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A Literature Review on the Adoption of Precision Agriculture Technologies: a Step-by-Step Process?

Emanuele Pierpaoli[1], Giacomo Carli[1], Maurizio Canavari[1]

[1]Department of Agricultural Sciences, University of Bologna, Italy
e-mail: emanuele.pierpaoli2@unibo.it; giacomo.carli@unibo.it; maurizio.canavari@unibo.it

ABSTRACT

A review of the recent literature on determinants and factors that influence intention to adopt and adoption of Precision Agriculture technologies was performed. The analysis covers both ex-ante and ex-post approaches to behavior modeling. Results suggest that some constructs are relevant both ex-ante and ex-post, while others are presented differently in the two situations. A discussion of adoption as a process, and, the need to include the consideration of this process in the analysis of new technologies is also provided.

Keywords: Precision agriculture, Technology adoption, Innovation in agriculture.

1. INTRODUCTION

The adoption of Precision Agriculture (PA) technologies in agriculture is rarely immediate, even though much effort is placed in persuading users to adopt new tools, it is a highly complex activity with many factors influencing the decision-making processes (Agarwal & Prasad, 1999). Many aspects of PA have been studied: technologies, environmental and economical outcomes, rates and the drivers of adoption and non-adoption. Many authors have confirmed the economical and the environmental benefits derived from PA (Batte & Arnholt, 2003; Pierce & Elliott, 2008; Swinton & Lowenberg-DeBoer, 1998). Nevertheless, a low PA adoption rate is still reported by academic surveys and professional reports (Ellis, Baugher, & Lewis, 2010; Lamb, Frazier, & Adams, 2008).

PA technologies adoption have been analyzed both ex-post and ex-ante. Ex-post studies demonstrate the reasons which have influenced, and probably are still influencing, farmers to adopt new PA technologies, while ex-ante studies allows the analysis of acceptance of a new technology prior to its introduction. The combination of ex-post and ex-ante studies would be useful to analyze farmer's choice when dealing with new technologies and their adoption (Useche, Barham, & Foltz, 2012).

This paper aims to provide an extensive review of the drivers of PA adoption, merging ex-post and ex-ante approaches to emphasis overlaps and relations, proposing a unifying picture of this technology adoption. This is relevant because, while a review of

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ex-post papers is available (Tey & Brindal, 2012), an complete review of ex-ante studies was absent.
The farm/farmer's characteristics included in all *Ex-post* and *Ex-ante* studies could be seen as drivers or factors affecting the adoption of new technologies. This paper organizes these factors into three different classes: competitive and contingent factors, socio-demographic factors and financial resources. As in Wejnert (2002), the farmer was identified as the pivotal element of the process and used to define the three classes of factors affecting the attitude to adopt (*Ex-ante*) and adoption of (*Ex-post*) a PA innovation.

2. DATA AND METHODS

Papers for this review were collected using different combined sets of keywords in Scopus, including "Precision agriculture adoption", "Technology adoption", "Technology acceptance", and "Agriculture". We found more than one thousand papers and research outcomes. Then, only empirical studies published on peer-reviewed journals were selected and work focused only on policy, energy, environmental issues was excluded. In the reading phase, a snowball approach was adopted aimed at finding other related papers. We ended-up with 20 papers divided in two groups: 1) ex-post studies, 2) ex-ante studies. Table 1 presents the list of the selected papers along with the details about data sources, sample sizes, and number of variables.

3. FACTORS INFLUENCING ATTITUDE TO ADOPT AND ADOPTION

Figure 1 demonstrates the drivers identified by the literature review and they are listed in Table 1. They have been organized in three classes: "Competitive and Contingent factors", "Socio-demographic factors" and "Financial resources". For each class of factors, two sections were defined. *Ex-ante* papers are based on the Technology Acceptance Model (TAM) or on other models and methods aimed at evaluating the Willingness to Pay (WTP), in order to investigate human perceptions and attitude towards technologies, prior to using them. *Ex-post* papers mainly analyze users' evaluations after using technology, mainly through a binary choice model approach.

3.1 Competitive and Contingent Factors

The *Ex-ante* constructs classified under "Competitive and Contingent Factors" are Perceived Ease of Use (PEU), Size, Trialability, Observability, and Facilitating Factors. The *Ex-post* drivers are Size, Geography, and Soil Quality.
Perceived Ease of Use is a construct introduced in the seminal TAM research by Davis (1989) and, after that, it has always been used in TAM studies (Davis & Venkatesh, 2004; Gefen & Straub, 2000; Karahanna & Straub, 1999). It was defined as "the degree to which a person believes that using a particular system would be free of effort" (Davis, 1989). PEU is affected by one of the other factors included in this section, such

as the availability of technical support. The presence of experts about PA triggers a learning process that makes potential users more aware and confident about PA tools, promoting the perception of an "easy to use" technology (Folorunso & Ogunseye, 2008; Rezaei-Moghaddam & Salehi, 2010). PEU is a construct that has been deeply investigated over time: the aspect of PEU that is of our interest in this section is the "objective usability" of that technology.

Trialability and Observability are two important variables affecting the intention to adopt a technology. These constructs act in the early stages of personal experience because they represent the possibility to test a technology, as well as the opportunity to observe the results (Aubert, Schroeder, & Grimaudo, 2012; Rezaei-Moghaddam & Salehi, 2010).

The constructs named "Facilitating factors" and "Geography", also called location, represent the presence of links between the farmer and the farming environment. That is, these constructs are strictly connected to the presence of PA technologies experts and consultants in the extension service, or to an economic policy that aims to stimulate the use of these technologies, e.g., financial support for those who purchase them, or to the diffusion of retailers (Folorunso & Ogunseye, 2008). "Geography" has a similar impact as "Facilitating factors" on the intention to adopt. It represents the surroundings context

Table 1. Ex-post and Ex-ante papers.

N°	Ex-Post Authors	Method	Data source	Sample Size	N° Var.
1	Daberkow and McBride, 1998	Logit	USDA's 1996 ARMS	950	11
2	Khanna, 2001	Logit	2 Mail surveys	650+405	10; 11
3	Fernandez-Cornejo et al., 2002	Tobit	USDA's 1998 ARMS	4040	7
4	Roberts et al., 2002	Logit	Survey	284	10
5	Daberkow and McBride, 2003	Logit	USDA's 1998 ARMS	8429	11
6	Roberts et al., 2004	Probit	Survey of cotton farmers	1131	10
7	Torbett et al., 2007	Logit	Cotton farmers survey	1131	22
8	Isgin et al., 2008	Logit	Ohio PA survey	491	10
9	Larson et al., 2008	Logit	Cotton producer survey	1215	11
10	Walton et al., 2008	Probit	Cotton producer survey	827	13
11	Reichardt and Jürgens, 2009	Cross tabulation analysis	Mail and telephone survey	6183	5
12	D'Antoni et al., 2012	Logit	Mail survey to cotton farmers	1692	13
13	Robertson et al., 2012	Logit	4 surveys	1376	8

N°	Ex-Ante Authors	Method	Data source	Sample Size	N° Var.
1	Hite et al., 2002	Partially censored probit model	Telephone survey in Mississippi	762	15
2	Hudson and Hite, 2003	Factorial design	Mail survey	423	14
3	Adrian et al., 2005	TAM and SEM	Survey in Alabama Extension meetings	85	7 constructs
4	Folorunso and Ogunseye, 2008	TAM and Regression analysis	Survey (Nigeria)	370	7 constructs
5	Marra et al., 2010	Dichotomous/Ordered polychotomous choice model Probit/Logit approach	Mail survey - Referendum contingent valuation approach	743	7 constructs
6	Rezaei-Moghaddam and Salehi, 2010	TAM and SEM	Survey to agricultural specialists (Iran)	249	7 constructs
7	Aubert et al., 2012	Partial Least Squares (PLS)	Survey to Quebec farm operators	438	15 constructs

characterizing the place where a farmer lives (Daberkow & McBride, 1998; Larson et al., 2008; Reichardt & Jürgens, 2009; Roberts et al., 2004).

Structural farm variables are size and soil quality. Size is one of the most cited aspect affecting new PA technologies usage (Daberkow & McBride, 2003; Khanna, 2001; Robertson et al., 2012; Walton et al., 2008). According to previous studies, a farm can be defined "large" if the total cultivable area is bigger than 500 hectares (Batte & Arnholt, 2003; Kutter, Tiemann, Siebert, & Fountas, 2011), which confirms the economy of scale effect related to PA technologies adoption. It is more likely that a bigger farm would plan to invest money in new technologies, in the current market situation (Adrian et al., 2005; Hudson and Hite, 2003; Marra et al., 2010). Soil quality is another important farm structural aspect. A better soil quality makes easier to obtain better performance and a higher quality production, as a consequence the farm activity would be more profitable and more inclined towards new technologies (Daberkow & McBride, 1998; Isgin, Bilgic, Forster, & Batte, 2008; Khanna, 2001).

The constructs inserted in this section are not determined by the farm manager. This means that the farmer's behavior depends on a set of variables determined by the

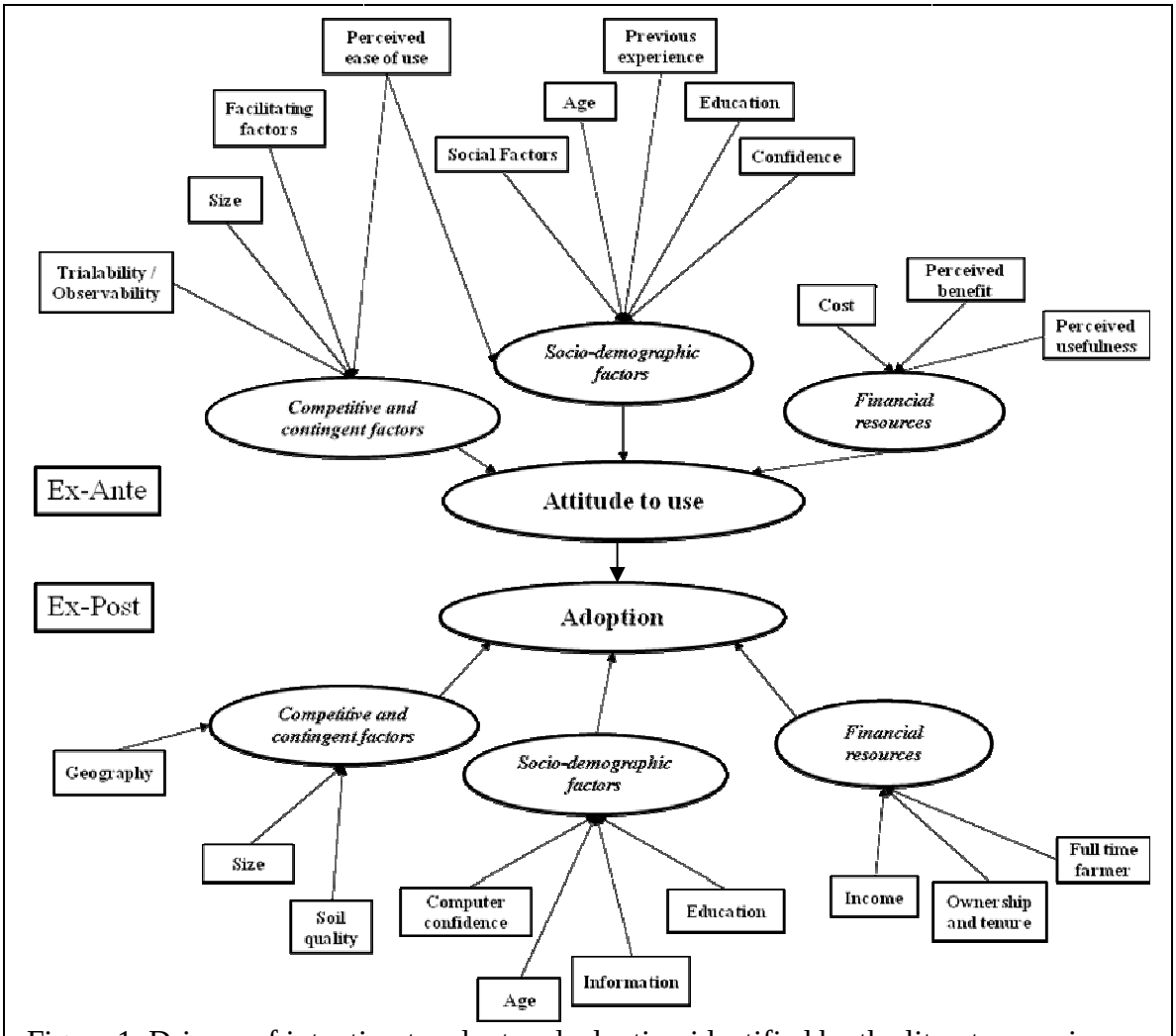

Figure 1. Drivers of intention to adopt and adoption identified by the literature review

external situation.

3.2 Socio-Demographic Factors

All the constructs and drivers included in this section are farmer specific, relating to the farmer's behavior, experience and perceptions and representing the farmer's point of view, beliefs and ideas towards the use of technology.

Drivers and constructs included in this section are Previous Experience/Confidence, Computer Confidence, Social Factors, Information, Age, Education, and Perceived Ease of Use (PEU), but the last construct refers to personal skills of potential users.

Some of these variables have similar meanings, but been classified differently between *Ex-post* and *Ex-ante* studies. For example, Previous Experience/Confidence and Social Factors, included in *Ex-ante* studies, in part include concepts of Computer Confidence and Information respectively, listed in the *Ex-post* section.

Confidence and Computer Confidence embody different human characteristics such as innovativeness and early adopter behavior. In *Ex-Ante* studies it is derived from the attitude to use technology (Adrian et al., 2005; Rezaei-Moghaddam & Salehi, 2010) since it is classified as "attitude of confidence". That is, a farmer more confident in technology than others, is far more likely use it. Previous experience with other similar technologies also affect the attitude towards adoption, since this previous experience operates as a type of training for the farmer (Aubert et al., 2012; Folorunso & Ogunseye, 2008; Marra et al., 2010).

Social Factors (*Ex-ante*) and Information (*Ex-post*) represent how the surrounding environment affects human behavior and farmer's attitude towards technology. The combination of these two drivers are the expression of the farmer's point of view and perception of the environment. Aspects summarized in Social Factors and Information are the peers/consultants influence on managerial decision: the farmer's belief to do something as influenced by others perception to do it (Daberkow & McBride, 1998, 2003; Folorunso & Ogunseye, 2008; Robertson et al., 2012). Furthermore, farmers who believe that the information from the extension services, universities and agricultural press are useful for farm management are more likely to become PA technology adopters (Larson et al., 2008; Reichardt & Jürgens, 2009).

Age shows mixed effects on adoption of PA tools (Tey & Brindal, 2012). In some cases, younger age was acknowledged as relevant because of the wider working horizons (D'Antoni, Mishra, & Joo, 2012; Folorunso & Ogunseye, 2008; Kutter et al., 2011; Larson et al., 2008; Walton et al., 2008). In contrast, some authors remarked that the age difference between adopters and non-adopters was inconsistent, even though significant (Daberkow & McBride, 2003). In other, cases age was found to be positively related to PA usage, therefore older farmers (over 50 years) seemed more likely to adopt new technologies than younger ones (Torbett, Roberts, Larson, & English, 2007).

PEU is a relevant construct for adoption, but it is affected by other variables such as Education, Previous Experiences, and Computer Confidence with other PA tools. These factors seem mutually related, since a more educated person is more confident with, and more inclined towards the use of computer technologies (Adrian et al., 2005; Aubert et al., 2012; Fernandez-Cornejo, Daberkow, & McBride, 2002; Hudson & Hite, 2003;

Khanna, 2001; Roberts et al., 2004). Furthermore, Computer Confidence or "personal skills", is influenced by experience, education, external influence and support availability. The clear general finding is that a more easy-to-use technology would encourages adoption by farmers (Adrian et al., 2005; Folorunso & Ogunseye, 2008; Karahanna & Straub, 1999; Venkatesh, 2000).

3.3 Financial Resources

This section gathers together all drivers depending on farmer's managerial aptitude. The choices made by the farmers define the current path and the future of their activity: a farm manager must know the market to decide when, how much and if to invest in a new technology, and furthermore to choose which crop and when and how to cultivate it.

We here deal with three constructs (*Ex-ante*) and three drivers (*Ex-post*) respectively named: Perceived Usefulness, Cost, and Perceived Benefit; and, Income, Ownership and Tenure, and Full Time Farmer.

The construct called Perceived Usefulness (PU) is defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1989). It embodies increasing performance/profitability as the main motivation stimulating the use of a new technology for business purposes (Adrian et al., 2005; Aubert et al., 2012; Folorunso & Ogunseye, 2008, 2008; Hite, Hudson, & Intarapapong, 2002; Rezaei-Moghaddam & Salehi, 2010). Cost is referred to as the economic burden that farmers have to sustain in order to use a new PA tool, and thus indicating only the perceptions about monetary aspects of the use of technology. If the cost is perceived as affordable, farmers have a more positive attitude towards the technology and a stronger intention to adopt (Hudson & Hite, 2003; Marra et al., 2010). Perceived Benefits represents the combination of the two above mentioned constructs in a single construct of the farmers' perception of the cost/usefulness ratio. In short, producers who perceive the cost to be greater than the benefit, have a less positive attitude and a weaker intention to adopt a new PA technology (Adrian et al., 2005; Hudson & Hite, 2003).

A new technology is perceived as a risky investment for a farmer, therefore, besides the attitude to risk, total income affects the ability, as well as the willingness, to pay for a new PA tool (D'Antoni et al., 2012; Daberkow & McBride, 1998; Walton et al., 2008). The driver Income can be influenced by production type, such as high value crops (Roberts, English,, & Larson, 2002), can be expressed as sales (Isgin et al., 2008), or, can represents the belief that PA technology could improve the farm profitability (Reichardt & Jürgens, 2009; Roberts et al., 2004).

The Ownership and Tenure driver reveals variable trends. Only a single paper shows that ownership/tenure is unrelated to adoption (Daberkow & McBride, 1998). In a subsequent paper, by the same authors, it was observed that "adopters own a significantly smaller share of the acreage they farm" (Daberkow & McBride, 2003). In two other papers, owners are less likely to adopt new PA technologies when compared to renters (Roberts et al., 2002; Torbett et al., 2007). In only one paper it was shown that

full-owners and owners of a larger farm portion, are more likely to adopt PA (Roberts et al., 2004).
The condition of being a full time farmer is the last driver for adoption of a new technology (Daberkow & McBride, 1998, 2003)

4. DISCUSSION AND CONCLUSIONS

Drivers and factors identified in this review outline a process, rather than a profile, of the "technology using" farmer. Hence, it is important to consider the previous research that already deals with the process that leads to the adoption of new approaches to farming.
The process of diffusion of innovation in agriculture has already been defined by Beal and Bohlen (1955), who attempted to provide an explanation of the factors that influence a farmer's decision for different groups of adopters and in each stage of the process. Innovators are the first farmers to adopt new technologies, as they work as "experimenters"; Community Adoption Leaders are those who are among the first to adopt something already tested, but not inclined to use something untested; Local Adoption Leaders have a strong reputation in their community, they are not early adopters but the community looks to them as opinion leader; Later Adopters are the majority of farmers and they use a new idea after its adoption by Local Leaders adopted; the last group is the Non-Adopters, those who opt-out and testify how things work without the adoption of the new technology. Rogers (1962) extended this classification to any new technology, distinguishing between Innovators, Early adopters, Early Majority, Late Majority and Laggards.
The process that leads to farmer adoption entails several steps: awareness, interest, evaluation, trial, adoption (Beal & Bohlen, 1955; Rogers, 1962). Different sources of information are important in each step. Mass media has more influence in the first two steps, then subsequently, in the evaluation stage neighbors and friends are most important. In the trial stage, agricultural agencies contribute to the perception of neighbors and friends', while in the last step of adoption, dealers and salesmen are the most important sources of information due to the presence of a "commercial product involved".
Further researches focused on the three principal variables of the diffusion process, Innovations, Innovators, Environmental Context (Wejnert, 2002).
What emerges from these works is the central role of the actor's characteristics in influencing the diffusion process. The characteristics of potential adopters determine when and how information arrives, how the value of a new technology is perceived and, ultimately, the decision making process about whether to adopt an innovation. The process that starts from awareness and leads to the decision to adopt a new technology is the same for Innovators as for Laggards, however it is simply the characteristics of the actors that accounts for differences in the time frames required for adoption.
In the PA context, the challenge for the future is to extend the limited diffusion of PA technologies and increase the number of adopters. The reconstruction of the managerial process leading to adoption enables a consideration of the different roles generated by

the drivers at different stages of the adoption process, also considering the three classes of drivers altogether allowing a more holistic understanding of this process.
The center of this process must always be the farmer, the farmer perceptions, values, beliefs, skills, experience, and all the environment factors that simultaneously affect behavior. Research and development activities may combine actual needs with farmers' skills in defining technological functions of a tool; subsequently, an appropriate promotional strategy can increase farmer awareness and favor a focused distribution policy, and the process ends when the farmer decide whether to adopt the PA tool. This review demonstrates that to achieve a greater PA adoption, efforts should be directed towards Non-Adopters, usually characterized by small size, low income, and less education, in the attempt to remove or mitigating the effects of the specific barriers to adoption.

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