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FARMER PERCEPTIONS OF PRECISION AGRICULTURE TECHNOLOGY BENEFITS

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Abstract. The objective of this research was to evaluate producers' perspectives of four key precision agriculture technologies (variable rate fertilizer application, precision soil sampling, guidance and autosteer, and yield monitoring) in terms of the benefits they provide to their farms (increased yield, reduced production costs, and increased convenience) using a best-worst scaling choice experiment. Results indicate that farmers' perceptions of the benefits derived from various precision agriculture technologies are heterogeneous. To better understand farmers' adoption decisions, or lack thereof, it is important to first understand their perceptions of the benefits precision agriculture technologies provide.

Key words. Best-worst scaling, choice experiment, farmer perceptions, precision agriculture

JEL Classification. Q16

1. Introduction

The promise of precision agriculture has been touted for nearly two decades. Based on the principle of applying the right amounts of inputs in the right places at the right times (Robert, Rust, and Larson, 1995), precision agriculture has long promised to revolutionize production agriculture through improved efficiency—increased yields with the same amount of inputs, equivalent yield with fewer inputs, or a combination of increased yield and fewer inputs. Despite the promise of its tremendous potential, the realization of precision agriculture technology's advantages on commercial farms has generally fallen short of expectations (Mintert et al., 2016).

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A plethora of studies evaluating the adoption rates of precision agriculture technologies in the United States have been conducted, including several in recent years (Erickson and Widmar, 2015; Schimmelpfennig, 2016; Torrez et al., 2016; Zhou et al., 2017). Although results among these studies vary, adoption rates have generally increased over the last two decades. However, adoption has lagged behind what many expected, with overall adoption rates rarely eclipsing 50% of farms or even 50% of planted acres. For perspective, compare this with the adoption of genetically engineered corn and soybeans in the United States, which over roughly the same time period have seen nearly universal adoption—market share approaching 90% of corn and soybean acres (Wechsler, 2017). Clearly, the value proposition presented by precision agriculture has yet to fully materialize in the eyes of many U.S. producers.

Learning more about what motivates farmers to adopt precision agriculture technology is of interest to technology providers, educators, and farmers. Previous research has consistently found that adoption rates vary with a variety of observable farmer and farm business characteristics. Most notably, adoption rates are generally higher among larger farms (Fernandez-Cornejo, Daberkow, and McBride, 2001; Schimmelpfennig, 2016). For example, according to the most recent U.S. Department of Agriculture (USDA) Agricultural Resource Management Survey (ARMS) for corn conducted in 2010, only 12% of the smallest farms (less than 600 acres) reported using at least one precision agriculture technology (Schimmelpfennig, 2016). Compare that with the largest farms (more than 3,800 acres) who reported adoption rates of 80%, 84%, and 40% for GPS soil/yield mapping, guidance systems, and variable rate technology, respectively (Schimmelpfennig, 2016). Unanswered, however, is the question of why larger farms were more likely to adopt precision agriculture. Moreover, even among larger farms, adoption rates for different technologies vary. Hence, the underlying benefits derived from various precision agriculture technologies are heterogeneous, and to understand farmers' adoption decisions, or lack thereof, it is important to first understand their perceptions of the benefits these technologies provide.

Previous research largely focused on economic benefits associated with precision agriculture technology adoption (Griffin et al., 2004; Schimmelpfennig, 2016, 2018; Schimmelpfennig and Ebel, 2016; Shockley, Dillon, and Stombaugh, 2011; Shockley et al., 2012; Smith et al., 2013). Although results have been mixed with respect to these technologies' impact on farm profits, recent research indicates precision agriculture use has a small (~2%), positive impact on net returns and operating profits (Schimmelpfennig, 2016). Improvements in financial returns associated with precision agriculture can arise from two different sources: reduced production costs or increased yields. Early precision agriculture research emphasized cost savings arising from reduced input usage. As precision agriculture technology evolved, however, interest in evaluating yield benefits associated with more tailored input applications, especially as variable rate input applications became more common, increased. Given these potentially confounding benefits, it is important to identify which technologies producers associate with cost savings versus yield benefits and how that affects technology adoption (Schimmelpfennig, 2016).

Examining precision agriculture adoption strictly through the lens of input cost savings and yield improvements alone may be too narrow. Precision agriculture technologies can also generate additional utility to farmers through improvements in overall well-being, most notably increased convenience to the farmer (Daberkow and McBride, 2003). For example, Shockley, Dillon, and Stombaugh (2011) describe reduced operator fatigue and increased ability to multitask with an autosteer system as potential benefits. Although quantifying productivity enhancements associated with increased operator convenience is difficult, it is clear that convenience is a potential benefit that may influence farmers' adoption of precision agriculture technologies.

Although previous research has belabored adoption rates and the observable farmer and farm business characteristics influencing adoption, no research has been conducted to identify how farmers perceive particular technologies in terms of the benefits they provide. The overarching objective of this study is to evaluate producers' perspectives regarding benefits provided by various precision agriculture technologies. This is accomplished through two specific objectives. First, we attempt to determine if preferences for four key precision agriculture technologies (variable rate fertilizer application, precision soil sampling, guidance and autosteer, and yield monitoring) differ depending on whether the producer is evaluating the technology for one of three potential benefits (increased yield, reduced production costs, and increased convenience) through the use of best-worst scaling. Second, we evaluate the relationship between producers' general perceptions regarding precision agriculture technologies and services and farm adoption of precision technologies, as well as preferences for precision agriculture technology benefits using logit models.

A better understanding of farmers' perceptions of precision agriculture technologies' benefits, and their impact on technology adoption, will provide important information to technology providers as they continue to develop and market precision agriculture technologies. More knowledge regarding factors influencing precision agriculture technology adoption will also assist educators developing educational programs, and it could help farmers better understand why competitors choose to adopt, or not adopt, precision agriculture technologies thereby helping them improve the management of their own farm.

2. Conceptual Framework

In order to achieve the objectives outlined previously, it is important to provide an economic framework that justifies the methods used. Discrete choice experiments utilized here are rooted in random utility theory (McFadden, 1974; Scarpa et al., 2013). That is, as rational agents decision makers are assumed to make choices that maximize utility. Although the actual utility of a given choice is latent, the choice itself can be observed, and the utility derived from that choice can be decomposed into two parts: systematic utility, which is a function of observable attributes or characteristics, and a random component that is composed of the imperfect knowledge associated with unobservables. It is important to note that maximizing utility may not directly correspond with maximizing profit. This point is especially important for this study where respondents are asked to make choices about precision agriculture technologies and services that do not necessarily correspond with profit maximization (i.e., increased convenience). The foundations of random utility theory are well established and for this reason are not discussed in detail here. Interested readers should consult Train (2003) for a more detailed treatment of random utility theory.

3. Materials and Methods

Data used in this study were obtained from a phone survey of U.S. commercial crop producers conducted from June 5, 2017, to July 6, 2017. The survey list frame of commercial crop producers was purchased from *Farm Journal*. The survey was targeted toward corn, soybean, wheat, and cotton producers. Producers of these crops were chosen for the study because acreage devoted to production of these crops comprised approximately 70% of 2017 U.S. planted crop acreage and a wide variety of precision agriculture technologies focused on producing these crops have been developed and marketed. Respondents were asked a series of questions regarding their use of, preferences for, and beliefs regarding the impact of precision agriculture technologies and services on their farms. Additionally, a pairwise best-worst choice experiment was used to determine respondents' preferences regarding precision agriculture technology benefits. To encourage producer responses, the survey was designed so that it could be completed by respondents in less than 10 minutes using questions that were short and easy to understand. A copy of the survey is available in the online supplementary appendix (Appendix A).

Given that the primary purpose of the study was to identify farmer perceptions of the benefits provided by various precision agriculture technologies, and not to estimate adoption rates, the sample focused solely on commercial-scale operations (crop acreage of 1,000 acres or more), which previous research indicated are the operations most likely to use precision agriculture technology. To ensure operation size diversity within the sample, quotas were imposed for survey sampling procedures. The USDA's *2012 Census of Agriculture* reported there were nearly 173,500 farms with more than 1,000 acres in the United States (USDA, 2014). Given this population, a survey sample size of 384 is necessary to ensure a sample with a confidence level of 95% and a margin error of 5%.

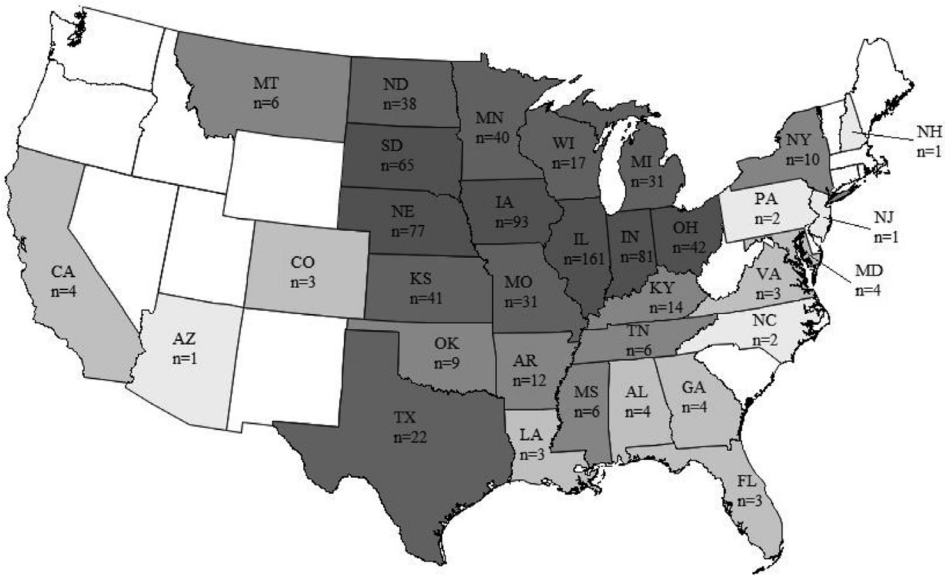

Figure 1. Number of Responses by State (n = 837).

However, nearly half of the farms with more than 1,000 acres (91,273) have less than 2,000 acres. To ensure that the sample was representative of larger-scale farms, and not just those operating less than 2,000 acres, quotas were imposed on the sample that required the final sample to include at least 400 respondents farming between 1,000 and 1,999 acres and at least 400 respondents farming 2,000 acres or more. To further ensure that the sample was representative of U.S. crop producers, 20.5% of the sample was composed of farms with wheat acreage and 4.5% of the sample was composed of farms with cotton acreage. The remainder of the sample was composed of farms with corn or soybean acreage. Stratifying the sample based on these enterprise targets was done to obtain a cross section of farms consistent with the distribution of corn, soybean, wheat, and cotton acres reported by USDA in the *2012 Census of Agriculture* (USDA, 2014). In total, 5,295 producers were contacted that met this size criteria, and 837 of them completed the survey, for a completion rate of 15.8%. A map of responses by state is provided in Figure 1.

3.1. Use of and General Beliefs about Precision Agriculture Technology

The first part of the survey was designed to elicit general information about respondents' use of and beliefs regarding precision agriculture technology and its impacts on their farms. These were primarily multiple-choice questions, with two of the questions utilizing Likert scales.

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3.2. Best-Worst Choice Experiment of Precision Agriculture Technology Benefits

Likert scales are commonly used to elicit respondents' preferences. However, a weakness of using Likert scale–type questions to elicit preferences is that respondents are not forced to make trade-offs and can select all attributes as important. Choice experiments force respondents to make decisions between attributes resulting in a ranking of preferences that provide more insights into respondents' attribute evaluation. As part of the choice experiment employed in this survey, respondents were randomly assigned to participate in one of three different pairwise best-worst choice experiments. One-third of respondents (group A) were asked to choose the precision agriculture technology most likely to *increase yield*, a second group (group B) was asked to select the precision agriculture technology most likely to *reduce production costs*, and the third group (group C) was asked to choose the precision agriculture technology most likely to *increase convenience*. In each case, respondents were asked to make a series of choices regarding which precision agriculture technologies were most likely to achieve the stated purpose: increase yields, reduce costs, or increase conveniences. All three experiments included the same four precision agriculture technologies (variable rate fertilizer application, precision soil sampling, guidance and autosteer, and yield monitor) and had the same experimental design making comparisons of all six possible pairwise choice scenarios. These four technologies were chosen for evaluation because they are widely available and are used by producers of corn, soybeans, wheat, and cotton. The three experiments employed were identical except for the specific benefit being addressed in the question preceding each choice scenario.

The best-worst scaling approach was first introduced by Finn and Louviere (1992) and has since been rooted in random utility theory by Marley and Louviere (2005). The pairwise experimental design was chosen for its simplicity to reduce respondent fatigue and keep the telephone survey short enough to encourage participation. The presentation of only two attributes at a time greatly reduces complexity, as respondents only need to select the "best" rather than choosing both the best and the worst—worst can be inferred—thus simplifying the choice task for the participant (Byrd, Widmar, and Gramig, 2018; Thompson, Bir, and Widmar, 2018).

The choice of the technology in each scenario that was most likely to increase yield, reduce production costs, or increase convenience was used to determine the technology's location along the continuum from most likely to least likely. The location of the technology j on the scale of most to least likely is represented by λ_j. As a result, how likely a respondent views a technology, which is unobservable to researchers, for respondent i is

$$I_{ij} = \lambda_j + \varepsilon_{ij}, \tag{1}$$

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where ε_{ij} is the error term. If respondent i chooses the technology j as most likely and technology k as least likely, the probability of selecting that choice is the probability that the difference between I_{ij} and I_{ik} is greater than all other differences from the choices presented to each respondent. This probability is based on the assumption the error term is independently and identically distributed type I extreme value (Lusk and Briggeman, 2009). The probability of choosing any most likely/least likely combination takes the multinomial logit form (Lusk and Briggeman, 2009):

$$Prob(j = best \cap k = worst) = \frac{e^{\lambda_j - \lambda_k}}{\sum_{l=1}^{j} \sum_{m=1}^{j} e^{\lambda_l - \lambda_m} - J}, \tag{2}$$

where J is the total number of technologies included and $j, k, l, m \in J$. Parameter λ_j is estimated using maximum likelihood estimation, which represents how important technology j is relative to the least important technology. To avoid the dummy variable trap, one technology must be normalized to zero to prevent multicollinearity (Lusk and Briggeman, 2009).

In addition to the multinomial logit model (MNL), which assumes respondents are homogenous, a random parameters logit model (RPL) was specified. Within the RPL model, respondents are assumed to have heterogeneous preferences amongst individuals (Lusk and Briggeman, 2009). The coefficients from the model are not easily interpretable, so individual-specific parameter estimates were used to calculate individual preference shares (Wolf and Tonsor, 2013). Following Wolf and Tonsor (2013), preference shares were calculated as

$$share_j = \frac{e^{\lambda_j}}{\sum_{k=1}^{J} e^{\lambda_k}}. \tag{3}$$

Given equation (3), the preference shares for the four technologies must sum to 1, and the preference share is the forecasted probability that the technology is chosen as most important for generating a particular benefit (Wolf and Tonsor, 2013). NLOGIT 5.0 was used to conduct the estimations. A likelihood-ratio (LR) test was employed to determine if the three groups (increase yield, reduce production costs, and increase convenience) could be pooled for analysis (Louviere, Hensher, and Swait, 2000). In addition, confidence intervals for each preference share were determined using the Krinksy-Robb (1986) method to determine if preference shares were statistically different within groups, and the complete combinatorial method outlined by Poe, Giraud, and Loomis (2005) was used to test for differences in the size of the preference shares across groups.

3.3. *Logit Models of Perceptions/Beliefs about Precision Agriculture Technology*

To further analyze the relationship between respondents' general beliefs about precision agriculture and their use of specific precision agriculture technologies,

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four logit models were employed. Logit models were chosen because the probability of having a particular perception of precision agriculture takes the form of either a 1 or 0, meaning the respondent either does or does not have the perception. The latent utility (V_{in}) associated with a particular perception of precision agriculture technologies is represented by the equation:

$$V_{in} = \beta_n' x_{in} + e_{in}, \tag{4}$$

where x_{in} is the vector of observed variables that relate to perception n for respondent i, and e_{in} is the unobserved error term (Train and Weeks, 2005). Following Train and Weeks (2005), the error term is assumed independently, identically, distributed extreme value and the logit probability (P_{in}) for respondent i and perception n becomes:

$$P_{in} = \frac{e^{\beta_n' x_{in}}}{\sum_n e^{\beta_n' x_{in}}}. \tag{5}$$

The four equations were estimated independently,[1] and dependent variables in these equations were equal to 1 if the respondent indicated agreement with the following statements, and 0 otherwise:

1. Precision farming technologies and services are an important contributor to your farm's current financial profitability.
2. Precision farming technologies and services have made you a better farm manager.
3. Precision farming technologies and services have made your job as a farm manager easier.
4. Would you consider your farming operation an early adopter of precision farming technologies and services?

The same set of independent variables was included in each of the four equations. These variables measured respondents' reported use of seven precision agriculture technologies (variable rate fertilizer application, variable rate seed application, yield monitor, autosteer, precision soil sampling, drone/unmanned aerial vehicle (UAV), and satellite/aerial imagery) and their pairwise selections of the benefit most compelling for precision agriculture adoption (increased yield, reduced costs, or increased convenience). It was hypothesized that use of each of the seven precision agriculture technologies would positively influence the probability that producers agreed with the statements about precision agriculture. The one exception is that some technologies may be negatively

1 Given the potential for the error terms of the four equations to be correlated, it is possible that the estimates of the univariate logit models are inefficient, although consistent. For this reason, a multivariate probit model was also estimated to check the robustness of the results. Although the results indicate the presence of significant correlation among the error terms of the four equations ($\chi^2_6 = 158.88$, $P < 0.001$), parameter estimates and inferences are nearly identical to the univariate logit models, so they are maintained as the models of interest.

Table 1. Percentage of Respondents Who Reported Using Particular Precision Agriculture Technologies or Agreement with Statements about Precision Agriculture Technology Use (n = 837)

Precision Agriculture Technology/Service or Statement	Percent of Respondents
Farm uses variable rate fertilizer application	73
Farm uses variable rate seed application	60
Farm uses yield monitors	93
Farm uses autosteer	91
Farm uses precision soil sampling	66
Farm uses drones or unmanned aerial vehicle	25
Farm uses satellite/aerial imagery	56
Agrees that precision farming technologies and services are an important contributor to their farm's current financial profitability	88
Precision farming technologies and services have made them a better farm manager	80
Precision farming technologies and services have made their job as a farm manager easier	77
Would consider their farming operation an early adopter of precision farming technologies and services	68

associated with the perception that precision farming technologies and services makes farm management easier. It is more difficult to hypothesize about the impact of pairwise selections of the benefit most compelling for precision agriculture adoption on these perceptions, especially selections between cost savings and yield improvements. However, producers who select increased convenience over yield improvements or costs savings as the most compelling reason for adopting precision agriculture are expected to be more likely to agree with the statement that these technologies have made their jobs easier. The coefficients of logit model estimation are not directly interpretable, other than sign, so marginal effects were calculated at the means of the independent variables. Stata 14.2 was used to conduct estimations and calculate marginal effects.

4. Results and Discussion

4.1. Use of and General Beliefs about Precision Agriculture Technology

Results indicate that a high percentage of respondents reported using yield monitors (93%), autosteer (91%), and variable rate fertilizer application (73%) (Table 1). Sixty-six percent of farms reported using precision soil sampling; 60%, variable rate seed application; and 56%, satellite/aerial imagery. The least commonly reported precision agriculture technology was a drone or UAV, used by only 25% of respondents.

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These rates of adoption are generally much higher than reported by other researchers (Schimmelpfennig, 2016; Torrez et al., 2016; Zhou et al., 2017). The smaller number of nonadopters reported here is primarily the result of excluding small-scale farms (e.g., less than 1,000 crop acres) from our sample and use of a more recent data collection period than reported in other research. Most notably, Schimmelpfennig (2016) reported much lower overall adoption rates using USDA ARMS data for corn and soybeans. However, when evaluated for different farm sizes, corn farms with 1,700–2,000 acres (similar to the median farm size in our sample), adoption rates of 54%, 60%, and 32% for GPS soil/yield mapping, guidance systems, and variable rate technology, respectively, were reported (Schimmelpfennig, 2016). Although these values are still lower than the adoption rates reported in our sample, it is also important to note that these data are nearly 10 years old—the 2010 survey is the most recent version of the ARMS survey for corn. Hence, overall adoption rates have likely continued to increase, especially among larger farms, and high levels of adoption made this an ideal sample for better understanding producer perceptions of the benefits these technologies provide, which is the primary objective here.[2] With that said, it is important to keep in mind that our result are conditional on our sample, and thus, results presented subsequently are representative of commercial crop farms (crop acreage of 1,000 acres or more), which tend to have higher rates of precision agriculture technology adoption than the general crop farm population.

In addition to information about their use of precision agriculture technologies, respondents were also asked a series of questions regarding their general perceptions of precision agriculture. A high percentage of respondents in our sample (88%) indicated they agreed that precision farming technologies and services are an important contributor to their farm's current financial profitability (Table 1). Similarly, 80% of respondents indicated using precision farming technologies and services made them a better farm manager, and 77% indicated these technologies made their job as a farm manager easier. When asked if they considered their farming operation an early adopter of precision farming technologies and services, 68% of respondents agreed.

As a precursor to the best-worst choice experiment and to gain more insight into motivations for precision agriculture technology adoption, respondents were asked to make three pairwise selections of the most compelling benefit for precision agriculture adoption. Reasons included cost savings, yield improvement, and convenience. When asked to choose between cost savings and yield improvement, 51% of respondents chose cost savings and 49% of

2 Another important distinction related to adoption rates is the difference between what is now "standard equipment" on new machinery purchases and what are actual adoption decisions of new technology or "add-on" equipment. Given that adoption rates were not the primary focus of this article, little attention was paid to this point here. However, this will be an important distinction for the adoption literature moving forward.

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Table 2. Percentage of Respondents Who Selected Each Reason as the Most Compelling Reason to Adopt Precision Agriculture Technologies and Services (n = 837)

Pair 1	Cost Savings	Yield Improvement
Percentage of respondents who selected	51	49
Pair 2	Yield Improvement	Convenience
Percentage of respondents who selected	65	35
Pair 3	Convenience	Cost Savings
Percentage of respondents who selected	31	69

Note: The reasons were shown in three pairs of two and the respondents were asked to choose between the pair.

respondents chose yield improvement (Table 2). Between yield improvement and convenience, 65% selected yield improvement and 35% selected convenience. Similarly, when choosing between convenience and cost savings, 31% chose convenience and 69% chose cost savings. Although it was not surprising that the majority of respondents were more compelled by financial benefits (yield improvement or costs savings) than convenience as a reason to adopt precision agriculture, it is interesting that about a third of respondents selected convenience benefits as more compelling than both yield improvement and cost savings. This implies that at least a portion of adoption decisions may be motivated by nonmonetary benefits. The question that remains is which specific technologies do producers most associate with these various benefits.

4.2. Best-Worst Choice Experiment of Precision Agriculture Technology Benefits

It was hypothesized that responses to the best-worst choice experiments would differ depending on whether respondents were asked to select the technology most likely to increase yield, reduce production cost, or increase convenience. Results indicate that the three groups could not be pooled (LR = 92.22, df = 8, $P < 0.01$). However, pairwise LR tests among the three groups indicated that the results from groups A (increase yield) and B (reduce production costs) were not statistically different at the 1% level (LR = 10.71, df = 4, $P = 0.03$), and so these two groups were pooled for analysis. This indicates that producers did not differentiate between technologies that increase yield and those that reduce production costs. Although increasing yield and reducing production costs are not always directly related, they can both positively influence the profit function. Therefore, it seems as though respondents viewed these more generally as technologies that "increase profit." Group C (increase convenience) remained independent.

The statistically significant standard deviations of the RPL models indicate that respondents do have heterogeneous preferences, making the RPL models the more appropriate models. Although the results of both models, MNL and RPL, are in Table 3, the results of the RPL models will be the focus of this discussion. Coefficients are not directly interpretable, so preference shares were calculated for the RPL coefficients.

For the pooled groups A (increase yield) and B (reduce production costs), variable rate fertilizer application had the largest preference share (29%) (Table 3, Figure 2). The preference for variable rate fertilizer application as the technology most likely to increase profit, either through increased yield or reduced production costs, is not particularly surprising. Although variable rate technology is just one component of a larger precision agriculture system, it is the culmination of the ultimate goal of precision agriculture—applying the right amounts of inputs in the right places at the right times (Robert, Rust, and Larson, 1995). Depending on the application, this may mean a reduction in overall input use by applying less in areas that do not need it or are not expected to respond; in other cases, this may mean a yield increase as a result of applying more inputs in areas where the crop demands it; and in some cases, it may be both.

Precision soil sampling (25%) and guidance and autosteer systems (25%) had the next highest preference shares and were not statistically different from one another. Yield monitors had the smallest preference share (21%), indicating it was the technology least likely to increase yield or reduce production costs. Producers' lower ranking of yield monitors impact on farm profits is likely multifaceted. On one hand, there is much ado about the accuracy of yield monitor data and the importance of yield monitor calibration, as well as postharvest data processing, that may be contributing to this perception (Nielsen, 2016, 2017). Yet, even when properly calibrated, there seems to be a lack of intuition among many producers regarding how to use yield monitor data. Lowenberg-DeBoer (2003) outline the key benefits associated with yield data but note that many of these benefits accrue at the whole-farm level and may extend over many years, making them difficult to quantify. These results are interesting in that one of the oldest precision agriculture technologies, yield monitors, was perceived by farmers as being less likely to reduce costs or increase yields than the newer technologies: variable rate fertilizer, precision soil sampling, and guidance/autosteer.

For group C (increased convenience), guidance and autosteer systems (30%) and yield monitors (27%) had the largest preference shares (Table 3, Figure 2). Previous research linked guidance and autosteer systems with convenience given their potential to reduce operator fatigue and increase operators' ability to multitask (Shockley, Dillon, and Stombaugh, 2011). However, the perception that yield monitors are a convenience technology is interesting, especially when considered jointly with the previous finding that relative to the other technologies considered, respondents did not associate yield monitors with increased farm profits. This seems to imply that even if producers have yet to leverage yield data to improve farm profits, they do enjoy the convenience of being able to easily measure yield within and across fields.

Table 3. Multinomial logit (MNL) and Random Parameters Logit (RPL) Models for Precision Agriculture Technology Preferences by Precision Agriculture Benefits

	Pooled Model for Precision Agriculture Technology Most Likely to Increase Yield and Most Likely to Reduce Production Costs (n = 574)				Precision Agriculture Technology Most Likely to Increase Convenience (n = 263)			
	MNL	RPL			MNL	RPL		
Precision Agriculture Technology	Coefficient	Coefficient	Standard Deviation	Preference Share	Coefficient	Coefficient	Standard Deviation	Preference Share
Variable rate fertilizer application	0.27***	0.31***	0.48***	0.29a† (0.27, 0.31)	– 0.29***	– 0.31***	0.38***	0.20b† (0.18, 0.22)
Precision soil sampling	0.14***	0.15***	0.01	0.25b (0.23, 0.26)	– 0.19***	– 0.20***	0.03	0.23b (0.21, 0.24)
Guidance and autosteer	0.13***	0.14***	4.70E-4	0.25b† (0.23, 0.26)	0.08**	0.09**	0.01	0.30a† (0.28, 0.32)
Yield monitor				0.21c† (0.21, 0.22)				0.27a† (0.26, 0.29)

Notes: Asterisks (** and ***) indicate significance at the 5% and 1% levels, respectively. Within each model preference shares with matching letters are not statistically different at the 5% level, whereas differing letters indicate they are statistically different. For example, a preference share with an "a" is not statistically different within the model when compared with another preference share with an "a." However a preference share with an "a" is statistically different within the model when compared with another preference share with a "b." The dagger symbol (†) indicates the preference shares for the same technology are statistically different at the 5% level across models.

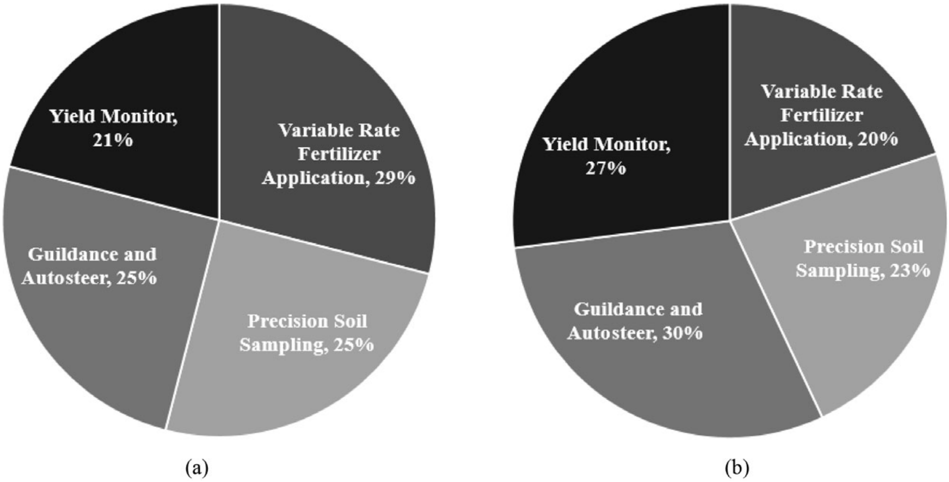

Figure 2. Random Parameter Logit Preference Shares for Precision Agriculture Technology That Is Most Likely to Increase Yield and Most Likely to Reduce Production Costs Pooled (n = 574) (a) and Most Likely to Increase Convenience (n = 263) (b).

Preference shares for precision soil sampling (23%) and variable rate fertilizer application (20%) were smaller, indicating they were perceived as less likely to increase convenience when compared with other technologies included in the experiment. Interestingly, technologies that were perceived as relatively less likely to increase convenience, in particular variable rate fertilizer application, were perceived as relatively more likely to increase farm profits. Hence, there seems to be a trade-off between financial and convenience benefits associated with precision agriculture technologies. That is, technologies perceived as being more likely to offer tangible financial benefits are less likely to be perceived as making farming more convenient. This supports the hypothesis presented by Lowenberg-DeBoer (2003) that management time and effort are required to fully leverage and implement a profitable precision agriculture system.

These results offer a variety of interesting insights into respondents' perceptions of the benefits provided by various precision agriculture technologies. However, it is also important to take a moment to consider the broader picture. That is, a quick glance at Figure 2 reveals little differences in the relative size of preference shares for technologies within and even between the two groups—less than 10 percentage points, ranging from 20% to 30%. Therefore, even though the relative ranking of technologies offer interesting and intuitive results, supported by statistical significance, the relative size of preference shares offers a less pronounced take-home message. Results suggest that in the eyes of farmers, precision agriculture technologies are largely undifferentiable in

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terms of the benefits they provide. Although many of these technologies are theoretically complementary, they are rarely vertically integrated creating a less than seamless environment. The ability to leverage synergies among various precision agriculture technologies, as well as clearly communicating a cohesive message of how value is created at the farm level, would likely benefit the industry as a whole.

4.3. Logit Models of Perceptions/Beliefs about Precision Agriculture Technology

Respondents indicating their farms used variable rate fertilizer application, variable rate seed application, yield monitors, and autosteer were significantly more likely to agree with the statement "precision farming technologies and services are an important contributor to my farms current financial profitability" (Table 4). The positive impact of variable rate fertilizer application on increased farm profitability is consistent with the results of the best-worst choice experiment given previously. However, producers were less likely to associate yield monitors and autosteer with increased farm profitability in the best-worst choice experiment. This may have occurred because when forced to make trade-offs between technologies in the best-worst choice experiment, respondents were more likely to associate variable rate fertilizer application with increased farm profitability. However, in practice, variable rate applications do not happen in isolation of other technologies. Hence, these results support previous findings that producers seeking to maximize the economic potential of precision agriculture do so by utilizing a bundle of technologies (Lambert, Paudel, and Larson, 2015; Miller et al., 2017).[3]

In addition, respondents who chose cost savings over yield improvements and yield improvements over convenience as the most compelling reasons to adopt precision farming technologies were significantly more likely to agree with the statement "precision farming technologies and services are an important contributor to my farms current financial profitability." This result is not particularly surprising given that these choices are directly related to improved financial profitability.

Respondents indicating their farms used variable rate seed application, yield monitors, autosteer, and precision soil sampling were significantly more likely to agree with the statement "precision farming technologies and services have made me a better farm manager" (Table 4). Similarly, those who chose cost savings over yield improvements and yield improvements over convenience as the most compelling reasons to adopt precision farming technologies were significantly more likely to agree with the same statement. Looking at the relative size of the marginal effects, the link between precision agriculture technology use and becoming a better farm manager was strongest for precision soil

3 Technologies bundles are generally defined as any two or more technologies.

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Table 4. Logit Models of Perceptions/Beliefs about Precision Agriculture Technology Use

Variable	Precision Farming Technologies and Services Are an Important Contributor to Their Farm's Current Financial Profitability		Precision Farming Technologies Have Made Them a Better Farm Manager		Precision Farming Technologies and Services Have Made Their Job as a Farm Manager Easier		Respondent Would Consider Their Operation and Early Adopter of Precision Farming Technologies and Services	
	Coefficient (SE)	Marginal Effect (SE)	Coefficient (SE)	Marginal Effect (SE)	Coefficient (SE)	Marginal Effect (SE)	Coefficient (SE)	Marginal Effect (SE)
Farm uses variable rate fertilizer application	0.81*** (0.26)	0.07*** (0.02)	0.24 (0.22)	0.03 (0.03)	0.13 (0.21)	0.02 (0.04)	0.45** (0.19)	0.09** (0.04)
Farm uses variable rate seed application	0.73*** (0.25)	0.06*** (0.02)	0.50** (0.20)	0.07** (0.03)	– 0.06 (0.19)	– 0.01 (0.03)	1.15*** (0.17)	0.24*** (0.03)
Farm uses yield monitor	0.70** (0.34)	0.06** (0.03)	0.64** (0.32)	0.09** (0.04)	0.60* (0.32)	0.10* (0.05)	0.38 (0.32)	0.08 (0.07)
Farm uses autosteer	0.88*** (0.33)	0.07*** (0.03)	0.68** (0.29)	0.10** (0.04)	0.44* (0.27)	0.08* (0.05)	0.84*** (0.27)	0.18*** (0.06)
Farm uses precision soil sampling	0.32 (0.25)	0.03 (0.02)	1.03*** (0.20)	0.14*** (0.03)	0.33* (0.19)	0.06* (0.03)	0.38** (0.18)	0.08** (0.04)
Farm uses drone/unmanned aerial vehicle	0.39 (0.32)	0.03 (0.03)	0.23 (0.24)	0.03 (0.03)	– 0.11 (0.20)	– 0.02 (0.03)	0.62*** (0.21)	0.13*** (0.04)

Table 4. Continued

Variable	Precision Farming Technologies and Services Are an Important Contributor to Their Farm's Current Financial Profitability		Precision Farming Technologies Have Made Them a Better Farm Manager		Precision Farming Technologies and Services Have Made Their Job as a Farm Manager Easier		Respondent Would Consider Their Operation and Early Adopter of Precision Farming Technologies and Services	
	Coefficient (SE)	Marginal Effect (SE)	Coefficient (SE)	Marginal Effect (SE)	Coefficient (SE)	Marginal Effect (SE)	Coefficient (SE)	Marginal Effect (SE)
Farm uses satellite/aerial imagery	0.32 (0.24)	0.03 (0.02)	0.27 (0.19)	0.04 (0.03)	0.17 (0.18)	0.03 (0.03)	0.30* (0.17)	0.06* (0.03)
Chose cost savings over yield improvement	0.45* (0.23)	0.04* (0.02)	0.49** (0.19)	0.07** (0.03)	0.44** (0.17)	0.08** (0.03)	– 0.14 (0.17)	– 0.03 (0.04)
Chose yield improvements over convenience	0.45* (0.24)	0.04* (0.02)	0.40** (0.20)	0.06** (0.03)	– 0.51*** (0.20)	– 0.09*** (0.03)	– 0.09 (0.18)	– 0.02 (0.04)
Chose convenience over cost savings	– 0.10 (0.25)	– 0.01 (0.02)	– 0.12 (0.21)	– 0.02 (0.03)	– 0.03 (0.19)	– 0.01 (0.03)	– 0.14 (0.18)	– 0.03 (0.04)
Constant	– 1.15**** (0.44)		– 1.45*** (0.40)		– 0.07 (0.38)		– 1.66*** (0.39)	
Log likelihood	– 268.82		– 369.42		– 437.36		– 456.66	
Prob > χ^2	<0.01		<0.01		<0.01		<0.01	
Pseudo R^2	0.14		0.12		0.03		0.13	
N	837		837		837		837	

Note: SE, standard error.

sampling (14%). This suggests that although a smaller portion of respondents in our sample indicated using precision soil sampling (66%; Table 1), those who did found it particularly useful at helping them better manage their farms.

Respondents indicating their farms used a yield monitor, autosteer, and precision soil sampling were significantly more likely to agree with the statement "precision farming technologies and services have made my job as a farm manager easier." The association of yield monitors and autosteer with the ease (or increased convenience) of farm management is consistent with the best-worst choice experiment. However, the association of precision soil sampling with making farm management easier is interesting. There could be several explanations for this result. One possibility is that precision soil sampling could make crop nutrient application decisions easier by removing uncertainty when choosing application rates. Also note that respondents who chose cost savings over yield improvement as the most compelling reason to adopt precision agriculture technologies were 8% more likely to agree with the statement that "precision farming technologies and services have made my job as a farm manager easier." However, those who chose yield improvement over convenience were 9% less likely to agree with the same statement. This supports our previous conclusion that trade-offs exist between technologies that increase financial returns and those that increase convenience. This also is consistent with the notion that management time and effort required to implement a precision agriculture program designed to increase yield, as opposed to reduce production costs, is particularly demanding.

Lastly, and not surprisingly, reported use of each of the seven precision agriculture technologies positively influenced the probability that a respondent agreed with the statement "your farming operation is an early adopter of precision farming technologies and services." Each of these marginal effects were statistically significant, except for the use of yield monitors, and the marginal effects indicate that this belief was strongest among those who adopted a drone/UAV (13%), autosteer (18%), and variable rate seed application (24%). Although it is not surprising that those who use drones/UAVs and variable rate seeding would likely consider themselves early adopters, it is somewhat surprising that this belief was also connected with the use of guidance/autosteer, which is generally considered one of the most readily available and widely adopted precision agriculture technologies. Given that 91% of respondents in our sample indicated using guidance/autosteer (Table 1), this could be the result of social desirability bias, which is the tendency of survey respondents to answer questions in in a way that they perceive will be viewed favorably, even if it is not true (Fisher, 1993; Widmar et al., 2016). So, it is possible that many respondents agreed with this statement not because it was necessarily reflective of reality, but because they felt that perception would be viewed positively by others.

5. Conclusions

Adoption rates for various precision farming technologies have been examined by a number of researchers over the years, but very little is known about the reasons behind producers' adoption decisions. This research provides a novel look at perceptions producers have regarding precision agriculture technologies—in particular the benefits they provide. Developers of precision agriculture technologies, educators, and farmers themselves can all benefit from an improved understanding of farmers' perceptions about various technologies and their motivations for adopting these technologies. When interpreting these results it is important to keep in mind that they are conditional on our sample which is representative of commercial crop farms (crop acreage of 1,000 acres or more). This is particularly important given that these larger farms tend to have higher rates of adoption of precision agriculture. Therefore, caution should be exercised when extrapolating or generalizing the results presented here to all crop farms. Key findings are summarized subsequently.

First, producers are heterogeneous in their perceptions about precision farming technologies. When asked about the attributes that were most important, most reported the benefits to be yield improvement or cost reduction—two categories this research could not distinguish from each other statistically. Another group of producers, more than 30%, reported convenience as the most important factor. The implication is that least some producers may be looking beyond economic reasons when making technology adoption decisions. In a best-worst choice experiment that forced trade-offs among technologies, producers were most likely to associate variable rate fertilizer application with increased profitability, by increasing yield, reducing production costs, or both. Guidance and autosteer and yield monitors, on the other hand, were the technologies producers most associated with increased convenience. Hence, a distinguishable trade-off between financial and convenience benefits was observed, where technologies perceived as most likely to increase profits were not the ones perceived as making farming more convenient. Results suggest that farmers seeking to reduce production costs and/or increase yields recognize that management time and effort will be required to fully leverage and implement a profitable precision agriculture system.

Second, producers' perceptions are also affected by the technologies they use. For example, the use of variable rate fertilizer application, variable rate seed application, yield monitor, and autosteer increased the likelihood that producers perceived precision farming technologies and services as an important contributor to their farm's current financial profitability. Other perceptions, such as precision technologies making them better farm managers or making their job as a farm manager easier, were affected differently by the use of various precision agriculture technologies. These perceptions of precision agriculture were also affected by pairwise selections of the most compelling benefit for adopting precision agriculture. For example, when producers picked yield improvement over convenience, it increased the likelihood they perceived precision agriculture as a significant contributor to their farm's current financial profitability and the perception that these technologies made them a better farm manager. On the other hand, selecting yield improvement over convenience decreased the likelihood that farmers perceived precision agriculture technologies and services as making their job as a farm manager easier, again highlighting the trade-off between financial and convenience benefits associated with precision agriculture technologies.

In conclusion, this work highlights the need to think about precision agriculture technologies on a product- or service-level basis. Producers' perceptions of the benefits these technologies provide to their operations vary. Compounding these differences, producers' general beliefs about precision agriculture technologies and services (do they contribute to financial profitability, do they make you a better farm manager, etc.) are influenced by the technologies the farm uses. Precision agriculture technology developers and marketers seeking to encourage technology adoption need to carefully evaluate each technology and make sure they fully understand why producers would consider adopting the technology. Focusing on convenience attributes versus cost reduction or yield improvement can influence technology adoption. Likewise, to be successful, educational programs focused on precision agriculture technology need to consider convenience attributes as well as possible impacts on cost reduction and yield improvement. To better understand, and possibly influence, producers' precision agriculture technology adoption decisions, consideration of the perceived benefits these technologies provide is needed.

Supplementary material

To view supplementary material for this article, please visit https://doi.org/10.1017/aae.2018.27

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