Information and the Adoption of Precision Farming Technologies

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ABSTRACT

This study examines the relationship between precision farming information sources and precision farming adoption. The analysis accounts for the fact that not all farmers are aware of precision farming techniques and that those who are aware may not be a random sample. Results indicate that many information sources increase adoption relative to information only from the media, but contact with crop consultants has had the greatest impact on the adoption of precision farming technologies.

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INTRODUCTION

Precision farming (PF) technologies offer a way to manage the sub-field variability of soils, pests, landscapes, and microclimates by spatially adjusting input use to maximize profits and potentially reduce environmental risks. Examples of PF technologies include variable rate applicators for seed, fertilizer and pesticides; yield monitors; guidance systems; and soil and plant attribute sensors. These monitoring and input application technologies often involve geo-referencing which allows producers to micro-manage soil and plant processes within small areas of a single field. PF technologies have been commercially available since the early 1990's. However, not only has the pace of adoption in the U.S. been relatively modest, but a large number of producers are apparently not familiar with these technologies. A 1998 nationwide survey of over 8,400 U.S. farms indicated that nearly 70 percent of farmers were not aware of PF technologies, while less than 5 percent had adopted some aspect of PF (Daberkow and McBride, 2000).

A number of public policy issues have surfaced about the potential impact of PF adoption on farm income, farm structure, and environmental quality (Pierce and Nowak, 1999; NRC, 1997). Questions have been raised about 1) the level of public funding of PF research, education, and extension activities, and 2) appropriate public-private roles in assisting producers in gaining access to PF technologies (Cowan, 2000). In light of these concerns, the general objective of this study is to examine the factors that influence PF adoption among U.S. farmers and specifically to examine the hypothesis that different sources of PF information have different impacts on the probability of PF adoption. These results provide insight about the impact that various providers of PF information or "agents of change" are having on PF adoption, and suggest how public policy could be used to influence PF adoption.

RELATED LITERATURE

The technology adoption literature, especially from rural sociologists, often alludes to different stages in the adoption process and the role that information plays in each stage. Beale and Bolen (1955) were among the first to synthesize research that suggested awareness was the critical first stage of the agricultural technology diffusion process[3]. They defined awareness as the stage where an individual learns of the existence of a technology or practice but has little knowledge about it. Most individuals were thought to become aware of new ideas through the mass communications media. Carlson and Dillman (1986) note that "---different sources of information become important at different stages of adoption." The usual assumption is that the media is important in the early awareness stage; neighbors, crop consultants, and agricultural professionals provide input during the testing and evaluation stage; and personal experience is critical during the adoption, intensification, and/or retention stage (Kromm and White, 1991).

[3] The awareness stage was hypothesized to be followed, over time, by the interest, evaluation, trial and, finally, the adoption stages.

Rollins (1993) found that most potential adopters of new technology rely on several information sources and that preferred information sources change during the various stages of adoption. Hence, he suggests that certain information sources can be more "effective change agents" than others and that different information sources can influence the probability of adoption. Similarly, research by Rogers (1995) and Korsching and Hoban (1990) indicated that different sources of information are influential during different stages of the adoption process with mass media (i.e., radio, newspapers, television, and magazines) most important during the initial stages and information about the specific technology critical in the latter stages. McBride, et al. (1999) suggested that the mass media is a more passive form of information about PF relative to more active or "how-to" technical sources.

Longo (1990) categorizes the delivery of information to potential adopters under two different labels: 1) mass media and 2) interpersonal communication (i.e., crop consultants, extension agents, demonstrations, input suppliers, etc.). She tested the traditional assumption that mass media is important in creating awareness of the existence of agricultural innovations (but such information sources seldom led to adoption) whereas interpersonal communication typically involves contacts in face-to-face situations and is the basic means of transferring more technical (and adoption promoting) information. While Longo notes that the effects of mass media and interpersonal communication are likely inter-related, she cites several studies which did not find any relationship between mass media, interpersonal communication and agricultural technology adoption. However, she found that in Brazil, mass media channels were more important in explaining the adoption of cropping innovations than the interpersonal channels of communication.

Several adoption studies imply that perceptions and attitudes about emerging technologies are also influenced by different sources of information. Empirical analyses by Adesina and Zinnah (1993) found that farmer's perceptions about characteristics of rice varieties affected the adoption decision, while Lynne, et al. (1988) concluded that attitudes about conservation influenced the adoption of soil conservation practices. McBride, et al. (1999) reported that different information sources influenced producer attitudes about PF with crop consultants more influential relative to media sources. Thomas, et al. (1990) found that information from personal contacts was most likely to influence attitudes about IPM adoption. Feather and Amacher (1994) noted that producer perceptions play an important role in the adoption decision and that providing information to producers can change their perceptions by reducing uncertainty about the technology. Other research has suggested that awareness, and the formation of attitudes, is also influenced by agricultural producers' socio-economic characteristics (e.g., Rogers, 1995).

The nature of the agricultural technology or practice, along with farm and operator characteristics, also interacts with information sources to influence adoption[4]. For example, Saltier, et al.(1994) found that access to information "---plays a stronger role in the adoption of management-intensive practices than it does for low-input methods." Furthermore, they found that the adoption of management intensive technologies was closely linked to large, less diversified farms. Feder and Slade (1984) noted that farm size influences both the access to

[4] For a discussion of other key farm and operator characteristics that have been found to influence agricultural technology adoption in previous studies see Daberkow et al., 2000.

information and the adoption decision. Rather than rely on passive forms of information, some research has suggested that producers may actively seek information about innovations and that the effort to gain information about a technology is related to the expected gain from that knowledge (Feder and Slade (1984); Feder, Just and Zilberman (1985).

In summary, information appears to influence adoption via several pathways and different sources of information are expected to be more influential during each phase of the adoption process. One pathway is through creating the awareness of the existence of an innovation; another is by influencing attitudes and perceptions of an innovation; and a third pathway is by providing technical (or how-to) information to the potential adopter.

DATA

Data for the analysis comes from USDA's 1998 Agricultural Resource Management Study (ARMS). Each farm sampled in the ARMS represents a known number of farms with similar attributes so that weighting the data for each farm by the number of farms it represents provides a basis for calculating estimates for the U.S. farm population. The definition of a farm, and thus the target population of the ARMS, is any business that produced $1,000 worth of agricultural production during the calendar year. Because the development of PF technologies has been mainly for field crop production, this analysis assessed the impact of information on adoption for the population of U.S. corn and soybean producers. Corn and soybean farms were defined as those harvesting one or more acres of corn or soybeans during 1998.

The ARMS survey collected data to measure the financial condition and operating characteristics of farm businesses. The PF component of the ARMS was structured to elicit information from producers about their awareness of PF techniques, sources of information about PF, and adoption of various PF technologies. Producers were asked whether or not they were aware of PF techniques[5]. Those reported as aware of PF technologies were asked about their primary source of information about PF. These producers were also asked about their use of various PF technologies for crop production in 1998. Farmers reporting the use of one or more PF technology, including grid soil sampling, input applications at variable rates, yield monitoring, yield mapping, and remote sensing (aerial or satellite), were classified as adopters.

Respondents to the ARMS survey included nearly 3,200 corn and soybean producers representing a population of over a half-million farms (table 1). About 40 percent of the farmers, or roughly 230,000, indicated that they were not aware of PF technologies. Among these farmers, 29 percent produced less than $10,000 worth of agricultural products in 1998, while more than 77 percent produced less than $40,000. Farmers aware of PF included about 68,000, roughly 20 percent, who had adopted one or more of the technologies. About 15 percent of these farmers produced $250,000 or more worth of agriculture products in 1998, compared to only 5 percent of the farmers who were aware of PF but had not adopted a PF technology.

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[5] The question was phased as follows: Precision farming techniques are relatively new innovations in production agriculture. Are you aware of various precision farming techniques?

MODELING PF AWARENESS AND ADOPTION

The approach used to modeling PF technology adoption in this study is conceptually similar to that of Saha, et al. (1994) and Klotz, et al. (1995) who analyzed the adoption of rBst among dairy producers. The model developed in this study utilizes a two-stage logit approach where PF awareness is modeled in the first-stage and used to correct for self-selection in a second-stage model of PF adoption. Of primary interest is how changes in the various information source variables affect the adoption of PF technologies. The various information sources include the extension service, crop consultants, input suppliers, special events/project demonstrations, other growers/grower associations, and the news media.

Previous studies of technology adoption have assumed that the entire population under study is aware of the technology being studied (e.g., Adesina and Zinnah, 1993; Gould, et al., 1989; and Norris and Batie, 1987). Based on this awareness and other factors, producers make a choice whether or not to adopt the technology. However, PF techniques are relatively recent and complex innovations of which many farmers may not be aware, and those aware are not likely to be a random sample of all farm operators. This presents the problem of self-selection. If this self-selection problem is left uncorrected, results from the adoption model could be biased. Heckman (1979) proposed a two-stage estimation method to test and to correct for self-selectivity in regression models. Applying Heckman's technique in this study involves the estimation of PF awareness in a logit analysis, and using the estimated parameters to estimate the inverse Mills ratio (IMR). In applying the second stage of Heckman's technique, the IMR is used as a regressor in the logit model for PF adoption. The significance of the IMR can be interpreted as a test for selectivity bias, and its inclusion allows for the consistent estimation of the parameters in the PF adoption model.

The dependent variable of the first-stage logit awareness model was specified as binary, equal to 1 if the producer was aware of PF techniques, and equal to 0 otherwise. Only the portion of the population that was aware of PF was included in the second-stage adoption model. The dependent variable of the logit adoption model was equal to 1 if the producer used one or more PF technique in 1998, and 0 otherwise. Several regressors were used in both the awareness and adoption models, including operator and farm demographics. (See Maddala (1992) for a discussion of the theory, estimation, and interpretation of the logit model.) PF information sources and other management attributes were added to the adoption model. Table 2 includes mean values of the variables included in the logit models.

Independent variables included farm and operator variables. Size was measured as the total harvested crop acres, and was specified with a quadratic term[6]. Specialization in corn and soybean production was specified as the percent of harvested crop acreage in corn and soybeans. The importance of livestock to the farm operation was indicated by the percent of farm product value from livestock products. Operator age was measured in years. Operator education was the number of years of formal education including high-school, college, and any post-graduate work.

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[6] The role of farm size in the adoption of precision farming technologies is explored in detail by Fernandez-Cornejo, Daberkow, and McBride.

The major occupation of the operator was specified with binary variables for retired and off-farm employment that were based on a self-assessment by the survey respondent. Farming occupation was the omitted group, thus estimates for the other occupations indicate differences from the primary occupation of farming. Use of a related or complementary technology was indicated by the use of computer records for farm income and expense accounting, measured as a binary variable. A regional identifier was included to account for spatial variation in the diffusion of PF and availability of PF vendors. The Heartland (fig. 1) was used to identify the major corn and soybean region, and thus the region where PF vendors would be most likely to concentrate.

The major source of information about PF was specified as a series of binary variables in the adoption model that represented "how-to" information sources. These variables indicated the major information source as the extension service, crop consultants, input suppliers, special events/demonstration projects, or other growers/grower associations. The news media was assumed to be a passive source of PF information relative to the other more active information sources. Media sources were omitted during estimation to determine if adoption differed for the various how-to information sources, compared to simple awareness information most often obtained via the media. In fact, among farmers who were aware of PF but had not adopted any PF technologies, 53 percent indicated that media was their major source of PF information (table 2). However, among PF adopters, only 24 percent listed media as a PF information source.

Measures of risk management and credit availability were also included in the adoption model. A risk management score was developed from a series of 10 self-assessment questions about risk management practices (Bard and Berry, 1998) to determine if producers who more actively managed risk would be more likely to adopt PF techniques. A variable indicating maximum borrowing capacity (Ryan, 1999) was included to examine whether the capital investment required for PF technologies posed a significant barrier to adoption. Also included was a measure of land tenure as the percent of operated acreage that was owned.

Parameters of the logit models were estimated using the ARMS survey weights in a weighted least squares version of the maximum likelihood method. Due to the complex design of the ARMS sample, standard errors were estimated using a jackknife replication approach (Dubman, 2000).

RESULTS

The multivariate logit regression model is useful for simultaneously assessing the impacts of specific variables on the probability of a farm operator belonging to a given group, while accounting for the impact of other variables. Human capital attributes of the farm operator, size and specialization of the operation, operator occupation, and use of a complementary technology were found to have a significant effect on the probability of being aware of PF technologies (table 3). PF awareness did not vary significantly by operator age, but greater education and the use of a computer record-keeping system for farm financial management increased the likelihood of PF awareness. Retired farm operators and operators whose major occupation was off-farm employment were significantly less likely to be aware of PF technologies. Operators dependent on farming as the primary income source and those with a greater investment in human capital tend to seek out information on new farming techniques and are thus more likely to be exposed to PF technologies. Increasing farm size also led to a greater likelihood of PF awareness, with the probability increasing at a decreasing rate[7]. Specialization in corn and soybean production also increased the likelihood that the farm operator was aware of PF technologies. More crop acreage and greater specialization in corn and soybeans are likely to enhance the information exposure to PF technologies because most PF technologies have applications to corn and soybean production.

The second stage of the analysis examined the PF adoption decision, given that a farm operator was identified as being aware of PF. Farm size, specialization of the operation, and computer familiarity were found to positively affect the probability of adoption (table 3). Increasing farm size increased the probability of PF adoption at a decreasing rate[8]. These results are consistent with previous PF adoption research where farm size and computer records use increased the likelihood of adoption (Daberkow and McBride, 1998). Increasing operator age was found to decrease the likelihood of PF adoption, while greater education made adoption more likely. Younger and more educated farm operators have a longer planning horizon and more of the skills required to experiment with PF technologies. Location in the Heartland, the leading corn and soybean production region, also increased the probability of PF adoption. This could be due to the presence of more PF vendors in the area. Also, the likelihood of PF adoption increased with the proportion of acreage owned. PF information is site specific and long-term in nature, and thus is likely to be more valuable to the land-owner than to the tenet-farmer. Previous research had identified risk attitudes and capital availability as factors influencing technology adoption, but these factors were not statistically significant in this analysis. However, the selection variable was significant in the analysis indicating that failure to account for the differences between the aware and unaware respondents would have biased the results.

PF information sources were included in the analysis to assess the relative importance of various sources to the PF adoption decision. The variable identifying the news media as the primary PF information source was the deleted group in the estimation so that the coefficients on the other information sources indicate differences from the news media. For example, the significant and positive coefficient on the extension service variable indicates that operators that had the extension service as their primary PF information source were more likely to adopt PF technologies than were those with the media as their primary source of information (table 3). Obtaining the major source of PF information from the extension service, crop consultants, input suppliers, or growers or grower associations all increased the likelihood that, relative to information from the media, a producer would adopt one or more PF technology. Only when the major source of information was from special events or product demonstrations was the probability of adoption not statistically different from the media source.

The relative impact of the various information sources on the probability of adoption is shown in table 4. The change in probability of PF adoption from each information source indicates the

[7] The likelihood of PF awareness increased with farm size up to a size of more than 8,500 harvested crop acres.

[8] The likelihood of PF adoption increased with farm size up to a size of more than 11,000 harvested crop acres.

impact each had relative to information from the media. For example, the probability of adoption goes up by 0.106, or about 11 percent, when the extension service provides the major source of PF information relative to the media. Information from crop consultants had the largest impact on PF adoption, increasing the adoption probability by nearly one-third. Information from input suppliers increased the PF adoption probability by nearly 20 percent while the extension service and other growers or grower associations each had about a 10-12 percent impact.

CONCLUSIONS/IMPLICATIONS

PF technologies are relatively new technologies that typically require a significant investment in human capital and currently have an uncertain payoff. Hence, farm operator attributes, including operator age, education, and familiarity with computer uses, are particularly important in explaining PF adoption. This study did not find financial capital to be limiting PF adoption. A growing service sector for PF technologies means that custom operators can be used to apply PF methods, limiting the capital requirement. However, the significant human capital investment likely makes PF more attractive to larger and specialized operations where this investment can be spread over more units of production.

The information sources utilized by farm operators about PF have had a significant influence on adoption. Results of this study suggest that the adoption of PF has been driven primarily by private sector agents. Commercial crop consultants appear to be the agents that are having the greatest influence on adoption. Crop consultants are specialists who most likely have the greatest technical expertise about PF, and are thus more able to ease the human capital burden confronted by farm operators. Input suppliers have also impacted adoption at a greater rate than other agents. Input suppliers have an incentive to provide support services for the inputs they supply (e.g. fertilizer, pesticides). PF services may be seen as a method for developing a closer and longer-term relationship with customers. The extension service and grower associations deal with a wide variety of issues that affect crop producers. This lack of specialization in issues addressed by PF means that they may not provide the level of technical support as the other agents, and thus have had less of an impact on adoption.

The survey results also give credence to several earlier studies that found the media to be important during the awareness stage of the technology adoption process but that more active or "how-to" information sources are critical to the later stages. Producers who were aware of PF but not yet adopters were more likely to identify the media as their source of information whereas the PF adopters were heavily dependent on the more active or technical information sources.

An implication from the role that information sources have had in the adoption of PF technologies is that personalized technical support, like that provided by crop consultants, appears to have the greatest impact on adoption. If public policy pursues a goal of expanding PF adoption, programs providing personalized technical assistance would likely be the most effective strategy. However, this type of technical support would be much more expensive than generic information programs. A similar, but less direct avenue to enhanced PF adoption appears to be by training producers in the use of complementary technologies, such as computers, in order to enhance their stock of human capital.

The results of this study also imply that analytical studies of agricultural technology adoption need to carefully assess any assumption about the extent of technology awareness by potential adopters. Significant and systematic differences were found between farm operators who were aware of PF technologies and those who were unaware. Left uncorrected, these differences would have introduced bias into the analysis of PF adoption.

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Table 1. Distribution of the ARMS sample of corn and soybean farms[1], population estimates, and the distribution of farm by production value, 1998

	All farms		
Item	Not aware of PF	Aware of PF	Total
Sample N	1,025	2,168	3,193
Number of farms	229,370	325,674	555,044
Percent of farms	41	59	100
Percent by production value			
Less than $10,000	29	13	20
$10,000-$39,999	48	35	41
$40,000-$99,999	15	29	23
$100,000-$249,999	5	16	11
$250,000 or more	3	7	5
	Farms aware of PF		
Item	Not adopting PF	Adopting PF[2]	Total
Sample N	1,607	561	2,168
Number of farms	258,008	67,666	325,674
Percent of farms	79	21	100
Percent by production value			
Less than $10,000	13	13	13
$10,000-$39,999	38	25	35
$40,000-$99,999	29	26	29
$100,000-$249,999	14	22	16
$250,000 or more	5	15	7

[1]Corn and soybean farms were defined as operations producing at least $1,000 worth of agricultural products and harvesting one or more acres of corn or soybeans in 1998.
[2]Adoption was defined as the reported use of any one of the following precision farming technologies: grid soil sampling, input applications at variable rates, yield monitoring, yield mapping, or remote sensing.

Table 2. Means of variables used in the precision farming awareness and adoption models for corn and soybean farms[1], 1998

Item	All farms		Farms aware of PF	
	Not aware of PF	Aware of PF	Not adopting PF	Adopting PF[2]
Harvested crop acres (acres)	251	544	483	778
Specialization (percent acres in corn/soy)	59	67	63	78
Livestock (percent of farm product value)	48	32	36	25
Operator age (years)	52	49	49	48
Operator education (years of school)	12	13	13	14
Farming occupation (percent of farms)	54	68	68	70
Retired (percent of farms)	7	2	3	1
Off-farm occupation (percent of farms)	39	29	30	29
Heartland region (percent of farms)	47	59	55	74
Computer records used (percent of farms)	6	19	16	35
Risk management (score)	31	32	32	33
Credit availability (1,000 dollars)	166	261	249	308
Acreage owned (percent of acreage)	54	36	37	32
PA information from: (percent of farms)				
Extension service	0	12	11	17
Crop consultant	0	5	3	10
Input supplier	0	25	22	38
Demonstration	0	3	3	3
Grower association	0	7	7	7
Media	0	47	53	24

[1]Corn and soybean farms were defined as operations producing at least $1,000 worth of agricultural products and harvesting one or more acres of corn or soybeans in 1998.
[2]Adoption was defined as the reported use of any one of the following precision farming technologies: grid soil sampling, input applications at variable rates, yield monitoring, yield mapping, and remote sensing.

Table 3. Regression results for precision agriculture awareness and adoption models for corn and soybean farms, 1998

		Awareness		Adoption[1]	
Variable	Description	Parameter	Std. Error	Parameter	Std. Error
Intercept	-	-2.44221*	1.29858	-4.89247**	1.28468
Crop acres	Acres harvested (X100)	0.12701**	0.02378	0.12664**	0.04508
Crop acres squared	-	-0.00149**	0.00051	-0.00115**	0.00048
Specialization	Percent of acres corn/soy	0.01240**	0.00380	0.01623**	0.00508
Livestock value	Percent of product value	0.00092	0.00276	-0.00425	0.00242
Age	Years	-0.01173	0.00761	-0.01949**	0.00847
Education	Years of school	0.16164**	0.06408	0.10822**	0.03385
Occupation[2]:	Retired	-0.67134*	0.36710	-0.26970	0.17326
	Off farm employment	-0.39978*	0.21319	-0.21506	0.12688
Region	Located in Heartland	0.23622	0.20103	0.73956**	0.32042
Like technology	Computer record use	0.91109*	0.43678	1.31487**	0.44202
Risk management	Risk assessment score	na	na	0.00149	0.00104
Credit availability	Repay ability (X$1,000)	na	na	-0.00003	0.00002
Land tenure	Percent of acres owned	na	na	0.66059*	0.36510
Information[3]:	Extension service	na	na	0.71964*	0.39957
	Crop consultant	na	na	1.87695**	0.25506
	Input supplier	na	na	1.31854**	0.25149
	Demonstration	na	na	0.50556	0.28931
	Grower association	na	na	0.82448**	0.32927
Selection variable	Inverse Mills ratio (IMR)	na	na	-0.51849*	0.28766
Overall model:	Samples w/ attribute	2,168		561	
	Samples w/o attribute	1,025		1,607	
	Total samples	3,193		2,168	
	Likelihood ratio	101,027		61,113	
	McFadden R^2	0.13		0.18	
	Percent predicted (=1)	80		31	
	Percent correct prediction	71		83	

[1]Includes only those farms aware of precision farming technologies.
[2]Coefficients interpreted relative to the deleted group, farming occupation.
[3]Coefficients interpreted relative to the deleted group, media.
Single and double asterisks (*) denote significance at the 10% and 5% levels, respectively.
Using the jackknife variance estimator with 15 replicates means that the critical t-values are 2.145 at the 5% level, and 1.761 and the 10% level. na=not applicable

Table 4. Change in the probability of adopting precision farming (PF) technologies associated with various information sources, 1998

Information source	Adoption probability without information source	Adoption probability with information source	Change in probability from information source[1]
Extension service	0.195	0.301	0.106
Crop consultant	0.194	0.513	0.319
Input supplier	0.160	0.354	0.194
Product demonstration	0.206	0.279	0.073[2]
Grower or grower association	0.201	0.324	0.123

[1]Change in the PF adoption probability compared to the media being the major source of PF information.

[2]Underlying coefficient not significantly different from zero.

Figure 1: Farm Resource Regions