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Agricultural Digitalization and Farm Productivity: Insights from Dynamic Capabilities Theory in the Pakistani Context

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Abstract
Purpose: This research examines the effect of agricultural digitalization on farm productivity in Pakistan with the mediating role of Farmer Entrepreneurial Orientation (FEO) and the moderating effect of Agricultural Extension Support (AES). Grounded in Dynamic Capabilities Theory (DCT), the research focuses on the use of three forms of transformation (technological adoption, behavioural capabilities, and institutional support) that collectively enhance agricultural performance.
Design/Methodology/Approach: A quantitative and cross-sectional survey was conducted among 300 smallholder and medium-scale farmers in the provinces of Punjab, Sindh, and Khyber Pakhtunkhwa. A structured questionnaire was used to measure agricultural digitalization, FEO, AES, and farm productivity, utilizing validated scales. Data was analyzed with Structural Equation Modeling (SEM) to evaluate direct, mediating, and moderating relationships.
Findings: Findings show that agricultural digitalization has positive effects on farm productivity and FEO. FEO mediates the relationship between digitalization and productivity to some extent, providing evidence of it being a mechanism of behavior that converts technological adoption into tangible results. Additionally, AES supports the impact of digitalization on FEO, demonstrating that external support improves the ability of farmers to use digital tools effectively. The proposed model explains 51% variance of farm productivity, which highlights the significance of dynamic capabilities in agricultural performance.

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Practical Implications: Policymakers and agricultural organizations should pay attention to integrated interventions that include a combination of the deployment of digital technologies, entrepreneurship development, and extension support in order to maximize farm productivity and farm sustainability.
Originality/Value: This study is an extension of DCT to the agricultural context of a developing country that offers empirical evidence on the synergy effects of digitalization, entrepreneurial orientation, and institutional support towards improving farm performance.

Keywords: Agricultural Digitalization, Farmer Entrepreneurial Orientation, and Agriculture Extension Support. Farmers' Productivity, Dynamic Capabilities Theory, Pakistan.

Introduction

Agriculture is the backbone of many developing economies and plays a significant role in contributing to employment, food security, and economic growth (Li et al., 2020). In Pakistan, it contributes approximately 19% of the national GDP and supports the livelihood of nearly 42% of the population (Ul Hassan et al., 2023). Despite being critically important, agricultural productivity in developing countries tends to be constrained due to factors like climate variability, inefficient resource utilization, poor access to modern technologies, and poor market linkages, among others (Klerkx et al., 2019; Irshad et al., 2024). These challenges are further complicated by the inherent volatility of the agricultural environment, with swings in weather patterns, pest infestation, and global market influences having a significant impact on farm performance. Consequently, enhancing farm productivity and sustainability has become an important issue for policymakers, practitioners, and researchers alike (Gul et al., 2019).

Digital technologies are increasingly being identified as transformative technologies that can help overcome the challenges of modern agriculture .(Arshad et al., 2025) Agricultural digitalization, which can be defined as the adoption and integration of technologies such as artificial intelligence (AI), drones, sensors, Internet of Things (IoT), precision farming machinery, and mobile applications, is changing the way farms work (Klerkx et al., 2019; Li et al., 2020). These tools allow farmers to make better decisions by providing them with real-time information about the health of their crops, the condition of their soil, how much water their crops need, if they have an infestation of pests, and what price they can get for their crops on the market (Khan et al., 2021). In addition, digital platforms are able to facilitate access to financial services, input suppliers, and new market opportunities, thus reducing transaction costs and enhancing participation in markets (Barrett & Constas, 2014). Digitalization, thus, has the potential to transform industrial agriculture into knowledge-intensive, data-driven, more resilient, productive, and sustainable agriculture (ul Hassan et al., 2023).

However, the availability of digital technologies is not necessarily a sufficient condition for better farm performance (Gul et al., 2025). The effectiveness of technology adoption is contingent upon the ability of the farmer to utilise these tools strategically, and this

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is influenced by entrepreneurial mindset, skills, and willingness to experiment (Ul Hassan et al., 2023; Irshad et al., 2024). Farmer Entrepreneurial Orientation (FEO), which includes innovativeness, proactiveness, and risk-taking behavior, has a central role in this regard (Wiklund & Shepherd, 2005). Innovative farmers are more likely to look for new technologies and new ways of production; proactive farmers anticipate market demands as well as environmental risks, and risk-taking farmers are willing to invest in new opportunities despite the uncertainties. By displaying such activities, farmers can convert technological inputs into measurable results in terms of performance, which may include increasing productivity, profitability, and efficiency of operation (Rana et al., 2024).

The interrelationship of agricultural digitalization, FEO, and farm productivity can be explained theoretically based on the Dynamic Capabilities Theory (DCT) (Atif et al., 2024). DCT believes that competitive advantage is not only due to the availability of valuable resources to organizations but also to the ability to recognize opportunities and threats, to effectively capitalize on them, and to be able to reconfigure resources to sustain performance within dynamic environments (Teece, Pisano, & Shuen, 1997; Teece, 2007). In agriculture, digital technologies increase the sensing capability of the agricultural sector by using timely and accurate information on the environmental and market conditions. FEO strengthens its seizing capacities to enable farmers to work on the opportunities that are highlighted through digital tools. Finally, reconfiguration of resources (including labor, inputs, and knowledge systems) assures that technological and entrepreneurial capabilities are converted into enhanced farm productivity. In this way, DCT provides a coherent framework to understand the impact of digitalization on the outcome of the farm through the role played by entrepreneurial behavior (Gul et al., 2021).

Another important aspect in this ecosystem is Agricultural Extension Support (AES). Extension services such as advisory programmes, training programmes, technical advice, and digital literacy interventions are external enablers to increase the effectiveness of internal dynamic capabilities (Anderson & Feder, 2007; Ul Hassan et al., 2020). AES is supporting the farmers to sense make complex digital information, develop competencies to use digital tools effectively, and experiment with innovative production methods (Gul et al., 2024). By easing any uncertainty that new technologies bring, extension support helps to build up confidence in decision-making and encourages farmers to be proactive and innovative in their behaviour. Therefore, the adoption of technology is not only supported by AES but also contributes to the impact of digitalization on entrepreneurial orientation and finally farm productivity (Khan et al., 2020).

Despite the awareness of the importance of digitalization in agriculture, very few empirical studies have been undertaken to study the effects of digitalization on farmer behaviour and performance in developing countries (Mumtaz et al., 2025). Existing research is often on technology adoption rates or operational efficiency, but there is no explicit research on mechanisms of behavioral and organizational causes that lead to productivity improvements (Klerkx et al., 2019; Li et al., 2020). Moreover, the role of entrepreneurial orientation as a mediating mechanism and extension support as a

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moderating factor has been underexplored, especially as related to smallholder farming systems in Pakistan (Hanif et al., 2023). Addressing these gaps is important towards creating a holistic understanding of how digital technologies could be leveraged to improve farm productivity in resource-constrained and volatile environments.

This research study is designed to bridge these gaps by examining the links between agricultural digitalization and Farmer Entrepreneurial Orientation and farm productivity, with emphasis on the moderating role played by Agricultural Extension Support. Specifically, the present study examines (1) the role that digital technologies play in farm productivity, (2) the extent to which entrepreneurial orientation mediates the relationship between digital technologies and farm productivity, and (3) the extent to which extension support assists in the process of digitalisation in promoting entrepreneurial behaviour. By introducing DCT in the analysis, the research provides a theoretically based approach for explaining technological and behavioral capabilities in terms of improved farm performance in dynamic agricultural contexts.

The relevance of this research is increased in the light of Pakistan, where smallholder farmers are the majority of agricultural producers, are facing huge challenges associated with resource constraint, market access, and climate vulnerability (Ul Hassan et al., 2023; Irshad et al., 2024). By focusing on the relationship between digitalization, entrepreneurial orientation, and extension support, the study offers practical information for decision-makers in the government and agricultural extension sectors and technology providers who are looking to enhance farm productivity and sustainability. Furthermore, the research adds to the literature by showing the usefulness of the Dynamic Capabilities Theory in explaining the role of resource integration, sensing of opportunities and capability reconfiguration in driving performance in the agricultural sector, a field that has received little attention in DCT research to date.

In sum, this study contributes in the light of the knowledge of modern agricultural practices in showing the importance of digital technologies as dynamic capabilities that can, when complemented with entrepreneurial orientation and with the support of extension services, have a great impact on farm productivity. The results of the study are expected to be applied in designing interventions, policies and capacity building programs intended to build a technologically empowered, entrepreneurial and resilient farming sector in Pakistan and other developing economies. By combining the technological, behavioural and institutional aspects the research presents a holistic framework for the promotion of sustainable agricultural development in dynamic and uncertain environments.

2 Literature Review

Agricultural systems, in particular in developing countries like Pakistan, are working in a highly dynamic and uncertain environment, which is characterised by climate variability, volatile markets, resource constraints and rapid technological change (Klerkx et al., 2019; Li et al., 2020). In such contexts, the adoption of digital technologies may be seen as a dynamic capability that enables farmers to become sensitive to emerging opportunities, to successfully seize these opportunities, and to

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reconfigure resources to achieve sustained performance (Teece, Pisano, & Shuen, 1997). Dynamic Capabilities Theory (DCT) provides a coherent window of understanding, within which the interaction of digitalization, entrepreneurial orientation and extension support can contribute to transforming productivity on the farm. DCT assumes that firms - or in this case, farms - get a competitive advantage not by just a possession of resources, but through processes of sensing, seizing, and reconfiguring capabilities (Teece, 2007). In the agricultural sector, digitality can be considered as a host of strategic enabler technologies to enhance these capacities and allow farmers to react to environmental complexity and market uncertainty on a proactive level.

2.1 Digitalization of Agriculture And Farm Productivity

Agricultural digitalization is a broad term that encompasses many types of technologies, such as artificial intelligence (AI) based decision support systems, sensors, drones, internet of things (IoT) devices, precision machinery, mobile applications, and other types of data-driven platforms. These technologies revolutionise farming systems by helping in terms of better decision making, efficient allocation of resources, reduced wastage, and better efficiency in operations (Barrett & Constas, 2014; Li et al., 2020). From a dynamic capabilities perspective, digitalization boosts the level of sensing capacity of the farmers to monitor soil conditions, crop health, pest infestation and market rates in real time. Such a better awareness helps farmers to identify early signs of threats or opportunities to underpin timely and informed interventions (Klerkx et al., 2019).

Digital tools are also contributing to the seizing dimension of DCT through facilitated decision-making and resource mobilisation. For example, weather alerts powered by AI or predictive analytics are used to regulate the times of irrigation, planting, and harvesting, as well as reduce the risks associated with the variability of the climate (Ul Hassan et al., 2023). Likewise, the services that digital marketplaces and platforms offer to farmers (such as finding profitable sales channels, securing financial services and connecting with buyers more efficiently) can be instrumental in improving their ability to capture value from agricultural activity. In addition, digitalization allows to reconfigure of farm resources, such as labor, inputs, and knowledge, to enhance operational efficiency and productivity. With automation of the repetitive tasks, optimizing the input handling and integrating the information flow, farmers are able to transform fragmented resources into systems that are coordinated and productive (Li et al., 2020; Irshad et al., 2024).

Empirical evidence shines light on the notion that farms that exploit exhausting and less effective use of digital technologies have higher yields and an overall operational effectiveness and better sustainability factors (Klerkx et al. 2019; Rana et al. 2024). Digitalization, in this way, as a dynamic capability, does not just offer information but changes the ability of farmers to act strategically in complex environments. Therefore, it is the hypothesis that:

H1: *Agricultural digitalization has a positive effect on farm productivity.*

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2.2 Agricultural Digitalization and Farmer entrepreneurial Orientation

Farmer Entrepreneurial Orientation (FEO) refers to the tendency of farmers to be innovativeness, proactiveness, and risk-taking behaviour in search of new agricultural opportunities (Wiklund & Shepherd, 2005). From the perspective of dynamic capabilities, digitalization improves the FEO by boosting the ability of farmers to sense, seize and reconfigure the opportunities in the agricultural ecosystem. Digital technologies increase the sensing capacity of farmers by giving them timely and precise information on market trends, climate risks, and possible innovations (Teece et al., 1997). This information allows farmers to determine future entrepreneurial opportunities that were previously inaccessible or hard to detect, which helps generate entrepreneurial thinking.

Digital platforms and tools also increase the seizing capabilities of farmers, enabling them to properly exploit the opportunities detected. Through online marketplaces, integration of the supply chain, and digital financial services, farmers are able to diversify crop types, try new production methods, and access better markets (Barrett & Constas, 2014). These capabilities are very important in the world of entrepreneurship, where the ability to act quickly and strategically is the key to success. Furthermore, the digitalization promotes the reconfiguration towards entrepreneurial mentality through the learning, experimentation and adoption of innovative practices. Exposure to digital information builds confidence in farmers in decision-making and promotes controlled risk-taking, which is in line with the risk dimension of FEO (Ul Hassan et al., 2020).

Recent studies show digitised farms are more likely to adopt new technologies, seek innovative ways of production, and exhibit active market behaviour (Irshad et al. 2024; Rana et al. 2024). Digitalization, therefore, works as an enabler of entrepreneurial capabilities, i.e., it changes conventional, reactive ways of farming in growth-oriented, innovative strategies. Accordingly:

H2: *The effect of agricultural digitalization on Farmer entrepreneurial orientation is positive.*

2.3 Farmer Entrepreneurial Orientation and Productivity of Farms

Entrepreneurial orientation has been found to be a very important factor in determining farm performance, especially under conditions of uncertainty and competition. Innovativeness is the ability of farmers to adopt new technology, try out alternative methods of production, and use creative solutions to improve their productivity. This is in line with DCT's dimension of reconfiguration, where farmers restructure their internal resources to avail opportunities and overcome challenges (Teece, 2007). The other dimension of EO, proactiveness, enables farmers to look into market demands, climate fluctuations, and technological shifts, as the sensing capacity of DCT. Proactive behaviour is useful in preventing losses, taking advantage of favourable market conditions, and discovering productive avenues before their competitors do (Barrett & Constas, 2014).

Risk-taking, the third dimension of FEO, allows farmers to invest in new crops, new technologies or new diversified ways of producing. Through calculated risks, farmers improve their seizing capabilities and increase the likelihood of having better

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productivity outcomes (Wiklund & Shepherd, 2005). Empirical research shows that entrepreneurial farmers have higher adaptability, resilience, and growth orientation, which results in improved operational and financial performance (Klerkx et al., 2019; Ul Hassan et al., 2023). In keeping with dynamic capabilities, FEO provides for effective deployment of resources and technologies for enhancing farm productivity. Thus:

H3: *Farmer Entrepreneurial Orientation has a positive impact on farm productivity.*

2.4 Mediation Farmer Entrepreneurial Orientation

While agricultural digitalization does ensure that farmers have the tools and information they need to improve farm operations, the impact on productivity is often dependent on the skills the farmer has in using these resources entrepreneurially. Digitalization has added value to FEO with regard to increasing access to information, and further stimulating innovative thinking, reducing uncertainty, and establishing confidence in decision making - thus building entrepreneurial skills that are crucial in dealing with complex agricultural environments (Teece et al., 1997; Li et al., 2020). Entrepreneurial farmers in turn, are efficient in the utilization of innovations, experimentation with varied combinations of resources, and identification and pre-emptive response to emerging opportunities leading to higher productivity (Ul Hassan et al., 2023).

In DCT terms, digitalization improves sensing by providing better environmental awareness, FEO improves seizing by enabling the exploitation of opportunities and resource reconfiguration brings farm operations in line with strategic objectives (Irshad et al., 2024). Therefore, digitalization and farm productivity are related at least partially through FEO: entrepreneurial orientation is the process of taking technological inputs and converting them into effective value-creating actions:

H4: *Farmer Entrepreneurial Orientation mediates the relationship of agricultural digitalization and farm productivity, whereby digitalization increases FEO and increases farm productivity.*

2.5 Moderating Role of Agricultural Extension Support (AES)

Agricultural Extension Support (AES) encompasses advisory support services, capacity building programs, technical services, and digital literacy interventions that are aimed at improving the knowledge and skills of farmers (Anderson & Feder, 2007). From a dynamic capabilities perspective, AES is an external capability which amplifies internal sensing, seizing, and reconfigure processes, which are enabled by digital technologies. AES enhances sensing by helping farmers to interpret high-level digital data and identify entrepreneurial opportunities. Through workshops, field demonstrations, and customized advice, extension services improve knowledge of farmers on digital tools that can increase their knowledge regarding production, market, and technological trends (Ul Hassan et al., 2020). In terms of seizing capabilities, AES helps in reducing the uncertainty and risk involved in new technologies by providing the farmers with some practical guidance and thus promoting the farmers to adopt new and innovative practices confidently (Barrett & Constas, 2014). Moreover, AES facilitates resources reconfiguration by helping farmers to reorganize their production systems, embrace

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digital solutions, and try new practices according to strategic objectives (Rana et al., 2024).

Several empirical studies have found that extension support increases technology adoption, entrepreneurial behavior and farm performance (Anderson & Feder, 2007; Klerkx et al., 2019). Complementing the process of digitalization, AES develops the entrepreneurial orientation of farmers and assures that digital investments will provide measurable new levels of productivity. Therefore, AES can be one threshold condition to promote positive effects of agricultural digitalization on FEO:

H5: *Agricultural extension support has a positive moderating effect on the relationship between agricultural digitalization and farmers Entrepreneurial Orientation.*

In a nutshell, the application of the Dynamic Capabilities Theory provides a very coherent and integrated framework to understand improvements in farm productivity due to agricultural digitalization. Digital tools enhance the capacity of farmers to 'sense the opportunities and strategically exploit them and reconfigure resources' and Farmer Entrepreneurial Orientation mediates these effects through converting digital information to actionable strategies. Extension support is used to strengthen this mechanism further, in the form of an external capability that complements internal capabilities. This is theoretically grounded with the aim of being consistent across the direct, mediating, and moderating relations, and also in accordance with the empirical findings recently studied in the context of developing agriculture (Li et al., 2020; Ul Hassan et al., 2023; Irshad et al., 2024; Rana et al., 2024). Overall, the integrated DCT perspective shows that it is the effective use of digital technologies, entrepreneurial behaviour, and extension support together that are the reasons for higher farm productivity in the volatile agricultural environments.

Theoretical Framework

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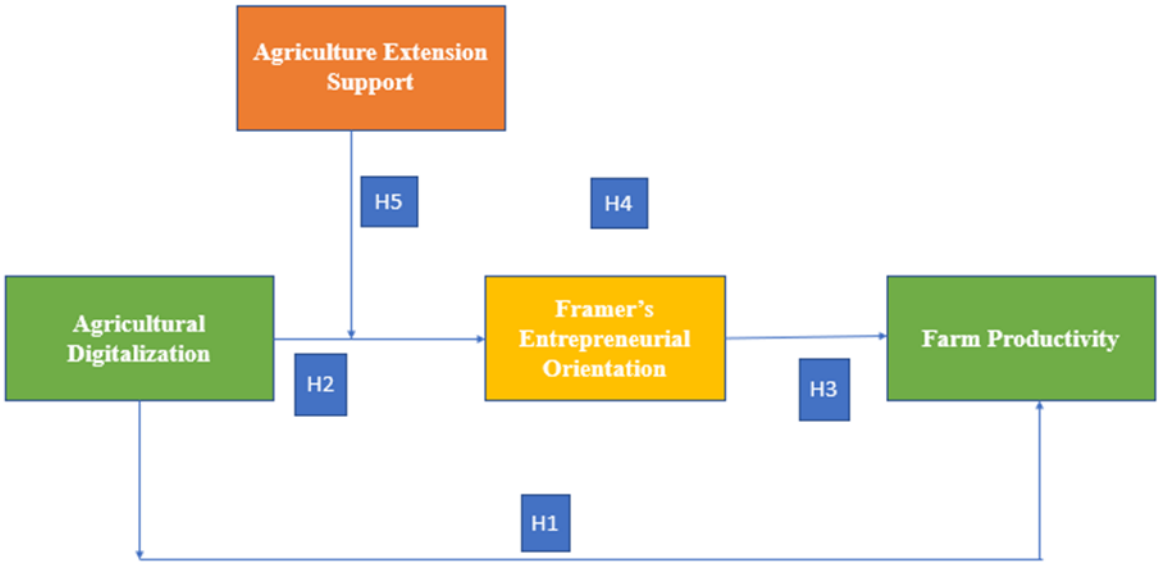

3 Methodology

3.1 Research Design

This study adopted a Quantitative research design through a Cross-sectional survey method to investigate the relationship among the elements of agricultural digitalization, Farmer Entrepreneurial Orientation (FEO), Agricultural Extension Support (AES) and farm productivity in Pakistan. Quantitative methods are suitable for testing hypothesis and the strength and significance of relations between variables (Creswell, 2014). A structured questionnaire was used for data collection from the farmers to enable the making of standard measurements and statistical analysis.

3.2 Population and Sample

The population for this study was smallholder and medium-scale farmers located in Punjab, Sindh, and Khyber Pakhtunkhwa province, representing the largest agricultural region in Pakistan. The target population comprised farmers having at least 3 years of farming experience who have adopted at least 1 digital technology in their farming practices.

A stratified random sampling technique was employed to assure representation among provinces, size, and kinds of farms, and crops. Using Krejcie and Morgan (1970) table on sample size estimation and taking into consideration the large population of farmers in these regions (around 3 million), a total of 3,000 responses were gathered. This sample size is sufficient to conduct advanced statistical analyses such as mediation and moderation analysis, and provides sufficient statistical power (Hair et al., 2019).

3.3 Instrument Development

A structured questionnaire was created upon validated scales from previous literature. The questionnaire had 4 sections:

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Demographics: Age, gender, education level, sizes of farm, years of farming experience, type of crops grown
Agricultural Digitalization: A scale of 12 items developed based on Klerkx et al. (2019) and Li et al. (2020) for the adoption of AI tools and IoT devices, mobile platforms, and precision machinery. Sample items included "I use digital platforms to track the health of my crops," and "I use data-driven tools for irrigation planning."
Farmer Entrepreneurial Orientation: A 9-item scale based on Wiklund and Shepherd (2005) to cover innovativeness, proactiveness, and risk-taking. Items included "I often experiment with new farming techniques" and "I take calculated risks to improve farm performance."
Agricultural Extension Support: A 6-item scale from Anderson and Feder 2007 which captures Advisory services, Training, and technical guidance. Items included "I get suggestions frequently from extension officers on new technologies" and "Extension programs help me to use digital tools effectively".
Farm Productivity: A Massachusetts 6-item self-reported productivity item bank adapted from Li et al (2020) and Ul Hassan et al (2023). Yield improvements, efficiency of farming operations, and resource optimization. Items included "Digital tools have helped me improve my crop yields" and "I use farm inputs more efficiently than before."
All measurements were done on a Likert scale of 5 (Strongly agree/strongly disagree). The questionnaire was first drafted in English and translated into Urdu for easier understanding of the subject matter, and then translated to English again to ensure the accuracy of the questionnaire. A pilot test on 50 farmers was carried out to establish that it is clear, reliable and valid.

3.4 Data Collection Procedure

Data were gathered over three months (May-July 2025) using face-to-face surveys and online forms disseminated through the channels of farmer associations and agricultural extension networks. Enumerators were instructed to help farmers complete the questionnaire in order to get quality and reliable answers. Out of 3200 distributed questionnaires, 3,00 valid responses were obtained with a response rate of 93.75%.

4 Results and Data Analysis

The present study aimed to verify the relationship between agricultural digitalization, Farmer Entrepreneurial Orientation (FEO), Agricultural Extension Support (AES), and farm productivity in Pakistan using a quantitative investigation approach and Structural Equation Modeling (SEM). Data analysis was descriptive, reliability and validity analysis, analysis of correlation, direct effect, mediation and moderation.

4.1 Missing Data and Normality

Data were checked for completeness and normality. Less than 2% of the responses had missing values, which were addressed using mean imputation. Skewness, kurtosis values ranged from -0.82 to + 0.91 for all constructs; this indicated acceptable univariate normality for SEM analysis (West et al., 1995).

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4.2 Reliability and Validity

The reliability of constructs was evaluated by using Cronbach's alpha and composite reliability (CR). All constructs showed internal consistency above a minimum threshold of .70. Convergent validity was assessed by AVE values that were greater than 0.50, and discriminant validity was assessed by the Fornell-Larcker criterion.

Table 1: Reliability and Validity

Construct	Cronbach's α	Composite Reliability (CR)	AVE
Agricultural Digitalization	0.88	0.90	0.55
Farmer Entrepreneurial Orientation (FEO)	0.91	0.92	0.62
Agricultural Extension Support (AES)	0.84	0.86	0.52
Farm Productivity	0.87	0.88	0.56

The constructs demonstrate high internal consistency and adequate convergent and discriminant validity, making the measurement model robust for hypothesis testing.

4.3 Descriptive Statistics

The sample included 3,00 farmers, comprising 62% males and 38% females, with an average age of 42 years. Education levels indicated that 56% had completed secondary education, while 44% had higher education. Farm sizes ranged from 2 to 15 acres, and participants cultivated crops such as wheat, rice, maize, and vegetables.

Table 2: Descriptive Statistics

Variable	Mean	SD	Min	Max
Agricultural Digitalization	3.78	0.72	1	5
Farmer Entrepreneurial Orientation (FEO)	3.65	0.70	1	5
Agricultural Extension Support (AES)	3.54	0.68	1	5
Farm Productivity	3.81	0.69	1	5

The data indicate moderate-to-high adoption of digital tools, entrepreneurial behaviors, extension support, and perceived productivity improvements.

4.4 Correlation Analysis

Pearson correlation coefficients revealed significant positive associations among all study variables.

Table 3: Correlation Matrix

Variable	1	2	3	4
1. Agricultural Digitalization	1			
2. Farmer Entrepreneurial Orientation (FEO)	0.52**	1		
3. Agricultural Extension Support (AES)	0.46**	0.41**	1	
4. Farm Productivity	0.48**	0.50**	0.37**	1

Note: **p < 0.01

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Digitalization is strongly correlated with FEO and farm productivity, while AES shows moderate positive correlations with both digitalization and FEO, supporting the theoretical foundation of dynamic capabilities.

4.5 Structural Equation Modeling (SEM)

SEM was employed to test direct, mediation, and moderation hypotheses. Bootstrapping with 5,000 resamples ensured robust estimates of path coefficients and significance.

4.1 Direct Effects

Table 4: Direct Effects

Hypothesis	Path	β	t-value	p-value	Result
H1	Agricultural Digitalization → Farm Productivity	0.42	12.34	<0.001	Supported
H2	Agricultural Digitalization → FEO	0.51	15.67	<0.001	Supported
H3	FEO → Farm Productivity	0.37	11.29	<0.001	Supported

All direct effects were significant and positive, confirming that digitalization enhances both entrepreneurial orientation and farm productivity, while FEO itself positively impacts productivity.

4.6 Mediation Analysis

FEO was tested as a mediator between agricultural digitalization and farm productivity using bootstrapping.

Table 5: Mediation Analysis

Path	β (Indirect)	t-value	p-value	Type of Mediation
Agricultural Digitalization → FEO → Farm Productivity	0.19	8.91	<0.001	Partial

Interpretation: FEO partially mediates the relationship between digitalization and productivity, indicating that entrepreneurial orientation is a crucial mechanism through which digital technologies enhance farm outcomes.

4.7 Moderation Analysis

AES was tested as a moderator on the relationship between digitalization and FEO. The interaction term was significant, suggesting that extension support strengthens the effect of digitalization on entrepreneurial orientation.

Table 6: Moderation Analysis

Moderator	Path	β	t-value	p-value	Result
AES	Agricultural Digitalization × AES → FEO	0.13	3.24	0.001	Supported

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Interpretation: Farmers receiving higher extension support exhibited stronger entrepreneurial behaviors in response to digital technology adoption, highlighting the role of AES as an external dynamic capability.

4.8 Model Fit and Explained Variance

The structural model demonstrated good fit:

- **SRMR:** 0.045 (acceptable, <0.08)
- **R^2 Values:**
  - FEO = 0.42 (moderate explanatory power)
  - Farm Productivity = 0.53 (substantial explanatory power)
- **Q^2 Values:** > 0 for all constructs, confirming predictive relevance.

Interpretation: The model explained 53% and 42% variance in the farm productivity and FEO, respectively, which proves that the digitalization, entrepreneurial orientation, and extension support are collectively significant contributing factors to the farm performance.

5 Discussion

The results of this research provide significant evidence on the impact of agricultural digitalization on improving farm productivity in Pakistan. Farmers who have adopted the use of AI-driven decision support systems, IoT devices, and drones and mobile platforms have reported on the increasing efficiency of their operations, better allocation of resources, and better production. These results are consistent with the tenets of the theory of Dynamic Capabilities Theory (DCT), which focuses on the importance of sensing, seizing, and reconfiguring capabilities to maintain competitive advantage in dynamic environments. Digital technologies help to make the possible: farmers gain access to digital tools that help them monitor the condition of their soils, forecast risks posed by weather phenomena, plan irrigation systems with more efficiency, and inform them about real-time prices in the market, turning scattered resources into productive systems. This implies that digitalization is a dynamic ability that helps farmers to react well to the variability of the environment and also to the variability of price and supply in the market.

The study has also shown that agricultural digitalization has a positive effect on Farmer Entrepreneurial Orientation (FEO) and supports the notion that adoption of digital tools leads to innovative, proactive, and risk-taking behaviour by farmers. Access to real-time data and digital platforms helps farmers to have better access to information that can help them better know what opportunities there are to modify production processes of potential new techniques, and help them proactively react to market changes. From the standpoint of DCT, this process is the evolution of internal behavioral abilities in the face of technological stimuli. By improving information availability and lowering uncertainty, digital technologies help farmers to seize opportunities that will be missed and cannot be identified, thus contributing to the enhancement of entrepreneurial orientation.

Furthermore, the results confirm that FEO makes a positive contribution to farm productivity. Farmers who had high levels of innovativeness, proactiveness, and calculated risk-taking skills were more successful in restructuring resources, efficient

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use of inputs and how they reacted to environmental problems. Entrepreneurial orientation is a behaviour mechanism to convert the benefits of digitalization into concrete results, which is evidence that technology is not sufficient to enhance productivity, unless it is accompanied by adaptive and proactive farmer behaviour. The mediation analysis supports this argument and indicates that the relationship between agricultural digitalization and farm productivity is mediated to some extent by FEO. This finding underlines the importance of digital technologies not only for direct improvement of performance, but also indirectly through the development of entrepreneurial capabilities, and gives empirical support to the behavioral pathways proposed by DCT.

Agricultural Extension Support (AES) also supplements this dynamic. The analysis of moderation shows that the positive impact of digitalization on FEO is increased when farmers receive higher support from extension. AES will help farmers to better interpret and use digital tools, which will reduce barriers to uptake and build confidence to experiment and innovate. In line with DCT, extension support acts as external dynamic support, which enhances the internal capabilities of farmers, in order to facilitate the processes of sensing, seizing, and reconfiguring that are necessary for productivity improvement. Together, these results show that this combination of technology, behavioral orientation, and institutional support is critical when optimizing farm performance in dynamic and resource-constrained agricultural environments.

6 Conclusion

This study validates that agricultural digitalization is a key factor in improving agricultural productivity levels in Pakistan, with its impacts being both direct and indirect through Farmer Entrepreneurial Orientation. The research shows that digital technologies are dynamic capabilities, which help farmers to feel the environmental and market opportunity, to capitalize on the opportunity through informed decision-making, and to reconfigure the resources to obtain a preferable productivity outcome. Farmer Entrepreneurial Orientation is found to be a key mechanism of behavior that converts digital inputs into actionable strategies that ensure that technology adoption results in tangible improvements in performance. Moreover, Agricultural Extension Support acts as an external dynamic capacity to reinforce the relationship between digitalization and entrepreneurial behavior through support in the form of guidance, training, and technical assistance. Collectively, these results imply the synergistic roles of adoption of technology, behavioral capabilities, and institutional support on farm performance. The contribution of the study is theoretical as it provides an extension of the application of Dynamic Capabilities Theory in the agricultural sector within a developing country context, with special emphasis on the behavioral and institutional aspects that lead to improvements in productivity through technology. Practically, the results support the importance of combining digital technology deployment, capacity building, and extension in conflict situations to support entrepreneurial behaviours to improve agricultural outcomes.

7 Implications

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The findings have important implications both in theory and practice. Theoretically, the research extends the theoretical approach, which was known as Dynamic Capabilities Theory, into the smallholder and medium-scale agricultural environment, as well as by demonstrating that the concepts of technological adoption and entrepreneurial behaviour, along with institutional support, can be conceptualised as inter-linked dynamic capabilities that contribute together to improved performance. By identifying an individual (FEO) and an organization (AES) as the key mediators and moderators, the research is demystifying processes by which digital technologies are likely to lead to improvements in productivity by explaining the behavioral and institutional pathways for how digital technologies do so. Practically, the results seem to indicate that policymakers and agricultural development agencies could put more emphasis on promoting digital infrastructure and tools while, at the same time, promoting entrepreneurial skills among farmers. Extension services have an important role to play in this process, as they facilitate the interpretation of digital data, help farmers to choose the right technologies, and put innovative practices in place. Integrated programs that integrate technology adoption, capacity building, and extension support are therefore an essential step to ensuring maximum benefits of agricultural development.

8 Future Research Directions

Future research could expand on this research in a number of ways. Longitudinal research designs would provide information about the long-term impact of digitalization on issues such as productivity and entrepreneurial orientation in order to allow scholars to study the development of dynamic capabilities over time. Comparative studies across regions/countries could point out the contextual factors that affect the effectiveness of digital technologies, entrepreneurial orientation, and extension support. Additionally, an analysis of other moderating variables, such as access to finance, social networks, or market infrastructure, could bring insight into why digitalization is more successful in improving the performance of farms. Finally, technology-specific analyses could look at the differential effect of specific technologies, such as drones, artificial intelligence (AI) platforms, or precision sensors, on both behavioural orientation and productivity, while qualitative studies could gain a deeper understanding of what farmers think, how they reason, and their experiential learning during the adoption of digital technologies.

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