In survey analysis, it is common to find respondent attributes and farm business characteristics to be jointly determined with the outcome or dependent variable (Walton et al., 2008). The number of establishments (TOTALEST) providing farm input services in a county may be codetermined with the information-source-use decisions. For example, the likelihood of using crop consultants and/or farm input dealerships as a source of precision farming information might be higher in a county where there are more firms of that nature. Input supply firms may attract farm input dealerships and/or crop consultants providing precision farming information sources. More businesses may lead to increased availability of information sources, which would heighten competition between these sources and potentially lower cost of these consulting services. At the same time, larger demand for crop consultants and/or farm input dealerships by farmers may attract more input supply to locate in a particular county.

A data-driven approach is used to statistically test for the exogeneity of the total number of establishments' variable (TOTALEST). An OLS regression model is used to regress TOTALEST against a vector of instrumental variables. The instruments used included all exogenous variables in the information-source-use equations along with additional pre-determined variables including 1) a dummy variable measuring whether a particular county was classified as micropolitan according to the Bureau of Economic Analysis definition (BEA, Office of Management and Budget, U.S. Census Bureau, 2003), 2) county population density in 2000 (U.S. Census Bureau, U.S. Census 2000), 3) county average wage in 2000 (U.S. Census Bureau, U.S. Census 2000), and 4) a dummy variable reflecting the county's dependence on farming (USDA/ERS, 2004). The selected instrumental variables are hypothesized to be correlated with TOTALEST but uncorrelated with the error terms in (6a), (6b), and (6c) since they are outside the production-decision making framework but are correlated with the number of farm dealerships in a county. The residuals from this regression were included in the baseline multivariate probit model. A Wald test statistic tests the joint significance of the residual terms across the three equations (Wooldridge, 2002). Failing to reject the null hypothesis provides evidence that TOTALEST is an exogenous variable in (6a), (6b), and (6c).

Results and Discussion

Descriptive Statistics and Correlation Coefficient

Table 4 summarizes the information use patterns. The percentage of producers in the sample using private information sources (crop consultants and/or farm dealers) is 69%. Producers who utilize Extension and media sources comprise 66% and 64% of the sample, respectively. About 15% of producers used only one source of information. The percentages of cotton farmers in the sample who used only private, only Extension, or only media sources were 5.3%, 3.9%, and 5.2%, respectively. On the other hand, 66.5% of cotton producers used different combinations of information sources. About half (51.2%) used all the sources of information considered in the survey. This finding suggests that the decision to use one source of information might be correlated with the use of information sources. This hypothesis was tested by calculating pairwise correlation coefficients across the residuals in the system of equations for the three information-source decisions after controlling for the influence of the observed factors (Greene, 2003) (Table 5). All correlation coefficients were positive and statistically significant at the 1% level. This result supports the hypothesis that the error terms in the information-source-use equations are correlated, suggesting that the multivariate probit approach is appropriate in this case. Moreover, the positive signs of the correlation coefficients suggest that the decision to use one source of information increases the likelihood that another source will be used. For example, a producer who uses the internet may also tend to use farm input dealerships as a source of precision farming information.

The null hypothesis of the exogeneity test was not rejected in the information-source-use equations (Wald statistic=3.64, df=3, P=0.30), providing evidence that TOTALEST is exogenous to the information-source-use decision equations. In addition, evident multicollinearity problems were not found, given that all condition indexes were less than 30.

Parameter Estimates and Marginal Effects: Multivariate Probit Model

The parameter estimates from the multivariate probit and (for comparison) the individual probit models are presented in Table 6. Table 7 presents the marginal effects from the multivariate probit model for the variables that were significant in Table 6. Conclusions about magnitudes and signs of independent-variable effects on information-use patterns are discussed using the marginal-effect results (Table 7).

The observed factors that significantly affected the use of private sources (y_{PR} -crop consultants and/or farm input dealerships) were age (AGE), attainment of a Bachelor's degree (BS) relative to a high school diploma (HS), income (INC150), farm size (FARMSIZE), and farm density (FARMDENSITY) (Table 7). Older farmers were less likely to use private sources to obtain precision farming information, while farmers with income greater than $150,000 tended to use private sources for precision farming information. Larger farmers used private sources to obtain precision farming information. Farmers with a Bachelor's degree were more likely to use private sources relative to those with a high school diploma or less formal education. The significant effect of farm density suggests that farmers located in high farm-density counties were less likely to use private sources. This negative effect of farm density could be explained by farmers in these counties using other farmers as a source of information.

The significant effects in the multivariate probit model for the use of Extension information (y_{EX}) were age, farm size, distance to a metropolitan county from county centroid (ROADDIST), and the Alabama (AL) and Louisiana (LA) state dummy variables relative to Tennessee (TN) (Table 7). Older farmers were more likely to use Extension as a source of precision farming information, in contrast to the negative effect found for private-source. Larger farmers tended to use Extension as source of precision farming information. Farmers with a Bachelor's degree tend to use Extension less compared to those who have a high school degree, while those with a Graduate degree (GD) seem to use Extension more than farmers with a high school degree or less formal education. Additionally, distance to a metropolitan county has a negative impact on the likelihood of the use of Extension as source of information. The positive marginal effects for the state dummy variables for Alabama and Louisiana reflect a higher likelihood of Extension use for producers located in these states relative to farmers in Tennessee.

The significant effects for media use (y_{MM} - news media and/or internet) were age, attainment of an Associate's (AS), Bachelor's, or Graduate degrees relative to a high school diploma, income, farm size, distance to a metropolitan county, January sunshine (JANSUNZ), and Alabama, Arkansas (AR), Louisiana, Mississippi (MS), and Missouri (MO) state dummy variables relative to Tennessee. The negative marginal effect for age implies that older farmers were less likely to use information from media sources. Farmers who have an Associate's, Bachelor's, or Graduate degree tended to use media sources more than those with a high school degree or less formal education. Farmers with incomes larger than $150,000 were more inclined to use media as a source of precision farming information. Additionally, distance to Metropolitan County had a negative impact on the likelihood of media use. Farmers located in Alabama, Arkansas, Louisiana, Mississippi, and Missouri were more likely to use media sources relative to farmers located in Tennessee.

In summary, older farmers in the sample were less likely to use private and media sources and more likely to use Extension. Farmers with incomes larger than $150,000 were more likely to use private and/or media information sources. As hypothesized, farmers with higher incomes were more likely to use information sources that require not only implicit search and processing costs (e.g. time), such as media sources, but also monetary costs, such as crop consultants and farm input dealerships. Farmers with Bachelor's degrees tended to use media sources. This result is supported by Just et al. (2002) who suggest that individuals with higher levels of education are more likely to use sources that provide relatively unprocessed data, raw statements or facts (e.g. media sources).

Conclusion

Farmers have a number of options to obtain information about precision farming and many of them utilize these information sources simultaneously. The implicit assumption is often made that the decision to use one information source is independent of the decision to use other information sources (Schnitkey et al. 1992). In this study, we specifically investigated the factors that affect farmers' use patterns of private, Extension, and media information sources, while taking into account the potential for simultaneous use and/or correlation among information-source-use decisions. Using a multivariate probit approach, we found that information-source-use decisions are indeed correlated even after controlling for observable factors. Furthermore, our analysis suggests that the decision to use one information source positively influences the decision to use other information sources.

Given the correlation among information-source-use decisions, it appears more appropriate to investigate factors that affect these decisions in a multivariate context rather than separately estimating an equation for each information source. Future studies will provide more accurate parameter estimates and inferences if they account for correlation among information-source-use decisions.

Our results pointed to the importance of age, education, income, and farm size as factors that determine use of private, Extension, and media sources of information. Information suppliers (crop consultants, farm input dealerships, Extension educators and media information providers) may be able to tailor their services to clientele, based on this research. Using our results, information providers can better anticipate which types of farmers would use their information in combination with other information sources. This finding might help different information suppliers to combine efforts to better serve precision farming information consumers. For instance, crop consultants could use this information to target younger, more educated farmers with a high income who farm large farms. They could design programs specific to producers who fit this profile.

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Appendix

Table 3. Definitions and Descriptive Statistics of Variables (n=989)

Variable	Description	Mean	Std Dev
A. Dependent variables:			
y_{PR}	= 1 if producer uses crop consultants and/or farm dealers, zero otherwise	0.7159	
y_{EX}	= 1 if producer uses University Extension, zero otherwise	0.6855	
y_{MM}	= 1 if producer uses media and/or Internet, zero otherwise	0.6754	
B. Independent variables:			
AL	= 1 if farm is located in Alabama, zero otherwise	0.1143	
AR	= 1 if farm is located in Arkansas, zero otherwise	0.0819	
FL	= 1 if farm is located in Florida, zero otherwise	0.0192	
GA	= 1 if farm is located in Georgia, zero otherwise	0.1820	
LA	= 1 if farm is located in Louisiana, zero otherwise	0.0698	
MS	= 1 if farm is located in Mississippi, zero otherwise	0.1355	
MO	= 1 if farm is located in Missouri, zero otherwise	0.0394	
NC	= 1 if farm is located in North Carolina, zero otherwise	0.1719	
SC	= 1 if farm is located in South Carolina, zero otherwise	0.0617	
TN	= 1 if farm is located in Tennessee, zero otherwise	0.0971	
VA	= 1 if farm is located in Virginia, zero otherwise	0.0273	
AGE	Age of producer as of 2004	49.6997	12.0334
HS	1=if Producer has a High School degree or less, zero otherwise	0.4934	
AS	1=if Producer has Associate's degree, zero otherwise	0.1274	
BS	1=if Producer has Bachelor's degree, zero otherwise	0.3054	
GD	1=if Producer has Graduate degree, zero otherwise	0.0738	
INC150	1=if Producer's income is greater than $150,000, zero otherwise	0.3478	0.4765
INCFP	Percentage of income from farming divided by 100	0.7219	0.2866
FARM SIZE	Owned acres plus rented acres divided by 100	13.6229	15.8422
LAND_TENURE	Owned acres divided by owned acres plus rented acres	0.3229	0.3184
TOTALEST	Total number of farm and garden machinery and equipment merchant wholesalers, plus farm supplies merchant and wholesalers in the county	5.6694	4.3273
FARMDENSITY	Number of farms in the county divided by acres of crop land in the county	0.0053	0.0042
ROADDIST	Distance to a metropolitan county from county centroid	32.8935	27.6147
JANSUNZ	January sunlight hours, normalize (0,1)	0.2049	0.4912
JULHUMZ	July Humidity, normalize (0,1)	-0.9222	0.4862
SALESLN	Natural log of sales per acre 2002 divided by sales per acre 1997	-0.2066	0.2413
LIFLN	Natural log of land in farm 2002 divided by land in farm 1997	-0.0600	0.0888

Table 4. Proportion of Producers Using Different Combinations of Information Sources

Possible Information Sources Combinations	Number of Farmers	Proportion
None of the sources considered in the survey	232	19.11%
Private sources only	64	5.27%
Extension sources only	48	3.95%
Media sources only	63	5.19%
Private and Extension sources	94	7.74%
Private and media sources	57	4.70%
Extension and media sources	35	2.88%
Private, Extension, and media sources	621	51.15%

Table 5. Correlation Coefficients of Information-Source Use Decisions

Information Source Decision	Correlation Coefficient[a]	Standard Deviation
Private and Extension	0.82***	0.03
Private and Media	0.72***	0.04
Extension and Media	0.69***	0.04

[a] Correlation coefficients between the residuals from the multivariate probit equations.
*** indicates statistical significance at the 1% level.

Table 6. Parameter Estimates from the Multivariate Probit and Individual Probit Models for Estimating the Factors Influencing Sources of Precision Farming Information

Independent Variables	Parameters Estimates from the Multivariate Probit Approach			Parameter Estimates from the Individual Probit Approach		
	Usage Patterns Equations			Usage Patterns Equations		
	Private	Extension	Media	Private	Extension	Media
Intercept	1.4969*** (0.3203)	1.0922*** (0.3161)	1.2527*** (0.2991)	1.4164*** (0.3066)	1.0867*** (0.2923)	1.2393*** (0.2959)
AL	0.1161 (0.2584)[a]	0.5902** (0.2517)	0.6901*** (0.2633)	0.1075 (0.2502)	0.6350*** (0.2436)	0.6813*** (0.2484)
AR	0.0712 (0.2548)	0.3545 (0.2376)	0.6774*** (0.2355)	0.0992 (0.2497)	0.3757 (0.2288)	0.7090*** (0.2348)
FL	-0.7048 (0.5733)	-0.5181 (0.5767)	-0.6317 (0.5880)	-0.6690 (0.5249)	-0.5105 (0.5133)	-0.6841 (0.5230)
GA	-0.2092 (0.4063)	0.1422 (0.4146)	0.2629 (0.4300)	-0.2220 (0.3928)	0.1705 (0.3863)	0.2281 (0.3962)
LA	0.3920 (0.2908)	0.5609* (0.2889)	0.7528** (0.2986)	0.3505 (0.2940)	0.5733** (0.2768)	0.7276** (0.2864)
MS	0.1022 (0.2261)	0.3353 (0.2256)	0.7103*** (0.2265)	0.1212 (0.2254)	0.3554* (0.2145)	0.7154*** (0.2231)
MO	0.0659 (0.3521)	0.1664 (0.3148)	0.6428* (0.3306)	0.0545 (0.3305)	0.2003 (0.3041)	0.6615** (0.3124)
NC	-0.2029 (0.4240)	0.1064 (0.4356)	0.1442 (0.4442)	-0.2494 (0.4108)	0.1135 (0.4026)	0.0951 (0.4117)
SC	-0.4265 (0.4740)	-0.3360 (0.4783)	-0.0615 (0.4852)	-0.4356 (0.4539)	-0.3428 (0.4442)	-0.0758 (0.4529)
VA	-0.0133 (0.4705)	0.3655 (0.4705)	0.1688 (0.4694)	-0.0101 (0.4365)	0.4115 (0.4331)	0.1584 (0.4279)
AGE	-0.0245*** (0.0044)	-0.0162*** (0.0041)	-0.0277*** (0.0043)	-0.0244*** (0.0041)	-0.0158*** (0.0039)	-0.0274*** (0.0040)
AS	0.0180 (0.1475)	0.2489 (0.1544)	0.3116** (0.1476)	0.0102 (0.1422)	0.2490* (0.1425)	0.3018** (0.1421)
BS	0.3350*** (0.1161)	0.2734** (0.1119)	0.5430*** (0.1108)	0.3639*** (0.1101)	0.2785** (0.1034)	0.5635*** (0.1066)
GD	0.2530 (0.2057)	0.3744* (0.1947)	0.5332*** (0.1897)	0.2633 (0.1868)	0.3759** (0.1820)	0.5587*** (0.1831)
INC150	0.2241** (0.1017)	0.1119 (0.0997)	0.1968* (0.1009)	0.1934** (0.0982)	0.1048 (0.0935)	0.1841* (0.0952)
INCFP	0.1681 (0.1743)	0.0527 (0.1754)	0.0794 (0.1722)	0.1783 (0.1647)	0.0580 (0.1597)	0.1101 (0.1619)
FARM SIZE	0.0144*** (0.0037)	0.0086*** (0.0033)	0.0084** (0.0035)	0.0181*** (0.0045)	0.0085** (0.0035)	0.0081** (0.0036)
LAND_ TENURE	0.0233 (0.1577)	-0.1361 (0.1529)	-0.0376 (0.1535)	0.0323 (0.1503)	-0.1387 (0.1439)	-0.0341 (0.1464)
TOTALEST	0.0208 (0.0146)	0.0055 (0.0111)	-0.0030 (0.0130)	0.0250* (0.0128)	0.0061 (0.0108)	-0.0032 (0.0112)

[a] Numbers in parenthesis are standard errors.

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

Table 6. Continued.

Independent Variables	Parameters Estimates from the Multivariate Probit Approach			Parameter Estimates from the Individual Probit Approach		
	Usage Patterns Equations			Usage Patterns Equations		
	Private	Extension	Media	Private	Extension	Media
FARM DENSITY	-36.3279** (16.6818) [a]	-22.2878 (15.4432)	-0.4016 (15.4583)	-37.9251** (15.0208)	-24.1594* (14.6106)	-2.7737 (14.8922)
ROADDIST	-0.0034 (0.0023)	-0.0043** (0.0022)	-0.0037* (0.0021)	-0.0036 (0.0022)	-0.0047** (0.0021)	-0.0043** (0.0021)
JANSUNZ	0.2229 (0.2922)	0.3607 (0.3041)	0.6168** (0.3090)	0.2063 (0.2901)	0.3786 (0.2870)	0.6317** (0.2907)
JULHUMZ	-0.0779 (0.2386)	0.0907 (0.2496)	0.2359 (0.2619)	-0.1212 (0.2366)	0.1069 (0.2315)	0.2096 (0.2439)
SALESLN	-0.0226 (0.2283)	-0.0618 (0.2099)	-0.3237 (0.2314)	-0.0102 (0.2105)	-0.0687 (0.2046)	-0.3258 (0.2094)
LIFLN	0.7121 (0.5445)	0.6270 (0.5480)	0.6892 (0.5557)	0.7250 (0.5252)	0.6631 (0.5157)	0.6707 (0.5208)
LLikelihood value		-1371.916		-520.6816	-572.4637	-552.1142

[a] Numbers in parenthesis are standard errors.

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

Table 7. Marginal Effects from the Multivariate Probit Model for Estimating the Factors Influencing Sources of Precision Farming Information.

	Marginal Effects from the Multivariate Probit Approach		
	Usage Patterns Equations		
Independent Variables	Private	Extension	Media
AL		0.0934 (0.0060)	0.1409 (0.0056)
AR			0.1607 (0.0029)
LA		0.0574 (0.0081)	0.1397 (0.0076)
MS			0.1661 (0.0032)
MO			0.1646 (0.0023)
AGE	-0.0012 (0.0008)	0.0001 (0.0004)	-0.0046 (0.0003)
AS			0.0662 (0.0022)
BS	0.0006 (0.0155)	-0.0002 (0.0065)	0.1065 (0.0047)
GD		0.0352 (0.0057)	0.1003 (0.0053)
INC150	0.0193 (0.0053)		0.0295 (0.0028)
FARMSIZE	0.0013 (0.0003)	0.0003 (0.0002)	0.0006 (0.0002)
FARM DENSITY	-4.6090 (0.3780)		
ROADDIST		-0.0005 (0.00005)	-0.0004 (0.0001)
JANSUNZ			0.1282 (0.0045)

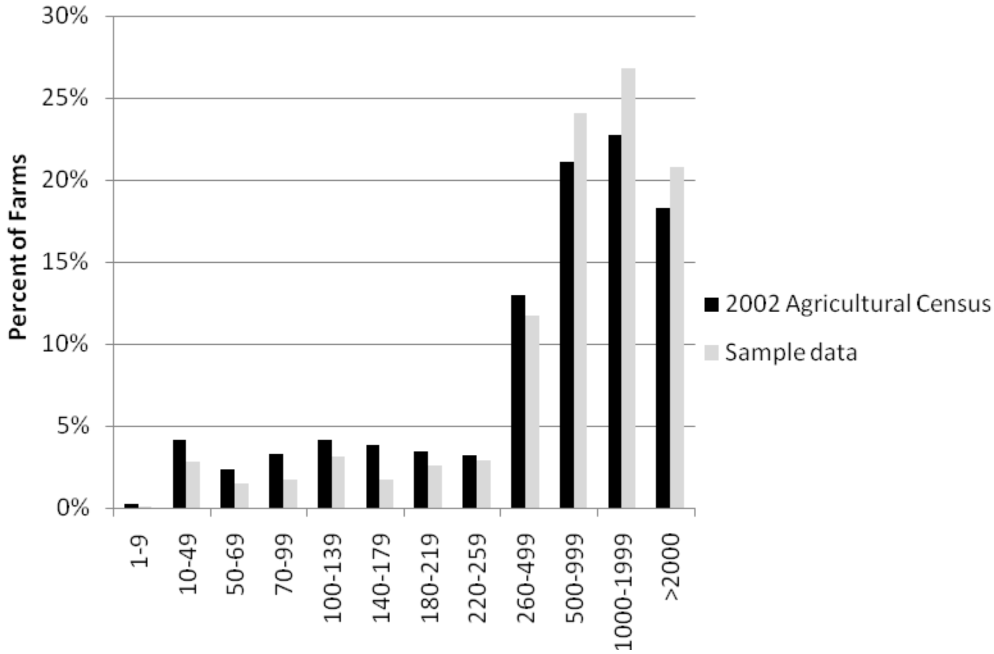

Figure 1. Farm size distribution for sample data compared with the 2002 Census of Agriculture

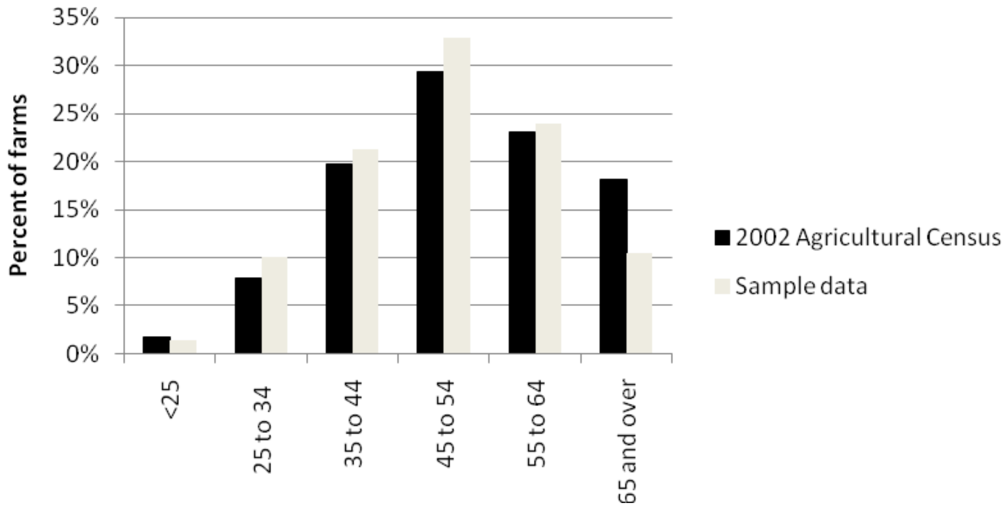

Figure 2. Age distribution of sample data compared with the 2002 Census of Agriculture

Part 4: Summary

Summary

This study evaluates the factors affecting the use of different information sources in the general context of precision farming. Factors affecting the use of information sources such as private, Extension, and media sources were investigated.

The first part of this study examined the sources of information farmers used to obtain precision farming information focusing on Extension use through a basic statistical analysis. The results suggested that farmers use different sources simultaneously to obtain precision farming information. Seventy five percent of the farmers using Extension combined information from this source with all the other information sources (farm input dealerships, crop consultants, media, and other farmers). In turn, it seems that decisions to use different information sources are not mutually exclusive. Furthermore, given that information sources provide similar services they may share similar attributes making use decisions not independent from each other.

Independent samples t-tests were used to evaluate systematic differences between Extension users and non-users in terms of farm business and operator characteristics. Producers, who use Extension, either solely or in combination with other information sources, tend to be younger in age, a larger proportion have a higher education, larger farms, larger incomes, and rent a larger percentage of land than those who did not use Extension.

In the second essay, farm business attributes, farmer characteristics, and regional factors influencing cotton farmers' choices of precision farming information sources were evaluated using appropriate econometric methods. Results from the first essay provided some insights about how farmers make decisions about the use of information sources. This information helped to identify a multivariate probit approach as the model that best suited the problem considered in the second essay. A multivariate probit approach allows for correlation of error terms in the different information-source equations. Furthermore, mutual exclusion is not assumed for choices over multiple alternatives. Correlation of errors between the different choice equations were evaluated by calculating pairwise correlation coefficients across the three information-source equations. All correlation coefficients were positive and statistically significant supporting the hypothesis that the information-source-use decisions are correlated and a multivariate probit approach is appropriate in the second essay analysis. Neglecting the correlation among the use of different information sources could provide misleading parameter estimates and inferences.

Results indicated that younger farmers in the sample and those with a higher income tend to use private and media sources, while older farmers use Extension services. Farmers with a Bachelor's degree are more likely to use private and media sources and less likely to use Extension as a source of information. The size of the farm is positively related to the use of all information sources, while the distance to a metropolitan county has a negative impact on the use of Extension and media sources. State dummy variables indicated Extension may be able to differentiate their information based on state differences.

It is important to notice that results from essay one and essay two regarding factors affecting the use of Extension as a source of precision farming information differ considerably. Essay one showed that younger farmers and those with a Bachelor's degree are more likely to use Extension. In contrast, the second essay indicates that older farmers are more likely to use Extension; while, farmers with a Bachelor's degree are less likely to use Extension. Additionally, the first essay suggested a systematic difference in terms of income levels between Extension users and non users. On the other hand, the second essay showed no impact of income levels on the probability to use Extension as a source of precision farming information.

The first essay uses an independent samples t-test to compare Extension users and non-users, while the second paper uses a multivariate probit approach to identify characteristics of different information source users, taking into account the potential correlation between information-source-use decisions. This difference in methods and procedures leads to contrasting results between the two essays in terms of inferences about the factors affecting information-source decisions. The first essay did not control for other variables that may influence the use of precision farming information sources while the second essay controlled for other factors that may influence the use of precision farming information sources.

In general, empirical results from the multivariate probit approach pointed to the importance of age, education, income, and farm size as factors that determine use of private, Extension, and media sources. Information providers can use these results to understand characteristics of farmers likely to use their services. As a result, they can tailor their services for their target clientele. This information might help them to determine the most effective methods of distributing information to farmers.

Vita

Amanda Renee Jenkins was born in St. Louis, Missouri on January 2, 1986, to Carl and Lisa Jenkins. She graduated from Rossview High School in May, 2004. She then attended Murray State University where she obtained a B.S. degree in Agriculture with an area in Agricultural Science/Agribusiness Department in December, 2007. Later, she attended the University of Tennessee, Knoxville, where she earned an M.S. degree in Agricultural Economics in December, 2009.