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Factors influencing the adoption of Precision Farming Technologies in developed and developing countries: A Mediated Causal Conceptual Framework Model

Donika Maloku[1] Peter Balogh[2,3]

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A B S T R A C T
Precision farming has developed as a pivotal advancement in modern agriculture, tackling key challenges associated to economic, environmental and social sustainability. This article explores the implementation of precision farming technologies (PFTs) across developed and developing countries, focusing on the driving factors and challenges. A Mediated Causal Conceptual Framework Model is developed to analyse the factors influencing farmer's decisions on the adoption of precision farming technologies across national contexts. Based on a comparative approach and supported by empirical evidence from several studies, the research emphasizes how variations in farm sizes, degree of digitalization, capital availability, and the role of policy frameworks influence the adoption. The findings indicate that networking, government support, and training packages are fundamental in increasing awareness and willingness to adopt PATs. Likewise, high costs, limited information, and struggle to adjust continue to be substantial barriers in both advanced and emerging economies.

1. Introduction

Precision agriculture is a method of managing the entire farm that makes use of information technology, GNSS data, remote sensing, and close-proximity data collection (European Parliament, 2014). Since 1999 the development of precision farming has occurred concurrently with the fast progression and increased accuracy of the Global Navigation Satellite System (GNSS) and has been made possible by the development of sensor technologies (Uzunova & Dunchev, 2019). The foundations of precision agriculture is the modification of technological operations to the specifics of certain field locations and understanding a field's spatial variability along with using that knowledge to manage crops more precisely (Hallik, et al., 2022). Precision agriculture is often defined by the technologies, such as GPS (Global Positioning System), GIS (Geographic Information Systems), autosteer, yield monitors, and variable rate fertilizer which are shifting agriculture, and implementing opportunities to diminish the negative environmental effects (Shannon, et al., 2020). It has gained recognition in the continent of America in countries as USA, Canada, and Australia whereas in Europe, UK was the first country to adopt precision farming closely followed by France, and in Latin America it began in the middle of 1990 leading by Argentina and then later by Brazil (Tendulkar, 2020). Likewise, (Maloku, 2020) indicated in her study that United Kingdom, Denmark and Germany have higher rates of adoption compared with other countries in the EU, but the percentage rate of adoption is higher in the USA in comparison with EU countries where it prevails a diversification of precision agriculture technologies adopted by US farmers whereas in the EU, most research papers reported mainly some level of adoption of yield monitors/mapping and variable rate technologies for applying inputs.

[1] Donika Maloku
Doctoral School of Management and Business, University of Debrecen, 4032 Debrecen, Böszörményi street 138.
e-mail: donikamaloku03@gmail.com
[2,3]Peter Balogh
[2]Institute of Methodology and Business Digitalization, Faculty of Economics and Business, University of Debrecen, H-4032 Debrecen, Hungary
[3]HUN-REN-DE High-Tech Technologies for Sustainable Management Research Group, University of Debrecen, H-4032 Debrecen, Hungary
e-mail: balogh.peter@econ.unideb.hu

The main challenges of precision agriculture are the price of technological equipment, farmers' financial limitations, access to credit and the farmers' familiarity with digitization tools (Kritikos, 2017). Likewise, perceptions of net benefit, farm size, farmer educational levels and attitudes of confidence toward using the precision agriculture technologies certainly affected the aim to embrace precision agriculture technologies (Adrian, et al., 2005). Similarly, (Tamirat, et al., 2017) point out that farm size, farmer age, demonstration and networking events as joining workshops and exhibitions considerably influence farmers' adoption decision.

The main purpose of this study is to provide a systematic overview of the factors that are affecting the decision of farmers to adopt precision farming techniques. Therefore, this assessment provides a comprehensive literature review of the studies that are published in relation with current adoption trends in precision farming technologies.

2. Methodology

A Mediated Causal Conceptual Framework Model is developed to analyse the factors affecting the adoption of precision farming technologies in developed and developing countries. A mediated causal conceptual framework model enlightens how an independent variable affects a dependent variable indirectly through one or more mediator variables, and its main components are: a) Independent Variable (IV) which is supposed to make adjustments in the dependent variable, b) Mediator Variable (MV) which clarifies the way the independent variable impacts the dependent variable, and c) Dependent Variable (DV) which its result is predisposed by an independent variable through a mediator variable (Baron & Kenny, 1986). Likewise, employs a well-defined distinction between direct and indirect effects through the counterfactual framework (Byeon & Lee, 2023). The literature is collected from 1999 to 2023 through Scopus and Google scholar, and a review of the findings of PAT adoption studies is done. Many scientific articles were found, but only empirical papers were selected. A total of 31 empirical papers on factors influencing the adoption of precision farming technologies were collected. Published papers are based on different countries and highlight information as country, sample, scale, analysis method, type of technologies, variables and sources.

Table 1. Scientific articles published by authors.

Country	Sample	Scale	Method	Type of technology	Variable	Source
Iran	234	Farm	Descriptive research design	Different PATs	7	(Allahyari, et al., 2016)
Brazil	148	Farm	A duration Analysis	LEISA practices	4	(Filho, et al., 1999)
Philippines	30	Farm	Binary Logit and Poisson estimators	Modern rice technologies	5	(Mariano, et al., 2012)
Iran	183	Farm	Structural equation modelling	Different PATs	1	(Far & Rezaei-Moghaddam, 2017)
USA	816	Farm	An empirical analysis	Different PATs	5	(Isgin, et al., 2008)
EU	971	Farm	A multilevel random intercept regression	Machine Guidance; VRNT	7	(Barnes, et al., 2019)
Italy	200	Farm	A context-related analysis	Different PATs	6	(Vecchio, et al., 2020)
Netherlands	111	Farm	Factors analysis	Technologies for manure separation	3	(Gebrezgabher, et al., 2015)
Global	20	Farm	A Snowball approach	Different PATs	4	(Pierpaoli, et al., 2013)
Nigeria	480	Farm	A logit econometric model	Different PATs	5	(Onu, 2006)
USA	913	Farm	Tobit regression methods	Yield Monitoring; Remote Sensing; GSS	2	(Watcharaanantapong, et al., 2012)
USA	1, 692	Farm	A nested logit model	Different PATs	3	(Nair, et al., 2011)

Source: Author's own work

Table 1. Continued.

Denmark	178	Farm	Descriptive	Yield Mapping; Soil sampling; VRT	4	(Pedersen, et al., 2004)
Iran	27,670	Farm	Davis's acceptance model	Different PATs	1	(Salimi, et al., 2020)
Global	34	Farm	An innovation diffusion framework	Different PATs	2	(Pathak, et al., 2019)
Denmark and Germany	260	Farm	A binary logit model	GPS; Auto-guidance	3	(Tamirat, et al., 2018)
Czech Republic	228	Farm	Correlational	Different PATs	4	(KUŠOVÁ, et al., 2017)
Germany	227	Farm	Binary logistic regression model	Different PATs	3	(Paustian & Theuvsen, 2017)
USA	1,200	Farm	Probit and negative binomial regressions	Different PATs	5	(Kolady, et al., 2020)
USA	941	Farm	A logit model	Remote Sensing; VRT	5	(Larson, et al., 2008)
Hungary	72	Farm	Box-plot analysis	Tractor Guidance	3	(Lencsés, et al., 2014)
Brazil	119	Farm	Logit and Poisson models	Different SF technologies	6	(Pivoto, et al., 2019)
Hungary	634	Farm	Descriptive and Statistical tests	GPS; Autopilot	7	(Balogh, et al., 2020)
USA	13,783	Farm	Poisson-hurdle regression	Georeferenced precision soil testing (PST)	4	(Lambert, et al., 2014)
USA	102	Farm	Poisson regression	Different PATs	1	(Castle, et al., 2016)
USA	1,215	Farm	A multivariate probit regression	Different PATs	4	(Jenkins, et al., 2011)
Denmark and USA	198	Farm	Statistical tests	Different PATs	2	(FOUNTAS, et al., 2005)
Poland	21	Farm	Snowball Approach	Different PATs	6	(Yarashynskaya & Prus, 2022)
Australia	22	Farm	Cross-Case analysis	VRT; SST; auto-steer tractors	1	(C, et al., 2006)
India	110	Farm	Descriptive analysis	Drip and fertigation system	3	(Sangeetha, et al., 2013)
Italy	174	Farm	Cluster Analysis	VRT	5	(Masi, et al., 2023)

Source: Author's own work

3. Results

In developing countries, in general the main factors that influence the decision of farmers to adopt PATs are farm size, social influence, competition, government support and complexity of technology (Nguyen, et al., 2023). In developed countries, the count data analysis results of a random sample of Ohio farm operators demonstrate that various factors such as farm size, farmer demographics, soil quality, urban influences, farmer status of indebtedness, and farm location within the state, were significantly associated with the adoption intensity and probability of precision farming technologies (Isgin, et al., 2008). Apart from yield monitors with GPS, which were more likely to be adopted in counties with more cropland, more full-owner farmers harvesting crops, and fewer part-owner farmers harvesting crops, all technologies evaluated were more likely to be adopted in counties where part-owner farmers owned more land than the amount they rented. adoption of at least one precision farming technology (APF) was more likely in counties with more acreage in large farms, lower-valued crop production, more full-owner farmers harvesting crops, and fewer part-owner farmers harvesting crops (English, et al., 2000).

Table 2. PAT adoption factors.

FACTOR	EXPLANATION	SOURCE
SOCIO-ECONOMIC FACTORS		
AGE	Younger farmers are more likely to accept the risks associated with the new farm innovation	Tamirat, et al., 2018; Lencsés, et al., 2014; Jenkins, et al., 2011; Yarashynskaya & Prus, 2022; Larson, et al., 2008;
EDUCATION	Highly educated farmers were more likely to adopt PATs.	Allahyari, et al., 2016; Mariano, et al., 2012; Gebrezgabher, et al., 2015; Pivoto, et al., 2019; Jenkins, et al., 2011; Yarashynskaya & Prus, 2022; Larson, et al., 2008
GENDER	Higher adoption for men than women	Onu, 2006
NETWORKING	Attending networking events significantly influence farmers' adoption decision	Filho, et al., 1999; Nair, et al., 2011; Tamirat, et al., 2018; Onu, 2006;
EXPERIENCE	Having a long experience in farming influence the adoption of PATs.	Paustian & Theuvsen, 2017; Lambert, et al., 2014;
FINANCIAL FACTORS		
OFF FARM INCOME	Having an additional farming business or another source of income, increases the possibility of PATs adoption.	Paustian & Theuvsen, 2017;
FINANCIAL POWER	Financial situation can influence the use of PATs.	KUŠOVÁ, et al., 2017; Balogh, et al., 2020; Jenkins, et al., 2011; Barnes, et al., 2019;
CREDIT AVAILABILITY	The likelihood of obtaining an investment loan boosts the adoption of PATs.	Yarashynskaya & Prus, 2022;
AGRO-TECHNOLOGICAL FACTORS		
FARM SIZE	Larger farms have higher adoption rate.	Filho, et al., 1999; Barnes, et al., 2019; Gebrezgabher, et al., 2015; Nair, et al., 2011; Tamirat, et al., 2018; Kolady, et al., 2020; Balogh, et al., 2020; Lencsés, et al., 2014; Castle, et al., 2016; Jenkins, et al., 2011;
APPLICATION OF IRRIGATION SYSTEMS	Those using irrigation are more likely to adopt a higher number of PATs	Mariano, et al., 2012; Castle, et al., 2016; Larson, et al., 2008;
TECHNOLOGICAL FACTORS		
INTERNET CONNECTION	Lack of internet access can prevent the use of PATs.	Yarashynskaya & Prus, 2022; Pivoto, et al., 2019;
INSTITUTIONAL FACTORS		
GOVERNMENT FUNDING	Access to government funding was also rated as very important factor.	Balogh, et al., 2020;
INFORMATIONAL FACTORS		
LACK OF INFORMATION	Being well updated about technological innovations increases the probability of PATs adoption.	Yarashynskaya & Prus, 2022; Balogh, et al., 2020;

Source: Author's own work

In (Table 2) are briefly elaborated the main factors that influence the adoption of PATs based on the empirical papers that we collected and analysed. The main factors are divided and named into eight groups as: socio-economic, financial, agro-technological, technological, institutional, informational, regional and behavioural. Farm size, education, age, networking and financial power were mentioned more frequently by authors in their articles (Table 2). As a result, these are the key factors that influence the implementation of precision farming technologies. Farm size does affect the adoption of precision farming technologies in both developed and developing countries. Besides farm size, developing

countries are more affected by lack of financial sources, lack of government support and lack of technological infrastructure, whereas developed countries are more affected by financial capacity and education. However, not every developed country is facing a high adoption rate of PATS. For instance, in Italy which continues to stay behind of most other European Union nations in the application of PATs with only 1% of Italy's cultivated land managed by precision farming technologies is having the main problem computerization or how to decode the data since most of farmers who already use this technology face many difficulties in managing such a large amount of data collected by PATs (Bucci, et al., 2019).

Moreover, farmers who had long experience in farming had a higher chance of adopting one of PATs. Similarly, having under 5 years' experience in crop farming, having between 16- and 20-years' experience in crop farming, and having more than 500 ha of arable land (Paustian & Theuvsen, 2017). Attending networking events such as workshops and exhibitions (Tamirat, et al., 2017), and the more social organizations farmers belong to and participate in (Onu, 2006), significantly influences the farmers decision about adoption of PATs. Likewise, (Blasch, et al., 2022) supports that knowledge of fellow farmers who adopted the technology positively impacts the assessment of precision farming technology features, highlighting the value of networks. Lack of internet access was mentioned as an important technological factor which having non access can prevent the usage of PATs. Technological basics, like the accessibility and use of smartphones, computers, and the Internet, are indicatory of the overall technological advancement of farmers and farms, since farmers who are open to new technologies are more likely to embrace PATs as smartphones come with pre-installed applications and sensors, they can partially replicate PATs and serve as their complements, or integral parts and can be used for data collection, intermediate data storage, processing, and transfer to a computer for decision-making and storage (Yarashynskaya & Prus, 2022).

Access to government funding was also rated as a very important factor. The primary obstacle to spreading of PATs is the high cost of investment but adequate information and a particular package of subsidies included in the EU's Common Agricultural Policy's "greening" component as well as the Rural Development Program would boost the spread of PATs (Katalin, et al., 2017). Lack of information is also an important factor for adoption of PATs. The literature considers information awareness of PATs as an important component for adoption of these technologies from sources as: PA tech firms, universities, farmer's Unions, Governmental Agencies, educational centers and Extension services (Yarashynskaya & Prus, 2022). Moreover, regional factors such as the industrial structure of suppliers were mentioned also in the literature we collected. Regional factors such as the presence of farmers co-operatives and industrial structure of suppliers will determine the access to and availability of PATs (Barnes, et al., 2019). Likewise, apart from disparities in income and size, which indicate the financial burden on adoption, there is also a difference in attitude regarding the likelihood of technology uptake due to optimism about its financial return (Barnes, et al., 2019).

3.1. Mediated Causal Conceptual Framework Model

A Mediated Causal Conceptual Framework Model conceptual is developed to analyse the factors affecting the adoption of precision farming technologies in developed and developing countries. The noted framework model (Figure 1) highlights the mediated causal relationships participating in the adoption of Precision Farming Technologies. Specifically, demonstrates how various sorts of components which are classified as independent variables, mediating variables, and a dependent variable cooperate in the adoption process of Precision Farming Technologies.in other words, provides a comprehensive understanding of what drives and hinders the adoption of PATs. It demonstrates that the adoption is not simply based on one main general factor like high cost or farm size, but it's a challenging decision influenced by a mixture of other factors like socio-economic, financial, technological and regional elements which are also affected by other factors such as farmer's behaviour and access to information.

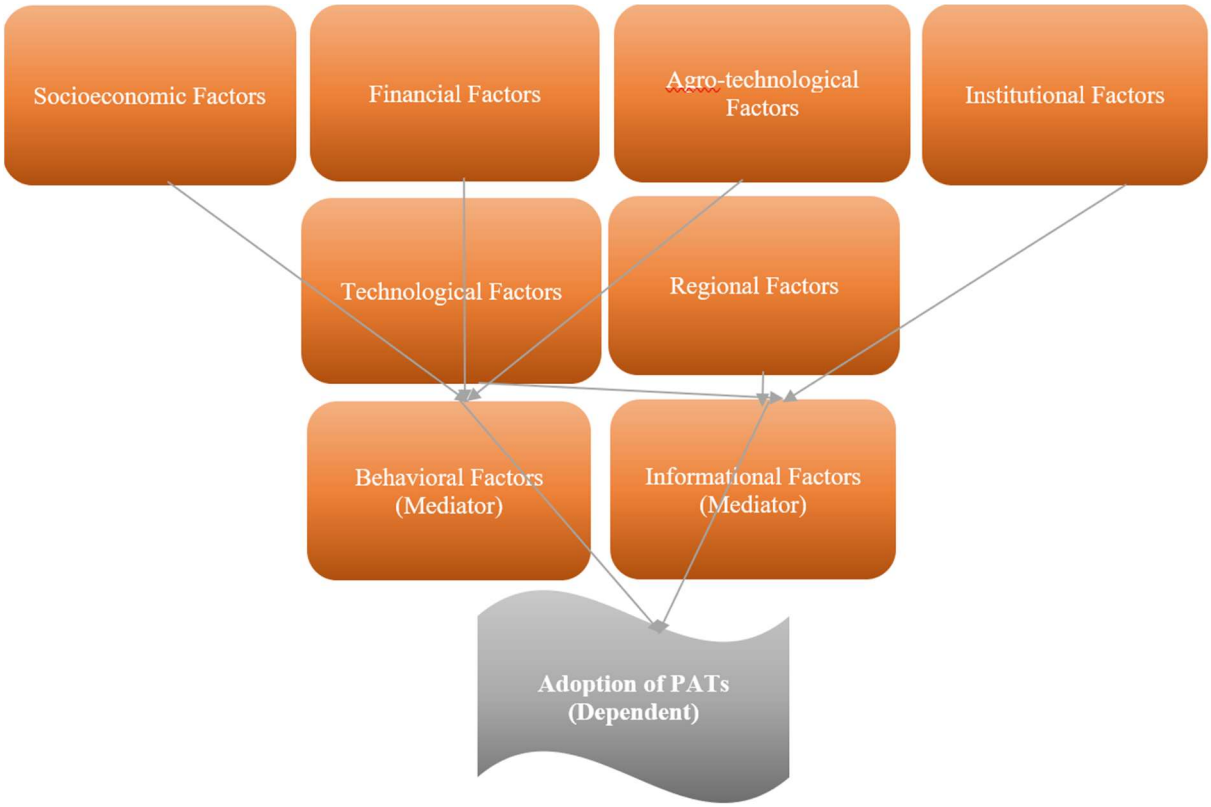


Figure 1. Mediated Causal Conceptual Framework Model of Adoption of Precision Farming Technologies in developed and developing countries (Source: Author's own affiliation).

The identified factors have direct and indirect influences on the adoption of Precision Farming Technologies. Independent variables are Socio-economic factors (education, gender, networking, experience), Financial Factors (off-farm income, financial power, credit availability), Agro-technological Factors (farm size, application of irrigation systems), Technological Factors (internet connection) and Regional Factors (industrial structure of suppliers). Mediation variables are Behavioural Factors (perceived usefulness, time requirement, personality) and Informational Factors (lack of information, awareness of technology). Dependent variables are the adoption of precision farming technologies. The independent variables all have direct routes to the dependent variable. These arrows demonstrate that these factors can influence the adoption directly. For example, age and education can directly influence the farmer's decision to adopt PATs because it determines whether younger or older farmers, and non-educated or well-educated farmers are more likely to adopt PATs. Similarly, size of the farm can directly impact farmer's decision because it demonstrates whether the farm is large enough to be able to apply these sophisticated technologies. Likewise, financial power and credit availability can directly influence the farmer's decision because it determines whether they are financially stable to buy precision farming technologies.

On the other hand, mediators perform an important position whether to accept or prevent the direct impact of independent factors. These factors cooperate with mediating variables like behavioural perceptions (perceived usefulness) and informational obstacles (lack of information), to initiate the possibility of adopting PATs. Behavioural factors express farmers' attitudes and willingness in embracing new technologies, while informational factors demonstrate farmer's access to information and consciousnesses toward innovations. Behavioural factors can indirectly impact the farmer's choice if they see profit from technology whereas informational factors can indirectly impact farmer's choice if they lack access to adequate information about the technology, despite having strong financial background. Networking and informational factors have indirect impact on the adoption of PATs. For example, networking allowed farmers to share information about new technologies and usage of technologies, as without networking farmers lack awareness. A cross-regional study of EU farmers

showed that information seeking behaviour evidenced significant when upgrading from machine guidance to variable rate technologies and advocated more indirect interventions such as informational support to oppose industry bias and demonstrate capability of economic profit (Barnes, et al., 2019).

Socio-economic factors with behavioural factors can indirectly influence adoption of PATs. For instance, well-educated farmers perceive precision farming technologies as essential for expanding production and efficiency. A study made in Nebraska presented that producers expressed concern over not knowing how to interpret and use the data as well as the overall affordability and cost of the technologies producing the data even though they have seen surges in profits and productivity due to use (Castle, et al., 2016). Similarly, age and behavioural factors can indirectly impact adoption of PATs. A study conducted in Denmark and Germany revealed that farmers below the age of 50 years showed a higher tendency to adopt in contrast to their older complements where in reality very young farmers lack the managerial practises and may have little understanding of adaptabilities in their farm whereas old farmers' may be liable to outdated resistance to changes and they may not see longer-term economic benefits possibly since they are reflecting retiring (Tamirat, et al., 2017). Likewise, financial and behavioural indirectly impact the use of PATs. For example, farmers who have access to micro-loans, strong financial stability and off-farm income tend to show more willingness toward PATs. Moreover, large farms perceived PATs as a lucrative investment showing more willingness to apply PATs, in contrast to small farmers which lack in willingness and confidence.

Furthermore, farmers who use irrigation systems tend to be more informative towards new trends and have more willingness to adopt PATs. A study about Texas cotton producers indicates that the adoption rate of both PA technologies and VRT is positively linked with adoption of efficient irrigation technologies like center pivot and sub-surface drip irrigation systems, and the PA adoption rate was found to be higher between producers with higher irrigated cotton output (Nair, et al., 2014). Next, government funding and informational factors indirectly impact the use of PATs. For example, farmers in those countries where government who offer obligatory workshops tend to be more informed about everything new that is occurring in agriculture industry. In Philippines, government interventions to improve the educational level of farming households is needed to increase technology adoption in the long run (Mariano, et al., 2012). A study in Iran indicated that performing training programs is needed for personnel staff and found that personnel and consultants with higher confidence about employing PATs have greater intention to adopt PATs (Far & Rezaei-Moghaddam, 2017). Also, farmers with limited internet access tend to be less informed and struggle to apply precision farming technologies.

In addition, the route to the decision to implement precision farming technologies is fairly complicated. However, providing farmers access to financial sources such as credit loans and providing training programs to be familiar about PATs may markedly enhance adoption ratios. Eventually, this framework model helps in identifying the main barriers and conquer them.

4. Conclusions

In general, in developing countries, the main factors that influence the decision of farmers to adopt PATs are farm size, social influence, competition, government support and complexity of technology. On the other hand, in developed countries, the main factors are farm size, farmer demographics, soil quality, urban influences, indebtedness, and location. Overall, the key obstacles are high costs, lack of information, time requirements, and data handling disputes. Adoption is slower in some regions, such as Italy, due to challenges with data management and computerization. A Mediated Causal Conceptual Framework Model is developed to analyse the factors affecting the farmer's decision on adoption of PATs. The framework model illustrates how the adoption of Precision Farming Technologies (PATs) is directly affected by several factors such as socio-economic characteristics, financial resources, farm size, and access to technology whereas behavioral attitudes and informational barriers mediate the process, determining farmers' decisions. Networking, government support, and training packages are fundamental in increasing awareness and willingness to adopt PATs. Nevertheless, high costs, limited information, and struggle to adjust continue to be substantial barriers in both advanced and emerging economies.

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