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Adoption of Precision Agriculture Practices and Their Effect on US Farm Expenditures on a Dollar per Acre Basis

Logan Krueger

INTRODUCTION

The percentage of corn acres planted using precision agriculture has increased approximately 23%, from 49% in 2005 to 72% in 2010 (USDA ERS ARMS, 2015). Precision agriculture (PA) encompasses a wide range of farming practices and ideas that are meant to maximize farm profits and efficiency while maintaining low negative impacts on the environment. PA practices are being adopted quickly across major corn producing states. Variable rate technology (VRT) used for any purpose is one PA practice increasing in its use on corn planted acres.

Previous studies have examined advantages and disadvantages of adopting PA practices such as variable rate application (VRA) of fertilizer, a VRT. However, the direct effect of the adoption of PA practices and its effect on farm expenditures on a dollar per acre basis in the US has not been thoroughly analyzed. The purpose of this study is to determine how the adoption of PA practices, including VRT, affect farm expenditures on a dollar per acre basis in the major corn production region of the United States. A uniquely constructed dataset and regression analysis will be used. Results are important to producers considering adopting PA practices because of the high costs. Data is only available for corn acres planted with PA. It will be assumed that a grower using PA to plant corn acres is also using PA for other production activities such as tillage, spraying, and harvesting. Data gathered from the USDA Economic Research Service and National Agricultural Statistics Service include: expenditures per operation, acres per operation, index of input prices paid, percentage of corn acres planted using PA, and percentage of corn acres planted using VRT. The following section will review the approaches and major findings of previous literature.

REVIEW OF LITERATURE

Previous studies have compared input expenses of yield monitor adopters to nonadopters, examined the consistency of yield response to site-specific nitrogen application, calculated the economic and environmental effects that occur with three different fertilizer application methods including the precision strategy of VRT, estimated the potential value of switching from single rate application to VRA of fertilizer, and theoretically studied VRT technology and the information available for VRT to be profitable for the producer. Although the studies discussed below have examined advantages and disadvantages of adopting specific PA practices, the effect of the adoption of PA practices on farm expenditures has not been thoroughly researched. The following discussion reviews selected studies that focus on the effects of PA.

Monitoring input expenditures such as PA is vital to the success of a farming operation. Schimmelpfennig and Ebel (2011) have compared fuel expenses of yield monitor (one PA practice) adopters and nonadopters by examining data collected from the Precision Agriculture

Dealership Survey. Data for corn expenditures were taken from 2001 and 2005 dealership surveys. Difference-of-means statistical tests were used to compare cost estimates for different groups of farms and PA practices at a 90 percent confidence level. According to the article, yield monitoring is usually the first PA practice adopted because the cost of doing so has decreased. Yield monitoring does not decrease input expenses; the information gained is used to make wiser input decisions for following years. Results indicated that average fuel expenses were lower for corn producers who utilized yield monitors in 2001 and 2005. Analyzing dealership service offering surveys was a good start to evaluating the effects of PA adoption. Although more data is needed to evaluate the true effects of PA on input cost per acre, the ideas and methods presented by Schimmelpfennig and Ebel are considered for this study.

Consistency of yield response to site-specific nitrogen application has impacted whether or not producers adopt VRA technologies. Using Michigan county data from 1999 to 2001 and regression analysis, Liu, Swinton and Miller (2006) estimated the yield response of fourteen different cornfields to site-specific nitrogen. The estimation model took into account weather, site specific characteristics expected to affect yield, and site-specific characteristics that affect the amount of nitrogen available to the plant. The nitrogen site-specific characteristics include: organic matter, cation exchange capacity, leaching, availability of water, and sunlight. The results indicated that a significant positive relationship exists between site-specific nitrogen and corn yield. However, consistency depends on whether the field was rain fed or irrigated (controlled water). The authors conclude that the benefits of site-specific nitrogen do not outweigh the increased costs of adopting such technology. VRA uses site-specific nitrogen information in an effort to maximize efficiency of corn production at a particular location within the field. The producer’s goal is to get the most out of every acre (higher yield and/or lower fertilizer rate).

Isik and Khanna (2002) examined the economic and environmental effects of three different fertilizer application methods on corn fields: 1) conventional (single/uniform rate) application based upon the field’s average conditions, 2) single rate application based upon gathered information, and 3) VRA (precision strategy) based upon gathered information. The authors used experimental data collected from 1950 through 2000 from fields in the Otter Lake Watershed in Macoupin County, Illinois, and estimated a linear plateau model where yield is a function of nitrogen. Overall, the results showed that the higher the degree of uncertainty about a field’s potential yield, the less of a positive impact the variable-rate nitrogen technology (VRNT) method had on an acre. VRNT produced its greatest benefits on fields with low potential yields. Also, VRNT benefited the environment with a significant decrease in over application of nitrogen compared to the conventional/average application method. The level of yield potential uncertainty significantly affected the potential benefits of the informative nitrogen application method. VRA can decrease the nitrogen (a portion of corn fertilizer) rate while boosting corn yields if proper information (yield potential) is known. VRA of fertilizer, a VRT, can be profitable to the producer while also having positive effects on the environment.

In addition to the comparison of the three different fertilizer application methods, the value of adopting VRA of fertilizer technology was examined at a time when single rate was the exclusive application method. Babcock and Pautsch (1998) estimated the corn yield increase and the reduction in fertilizer costs that occur with the adoption of VRA. They use a linear response and plateau relationship and assume yield responds to applied nitrogen fertilizer. The data, taken from the Soil Survey section of the Iowa State University's Department of Agronomy, included twenty randomly selected fields in each of twelve randomly selected Iowa counties. The controlled variables include cropping history, whether the soil received manure, previous fertilizer practices, and inherent soil characteristics such as nitrate levels, organic matter levels, field slope, and field orientation. Overall, the results indicate that switching to VRA of fertilizer was profitable with modest increases in gross returns over fertilizer costs, ranging from $1.52 per acre to $7.43 per acre. Corn yields increased anywhere from 0.05 to 0.50 bushels per acre while production costs decreased anywhere from $1.19 to $6.83 per acre. The largest difference was the effect of reduction in acres over-applied with nitrogen fertilizer when using single rate application technology. The authors recommended acquiring the specific costs of adopting VRT in order to estimate more accurate gains.

VRT, information available, and data for VRA have been theoretically and empirically analyzed to determine profitability, or lack thereof, for the producer. Bullock, et al. (2009) derived how fertilizer, herbicides, hybrids, field slope, and organic matter are related to the profitability of VRT. Moreover, an algorithm was used to measure the nitrogen fertilizer rate for a field by taking into account the yield goal and the amount of nitrogen that was applied as a starter fertilizer. Data was collected from commercial production sites in Logan County, Champaign County, and Piatt County, Illinois, in 2002 and 2003. Control variables include field slope, organic matter content, and weather; however, some of the farmers' management decisions were not taken into account. Results suggested that the cost of VRA of nitrogen is a dollar higher per hectare than applying nitrogen at a uniform rate across the field. The authors concluded that site-specific information, even free of charge, would not allow VRA of nitrogen fertilizer to be profitable each time it was used for corn production. However, contrary to the authors' previously stated conclusion, their study showed that with free site-specific information, six of the eight corn yields in the Illinois counties were profitable using VRA of nitrogen fertilizer.

Past studies have had conflicting results on the profitability of VRT and its use for fertilizer application. Babcock and Pautsch (1998) discovered that corn yields increased anywhere from 0.05 to 0.50 bushels per acre while production costs decreased anywhere from $1.19 to $6.83 per acre, and also that switching to VRA of fertilizer was profitable with modest increases in gross returns over fertilizer costs, ranging from $1.52 per acre to $7.43 per acre. On the contrary, Liu, Swinton and Miller (2006) and Bullock, et al. (2009) found that the benefits of site-specific nitrogen do not outweigh the increased costs of adopting the technology, therefore, not allowing VRA of nitrogen fertilizer to be profitable in every trial. Previous studies have examined many different ideas and data surrounding PA and costs, but this study analyzes the direct effect of the adoption of PA practices on farm expenditures on a dollar per acre basis. The following section will discuss the data and methods utilized in this study.

DATA AND METHODS

The following discussion describes the methods and data used in this study. Regression analysis is used to determine the effect of the adoption of PA practices on farm expenditures on a dollar per acre basis. Data was gathered from the USDA.

Methods

Average cost is the underlying economic theory behind this study. Based on theory, average cost curves are U-shaped. The U-shaped cost curve first reflects economies of scale, then constant returns, and eventually diseconomies of scale. It is expected that adoption of PA practices decreases production expenses. On average, holding all other factors constant, the average cost curve is expected to shift downward to reflect the lower costs with the adoption of PA practices. The following is the regression model used to estimate the relationship between PA adoption and farm expenditures.

$$EXP/AC = \beta_0 + \beta_1 AC/OP + \beta_2 AC/OP^2 + \beta_3 PPI + \beta_4 CBS + \beta_5 PAtech + \beta_6 2012 + \varepsilon$$

Two different variables are used to measure PA technology (PAtech) adoption. The first variable is percentage of corn acres planted using PA. The purpose of this measure is to capture the overall adoption of PA in the US, whereas the second measure is VRT, which measures one specific PA practice. Other variables included in the model are: farm expenditures (input costs) per acre (EXP/AC) measured in real 2013 dollars, all tillable acres per any farm operation (AC/OP), and this term squared (AC/OP^2) to capture farm size, percentage change in the prices paid index (PPI) to account for the adjustment of input costs over time, Corn Belt state binary variable (CBS) to compare expense per acre among Corn Belt states vs. non-Corn Belt states, and a year 2012 binary variable (2012) to capture a year effect.

The following relationships are expected to be estimated. As farm size increases, production costs on a dollar per acre basis are expected to decrease to a certain point and then increase, forming a U-shaped cost curve. Therefore, it is expected that AC/OP is negatively related to EXP/AC while AC/OP^2 is positively related. PPI is expected to positively affect EXP/AC because as crop input prices increase over time, production costs will also increase. CBS is expected to be negatively related to EXP/AC. Operations in a major corn producing state are more specialized and are more likely to have lower cost per acre compared to non-CBS states. PAtech, the main variable of interest, is expected to have a negative effect on EXP/AC. The PAtech variable captures a shift in the cost curve. Because of the high costs associated with adding PA practices to an operation, a grower would be very interested in knowing if the investment is financially feasible and leads to a decrease in EXP/AC. Similarly, VRT is expected to have a negative effect on EXP/AC because it is a specific PA practice. The year variable 2012 is expected to positively affect EXP/AC. Table 1 below summarizes the variables in the regression models and provides each variable's respective symbol, description, unit of measurement, source of data, and expected sign of their effect on EXP/AC.

Table 1.

Variable Symbols, Descriptions, Measurement, Sources, and Expected Signs

Variable	Symbol	Description	Unit	Source	Expected Sign
Expense per acre	EXP/AC	Real expense per acre	$/Acre 2013 Dollars	United States Department of Agriculture (USDA): National Agricultural Statistics Service (NASS)	N/A
Acres per operation	AC/OP	Acres (all farm land) per operation	Acres per Operation	USDA: NASS	-
Acres per operation squared	AC/OP^2	Acres (all farm land) per operation squared	Acres per Operation Squared	USDA: NASS	+
Prices paid index	PPI	Percentage change in prices paid index	Percentages	USDA: NASS for PPITW values	+
Corn belt state	CBS	Identifies Corn Belt state	1 if CB State 0 if Non CB State	Created Variable	-
Precision agriculture used	PA	Percentage of corn acres planted using precision agriculture	Percentage of corn planted acres	USDA: Economic Research Service (ERS): Agricultural Resource Management Survey (ARMS): Tailored Reports: Crop Production Practices- Report: Precision Agriculture	-

Variable rate technology	VRT	Percentage of corn acres planted using variable rate technology	Percentage of corn planted acres	USDA: ERS: ARMS Tailored Reports: Crop Production Practices- Report: Precision Agriculture	-
Year 2012	2012	Binary variable to capture the year effect	1 if 2012 0 if other	Created Variable	+

DATA

The data in this study is panel data. Sixteen states, producing at least 100 million bushels of corn in 2012 and having sufficient PA practice data available, were analyzed. The states include Colorado, Illinois*, Indiana*, Iowa*, Kansas*, Kentucky, Michigan*, Minnesota*, Missouri, Nebraska*, North Dakota, Ohio*, Pennsylvania, South Dakota, Texas, and Wisconsin (* denotes Corn Belt state). Ideally, an examination of the data on a year by year basis for every US state would be best, but because of the lack of data available on this specific topic, the only data available for acres, operations, expenses, and prices paid index is Census data for the years 2002, 2007, and 2012, found on the USDA website. Likewise, PA practices data closely matching with the previously mentioned years is only available for 2001, 2005, and 2010. All numerical data was gathered using the USDA, National Agricultural Statistics Service, Quick Stats 2.0 tool and from the USDA, Economic Research Service: Agricultural Resource Management Survey data on Crop Production Practices. Forty-eight observations are examined for PA and 37 for VRT, the two variables used to measure PAtech in the regression model. Results of the regression analysis models follow.

RESULTS

Descriptive Statistics

Average real production expense for the years 2002, 2007, and 2012, across all 16 states, was $368.00/acre. On average, nearly half of those acres (49.50%) were planted using at least one precision agriculture practice whereas 14.4% of acres were planted using VRT. Average farm size across the 16 states during the stated time period was 512 acres. Half of the states analyzed in this study are Corn Belt states and a third of the data analyzed were for the year 2012. On average, the prices paid index increased by 22% between each of the years analyzed. Table 2 below shows these descriptive statistics.

Table 2.

Descriptive Statistics

Variable	n	Mean	St. Dev.	Min.	Max.
EXP/AC	48	368.0	188.0	87.0	795.0
AC/OP	48	512.0	398.0	124.0	1,401.0
AC/OP^2	48	416,768.0	579,395.0	15,376.0	1,962,801.0
PPI	48	22.1	12.1	5.2	31.6
CBS	48	0.5	0.5	0.0	1.0
PA	48	49.5	21.3	13.7	84.5
VRT	37	14.4	10.5	0.5	38.3
2012	48	0.3	0.5	0.0	1.0

REGRESSION ANALYSIS

Two regression analyses were conducted. The first model includes the broader PA measure, PA, and the second model includes the specific PA measure, VRT. The estimated coefficients are similar for both the PA and VRT models. Table 3 displays the results including estimated coefficients, standard errors, p-value designations, and the overall fit of the models. The results discussion is based on the PA model.

A relationship exists between expense per acre and PA model variables. An R-squared value of 0.77 indicates that 77% of the variation in expense per acre around the mean is explained by the variation in acres per operation, acres per operation squared, percentage change in prices paid index, Corn Belt state, percentage of corn acres planted using a precision agriculture practice, and year 2012. Overall, results show an F-statistic value of 22.86 with a p-value of 0.00. This indicates that the estimated relationship is significant.

A relationship also exists between expense per acre and VRT model variables. An R-squared value of 0.74 indicates that 74% of the variation in expense per acre around the mean is explained by the variation of the variables in the model. Overall, results for the VRT model show an F-statistic value of 14.23 with a p-value of 0.00 indicating that the estimated relationship is significant.

Results confirm the expected U-shaped cost curve relationship involving acres per operation and acres per operation squared. Estimated coefficients of -0.6879 and 0.0003, respectively, indicate that as farm size increases, expense per acre decreases, reflecting economies of scale, but eventually begins to increase, reflecting diseconomies of scale. Using the model estimates, the farm size with the lowest expense per acre is at approximately 1000 acres. On average, given the other variables, as the size of an operation increases by one acre, the operation’s expense per acre decreases by $0.69 until the farm operation reaches approximately 1000 acres. A one acre increase beyond 1000 acres increases expense per acre by less than $0.01 on average. Moreover, given the other variables, a one percentage increase in the prices paid index increases expense per acre by $5.46, reflecting an upward shift of the U-shaped cost curve. Similarly, Corn Belt states, on average, have about $175 higher expense per acre than the non-Corn Belt states. Finally, real expenses per acre in 2012 were about $194 higher than the other years.

Consistent with what was expected, PA is negatively related to the dependent variable, expense per acre. Specifically, a one percent increase in corn acres planted using PA decreases expense per acre by $3.93, reflecting a downward shift in the U-shaped cost curve. Similarly, a one percent increase in corn acres planted using VRT decreases the operation's expense per acre by $3.54. All estimated coefficient values for the PA model are statistically significant at the less than one percent level. Estimated coefficient values for the VRT model are statistically significant at the less than one or five percent level except for VRT, which has a p-value of 0.13. The results of this study are consistent with the study conducted by Schimmelpfennig and Ebel (2011) in which the adoption of yield monitoring, one PA practice, led to a decrease in one input cost, fuel. Also, similar to the results of Babcock and Pautsch (1998), on average, VRT adoption is profitable and decreases production costs. The next section will provide the final remarks for this study.

Table 3.

Regression Results

	Estimated Coefficient			
Variables	**PA Model**		**VRT Model**	
Intercept	502.2686	**	447.7981	**
	(51.3938)		(65.5463)	
AC/OP	-0.6879	**	-0.9155	**
	(0.1756)		(0.2305)	
AC/OP^2	0.0003	**	0.0004	*
	(0.0001)		(0.0002)	
PPI	5.4624	**	5.2718	*
	(1.6258)		(1.9793)	
CBS	175.3013	**	168.3688	**
	(34.4124)		(46.1117)	
PA	-3.9348	**		
	(1.1904)			
VRT			-3.5390	
			(2.2524)	
2012	193.9428	**	129.5111	*
	(43.0558)		(48.1734)	

R-Squared	0.7699		0.7400	
F-Statistic	22.8612	**	14.2324	**
Observations	48		37	

Standard errors are in parenthesis.

*p-value<0.05 (two-tailed); **p-value<0.01 (two-tailed)

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to estimate how the adoption of PA practices, including VRT, affect farm expenditures on a dollar per acre basis in the major corn production region of the United States. As adoption of PA practices increases, a downward shift in the U-shaped cost curve was expected. Regression analysis was completed for the study using a uniquely constructed USDA dataset.

Given the amount of data available one can conclude, based on the regression results, that the adoption of PA practices decreases EXP/AC. On average, given the other variables, a one percent increase in corn acres planted using PA decreases an operation's expense per acre by $3.93, reflecting a downward shift in the U-shaped cost curve. Similarly, VRT decreases expense per acre by $3.54. The cost of adopting PA must be compared to the reduction in EXP/AC to more accurately evaluate if adopting PA is profitable to the producer. The results of this study are consistent with the study conducted by Schimmelpfennig and Ebel (2011) in which yield monitor adopters (one PA technology) incurred lower fuel input costs than nonadopters. Moreover, the VRT model results align with previous literature in which VRA of fertilizer (a VRT) was profitable (Babcock and Pautsch, 1998).

An unexpected result is the positive relationship between a state being a part of the Corn Belt and EXP/AC. CBS operations are known for farming a significant amount of acres; therefore, it was expected that expense per acre would, on average, be lower compared to that of non-Corn Belt state operations. However, the results indicate that EXP/AC was higher for CBS. Although the R-squared values were not as high as one would like to see, suggesting that the two models have room for improvement in being able to explain the majority of variation observed in the dependent variable, the p-values indicate a good overall fit of the estimated models.

The goal of commodity production is profit maximization. Decreasing EXP/AC is one part of accomplishing the goal. Results of this study would be very informative to a producer considering adopting PA practices. This study and its results can be strengthened with the availability of more data.

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