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Abstract

This literature review focuses on the role of the precision agriculture (PA) custom services industry in facilitating farmer adoption of PA technology. Based on the review, a series of stylized facts are developed that characterize the custom services industry's role in the PA adoption process in the United States. The literature suggests that increasing the availability of custom services in local agricultural production markets will positively influence the rate of PA adoption. Recent PA custom services industry field surveys, however, indicate that skilled labor, proficient in PA technology, is critical to develop and provide custom services needed to increase the supply of PA services to farmers. These surveys suggest that currently there is a shortage of qualified labor to work in the PA custom services sector. The PA labor issue appears to pose a potential barrier to the provision of PA technical training desired by customers, and the deployment of PA custom services to customers who have adopted or are considering the adoption of PA technology.

Key Words: Agribusiness, Agricultural Technology, Precision Agriculture, Workforce Development, Retail PA Services Industry

JEL Codes: Q10, Q13, J43, L8

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Introduction

Precision Agriculture (PA) is a generic term that refers to the wide variety of electronic technologies that have been commercially developed over the last quarter century, and specifically adapted for application to agricultural production (Shannon et al. 2018). These technologies can increase production efficiency by providing information on the input requirements and output levels over a heterogenous production space (Davis et al. 1998), which should decrease production cost per unit of yield. Shannon et al. (2018) provides a general overview of this array of technologies. However, PA adoption also increases complexity of the production system as producers move from homogenous to heterogeneous input applications (Aubert et al. 2012).

The commercial adoption of PA technology began at roughly the same time as changes occurred in U.S. agricultural production policy with the passage of the "Federal Agriculture Improvement and Reform Act of 1996," commonly referred to as the Freedom to Farm Act (McDonald et al. 2013: pp. 22-45; Fausti 2015). During this period, genetically modified organism (GMO) technology-based seed was commercially introduced to American agriculture. The commercial corn-based ethanol industry entered into its industrial growth stage with the passage of U.S. biofuels legislation at the turn of the 21st century (Fausti 2015). Fausti discusses how the convergence of biotechnology innovations combined with changes in U.S. agriculture and energy policy altered the U.S. crop production system. These policies and technological advancements changed producer production practices and allowed producers to pursue increased profit by expanding their production capacity. This lowered the average cost per acre by capturing economy of scale efficiencies and has contributed to farm consolidation in the U.S. row crop industry (McDonald et al. 2013).

The consolidation of farms also opened the door for innovation that transformed the physical capital structure of U.S. farming operations. For example, McDonald et al. (2013: pp. 23-25) reports that in 1970 the average-sized (horsepower) tractor could plant 40 acres per day. By 2010, the average-sized tractor could plant 945 acres per day. McDonald et al. reports that similar production scale effects occurred in harvesting and planting equipment. These production scale effects created an economic incentive to develop complementary technologies to enhance the economies of scale effect in grain and oilseed cropping operations.

These complementary production technologies, as a class, is now referred to as precision agriculture technology (Shannon et al. 2018). The PA adoption issue, and the diffusion of various PA technologies has been extensively discussed in the literature (e.g., Lowenberg-DeBoer 2003; Griffin and Lowenberg-DeBoer 2005; Schimmelpfennig and Ebel 2011; Tey and Brindal 2012; Aubert et al. 2012; and Schimmelpfennig and Ebel 2016). However, the adoption rate across categories of PA applications varies widely. As a result, the PA adoption rate literature suggests that PA adoption has been slow, relative to other technological innovations in agriculture. For example, biofuel technology and crop seed development using GMO technology have become industry standard practice. PA adoption rates, however, are highly dependent on which PA technology category is being discussed (Schimmelpfennig and Ebel 2016; Lowenberg-DeBoer and Erickson 2019). According to this literature, guidance system technology is almost universally used, whereas less than 20% of farms reported using variable rate technology (VRT). Therefore, when discussing PA adoption rates, one cannot take a "one size fits all" approach. In addition, for this review, adoption refers to a producer adding a new PA technology to their production management system.

The literature raises two issues when a farmer considers PA adoption. The first issue is the role management (i.e., the farmer) plays in the decision to adopt PA technology. The second issue is the availability of PA expertise in providing assistance to the farmer in making adoption decisions. In the United States, the retail custom services industry (seed/fertilizer/pesticide dealerships) is the most common source of local expertise needed to effectively navigate the PA adoption process (Erickson et al. 2018). Erickson also notes that recent industry survey results indicate that the custom services industry appears to be having difficulty finding qualified PA workers to fill vacant PA positions.

The objective of the literature review is to discuss the linkage between PA adoption rates and the PA retail custom services industry. A review and analysis of the PA literature allows a set of stylized facts to be drawn and provides a framework for discussion of the linkage among the PA rate of adoption, the PA custom services industry, and PA workforce development.

A Review of Labor and Management Factors Influencing the Diffusion of Precision Agriculture Technology Literature

PA Diffusion Literature

The PA literature has demonstrated that adoption of a variety of PA technologies increases productivity, decreases input costs, and reduces labor inputs (e.g., Lowenberg-DeBoer and Erickson 2019; Griffin et al. 2018; Schimmelpfennig and Ebel 2016; Bora et al. 2012; Tey and Brindal 2012; Griffin and Lowenberg-DeBoer 2005). These studies discuss the role of complexity and management in the PA adoption decision. Decision complexity associated with the adoption process is compounded by the level of investment needed to integrate PA technology into the farmer's production system. The advisory role played by PA vendors, university and government Extension services, and retail farm service providers, in the adoption decision process by management, has been widely discussed in this branch of the literature. The literature infers that PA custom services are a potentially underutilized management solution to the adoption conundrum.

Robertson et al. (2012) address the issue of adoption rates of VRT for fertilizer application in Australia. They identify the complexity of the decision, (e.g., where, when, how much fertilizer, crop, and cropping system) as a key component influencing the individual producer's adoption decision and industry wide diffusion of PA technology. Robertson et al. state that, "Adoption of complex technology requires the producer to modify a number of farming practices and the management of those practices," and they conclude that, "Producers need expert support and training to aid in the adoption process." Furthermore, Robertson et al. (pp. 194-95) argue that "Application of PA systems by farmers can be hindered by the lack of technical support and training…" Paraphrasing Robertson, he concludes that because of the complexity of a farming system, the site-specific nature of the decisions, the lack of local support, and at times the lack of definitive agronomic research to corroborate decisions, it is not unexpected that VRT technology is lagging in adoption relative to other PA technologies.

Aubert et al. (2012) also concludes that complexity is a key barrier to PA adoption for Canadian farmers. They argue that to increase adoption there is a dual prerequisite of increased compatibility across PA technologies and a need for increased farmer expertise to support integration of PA technologies into production systems. Aubert et al. then discusses the role of PA vendors in the adoption process and concludes that vendors play an important role in the farmer's adoption decision process.

Fountas et al. (2005) compare the farmer's experience with precision agriculture in Denmark and the U.S. Eastern Corn Belt. They reported that the role of complexity in the PA adoption process was similar for U.S. and Denmark producers. The authors highlight a steep PA learning curve, and the high cost of PA equipment as barriers to adoption. They also indicate a need for trained PA specialists in both the private and public sectors to facilitate adoption rates. They suggested that the willingness to pay for PA services may be a channel for transferring PA knowledge from experts to inexperienced operators.

Pierpaoli et al. (2013) focus on drivers of adoption and conclude that non-adopters lack skills for implementing PA in their operations and may lack the financial resources to purchase PA equipment. They infer that an opportunity exists to develop PA service firms specializing in the provision of contractual PA custom services. Contracting opportunities would provide non-adopters with option to purchase the technical PA knowledge and the application of PA services without the high fixed cost investment associated with purchasing PA technology (Pierpaoli et al. (2013: p. 67). McBride and Daberkow (2003: p. 24) state that "information from sources such as vendors and professional consultants is shown to be the most important to the potential adopter."

Tey and Brindal (2012) review 25 studies with a focus on the informational, behavioral, social, and economic aspects of PA adoption. They report that adoption is influenced by a multitude of factors and conclude that adoption decreases with the increasing complexity of a technology. However, the availability of outside advisors can help farmers overcome this barrier.

McBride and Daberkow (2003) report that the producer adoption decision is highly influenced by recommendations provided by crop consultants and retail input suppliers. They contend that areas with higher PA vendor concentrations have higher adoption rates. Shannon et al. (2018) also discuss the relationship between vendor concentration and adoption rates. They remark on the tendency of PA technology adopters to cluster around a service provider. Davis et al. (1998) suggest that farmers should consider using custom services as an alternative to the high fixed cost of capital and the steep management learning curve. With respect to the PA custom services sector, they indicate that service providers need a critical mass of PA adopters to justify the capital fixed cost and additional labor associated with providing PA services. These insights on PA adoption clusters suggest there may be a simultaneity issue.

However, the observed tendency of spatial clustering provides an opportunity for rural economic development initiatives at state and federal levels to incentivize PA technology adoption. Spatial clustering of PA adoption around service providers may provide an economic policy path to promote local PA knowledge spillover. In turn, the spillover effect could address the steep learning curve issue raised by Davis et.al. (1998), and by Fountas et al. (2005). Similar policy prescriptions have been proposed in the literature (e.g., McBride and Daberkow 2003).

Schimmelpfennig and Ebel (2011) discuss multiple PA technologies considered to be complementary in the production process. They document a positive relationship between the adoption of yield monitor technology and other more complex PA technologies, such as VRT. They conclude that the future cost structure of PA technologies will likely influence future adoption rates.

Schimmelpfennig (2016) also discusses how PA technology can be complementary and have a positive relationship among PA adoption rates, PA adopter profitability, and farm size. Schimmelpfennig (Table 3) reports that producers farming less than 400 cropland acres have a per acre cost 1.6 to 2.7 times greater than those farming more than 1,200 cropland acres using similar PA and non-PA custom services. Schimmelpfennig also discusses the relationship between farm size and PA adoption, and reports (p.12; Table 1) producers farming less than 600 cropland acres have adopted various PA technologies at a rate lower than producers farming more than 3,800 cropland acres. He concludes that economies of scale do play a role in the diffusion of PA technologies.

Schimmelpfennig and Ebel (2016) describe a sequential PA adoption process and the associated cost savings from adoption. They investigate the complexity of adopting complementary PA technologies with VRT as the final technology added to the production system. Notably, the number of farming operations adopting multiple technologies is inversely related to the number of PA technologies integrated into the farming operation. They report that highly educated producers using other non-PA technologies, such as GMO seed and soil testing, are more likely to be adopters of complex PA production systems.

The Schimmelpfennig contribution and the Schimmelpfennig and Ebel contributions tie directly to the PA complexity issue. Their findings support the conclusions of Robertson et al. (2012) and Aubert et al. (2012) that complexity, compatibility, economies of scale, and lack of farmer PA expertise pose barriers to PA adoption.

In a recent article by Lowenberg-DeBoer and Erickson (2019), they argue that rate of PA technology diffusion debate fails to see the "forest from the trees" (e.g., looking at the small details leads to missing larger overall issues). They assert that PA contains many tools, and producers select the tool(s) that best fits their farming operation, and some tools may not be needed. Lowenberg-DeBoer and Erickson (2019) discuss the idiosyncratic nature of PA adoption decision. For example, less complex technologies like Global Navigation Satellite Systems used in auto guidance have become standard practice in the United States due to its ease of implementation and its broad application to farming operations. On the other hand, they state that VRT applications have been adopted at a much lower rate. For example, VRT may not be appropriate for smaller fields or where field grade and soil variability are not issues. Their observation is consistent with the complexity hypothesis explanation of PA adoption.

Lowenberg-DeBoer and Erickson (p. 1554) argue that the literature has been focused on barriers to adoption and has not been "particularly useful in explaining or predicting national or regional PA adoption trends." This comment raises an interesting issue and suggests a need for additional research on this topic. A plausible supposition that would provide an explanation for this "lack of trend" is that the failure to explain regional or national trends in PA adoption may be associated with the variability in the availability of skilled PA workers in local markets.

Fausti et al. (2021) provides empirical support that indicates there is a positive association between the quality of the local PA labor force and farm size (a proxy for economies of scale) at the county level. Given that the supply of PA custom services is dependent on the size of its customer base, and on the availability and competency of the local PA labor force, this suggests that variability in regional PA adoption rates may be related to the variability in average farm size across counties. This discussion is consistent with the empirical work of Daberkow and McBride (1998). They report that larger crop farming operations have a higher probability of being PA adopters than smaller crop farming operations. In addition, they comment on producer demand for PA resources and surmise on page 154 that "such services may not be uniformly accessible."

The above discussion suggests that custom service providers in counties dominated by small and medium-sized farms have a smaller customer base and have greater difficulty finding qualified

PA labor relative to counties dominated by large scale farming operations. This is a plausible explanation for the lack of trend in the PA adoption rate reported by Lowenberg-DeBoer and Erickson (2019). If average farm size is the factor that explains the "lack of trend", then is there a policy prescription to address the lack of adoption issue in counties dominated by small and medium-sized farms? Daberkow and McBride (1998) discuss potential policy solutions. However, they qualify their discussion by questioning if it is worth the public expenditure to increase the rate of adoption in low adoption areas. Such a policy would be necessary to increase the presence of PA custom service firms in such areas. In addition, any policy proposed would have to address the issue of PA labor supply.

The PA Workforce Literature

The review of the PA literature lays the groundwork for a discussion of a subbranch of the literature which focuses on the PA workforce that supports the retail custom services industry. The ability of PA vendors to provide services to farmers relies on two factors, sustained demand for PA services and the availability of a trained PA workforce.

Kitchen et al. (2002) provides an overview of educational needs of the PA industry. They postulate that one barrier to PA adoption is the lack of well-educated and trained workers in the various areas of PA technology. Kitchen et al. argues that the supply of a well-trained workforce is dependent on the number of education programs offering PA instruction. They go on to make numerous recommendations for improving PA education in the United States.

Expertise in precision agriculture, as outlined by Erickson et. al. (2018), is defined as the *Knowledge, Skills, and Abilities* (KSA) to apply PA technology to agricultural production. The retail custom services industry provides the technology, equipment, and expertise to guide the adoption process.

Erickson et al. (2018) provides an overview of the U.S. PA retail custom services industry's view of the availability of skilled PA workers based on data collected in a retail dealership survey. In the survey, Erickson et al. asked retailers to rank past interviewees for PA positions on the interviewer's perception of the candidates' expertise in ten PA competency areas. This study focused on the relationship between types of PA expertise desired by the retailer, and the retailer's perception of the availability (or lack thereof) of new hires possessing the desired qualifications. Their survey findings suggest that a skilled PA workforce is not universally available across the retail dealership industry. Another question of interest concerning the PA workforce that was asked by Erickson et al. focused on the view of retail custom service firms with respect to the difficulty in finding qualified applicants. Erickson et al. reports that 60% of retail custom service firms had a difficult (2 to 3 months to fill) or very difficult (more than 3 months) time finding qualified applicants. In addition, approximately 50% of the respondents indicated applicants, even though applying for PA positions, have a low or deficient level of understanding across KSA categories. This lack of available labor may pose a potential barrier to the provision of PA services in locations where PA labor is in short supply.

Erickson et al. (2017; p. 22) also reports on the labor shortage issue and raises the issue of PA labor cost using data from a 2017 CropLife© survey of retail dealerships. They found that the percentage of dealerships surveyed indicating an increase in difficulty finding qualified PA employees rose from 47% in 2015 to 62% in 2017. Furthermore, Erickson et al. reports in the 2017 survey that 40% of the respondents agreed or strongly agreed with this statement: "The cost of employees who can provide precision services is too high for precision ag to be profitable."

The last study to be discussed looks at the issue of the availability of PA workforce training and development. In a study by Fausti et al. (2018) on education institutions with PA offerings, Fausti found a divergence in the educator versus industry expectations of student preparation in KSA areas. For instance, they report statistical means tests for the occupational category of equipment operator that indicate educational institutions gave 8 of 10 KSA categories a higher importance ranking than retail dealership respondents. In turn, retail dealership respondents rank math and statistical skills higher than educational institutions across occupation categories (Fausti et. al. 2018: Table 3). This divergence may be a partial explanation for the custom service industry's view that the PA labor pool lacks qualified candidates for PA positions in the industry. When one considers the findings in the studies discussed above, it suggests that the Kitchen et al. (2002) recommendations for developing curriculum, to turn out well-educated and trained workers in the various areas of PA technology, is still a work in progress.[5]

Literature Summary

The literature cited provides a series of common themes tying the rate of PA technology adoption to the ability of farmers to make the adoption decision. Commonly cited factors that pose potential barriers to adoption are: a) the complexity issue of adopting PA technology; b) lack of farmer expertise to identify PA technology suited for their farming operation and the lack of management skills to oversee a PA system once adopted; and c) the cost of adoption (both fixed and variable cost). The literature also identifies a set of potential solutions to overcome these barriers: a) PA expert services (consultants and Extension services) can function as a facilitator of farmer education programming to overcome the lack of farmer PA expertise; and b) farmer contracting for PA services through local retail agricultural custom service dealerships.

The literature has identified the custom services industry as a potential solution option to the rate of adoption issue. Evidence suggests that there is a linkage between custom services availability and adoption. This linkage is more relevant for small to medium-sized farming operations. The PA labor force education literature indicates that there is a shortage of qualified workers to meet the demand by the retail dealership industry in the United States. Thus, the rate of adoption for small and medium-sized farms is tied to the expansion of affordable custom services, and the expansion of custom services is tied to the size of a qualified PA labor pool. By extension, the shortage of qualified PA labor may be a partial explanation for differences in the cost per acre for custom services between large vs. small farms reported by Schimmelpfennig (2016). In turn, the cost differential combined with the positive association between average farm size and ability of custom PA service firms to find qualified PA labor (Fausti et al. 2021) provides a potential answer to the issue raised by Lowenberg-DeBoer and Erickson (2019) for the lack of a trend in the PA adoption rate at the regional or national level.

When the literature is viewed from this vantage point, it implies that there is a linkage among the literature issues of the PA adoption decision, PA custom services availability, and PA workforce development. This linkage allows a set of stylized facts to be drawn from the literature.

[5] Programs have been expanding. For example, South Dakota State University offers major & minor, North Dakota State University is developing a major. Kansas State University and the University of Missouri both have certificate PA programs.

Adoption Decision

- PA adoption increases farm management complexity.
- PA adoption requires a substantial fixed cost investment by producers who purchase PA equipment. Variable cost associated with PA implementation (purchase or contract) is dependent on economies of scale.
- Adoption of multiple PA complementary technologies increases production efficiency, and the benefits increase as production scale increases; however, complexity increases.
- Farm size, profitability, and PA adoption rates are positively related.
- Lacking economies of scale, small and medium-sized farming operations are at a cost disadvantage that may pose a barrier to PA adoption.

Custom Services

- Custom PA services are an alternative adoption option to purchasing PA equipment.
- Custom service firms provide PA expertise to overcome the complexity issue for producers who own PA systems or contract for PA production and management services.
- Economies of scale and cost per acre of custom PA services are inversely related.
- PA adopters tend to cluster around custom PA service providers.
- Custom PA service providers establish operation centers in areas where the PA adoption level supports the investment.
- The retail custom services industry reports a shortage of qualified trained workers.
- PA labor cost is affecting the profitability of custom services provision.
- A well-trained PA workforce is necessary for the retail custom services industry to support future expansion of PA adoption.

Conclusion

These stylized facts suggest that complexity and the lack of producer expertise are factors that do affect adoption rates. In turn, the literature implies that if farmers had access to PA Extension services and affordable PA vendor expertise, then adoption rates would be higher. However, greater access implies an increase in supply of custom PA services in local markets. PA service providers need a critical mass of PA adopters to set up operations in a local market. In turn, an increase in the supply of PA services will result in an increase in demand for PA skilled labor in local markets. Recent survey work indicates that the custom services industry is having a difficult time hiring qualified PA labor. It appears that the conditions necessary for the custom services industry to support the expansion of producer adoption of PA technology will require the development of policy that simultaneously incentivizes producer adoption and increases the supply of the qualified PA workers. Further research on these issues is needed.

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