Adoption of Precision Agriculture Technology: A Duration Analysis

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Abstract. *Precision agriculture technologies have been available for adoption and utilization at the farm level for several decades. Some technologies have been readily adopted while others were adopted more slowly. An analysis of 621 Kansas Farm Management Association (KFMA) farmer members provided insights regarding adoption, upgrading, and abandonment of technology. The likelihood that farms adopt specific technology given that other technology had been adopted are reported. The lag, in years, between a technology being commercially available and being adopted were evaluated using duration analysis. Results indicate some technologies were more readily adopted than others. Results are useful to farmers considering adoption, retailers in targeting farmers likely to adopt, and manufacturers in supply chain management.*

Keywords. *adoption, duration analysis, conditional probabilities, dis-adoption, obsolescence, profitability*

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Introduction

Farm-level adoption of precision agricultural technologies has generated recent interest among researchers. Precision technologies have been available at some level since the early 1990s yet adoption has been slow among some farmers. Olson and Elisabeth (2003) reported whole-farm impacts of precision agriculture adoption from Minnesota early in the infancy of these technologies. Their study attempted to evaluate technology impacts on profitability. They reported 59 of 212 farms surveyed used at least some precision technology in their operation. They suggested that the relatively small sample size was not adequate to discern relatively small expected differences between adopters and non-adopters during the time when even the most innovative farmers were still trying to find the best use of the technology.

Previous studies on technology adoption and profitability were disjointed, focusing on farm-level adoption in one study and *ex ante* profitability of technology in other studies. Besides Olson and Elisabeth (2003), no studies were found that jointly determined the profitability of technology adoption. However, a series of studies evaluated differing aspects of precision agriculture adoption. Schimmelpfennig and Ebel (2016) analyzed USDA ARMS data to report sequential adoption of variable rate technologies along with combine yield monitors with and without GNSS. Their study examined cost differences between technology adopters and non-adopters. Lambert et al. (2015) evaluated precision technology adoption on cotton farms across the Southeastern United States. They conclude that cotton farmers adopted technologies individually and in bundles. Likely the longest running annual survey of precision agricultural technology adoption focuses on agricultural service providers rather than farm-level (Erickson et al. 2017). A version of Erickson et al.'s survey has been conducted annually or biennially since 1997 and reports on similar technologies examined here.

Background and Literature Review

The profitability and sustainability benefits of precision agriculture have been said to be 'site specific'. Given that the economics of technology are a function of not only the specific grower's fields but also the management ability of the grower, profitability assessments of specific technologies have been elusive (Griffin et al. 2018). Furthermore, nearly all economic studies have been *ex ante* rather than *ex post*. Precision technology has been separated into two distinct groups for analysis, i.e. embodied knowledge or information-intensive (Griffin et al., 2004). Adoption rates of embodied knowledge technologies such as automated guidance and automated section control have been relatively higher than information intensive technologies such as yield monitors and grid soil sampling (Griffin et al. 2017). *Ex ante* analyses of embodied knowledge technologies typically show a very quick payback (Griffin et al. 2005; Shockley et al. 2011).

An indirect way that precision agriculture has been found to affect profitability is its ability to substitute information and knowledge for fertilizer, seeds and chemicals given soil and other conditions. Several researchers thus far have examined this savings from an environmental stewardship perspective and the reduction of purchased inputs leading to better sustainability of resources (Bongiovanni and Lowenberg-DeBoer 2004; Dhoubhadel and Griffin 2018; Roberts et al. 2004; Schimmelpfennig 2018; Torbett et al. 2007, Watson et al. 2005). Schimmelpfennig and Ebel (2016) examined the distortion between adoption of precision agricultural technologies given expected lower input costs. Their findings indicated differences in the size of operation, education of operator, and type of farm played significant roles in the adoption of technology. There was also an inconsistency in the savings as variable rate technology in some instances could result in increased inputs usage. At least one study evaluated technical efficiency of technology adoption (McFadden and Rosburg 2018).

The decision to adopt a technology or the choice of technology to use is an inherently dynamic process. This decision is based on past decisions as well as current and future conditions. Duration analysis is one means to examine the dynamic nature of the decision and specifically focus on the time or year in which the decision to adopt or dis-adopt is made (Burton et al. 2003; An and Butler 2012). An early study by Fuglie and Kascak (2001) examined the adoption of conservation tillage, soil nutrient testing, and integrated pest management. They found that differences in farm size, farmer education, and land quality could result in adoption lags of up to 20 years. Due to self-reported data limitations, they were somewhat constrained in their analysis, but they did make use of duration analysis methodology.

Dadi et al. (2004) used duration analysis to examine the adoption of fertilizer and herbicides by smallholder farmers in Ethiopia. They found that the most important determinant of the time farmers waited to adopt was economic incentives. It was likely that farmers were unwilling to adopt until evidence indicated if it was profitable or rewarding to do so. Alcon et al. (2011) examined the adoption of drip irrigation technology by farmers in Spain using duration analysis. The authors found that educational factors, technological trials, availability of credit, price, and information networks were among the most important factors influencing the timing of adoption.

Burton et al. (2003), in one of the first agriculture based adoption studies using duration analysis, provided a review of many of the theoretical studies that have looked at time to adoption for agricultural technologies. They illustrated that due to the dynamic nature of the decision and potential impactors, duration analysis was a proper means to analyze the time to adoption. D'Emden et al. (2006) used duration analysis to examine the adoption decision of no-tillage for Australian crop farms. They found the cost of inputs, specifically herbicides, to be the most important factor in the no-till decision. This study was complicated by the fact that there is a tradeoff regarding possible herbicide resistance following no-till practices. Lambert et al. (2015) used a multiple indicator multiple causation model to examine the use and adoption of 10 precision agriculture technologies by cotton producers as bundles. Their study differs from those discussed thus far in terms of methodology and the focus on bundling; however, the time to adoption was still an important factor and as discussed in the descriptive statistics below, certain technologies have a synergy or may be a gateway to adopting other precision agriculture technologies.

Data and Methods

Farm-level data were available from Kansas Farm Management Association (KFMA). The KFMA databank includes detailed farm-level agronomic and financial information from 1973-present. In 2015, KFMA economists began collecting information regarding members' adoption and utilization of precision agricultural technologies (Griffin et al. 2017). These data have been continually collected and updated during semi-annual farm visits and supplements existing KFMA production and financial data. By May 2018, 621 KFMA farms reported having 'used' or 'never used' from a list of technologies. Of the 621 farms reporting, 523 (84%) reported adopting at least one technology. Specific technologies examined included yield monitor, variable rate fertilizer and seeding, precision soil sampling, automated guidance, and automated section control.

Adoption of Precision Technology

Kansas farms have adopted precision technologies at varying rates over time (Figure 1). Since commercialization, embodied-knowledge technologies such as GNSS-enabled guidance and section control have been readily adopted. In 2008, the number of farms using automated guidance surpassed the number of farms using manual control lightbar guidance. In roughly 2011, the utilization of lightbar guidance began to plateau due to automated guidance continuing to be adopted (Figure 1).

Yield monitors have been one yardstick with which precision agriculture was measured (Griffin et al. 2004). Over the last several years, nearly all new combine harvesters come equipped with GNSS yield monitors although possession does not imply utilization. Less than half of KFMA farms have adopted yield monitors (Figure 1), an estimate shared at the national level and consistent with USDA ARMS estimates. Contrasted with the USDA ARMS results, relatively more yield monitors are associated with GNSS in Kansas than without GNSS (Figure 1).

Kansas farms make use of precision soil sampling such as grids and smart sampling. However, adoption rates for intensive soil sampling remain below 50% of respondents (Figure 1). Variable rate applications of fertilizer and seed are utilized by approximatively one-fourth and one-fifth of farms, respectively (Figure 1). These results are consistent with USDA ARMS reports.

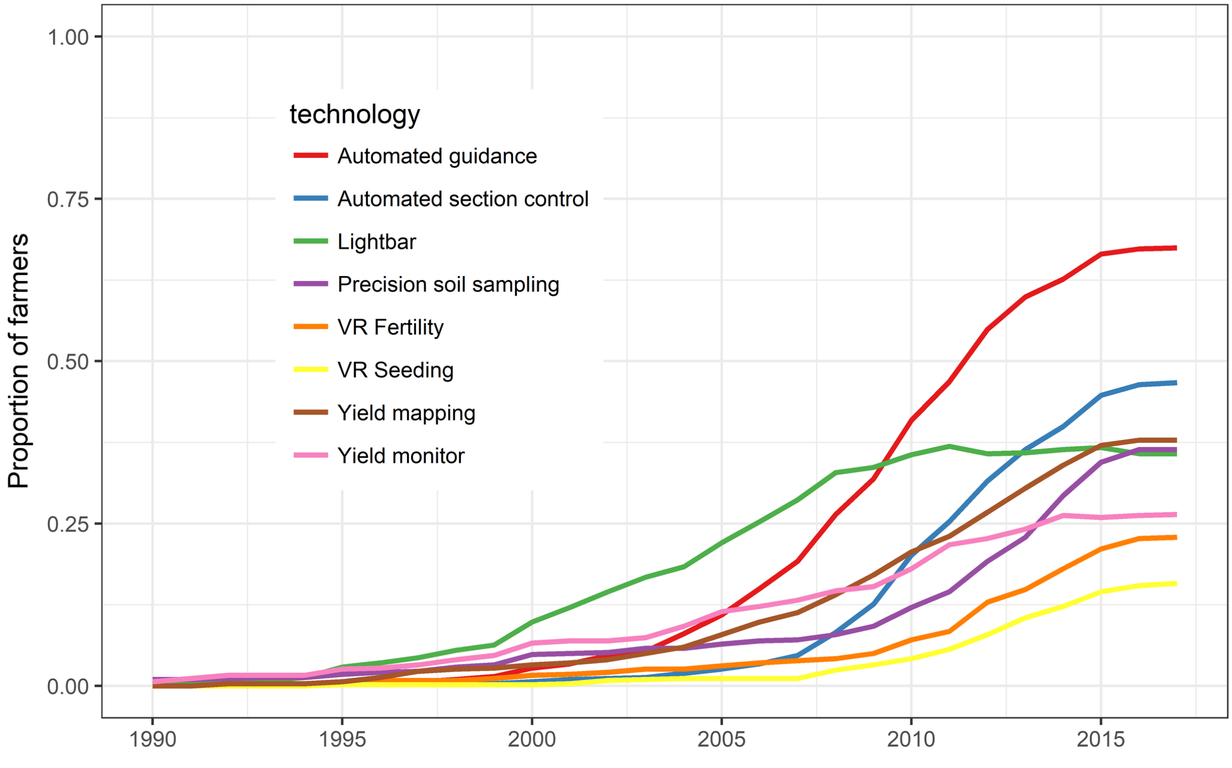

Figure 1. Percent of Kansas farms utilizing precision technologies over time

Nine of the most adopted precision agriculture technologies are listed in Table 1. Of the 621 respondents, 425 (68%) farms adopted automated guidance (Table 1). Almost 60% of farms have used lightbar guidance. Nearly half (47.8%) of Kansas farms utilize automated section control (Table 1). Only 16.4% of Kansas farms using variable rate technology to apply seeds at site-specific rates (Table 1).

Historical yardsticks for both embodied-knowledge and information-intensive precision agriculture technology served as basis for comparison. Specifically, technologies were compared to automated guidance, yield monitors with GNSS, and variable rate fertility (Table 1). Relative to automated guidance, 85% and 70% of farms adopted lightbar guidance and section control, respectively. The remaining information-intensive technologies were less than 60% of farms. Relative to yield mapping, 63% of farms used variable rate fertility and 42% adopted variable rate seeding.

Table 1. Number of Kansas farms adopting precision agriculture technology (n=621)

	Farms adopting	*% of total (N=621)*	*% of AGS (N=425)*	*% of GNSSYM (N=243)*	*% of VRF (N=153)*
Automated Guidance	425	68.4	**100.0**	174.9	277.8
Lightbar Guidance	362	58.3	85.2	149.0	236.6
Automated Section Control	297	47.8	69.9	122.2	194.1
Combine Yield Monitor	255	41.1	60.0	104.9	166.7
Grid Soil Sampling	248	39.9	58.4	102.1	162.1
Combine Yield Mapping	243	39.1	57.2	**100.0**	158.8
Variable Rate Fertility	153	24.6	36.0	63.0	**100.0**
Variable Rate Seeding	102	16.4	24.0	42.0	66.7
Telematics	53	8.5	12.5	21.8	34.6

AGS = automated guidance, GNSSYM = yield mapping, VRF=variable rate fertilizer

Abandonment, Obsolescence and Dis-adoption of Precision Agricultural Technologies

Analysis of KFMA data provides insights regarding farmers' transition from one technology set to another complement. Most precision technologies were dis-adopted by at least one farm and some by several dozen farms. Further evaluation examined whether farms abandoned the technology or simply upgraded or replaced obsolete technology. Specifically, manual control lightbar guidance and yield monitors had the highest number of farms dis-adopting (Table 2). Additionally, lightbar guidance, yield monitor without GNSS, and precision soil sampling had relatively large proportions of farmers ceasing to use the technology at 36.5%, 32.9% and 6.9%, respectively. However, these technologies included the two that were considered obsolete once more advanced technology became available. Lightbars were expected to become obsolete as automated guidance replaced the previous capabilities. Of the 362 farms adopting lightbar, 132 farms (37%) ceased to use the technology (Table 2). Of the 255 farms adopting yield monitors without GNSS, one-third (84 farms) abandoned the technology (Table 2). It was expected that yield monitors would be replaced with yield mapping, i.e. GNSS-enabled yield monitors. Of the nine precision technologies examined, all but variable rate seeding was abandoned by at least one farm (Table 2). The five remaining technologies with no expectation of upgrading or obsolescence had relatively low abandonment rates (<5%).

Only variable rate seeding was not abandoned. For the remaining technologies, it was less clear whether the abandonment was for obsolescence reasons or if the technology were abandoned for performance reasons. The 17 farms that abandoned grid soil sampling may have done so by replacing soil test analyses with on-the-go sensing or reverted to composite whole-field sampling. Many farms transition from grid soil sampling to another form of precision sampling such as 'smart' sampling based on *a priori* knowledge from higher density sampling. The five farms that abandoned variable rate fertility may have done so due to the steep learning curve and uncertainty regarding improved profitability. The four farms that abandoned yield mapping may have given up on the technology or may have resulted from trading combines before the technology became standard. Possibly the most interesting abandonment were the two farms that gave up automated guidance and the one farm that gave up automated section control. Both embodied-knowledge technologies have been known to not only increase profitability but increase utility of the equipment operator. Further analysis is necessary to address these uncertainties.

Table 2. Number of Kansas farms abandoning precision ag technology

	Adopters (farms)	*Farms abandoned*	*% farms abandoning*
Lightbar Guidance	362	132	36.5
Combine Yield Monitor	255	84	32.9
Grid Soil Sampling	248	17	6.9
Variable Rate Fertility	153	5	3.3
Combine Yield Mapping	243	4	1.6
Automated Guidance	425	2	0.5
Telematics	53	2	3.8
Automated Section Control	297	1	0.3
Variable Rate Seeding	102	0	0

Seven of the technologies evaluated had been abandoned by at least one farm. Three technologies, yield monitors, lightbar, and grid soil sampling were abandoned by more than 10 farms (Table 3). On average, these most abandoned technologies were abandoned after 5 to 7 years of utilization (Table 3). The maximum number of years of yield monitor and lightbar were nearly two decades. The maximum duration between adoption and abandonment for grid soil sampling was 29 years. Only a few farms abandoned other technologies such as yield mapping, automated guidance, and variable rate fertility. For each technology that has been abandoned, at least one farm abandoned the technology after the first or second year. It is expected that data technologies such as yield monitors, grid soil sampling, and variable rate application will take multiple years to realize any positive agronomic or financial results.

Upgrading via dis-adoption

The KFMA dataset accounted for farms that abandoned technology such that current utilization could be reported. These data provided the ability to determine how Kansas farms replaced or upgraded obsolete technology for more advanced capabilities. The two most dis-adopted technologies for purposes of upgrading are representative of the two types of precision technology; embodied-knowledge and information-intensive. Yield monitors have been the classic example of information-intensive technologies due to providing data but requiring additional management ability (Griffin et al. 2004). Lightbar represents embodied-knowledge technology since the user is not required to possess the same abilities as without the technology (Griffin et al. 2004). Given that more advanced forms of both these technologies were available, it logically follows that a proportion of farms dis-adopting yield monitors and lightbars were upgrading to newer albeit better technology.

Table 3. Duration in years between adoption and abandonment

	Farms abandoning	Mean	Minimum	Maximum
Lightbar	132	5.8	1	19
Combine Yield Monitor	84	6.7	2	20
Grid Soil Sampling	17	6.5	1	29
Variable Rate Fertility	5	3	1	9
Combine Yield Mapping	4	7.8	2	15
Automated Guidance	2	3.5	3	4
Telematics	2	4	4	4
Automated Section Control	1	4	4	4

For yield monitors, upgrading to yield mapping was expected to be adopted by the next harvest season after dis-adoption. For farms that ceased to use lightbar guidance, the expectation was that automated guidance was either already in the farm inventory or was immediately adopted by the next season. Of the 132 farms that dis-adopted lightbar guidance, 120 either already had automated guidance on the farm or adopted by the next growing season. When the farms that upgraded from lightbar to automated guidance were considered, only 3.3% of farms abandoned any guidance technology. Of the 84 farms that ceased to use yield monitors, only four farms gave up yield monitors without adopting yield mapping by the next harvest season. Eighty farms adopted yield mapping by the next harvest season, i.e. within one year (Table 4). Taking into consideration the number of farms that upgraded, four (1.6%) farms abandoned yield monitor technology. The proportion of farms that truly abandoned technology was similar across all technologies once upgrades were accounted. Results indicated that less than 7% of Kansas farm abandoned the technology and the majority of technologies were less than 4%.

Table 4 KFMA farms adopting, upgrading, and abandoning precision agriculture technology

	Adopters (farms)	Farms dis-adopted	Farms upgrading	Farms abandoned	% abandoned
Lightbar Guidance	362	132	120	12	3.3
Combine Yield Monitor (w/out GNSS)	255	84	84	4	1.6
Grid Soil Sampling	248	17	0	17	6.9
Variable Rate Fertility	153	5	0	5	3.3
Combine Yield Monitor (w/ GNSS)	243	4	0	4	1.6
Automated Guidance	425	2	0	2	0.5
Telematics	53	2	0	2	3.8
Automated Section Control	297	1	0	1	0.3
Variable Rate Seeding	102	0	0	0	0

Conditional Probabilities and Proportion of Farms

The KFMA data provides useful information on the likelihood of farms to engage in adoption of technology given other technologies being utilized. The proportions presented in Table 5 show a farm's probability of adopting one technology given that another technology was being used on the farm in the same year. These technologies include yield mapping (YMGNSS), yield monitor (YM), automated guidance (AGS), automated section control (ASC), lightbar (LB), precision soil sampling (PSS), variable rate application of fertilizer (VRFERT), and variable rate seeding (VRSEED).

The first column in Table 5 lists the technologies that are 'given', meaning that these are the technologies that are the basis for comparison. The top row lists the same technologies, but indicate the level of utilization for that technology (along the top row) 'given' that the other technology (along the first column) was being used on that farm. The values along the diagonal are blank since statistics on a technology given the same technology does not provide useful information. For a farm that uses a yield mapping (first row, YMGPS), the probability that the farm uses automated guidance (third column) was 94%. Farmers who use yield monitors are less likely to use section control and automated guidance than farmers who have GNSS on their combines (Table 5).

Farms that use variable rate application of fertilizer (7th row, VRFERT) have 86% likelihood of using precision soil sampling (6th column, PSS) while the probability of using variable rate seeding (8th column, VRSEED) is 41% (Table 5). In other words, farms that use variable rate application of fertilizer are more likely to use precision soil sampling than variable rate seeding. For farms that have yield mapping (YMGNSS), the probability of using variable rate seeding (VRSEED) is 35%, while the probability of having automated guidance (AGS) is 94%. Farms that have adopted yield mapping are therefore more likely to utilize automated guidance than variable rate seeding.

Table 5. Percent of farmers adopted a technology with respect to another technology.

	Conditional probabilities, n=545							
	YMGNSS	*YM*	*AGS*	*ASC*	*LB*	*PSS*	*VRfert*	*VRseed*
YMGNSS	NA	0.54	0.94	0.82	0.7	0.66	0.46	0.35
YM	0.51	NA	0.89	0.67	0.71	0.49	0.35	0.22
AGS	0.54	0.53	NA	0.66	0.7	0.5	0.33	0.23
ASC	0.67	0.58	0.95	NA	0.73	0.57	0.43	0.31
LB	0.47	0.5	0.82	0.6	NA	0.48	0.31	0.18
PSS	0.64	0.5	0.86	0.67	0.7	NA	0.53	0.29
VRfert	0.73	0.59	0.91	0.82	0.73	0.86	NA	0.41
VRseed	0.82	0.56	0.97	0.9	0.63	0.71	0.62	NA

Based on these conditional probabilities, some technologies are preferred to others for farms given other technology being utilized by that farm. The proportion of farms adopting automated guidance (3rd column) was highest, ranging from 82% (for farms that had previously adopted lightbar) to 97% (for farms that had previously adopted variable rate seeding) (Table 5). As reported above, the adoption of automated technologies such as automated guidance on tractors and combine harvesters has much greater adoption than information-intensive technologies such as yield monitors, grid soil sampling, and traditional variable rate applications of fertilizer and seeds.

Since most KFMA farms utilize automated guidance while less than half utilize yield mapping or variable rate applications, it logically follows that the proportion of farms adopting automated guidance given any other technology would be the highest values across any technology. In addition, GNSS is required to make controller-driven variable rate applications and to collect site specific yield monitor data (i.e. yield mapping, GNSS yield monitor). Since GNSS is already being utilized on the farm, it reasonably stands that one of the major uses of GNSS would be for automated guidance.

As opposed to automated guidance, variable rate seeding (8th column) had much lower adoption rates, and lower proportions ranging from 18% (for farms that had adopted lightbar guidance) to 41% (for farms that had adopted variable rate fertilizer). If a farm successfully utilizes variable rate fertilizer then making use of variable rate seeding intuitively seems the natural next step in the adoption process.

Prescriptive fertilizer application recommendations necessitate site-specific soil fertility information. Three of the leading methods to obtain data sufficient for variable rate applications are on-the-go sensor based and map based from yield monitors (for nutrient replenishment based on grain nutrient removal) and precision soil sampling (for sufficiency, buildup, and maintenance) (Ess et al. 2001). In the absence of on-the-go sensors, farms utilizing variable rate fertility (7th row, VRFERT) are expected to either use yield mapping (73%) or precision soil sampling (86%). Since the highest proportions given variable rate fertility is for precision soil sampling, it can be concluded that farms rely mostly on chemical analysis of soil samples rather than yield data as a proxy for nutrient removal especially when applying phosphorus and potassium. However, this relationship may change during times of relatively low commodity prices when farms desire to avoid costs associated with intensive grid soil sampling and to replace nutrient removal rather than building fertility levels.

Duration, the length of time between being able to adopt and adopting technology

As used here, duration is the length of time usually measured in years between the farm adopting technology and when the farm could adopt the technology (which is the later of the technology being introduced for commercial purchase or the farm entered operation if after the commercialization of the technology). In the case of precision technology adoption, the year that the technology or service was first made locally available was identified for this analysis (Figure 2). The remaining variable of the year that the farm operation began was used from the KFMA Operator Database. In the absence of farm operation beginning dates, the assumption each farm was operating when technologies were introduced may have led to wrong conclusions.

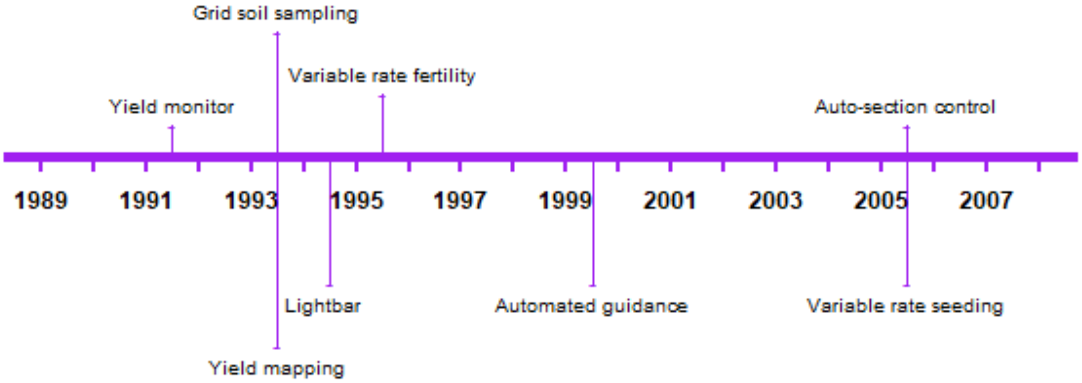

Figure 2. Timeline of commercialization of precision agricultural technology

Violin plots graphically represent the relative response of Kansas farms' adoption of each technology (Figure 3). Only farms that adopted precision agricultural technology were included (n=523). Violin plots were named given that they often look similar to the musical instrument. Violin plots are a type of box plot that represent the relative size of the numbers, here the adoption level of each technology each year after commercialization, i.e. duration. The x-axis scale is relative to when the technologies were available, with 0 as the base. The x-axis has negative years indicating some Kansas farms adopted individual technologies before being widely commercially available; in those cases, the farms likely sought out those technologies outside of their geographic region, potentially as beta users direct with the manufacturer, and can be considered the very earliest adopters. The wider the 'body of the violin' the more farmers adopted at that given level of duration. The purple dot represents the median duration year that KFMA farmers adopted the specific technology. The left side of the violin plot indicates when the first farmers adopted the technology and the right side represents the most recent adoption of the technology.

Relatively newer technologies such as variable rate seeding (VRS) and automated section control (ASC) that have only been on the market for a few years, have shorter violins (as measured from left to right). Other technologies introduced to the marketplace earlier and remained on the farm for longer periods of time have longer violin shapes. Yield monitors (YM) and lightbar (LB) have longer violin shapes than the other technology.

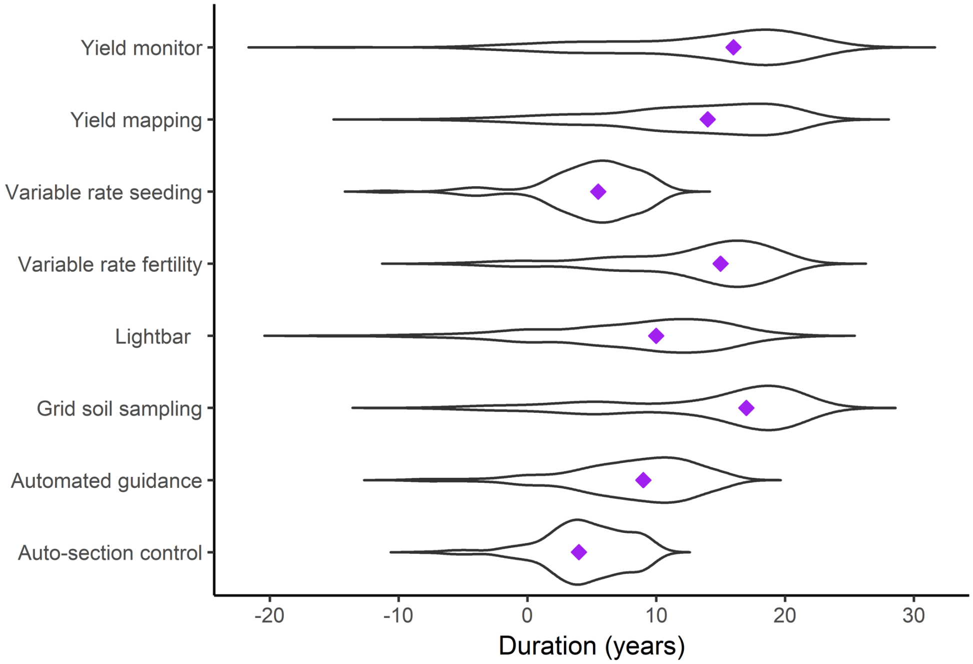

Figure 3. Violin plot of precision agriculture adoption (n=399)

Duration analysis

Duration analysis is concerned with the timing of events and when a person or group moves from one state of the world to another (An and Butler 2012). It is also referred to as survival analysis (medical field), reliability analysis (engineering), or event history analysis (sociology). In this study, the event of interest is adoption of a specific precision agriculture technology and the time it takes for an individual farm to adopt the technology. The specific question of analysis is "given that a firm has not adopted some technology at time *t*, what is the chance that this firm will adopt this technology shortly after time *t*?" (An and Butler 2012, p. 496).

The probability density function (pdf) is

$$f(t) = \frac{dF(t)}{dt}.$$

The cumulative distribution function (cdf) is

$$F(t) = \Pr(T \leq t) = \int_0^t f(s)ds \qquad (1)$$

where the random variable T has some duration less than t.

Equation (1) can be rewritten as a survivor function that is the probability that duration equals or exceeds t (An and Butler 2012)

$$S(t) = \Pr(T > t) = 1 - F(t). \qquad (2)$$

Duration analysis estimators are available from commonly used statistical software, specifically this analysis was conducted using R (R Core Team 2018). Kaplan-Meier (KM) and Nelson-Aalen (NA) estimators are asymptotically equivalent although the KM is the most commonly used in practice (Colosimo et al. 2002). Duration analyses were estimated as Kaplan-Meier (Therneau and Grambsch 2000) using the **survfit()**function from the *survival* contributed package (Therneau 2015) to R (R Core Team 2018).

Duration curves were created for each precision technology, then statistical tests were conducted to determine if curves were significantly different from each other. Duration results can loosely be interpreted to reveal whether one technology has been adopted at a faster rate than another.

Embodied-knowledge technology

The duration curves for automated guidance were compared to duration curve for lightbar; results indicated that these curves were statistically different. Automated section control was adopted in relatively shorter amount of time than automated guidance.

Information-intensive technology

Duration curves for yield monitors with and without GNSS were compared. No statistical difference was detected between the yield monitor curves. Precision soil sampling and GNSS-equipped yield monitors were not adopted at statistically different rates.

Embodied-knowledge versus information-intensive technology

Automated guidance was compared to all yield monitors (regardless of the yield monitor having a GNSS). The duration curve for automated guidance was statistically different than the curve for yield monitor, indicating that Kansas farmers did in fact adopt automated guidance ‘quicker’ than yield monitors.

Conclusion or Summary

It was expected that duration curves of similar technologies grouped as either embodied-knowledge or information intensive would not substantially differ and duration curves across these two broad categories of technology would significantly differ. Specifically, it was expected that automated technologies such as guidance and section control would be adopted at much higher rates than data technologies like yield monitors due to differences in human capital costs to use these technologies. These results may indicate that although lightbar was considered an embodied-knowledge technology, it provided information which equipment operators used as a visual aid without automating anything; therefore, it could be argued that even though substantial technology was embodied into the lightbar, it was analogous to information-intensive given that the user must make use of the information from the lightbar. For embodied knowledge technologies, automated section control was adopted quicker than automated guidance and automated guidance was adopted quicker than lightbar.

Future Work

These analyses will continue to be updated as the sample size grows both in terms of number of farmers as well as over time for existing farms and additional farm respondents. In addition to the analyses presented here, other analysis evaluating adoption trends such as transition probabilities and duration or survival analyses will be conducted. Analysis evaluating profitability and technical efficiency are being conducted using marginal propensity score matching, logistic regression, data envelopment analysis and other panel data methodologies.

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References

Alcon, F., Dolores de Miguel, M., & Burton, M. (2011). Duration Analysis of Adoption of Drip Irrigation Technology in Southeastern Spain. *Technological Forecasting and Social Change,* 78(6), 991-1001.

An, H. & Butler, L.J. (2012). A Discrete-Time Duration Analysis of Technology Disadoption: The Case of rbST in California. *Canadian Journal of Agricultural Economics,* 60, 495–515

Bongiovanni, R. & Lowenberg-DeBoer, J. (2004). Precision Agriculture and Sustainability. *Precision Agriculture,* 5(4), 359-387.

Burton, M., Rigby, D., & Young, T. (2003). Modelling the Adoption of Organic Horticultural Technology in the UK using Duration Analysis. *Australian Journal of Agricultural and Resource Economics,* 47(1), 29-54.

Colosimo, E., Ferreira, F., Oliveira, M. & Sousa, C. (2002). Empirical comparisons between Kaplan-Meier and Nelson-Aalen survival function estimators. *Journal of Statistical Computation and Simulation,* 72(4)

Dadi, L., Burton, M., & Ozanne, A. (2004). Duration Analysis of Technological Adoption in Ethiopian Agriculture. *Journal of Agricultural Economics,* 55(3), 613-631.

D'Emden, F.H., Llewellyn, R.S., & Burton, M.P. (2006). Adoption of Conservation Tillage in Australian Cropping Regions: An Application of Duration Analysis. *Technological Forecasting and Social Change,* 73(6), 630-647.

Dhoubhadel, S., & Griffin, T.W. (2018). The Impact of Precision Agriculture Technologies on Farm Profitability in Kansas. In Proceedings of the 14th International Conference on Precision Agriculture (unpaginated, online). Monticello, IL: International Society of Precision Agriculture.

Erickson, B., Lowenberg-Deboer, J. & Bradford, J. (2017) 2017 Precision Agriculture Dealership Survey. December 2017. Online:_ file:///E:/Duration%20analysis%20project/croplife-purdue-2017-precision-dealer-survey-report.pdf

Ess, D.R., Morgan, M.T., & Parsons, S.D. (2001). Implementing Site-Specific Management: Map-Versus Sensor-Based Variable Rate. Purdue University SSM-2-W. Applicationhttps://www.extension.purdue.edu/extmedia/AE/SSM-2-W.pdf

Fuglie, K.O., & Kascak, C.A. (2001). Adoption and Diffusion of Natural-Resource-Conserving Agricultural Technology. *Review of Agricultural Economics,* 23(2), 386-403.

Griffin, T.W., Lowenberg-DeBoer, J., Lambert, D.M., Peone, J., Payne, T., & Daberkow, S.G. (2004). Adoption, Profitability, and Making Better Use of Precision Farming Data. Staff Paper #04-06 Department of Agricultural Economics, Purdue University.

Griffin, T.W., Miller, N.J., Bergtold, J., Shanoyan, A., Sharda, A., & Ciampitti, I.A. (2017). Farm's Sequence of Adoption of Information-Intensive Precision Agricultural Technology. *Applied Engineering in Agriculture,* 33(4), 521-527.

Griffin, T.W., Lowenberg-DeBoer, J., & Lambert, D.M. (2005). Economics of Lightbar and Auto-Guidance GPS Navigation Technologies. In J.V. Stafford (ed.) *Precision agriculture '05*. 5th European Conference on Precision Agriculture, Uppsala, Sweden. pp 581-587

Griffin, T.W., Shockley, J., & Mark, T.B. (2018). Economics of Precision Farming. In D.K. Shannon and D.E. Clay (Eds.) Precision Agriculture Basics. USDA. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. ISBN: 978-0-89118-367-9 doi:10.2134/precisionagbasics.2016.0098

Lambert, D.M., Paudel, K.P., & Larson, J.A. (2015). Bundled Adoption of Precision Agriculture Technologies by Cotton Producers. *Journal of Agricultural and Resource Economics*, 40(2), 325-345

McFadden, J., & Rosburg, A., 2018. Yield Maps, Soil Maps, and Technical Efficiency: Evidence from U.S. Corn Fields. In Proceedings of the 14th International Conference on Precision Agriculture (unpaginated, online). Monticello, IL: International Society of Precision Agriculture.

Olson, K. & Elisabeth, P. (2003). An Economics Assessment of the Whole-farm Impact of Precision Agriculture. Annual Meeting of the American Agricultural Economics Association. Montreal, Canada, July 27-30, 2003.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Roberts, R.K., English, B.C., Larson, J.A., Cochran, R.L., Goodman, M.C., L, et. al. (2004). Adoption of Site-Specific Information and Variable-Rate Technologies in Cotton Precision Farming. *Journal of Agricultural and Applied Economics,* 36(1), 143-158.

Schimmelpfennig, D., & Ebel, R. (2016). Sequential Adoption and Cost Savings from Precision Agriculture. *Journal of Agricultural and Resource Economics*, 41(1), 97-115

Schimmelpfennig, D. (2018). Crop Production Costs, Profits, And Ecosystem Stewardship with Precision Agriculture. *Journal of Agricultural and Applied Economics*, 50(1), 81-103.

Shockley, J.M., Dillon, C.R., & Stombaugh, T.S. (2011). A Whole Farm Analysis of the Influence of Auto-Steer Navigation on Net Returns, Risk, and Production Practices. *Journal of Agricultural and Applied Economics*, 43(1), 57–75.

Therneau, T. (2015). _A Package for Survival Analysis in S_. version 2.38, <URL: http://CRAN.R-project.org/package=survival>. April 4, 2017.

Therneau, T.M. & Grambsch, P.M. (2000). _Modeling Survival Data: Extending the Cox Model_. Springer, New York. ISBN 0-387-98784-3.

Torbertt, J.C., Roberts, R.K., Larson, J.A., & English, B.C. (2007). Perceived Importance of Precision Farming Technologies in Improving Phosphorus and Potassium Efficiency in Cotton Production. *Precision Agriculture* 8(3), 127-137.

Watson, S., Bronson, K., Schubert, A.M., Segarra, E., & Lascano, R. (2005). Guidelines for Recommending Precision Agriculture in Southern Crops. *Journal of Extension,* 43(2), 1-8.