Research on World Agricultural Economy
https://journals.nasspublishing.com/index.php/rwae

ARTICLE

The Role of Mobile Technology Adoption in Developing Sustainable Agricultural Marketing Efficiency and Reducing Transaction Costs Among Smallholder Farmers

Hayder M. Ali [1], *Sathiyasuntharam Velayutham* [2], *Keerthi Samhitha Babu* [3], *Firas Tayseer Ayasrah* [4], *Aseel Smerat* [5,6], *Subhashree Balasubramanian* [7], *Asqar Absamatov* [8], *Sudhakar Sengan* [9,*]

[1] *Department of Information Technology, College of Science, University of Warith Al-Anbiyaa, Karbala 56001, Iraq*

[2] *Department of Computer Science and Engineering, School of Computer Science and Engineering, Sharda University, Greater Noida 201310, India*

[3] *Department of Computer Science and Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram 522502, India*

[4] *College of Education, Humanities and Science, Al Ain University, Al Ain P.O. Box 112612, United Arab Emirates*

[5] *Faculty of Educational Sciences, Al-Ahliyya Amman University, Amman 19328, Jordan*

[6] *Centre for Research Impact and Outcome, Chitkara University, Punjab 140401, India*

[7] *Department of Information Technology, V.S.B. College of Engineering Technical Campus, Coimbatore 642109, India*

[8] *Department of Finance and Tourism, Termez University of Economics and Service, Termez 190100, Uzbekistan*

[9] *Department of Computer Science and Engineering, PSN College of Engineering and Technology, Tirunelveli 627152, India*

ABSTRACT

The main objective of the present study is to investigate how smallholder farmers (SF) in Thanjavur, Tamil Nadu, India, are using mobile technology to develop sustainable access to markets for agricultural products and re-

*CORRESPONDING AUTHOR:
Sudhakar Sengan, Department of Computer Science and Engineering, PSN College of Engineering and Technology, Tirunelveli 627152, India; Email: sudhasengan@gmail.com

ARTICLE INFO
Received: 14 September 2025 | Revised: 3 November 2025 | Accepted: 10 November 2025 | Published Online: 29 April 2026
DOI: https://doi.org/10.36956/rwae.v7i2.2735

CITATION
Ali, H.M., Velayutham, S., Babu, K.S., et al., 2026. The Role of Mobile Technology Adoption in Developing Sustainable Agricultural Marketing Efficiency and Reducing Transaction Costs Among Smallholder Farmers. Research on World Agricultural Economy. 7(2): 371–387. DOI: https://doi.org/10.36956/rwae.v7i2.2735

duce transaction costs. This research employs a mixed-methods approach (MMA) to examine the effects of mobile payment systems, diverse technologies, and mobile devices on TC, MA, and LoI. A total of 273 farmers were surveyed, of whom 137 were initial adopters and 136 did not participate at any time. A subset of 27 farmers and vital stakeholder groups was then subjected to a complete evaluation. The experimental results of this investigation validate that MTA significantly minimises TC for SF, particularly search costs (SC) (by 35.85%) and negotiation costs (NC) (by 31.00%). The results showed a significant 83.97% increase in LoI and a 43.21% increase in MA among farmers who implemented MTA, compared with those who did not. The experimental results presented here show that MTA can improve MA and LoI in rural agricultural backgrounds, predominantly when challenged by environmental changes. This research study highlights problems with MTA, including limited setup and electronic data issues, but also validates that MTA supports livestock farmers in NC and MA by enabling real-time data collection for SA.

Keywords: Sustainable Agricultural Marketing; Smallholder Farmers; Mobile Technology Adoption; Mixed-Methods Approach; Short Message Service; Digital Literacy

1. Introduction

The importance of recognising that smallholder farmers (SF) are the primary focus of the majority of agricultural trials intended to increase environmental sustainability, yet these farmers face enormous challenges when seeking market access (MA) and improving their Level of Income (LoI) [1]. In addition, conventional marketing of agricultural products has high transaction costs (TC) because it involves logistics and conflict resolution, relies primarily on agricultural mediators, and has limited the availability of real-time market data [2]. The development of mobile technology adoption (MTA) has opened up entirely new potentials for addressing these problems; MTA has the probable to enhance market data flow [3], minimise TC, and improve market use [4]. Farmers can make better choices about when and where to sell their crops with the help of MTA platforms, such as electronic payment systems, mobile applications, and short message service (SMS), which provide real-time updates on service costs, buyer demand, and weather forecasts [5]. Agricultural mediators have been rendered redundant by these MTAs, which allow buyers direct access; at the same time, mobile-based payment methods revolutionise money transfers [6].

There is considerable trust that MTA might change SA marketing in this context, particularly for SF [7]. However, there has been limited investigation into the extent to which MTA improves MA and minimises TC, particularly in locations where digital setup is not readily accessible [8]. This investigation aims to determine how MTA affects MA, TC, and LoI to enhance SA marketing results for SF. The present study seeks to provide information about the distinctive challenges of MTA in South Asian markets by evaluating SF methods in Thanjavur, Tamil Nadu, India [9]. Research involving how to financially support and improve innovative mobile technologies that optimise the LoI of SF will provide significant advantages to policymakers, agricultural stakeholders, and researchers studying technology [10].

In Indian academic research, the Thanjavur district stands out for its distinctive culture, economic system, and geographic location. The city of Thanjavur in the Indian state of Tamil Nadu is known for its agricultural products, including animal products, wheat, vegetables, and rice [11].

In rural areas, where farmers face problems such as restricted access to marketplaces and high transportation costs, the location and environmental factors motivate investigating the impact of MTA in South Asia. Thanjavur, Tamil Nadu, India, has developed its financial sector around agricultural products, providing an essential foundation for questioning how MTA could improve MA, cut costs, and increase LoI [12]. Also, the entire region continues to face challenges in its information technology development, including limited digital learning and limited network access in remote areas. This environment enables researchers to investigate the potential and challenges of MTA.

A significant challenge to agricultural production is MTA, which is particularly challenging for SMEs, as most of their main demands are MA at acceptable TCs. Because of agricultural mediators, low selling prices, and a lack of expertise in MA, conventional SA marketing systems result in agricultural producers making less income on their financial investments. Additionally, there may be fewer demands for agricultural intermediaries if the MTA supports mobile-based communication and transactions between buyers and farmers. This initiative will help address these gaps. By integrating these factors, this revolutionary approach aims to improve market price estimation, increase transparency in agricultural product marketing, and minimise wasted resources.

The farmers may be running tight operations with limited resources and are thus unable to respond to market changes; hence, it is essential for MTA [13]. These farmers must use MTA to control when and where they sell their yield, reduce costs to improve profits, and obtain essential inputs such as seeds and fertilisers [14]. Also, MTA supports insurance, which is crucial for mitigating risks and achieving sustainability in agricultural innovation. The motivation for fetching in this study stems from the recognised physical requirements that challenge SF and the accepted benefits of changing the core of SA practices [15]. Thus, by finding that using MTA in marketing yields improvements in TC, this study proposes advancing the goals of the 2030 SA Development Agenda, aiming to improve the welfare of SF and support SA and food security. Therefore, policymakers, farmers, and technologists interested in SF use of MTA must identify and understand the impact of technology on several features of agricultural ecosystem development, and plan for active remedies to close the digital divide.

Despite increasing proof that MTA lowers data associates in agri-value chains, three gaps continue in the Thanjavur smallholder context: (G1) a lack of causally oriented, mixed-methods evidence linking MTA to disaggregated transaction cost (TC) components—Search Costs (SC), Negotiation Costs (NC), and Transportation Costs (TrC); (G2) insufficient theory–data integration, where Diffusion of Innovations (DoI) and Technology Acceptance Model (TAM) constructs are not explicitly mapped to measurable MA and LoI outcomes; and (G3) limited external validity guidance, i.e., policy-relevant scaling conditions (digital literacy, network coverage, and payment rails) required to replicate gains in comparable rural systems. Addressing G1–G3, we (O1) quantify MTA effects on SC, NC, TrC, MA, and LoI using a stratified design (N = 273) and convergent mixed methods; (O2) embed DoI/TAM constructs into an admirable method with testable hypotheses connecting adoption intensity to TC→MA→LoI pathways; and (O3) derive actionable scaling prescriptions from integrated quantitative–qualitative implication.

The first research hypothesis, derived from this research context, is that SF faces challenges with MA. These challenges include high TCs (SC, NC, TrC), restricted MA, and the need to develop buyers or negotiate for better terms. These barriers result in low LoI possibilities, high reliance on intermediaries, and less-than-ideal decisions with worse-off SFs regarding economic risk. However, this has not been made easier by challenges such as digital learning, poor mobile networks, and regional restrictions, even though MTA may help address these problems. Therefore, the study aims to assess the effects of MTA on factors such as MA, TC, and LoI, among others, as well as development factors that hinder the broader MTA. The objective is to develop a model that supports SFs using MTA, increases their market engagement, and optimises their development of agricultural ecosystem returns.

Conceptual Mapping and Hypotheses

This study operationalises DoI (relative advantage, compatibility, complexity, trialability, observability) and TAM (Perceived Usefulness—PU; Perceived Ease of Use—PEOU) as drivers of MTA intensity. Their economic significance materialises through TC reduction and MA development, yielding income effects (**Table 1**).

This study addresses key data gaps about how MTA impacts MA, TC, and LoI among SF.

The objectives are to:

1) To quantify MTA's impact on SC, NC, TrC, MA, and LoI.
2) To integrate the DoI and TAM to explain MTA adoption behaviour.

3) The proposed mode of the causal pathway MTA → TC → MA → LoI.

4) Recommend approaches to enhance digital inclusion and sustainable market efficiency.

Table 1. Theory–construct–variable mapping and hypotheses.

Theory Construct	Empirical Proxy (Proposed Study)	Expected Sign	Hypothesis
PU (TAM)	Perceived MA gain score	+	H1: PU ↑ ⇒ MTA intensity ↑
PEOU (TAM)	Digital literacy index	+	H2: PEOU ↑ ⇒ MTA intensity ↑
Relative advantage (DoI)	Prior price dispersion observed	+	H3: Advantage ↑ ⇒ MTA intensity ↑
Complexity (DoI)	App usability friction	–	H4: Complexity ↑ ⇒ MTA intensity ↓
MTA Intensity	Days of MTA use per month	on costs/ + on results	H5: MTA ↑ ⇒ SC, NC, TrC ↓
TC Components	SC, NC, TrC (USD)	→+ chain	H6: TC ↓ ⇒ MA ↑
MA	1–5 scale	+	H7: MA ↑ ⇒ LoI ↑
Mediation	MTA → TC → MA → LoI	n/a	H8: Indirect effect (MTA→LoI) via TC and MA > 0

The following section presents the hypothetical model, outlining the conceptual relationships between MTA, cost reduction, and income improvement.

This research study is organised as follows: Section 1 presents the introduction; Section 2 presents the theoretical model; Section 3 presents the proposed MTA; Section 4 presents the results and discussion; and Section 5 concludes the work.

2. Theoretical Model

MTA directly affects performance metrics such as MA, time to find potential buyers, and NC ratios. Better MA enables farmers to sell to better markets, saving time in reaching a buyer and shortening the time to complete the sale. Higher NC rates help farmers secure better deals than before. These improvements raise the LoI, which is exposed in the model as a critical variable.

2.1. Adoption Theories

The best approach to addressing the MTA in SF is to identify and adopt a combination of essential adoption hypotheses, such as the DoI and the TAM.

1) **DoI:** The measured application of novel innovations within a community has been defined by Everett Rogers. According to this hypothesis, farmers progress from innovative individuals to early adopters, the early majority, the late majority, and slow adopters as they move through the adoption process. Perceived ease of technology implementation, societal implications, and resource availability are factors that could impact the diffusion method in the SF context. It is probable that the initial people who embrace it, who are commonly more financially secure farmers, can demonstrate to the balance of the agricultural sector the significance of MTA in SA business and boost the implementation method [16].

2) **TAM:** In contrast, the TAM recommends a methodical approach to identifying the factors farmers consider when deciding whether to implement MTA, such as perceived ease of application and feasibility. Since MTA is accessible and farmers expect it to improve yields and reduce costs, TAM predicted that agricultural producers would be less reluctant to use it. Perceived ease of use of MTA can be limited in remote regions due to factors such as literacy levels, access to digital services, and the extent to which it is valued for its monetary value. To promote more common and frequent application among SF, this study analyses MTA employing these hypothetical scenarios. By doing so, it will develop a better understanding of the numerous variables that motivate or prevent deployment [17].

2.2. MTA in Marketing

MTA is a revolutionary tool in SA marketing. It has revolutionised the way SF analyses and uses market data. Agricultural mediators were historically required since SF had limited access to market costs, and TC was prohibitively expensive. By providing real-time data, connecting products MA to potential consumers, and minimising the requirement for agricultural mediators, MTA, particularly through mobile phones and SMS, can overcome these problems [18].

Farmers can make better decisions about when and where to sell their products with MTA services that provide real-time data on product costs, weather predictions, and buyer interest—all available on their mobile devices. With this type of access, farmers can better control NC, secure their businesses against the involvement of mediators in scams, and reduce the risk associated with markets for agricultural products [19].

There is a reduced need for cash exchanges and less risk associated with financial transactions when employing mobile banking, an electronic money transfer system [20]. The MTA also assists agricultural producers in reaching buyers across their immediate region. Marketplaces on the internet and mobile marketing enable SF to reach more individuals, whether they live in the metropolitan area or anywhere in the world [21]. By reducing TrC, time delays, and emphasis on physical selling places, the migration from local to international markets significantly enhances MA [22].

To advance the DoI and the TAM and their application to MTA in marketing, it is vital to connect these theories more directly to the effects of MTA. The DoI can elucidate how mobile technology diffusion occurs among farmers through the relative advantage, compatibility, complexity, trialability, and observability factors [23]. For instance, innovations such as mobile payment methods and SMS services provide obvious benefits in reducing TC and improving MA, and thus, they will be adopted. Meanwhile, TAM encompasses perceived ease of use and usefulness, key factors in MTA usage. This research work has established that farmers are more likely to use MTA if they find it easy to use and helpful in decision-making and marketing. Previous research that used these theories to examine the adoption of SA technologies, including cases on MTA in rural areas, would have presented real-life examples of how these models help explain MTA adoption [24].

The adoption theories should be more closely connected to MTA, with an evolution decision that could be as follows: 'These models serve as the basis for analysing MTA's marketing influence.' Existing research limitations include the lack of empirical studies on MTA use in environments with a limited setup or on the impact of social norms. It is crucial to discuss threats such as high costs, low literacy, and a high level of technology, while also recognising that MTA's view must be viewed positively. Drawing on several studies and empirical proof would strengthen MTA's position in shaping the development of agricultural ecosystem marketing [25].

3. Methodology

The first integration method involves collecting data in parallel, with quantitative and qualitative data analysed separately. Verifying and distinguishing the results from the source information is the next phase to ensure they agree. For instance, quantitative research has demonstrated that TC decreases with MTA. Qualitative data must be collected to understand, from the farmers' perspective, why these costs have decreased. Employing the above technique, one can obtain complete MTA results. A linear method is verified by the evidence that data collection in the initial phase starts before the next one. To develop a testable hypothesis, quantitative data must be collected after qualitative data. The Iterative Mixed-Methods Approach (MMA) involves collecting quantitative and qualitative data concurrently; however, until reading and analysis are complete, the two types of analyses must be conducted independently. The MTA improves MA by changing communication, decreasing TC, and boosting MA [26].

Farmers can attain up-to-the-minute data on buyers, sellers, and costs by MTA, eliminating all intermediaries and, by suggestion, SC. Higher cost savings have become practicable by reduced NC, which results in closer interaction [27]. With MTA's help, online banking systems can process transactions more efficiently, resulting in greater availability and shorter wait times for farmers. Farmers can reach additional markets through improved communication, which, in turn, improves MA. This has significant implications for rural financial systems, farmers' LoI, accurate evaluation, decision implementation, and SA methods [28].

The following measures were implemented to develop the questionnaire phases: price data access, negotiation efficacy, logistics frictions, and MA breadth. These rating systems were subsequently evaluated by professionals in the field of agriculture, comprising two extension professionals and one agricultural economist, and then localised for implementation in the present investigation [29]. Cognitive interviews were conducted in the present research to measure learning and response mapping (n≈8), and a trial test was conducted in a non-study county (n ≈ 30) to improve problem wording and skip-logical reasoning. The multi-item categories of PU, PEOU, and MA breadth demonstrated high internal coherence (Cronbach's alpha = 0.80). Construct validity was assessed via CFA (first-order reflective model): factor loadings ≥ 0.60, AVE ≥ 0.50, CR ≥ 0.70, and discriminant validity (Fornell–Larcker criterion satisfied). This work checked common-method bias using Harman's single-factor test (first factor < 50%) and a latent CMV factor sensitivity check; results did not indicate material inflation [30].

For mean comparisons, we used Welch's *t*-tests when Levene's test indicated unequal variances (α = 0.05). For linear models, this study verified: (i) linearity (component-plus-residual plots), (ii) homoskedasticity (Breusch–Pagan); where violated, we report HC3 robust SEs, (iii) normality of residuals (Q–Q plots, Shapiro–Wilk—diagnostic only, not decisive for large N), (iv) multicollinearity (VIF < 5), and (v) influential points (Cook's D < 4/n). This study prefers OLS with robust SE for continuous results (TC, MA treated as quasi-continuous specified scale distribution) and computes sequential models to align with the theory (MTA → TC; TC → MA; MA → LoI). As a sensitivity analysis to address selection into MTA, this work reports Propensity Score Matching (PSM) (nearest-neighbour with calliper 0.2 SD; covariates: farm size, education, distance, set-up access) and inverse probability weighting (IPW) ATEs on SC, NC, TrC, MA, and LoI [29].

3.1. Study Design

The study adopts an MMA, combining quantitative and qualitative data to comprehensively evaluate the impact of MTA on agricultural MA and TC among SF. This design is preferred to capture measurable results, such as changes in TC and MA, and to explore farmers' experiences and perceptions of MTA use in their daily SA practices [31]. The quantitative component of the study will involve a planned survey administered to a typical sample of SF who have MTA and those who do not. The patterns of MTA implementation, TC (SC and TrC), MA, LoI, and NC will be the main subjects of the questionnaire. To determine whether there is a connection among the decreases in MTA, MA, TC, and LoI, qualitative and practical statistical methods will be used [32].

To better understand the true challenges and benefits farmers experience when using MTA for SA sales, the qualitative phase will include random focus group discussions and interviews with several farmers. In this manner, the quantitative results can be understood in relation to the causes behind adoption, the perceived ease of use, and the impact of MTA on their respective market trading platforms. To understand how MTA has impacted the development of the SA system [33], researchers are also interviewing those involved, including crop extension agents, market intermediaries, and mobile service providers.

3.2. Random Sampling Approach (RSA)

Based on the area's track record for agricultural adoption and variable levels of MTA, the research investigation uses a tiered RSA to target SF in Thanjavur, Tamil Nadu, India (**Figure 1**). With this method, we are confident that farmers will have access to different types of MAs, farm sizes, and degrees of expert involvement. The research study includes an average range of MTA methods and findings, classifying people based on essential features such as farm size, distance to the central MA, and MAT.

The heterogeneous SA methods and MA situations in the area will be represented by a sample of 273 SF from different Thanjavur districts. To assess the impact of MTA on MA and TC, researchers will compare 137 farmers who have adopted it for SA marketing with 136 non-adopters. To ensure that a wide range of farming groups is represented, farmers will be selected at random from databases provided by local agricultural groups, agricultural extension agencies, and MTAs.

Out of all the farmers who completed the questionnaire, researchers will randomly select 27 for the qualitative section. Participants of this group will have different levels of MTA experience. Investigators can study the benefits and drawbacks of MTAs as marketing methods by including both helpful and adverse adopters. Analysts will conduct interviews with key sources, including agricultural research agents, local market officials, and mobile service provider experts, to better understand MTA systems.

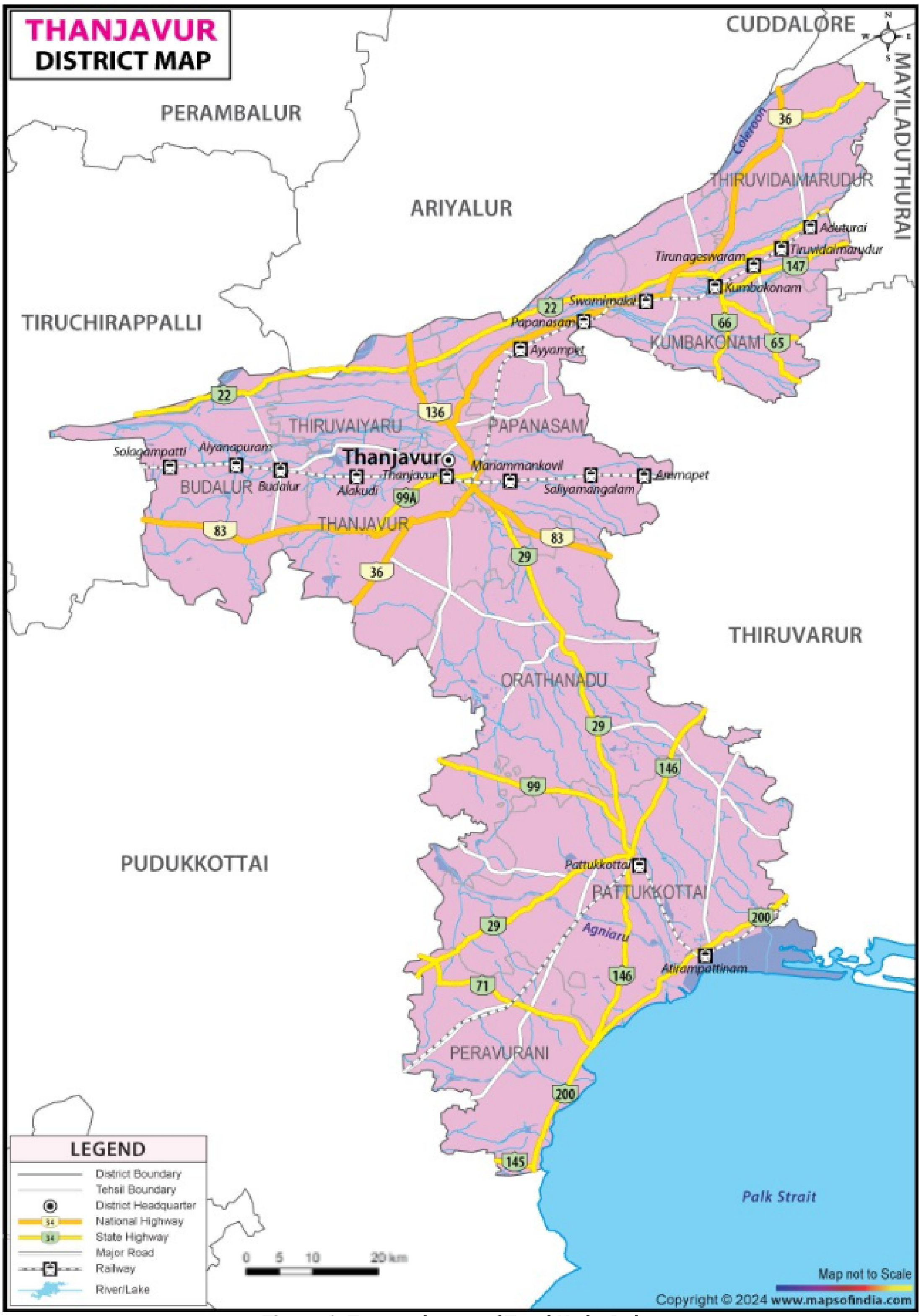

Figure 1. Tanjore district of Tamil Nadu, India.

3.3. Data Collection Methods

To collect real-time data on the MTA by SF in the Tanjore district of Tamil Nadu and its impacts on SA market access and TC, this investigation employs a range of quantitative and qualitative research methods.

The study's validity and reliability depend on evidence for the selection of questionnaire subjects. To preserve the tool's reliability while ensuring the questions are relevant to the intended group, it should be clearly stated whether any questions were tested or derived from standard questionnaires. Since demographic factors affect MTA, it is essential to include questions on age, gender, and education level in the survey. To better understand their impact on MTA, it is vital to examine adoption in relation to demographic factors.

1) **Quantitative Surveys:** The primary data collection tool was a methodical questionnaire administered during interviews with 273 SF from the Tanjore district. This included MTA and non-MTA participants. The goal of this questionnaire is to collect valid data on the following subjects: marketing methods, MTA implementation, TC (such as SC, TrC, and NC), and MA. The survey includes closed- and open-ended questions. The purpose of this research is to conduct interviews with agricultural producers to collect data about their adoption of SA marketing, any problems that they have experienced, and any positive experiences they have had with mobile devices, apps, or phone banking services. The surveys we conduct will be tested by in-person interviews with experienced study members who are proficient in the local language and have an agricultural background. The interviewers will ensure that the input is accurate and easy to apply. To ensure that every person receives the help they require, investigators are providing support to farmers in districts where data or smartphone access is restricted. With particular emphasis on the relationships among MTA, MA, and TC, statistical methods will be applied to input and analyse the data collected.
2) **Qualitative Interviews:** To confirm the survey's results, 27 farmers will be randomly selected to participate in the qualitative interviews. Important qualitative data can be collected in this way. Following this, researchers will conduct interviews with farmers to learn more about their involvement with MTA, how it has affected their marketing methods, and which social factors played an integral role in their decision to use MTA. The interviews will provide light on region-specific problems such as financial limitations, mobile network access, and proficiency in digital technologies. To further understand MTA's impact on the marketing system of South Asia, investigators are additionally conducting interviews with local extension services, mobile service providers, and agricultural mediators. The active participation of these people can enhance support within the organisation, highlight testing, and identify chances to improve MTA in agricultural regions.
3) **Focus Group Discussions (FGD):** In place of one-on-one focus group discussions, interviews will be conducted with farmer subgroups to collect data on their MTA and MA. Farmers in South Asia will have a chance to share their practices and address the challenges they have met during the FGD on how MAT has helped them market their products.

It would be helpful to have a brief background on the sample size, including the statistical analysis and other practical factors. The sample includes 273 farmers and 27 quantitative respondents. Including details on the statistical tests (e.g., ANOVA or regression) used would improve the quantitative analysis. Also included is information on the two primary methods employed in qualitative analysis, content analysis and thematic analysis. Private information, precise surveys, and investigative research are among the methods used to reduce response bias in surveys. The responses can be verified using multiple data collection methods, such as FGDs or surveys. Using a graded sampling approach that also accounts for demographic data such as age, gender, education level, and farming scale can help control for participant bias. Recruiting participants from minority groups and actively searching out their input are additional methods to increase balance.

3.4. Variables

The current research's main variables have been designed to evaluate the connection between MTA and its impact on TC and SA market access. Many TC subclasses are dependent factors that are important in this case. One of these is SC, which evaluates the total effort farmers put into collecting market data, such as the cost of goods, buyer demand, and market availability. The availability of real-time data frequently impacts NC, a further vital aspect that records the time and costs of the NC method between buyers and farmers.

To determine whether MTA aids transportation optimisation by providing better data on buyer locations or by eliminating redundant travel, TrC, which covers the costs of shipment to market, will also be analysed. In contrast, MA is another MA-measured dependent factor that examines how MTA influences farmers' capacity to reach out to new buyers, explore novel markets, and address cost implications. Researchers will continue to track the LoI change, paying special attention to how MTA affects farmers' total profitability and the LoI as a result of more effective MA.

Evaluating farmers' employment of different mobile applications, such as SMS and phone banking, will capture the independent factor, MTA. This variable examines the frequency and depth of MTA use, as well as whether farmers are MTAs. The size of the farm, level of education, accessibility, and distance to marketplaces are among the other control variables that will be included to consider potential impacts. **Table 2** presents the variables that, when combined, will provide light on how MTA impacted agricultural MA and TC.

Table 2. Study variables.

Type	Variable	Description
Dependent Variables	TC	Measures the overall costs incurred by farmers during marketing activities.
	SC	Time and effort spent in search of market data (e.g., costs, demand).
	NC	Costs related to NC and buyer agreements.
	TrC	Expenses related to transporting goods to markets.
	MA	Measures the efficiency of farmers in accessing and interacting with markets.
	MA	Farmers' ability to connect with new buyers and explore different markets.
	LoI	Changes in farmer LoI resulting from MA and MTA.
Independent Variable	MTA	Captures farmers' use of mobile applications, SMS platforms, and mobile payment systems.
Control Variables	Farm Size	The size of the farm, measured in hectares, affects resources and market value.
	Education Level	Farmers' educational context and the impact of MTA.
	MA to Set-up	MA to the essential setup (e.g., mobile networks, roads) to help MA.
	Geographical Distance to Markets	Distance to the adjacent markets, which impacts ease of MA and TC.

4. Result and Discussion

Figure 2 presents the statistical results comparing MTA adopters and non-adopters. The results indicate significant changes in a few critical variables related to agricultural MA and TC. Compared with non-adopters, whose TC is significantly higher (mean = $95.78, SD = $18.23), adopters' TC is significantly lower (78.45, SD = $15.67), demonstrating that MTA significantly reduces overall costs in secondary marketplace sectors. Adopters (mean = $12.34, SD = $3.78) have a much lower SC than non-adopters (mean = $19.23, SD = $4.89), providing evidence that MAT provides real-time market data. Adopters have a lower NC (mean = $9.28, SD = $2.54) than non-adopters (mean = $13.45, SD = $3.12), indicating that farmers have greater control over discussions when they have access to MA-to-cost data by MTA.

Another cost component that exhibited a lesser increase than the others was TrC, which was lower for adopters (mean = $23.67, SD = $5.34) than for non-adopters (mean = $28.56, SD = $6.45). Participants in the MTA have higher MA and are more capable of reaching average buyers, as the adoption rate is significantly higher (mean = 4.12, SD = 0.65) than for non-adopters (mean = 2.87, SD = 0.79) in the area of MA. The LoI findings mirror this increased MA. Adopters report an average LoI increase of 15.75% (SD = 4.12), compared with non-adopters, who report an average increase of 8.56% (SD = 5.23)—definitive proof of the financial implications of MTA. In conclusion, there is a clear difference in

MTA usage: adopters use MTA tools an average of 22.48 days per month (SD = 5.67), whereas non-adopters report no usage. This result highlights the adoption gap and the benefits of MTA in terms of cost, practicality, and MA. **Table 3** includes the descriptive statistics, and the t-test is demonstrated in the section that follows.

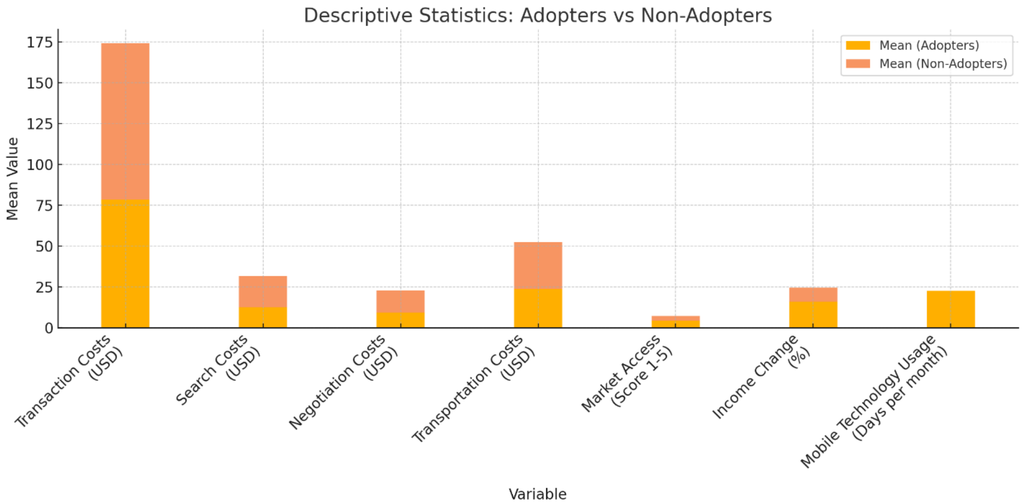

Figure 2. Descriptive statistics results.

Table 3. Descriptive statistics.

Variable	Mean (Adopters)	Mean (Non-Adopters)	SD (Adopters)	SD (Non-Adopters)
TC ($)	78.45	95.78	15.67	18.23
SC ($)	12.34	19.23	3.78	4.89
NC ($)	9.28	13.45	2.54	3.12
TrC ($)	23.67	28.56	5.34	6.45
MA (Score 1–5)	4.12	2.87	0.65	0.79
LoI (%)	15.75	8.56	4.12	5.23
MTA Usage (Days Per Month)	22.48	0	5.67	0

The findings of a *t*-test associating context-adopters and non-adopters of the MTA are presented in **Figure 3** and **Table 4.** Significant TC, MA, and several control factors improved significantly in the example above. There was a statistically significant difference between the two groups, as verified by the TC *t*-statistic of 3.56 (p = 0.001): the group that incurred the cost of MTA $17.33 less than the group that did not. It can be firm that MTA has the intended outcome of decreasing TC in SF. According to the test, there is a highly significant distinction between the average MA values of adopters and non-adopters, with the former having an average score 1.25 points higher (t = 5.23, p < 0.001).

This highlights the MTA's function in helping farmers' access to increasingly profitable markets. A difference with statistical significance (t = 2.91, p = 0.004) was experiential between adopters and non-adopters, with a median LoI increase of 7.19%. This increases the financial impact of MTA by improving market conditions and monitoring results. Among the states surveyed, 6.89% adopted SC (t = 2.45, p = 0.015), while 4.17% adopted NC (t = 2.89, p = 0.005).

The results achieved highlight how MTA can be deployed to deliver up-to-the-minute market data, enhance farmers' ability to control bartering, and thereby reduce transaction costs. By presenting more data on MA, MTA optimises logistics by minimising redundant travel and costs. Adopters' TrC was also significantly lower (mean = −4.89, t = 2.71, p = 0.008).

The MTA usage data indicate that adopters use the MTA an average of 22.48 more days per month than non-adopters, achieving a t-statistic of 8.32 (p < 0.001). The findings emphasise a highly significant difference in MTA between the two groups. Farm size is not an essential factor in the calculation of MTA, as there was no significant difference in the control variables relative to this variable (t = 1.45, p = 0.148). On the other hand, there was a minor but significant correlation between education level and MTA probability (t = 1.98, p = 0.049). In addition, there was a significant variance in the MA setup (t = 3.21, p = 0.002), implying that adopters could potentially make better use of MTA to report better MA. Lastly, adopters were, on average, 3.54 km closer to markets, which likely minimised TrC and improved MA, indicating that geographical proximity to marketplaces also had a significant impact (t = 4.11, p = 0.001).

Table 4. Independent Samples *t*-test.

Variable	*t*-Statistic	*p*-Value	Mean Difference (Adopters - Non-Adopters)	Statistical Significance
TC ($)	3.56	0.001	−17.33	Significant
MA (Score 1–5)	5.23	0.000	1.25	Highly Significant
LoI (%)	2.91	0.004	7.19	Significant
SC ($)	2.45	0.015	−6.89	Significant
NC ($)	2.89	0.005	−4.17	Significant
TrC ($)	2.71	0.008	−4.89	Significant
MTA Usage (Days Per Month)	8.32	0.000	22.48	Highly Significant
Farm Size (Hectares)	1.45	0.148	0.67	Not Significant
Education Level (Years)	1.98	0.049	0.98	Marginally Significant
MA to Set-up (Score 1–5)	3.21	0.002	0.87	Significant
Geographical Distance to Markets (km)	4.11	0.001	−3.54	Significant

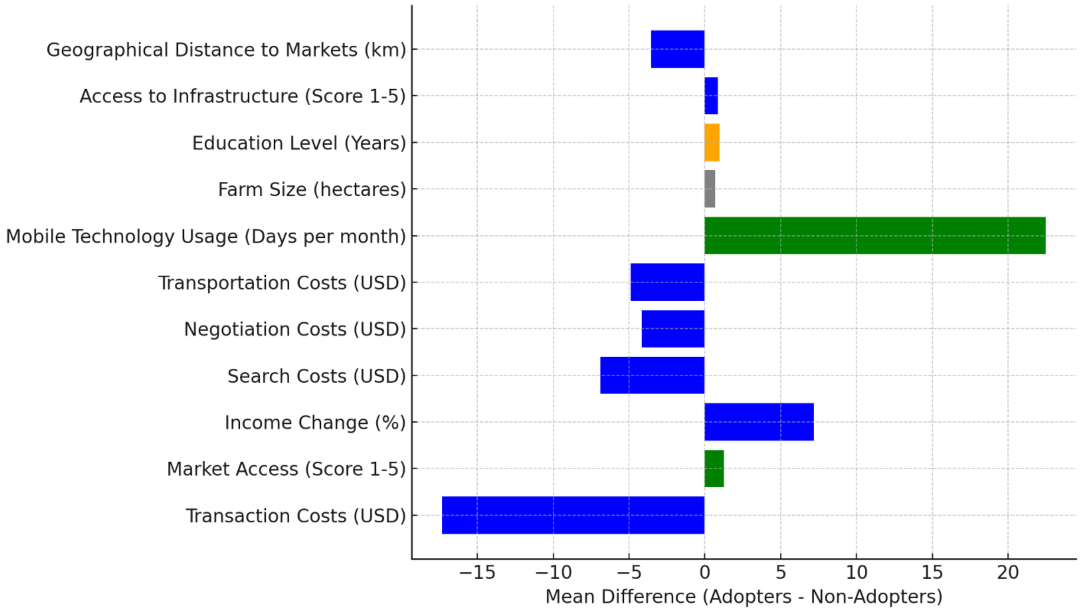

Figure 3. Independent Samples *t*-test.

This study selected the five variables in **Table 5** primarily because we consider them essential for MA in South Asia. To verify that the regression model is robust and accurate, diagnostic methods such as *t*-tests are used to assess statistical significance.

Table 5 and **Figure 4** present the MRA results, highlighting the crucial variables that influence the marketing strategies for TC and SF. Because the MTA has such a detrimental impact on TC, more mobile users would result in significantly lower costs. The lack of correlation between farm size and TC indicates that farm size does not impact TC. Training level has a significant, positive impact on marketing results when using MTA, as farmers with higher levels of training achieve better results. In the same direction, setup and MA show a positive correlation, signifying that improved design may enhance the mobile application of tools. Finally, despite the MTA, farmers will still face higher costs due to market distance if their fields are closer to key transportation hubs.

Table 5. Multiple regression analysis.

Variable	Coefficient (β)	Standard Error	*t*-Statistic	*p*-Value	Statistical Significance
MTA (Days Per Month)	−0.53	0.08	−6.63	0.000	Highly Significant
Farm Size (Hectares)	−0.12	0.07	−1.71	0.089	Not Significant
Education Level (Years)	0.18	0.05	3.60	0.000	Highly Significant
MA to Setup (Score 1–5)	0.29	0.06	4.83	0.000	Highly Significant
Geographical Distance to Markets (km)	−0.41	0.09	−4.56	0.000	Highly Significant

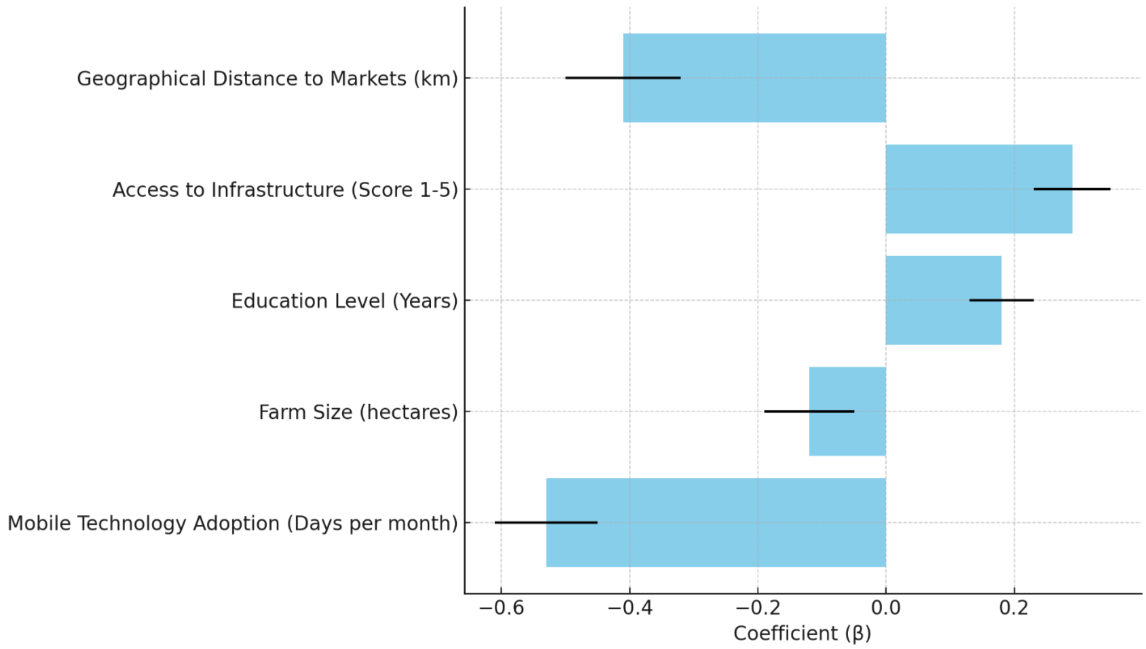

Figure 4. Multiple Regression Analysis (MRA).

Table 6 summarises the findings of the thematic evaluation, which highlights six primary problems with MTA among SF. With 52 responses, "normal MA to real-time MA" ranked the highest among frequently asked subjects. The farmers were highly supportive of MTA's timely weather, buyer demand, market cost, and trend updates, because they enabled them to make improvements in their selections.

"Before I leave the farm, I understand what the marketplace costs, so I can decide where to sell and for how much to sell," said one farmer. The TC reduction theme had a 38% prevalence, with farmers reporting that MTA helped keep costs down, particularly in SC and TrC. *"I can contact buyers directly, rather than investing money in visiting different markets,"* a farmer said.

Senior farmers, who may not be as proficient with technology, are most susceptible to problems when using MAT, and this loss of expertise was cited 28 times as a technology-related issue.

"I stick to the old methods" because, as one farmer put it, "I don't understand how to use mobile applications." The 33 references to the Impact on NC theme highlighted how the MA-to-cost data from the MTA reinforced this theme.

"*Being conscious of the costs before them provides businesses more influence when dealing with intermediary businesses,"* one farmer said. There were approximately 45 mentions of setup problems and limited MAT coverage in rural regions as impediments to adoption.

"The mobile tools are unreliable," a farmer stated, "*because there are times when I can't get a signal in my village."*

Lastly, 49 respondents mentioned perceived financial advantages. Farmers readily recognised that MTA contributed to higher profits by permitting MA to access more markets and reduce costs. According to a farmer, *"I've sold my crops at higher costs than before since using the mobile platform."*

Table 6. Thematic Analysis.

Theme	Description	Frequency of Mention	Example Quote
MA to Real-time Market Data	Farmers reported that MAT provides timely updates on market costs, buyer demand, and weather forecasts, helping them make informed decisions.	52	"*I now know the market costs before I leave the farm, so I can decide where to sell and for how much.*"
Reduction in TC	MTA helped farmers lower their TC, especially in reducing search and TrC.	38	"*I used to spend money travelling to different markets, but now I can contact buyers directly.*"
Challenges in Digital Literacy	A significant barrier mentioned by farmers was the lack of digital literacy, particularly among older farmers, affecting their ability to use mobile platforms.	28	"*I don't understand how to use the phone apps, so I stick to the old methods.*"
Impact on NC	MTA increased farmers' NC by providing them with cost data, enabling them to negotiate better deals with buyers.	33	"*Knowing the costs beforehand gives me more power to negotiate with the middlemen.*"
Barriers to Adoption (Set-up)	Many farmers cited poor mobile network coverage in rural areas as a barrier to adoption, limiting the benefits of MTA.	45	"*Sometimes I can't get a signal in my village, so the mobile tools are unreliable.*"
Perceived Economic Benefits	Farmers perceived MTA as beneficial for increasing profits through broader MA and for securing lower production costs.	49	"*Since using the mobile platform, I've sold my crops at higher costs than before.*"

Summary results from the Impact on MA study are presented in **Table 7** and **Figure 5**, indicating that MTAs outscored non-adopters on several significant parameters. The mean percentage for improvement in MA was 43.21%, with a mean score of 4.12 for adopters and 2.87 for non-adopters on a 1–5 scale. The time to find vendors was cut almost in half, from a median of 3.45 days for adopters to 6.78 days for non-adopters. This is a 49.12% improvement. Success rates in India also showed a clear boost. Those who adopted the program had a median success rate of 78.34%, which was 39.22% higher than the 56.29% of non-adopters. Adopters earned $78.45 in TC, compared with $95.78 for non-adopters, resulting in an 18.13% reduction in the median. With a median increase of 15.75% for adopters and 8.56% for non-adopters, and an overall improvement of 83.97%, the LoI change exhibited the most improvement. In the TC Reduction analysis (**Table 8** and **Figure 6**), adopters reported 35.85% lower SC (12.34 $ vs. 19.23 $ for non-adopters) and 31.00% lower NC (9.28 $ vs 13.45 $). TrC was also reduced by 17.10% (from $23.67 for adopters to $28.56 for non-adopters). Overall, the total TC for adopters was 18.10% lower than for non-adopters (78.45 vs. 95.78). These reductions underscore the positive impact of MTA on alleviating the financial problem of contributing to agricultural markets.

A significant analysis of TC decreases and MA developments using MTA was ensured by using statistical tests, such as matched *t*-tests and ANOVA, to compare means between adopters and non-adopters.

Table 7. Impact on MA.

Efficiency Metric	Mean (Adopters)	Mean (Non-Adopters)	Improvement (%)
MA (Score 1–5)	4.12	2.87	43.21
Time to Find Buyers (Days)	3.45	6.78	49.12
NC Success Rate (%)	78.34	56.29	39.22
Average TC ($)	78.45	95.78	18.13
LoI (%)	15.75	8.56	83.97

Table 8. TC Reduction.

Cost Component	Mean (Adopters)	Mean (Non-Adopters)	Reduction (%)
SC ($)	12.34	19.23	35.85
NC ($)	9.28	13.45	31.00
TrC ($)	23.67	28.56	17.10
Total TC ($)	78.45	95.78	18.10

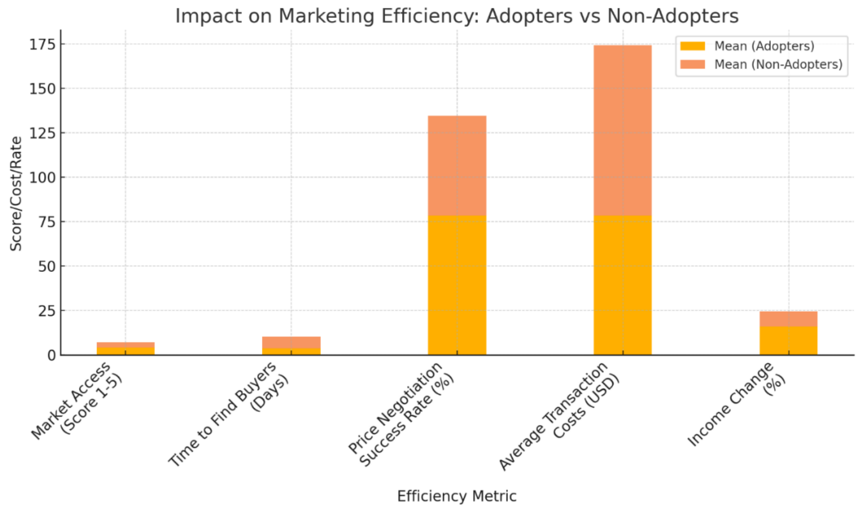

Figure 5. Impact on MA.

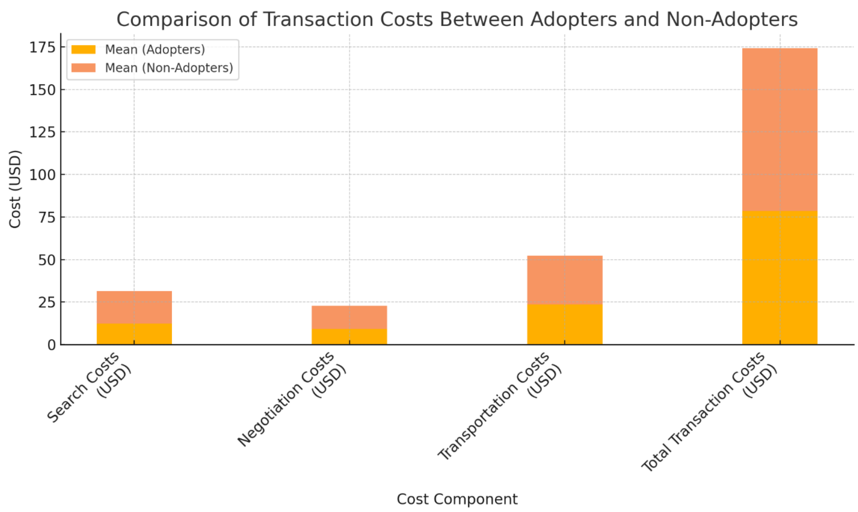

Figure 6. TC Reduction.

The econometric analysis of this research aims to start with the impacts of MTA on agricultural TC and MA. Regression analysis was used to find how factors such as MTA usage, farm size, level of education, MA-to-mobile setup, and distance to markets prejudiced TC and MA. The highly significant negative coefficient for MTA (Days Per Month) implies that more frequent MTA use reduces TC, enhancing the MA.

The positive signs in "Education Level" and "MA to Setup" indicate that a farmer with a higher training level is better positioned to use MTA for informed decision-making, as well as MA and NC, particularly when he has a better MA-to-setup ratio. On the other hand, "Farm Size" and "Geographical Distance to Markets" exhibit an equal weighting of the two extremes of significance. It also revealed that the effect of farm size on MTA use is insignificant, whereas the effect of distance is adverse, indicating that distance reduces MTA use. In general, the econometric results recommend that MTA adoption reduces TC and increases MA efficiency, while training level and technology MA contribute positively to better results.

The most extensive elasticities occur in information-intensive frictions (SC, NC), consistent with PU/PEOU-driven adoption and DoI's relative advantage in price discovery and bilateral search. The more minor but significant TrC reductions align with logistics optimisation (trip consolidation, remote matching) rather than pure transport technology change. The positive MA shift supports LoI gains, indicating that search and negotiation efficiency translate into market scope and cost realisation, a pathway consistent with prior agri-ICT findings in LMIC settings. Our pattern (SC ≫ TrC reductions; MA-mediated profits effects) verifies the digital extension and market platform literature presentation data conflicts as first-order constraints, while extending it by quantifying NC and sequentially testing mediation within a DoI–TAM base model. The mixed-methods triangulation validates mechanism claims: interviews feature funds to real-time price/quality verification and direct buyer contact, not merely to generic "phone use."

The study proposes an assessment of MTA's impact on the marketing of agricultural yields among SFs in Thanjavur district. The results show that adopting the MTA significantly decreases TC (SC and NC) and increases MA. MTA adopters had a significant increase in their MA to the market and LoI compared to non-adopters. The second objective of the study is to find how digital resources can help SF minimise market impacts, fill gaps, and make future profits. It provides an extensive overview of the factors impacting MTA adoption via quantitative and qualitative analysis. Since the research results point to improvements, change, and system-level change, they have important policy implications. The research paper breaks down the challenges and recommends practical solutions, addressing problems such as digital learning and implementation. According to the results, the MTA might increase SF's financial resources and make it easier for trades to market agricultural products.

5. Conclusions and Future Work

The findings from this research demonstrate how MTA is essential for decreasing TC and boosting SF's agriculture-related MA. Farmers can make more informed selections about when and where to market their produce owing to the MTA's SMS and mobile banking systems, which provide real-time market data. Farmers also decrease the demand on agricultural mediators. Implementing MTA led to significant improvements in MA and LoI, as well as an essential decrease in TC, particularly in SC and NC, for farmers. Despite these positive results, the investigation identifies several challenges to broader application, including digital learning, limited mobile access, and geographic restrictions. To reap the MTA's benefits in the SA market, we must overcome these problems. The present study aims to analyse the impact of MTA on MA and the reduced impact of TC on SFs' crop marketing methods.

This study's MTA can be utilised to quantify the changes it generates by analysing adopters and non-adopters using factors such as MA, TC, and LoI. The investigation's results show that adopters benefit in numerous contexts, including higher LoI (83.97%), lower TC (18.10%), and better MAs (43.21%). The above results reinforce support for MTA as an architecture that provides farmers with choice in decision-making and MA. Digital learning and technical problems are two factors that require concentrated effort to improve overall acceptance. Possible response bias, difficulties engaging a significant number of participants, sampling from organisations, limited generalisability, and inadequate attention to digital learning and MTA setup problems are among the research limitations.

Several limitations remain, despite the research's robust mixed-methods design. Improvements to the layer and PSM/IPW methods may not eliminate residual self-selection bias. Measurement errors in self-reported financial data could significantly degrade predictive performance. Dynamic adoption patterns and periodic cost unpredictability have been excluded due to the cross-sectional approach, which limits historical implications. Furthermore, Tanjore's system may have a limited scope of use due to its unique differentiation from neighbouring regions. Future research should include dashboard or stepped-wedge trials, experiments based on user interface tools, and geographic-specific designs that leverage emerging smartphone tool deployments. Quantitative cost-effectiveness analyses of digital literacy, coverage, and subsidy interventions can further support scalable digital transformation in agriculture and sustainable policy development.

Future research should focus on identifying solutions to these problems, with particular emphasis on improving farmers' access to digital learning and expanding MTA in rural regions. The potential long-term impact of MTA on farmers' market share and the agricultural ecosystem might also be investigated through longitudinal research.

Author Contributions

Conceptualisation, methodology, formal analysis, writing—original draft, writing—review & editing, investigation, S.S.; software, H.M.A. and A.A.; validation, S.V.; resources, K.S.B.; data curation, F.T.A.; visualisation, A.S. and S.B. All authors have read and agreed to the published version of the manuscript.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data supporting the reported results in this study are available upon request from the corresponding author. The datasets analysed or generated during the study are not publicly available due to privacy and ethical restrictions. However, data can be made available for academic research purposes upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] Ma, M., Sexton, R.J., 2021. Modern agricultural value chains and the future of smallholder farming systems. Agricultural Economics. 52(4), 591–606.
[2] Li, G., Zhang, H., 2024. The efficiency and challenges of e-commerce logistics in enhancing market access for agricultural products in rural China. Law and Economy. 3(2), 31–43.
[3] Fan, S., Rue, C., 2020. The role of smallholder farms in a changing world. In The Role of Smallholder Farms in Food and Nutrition Security. Springer: Cham, Switzerland. pp. 13–28.
[4] Abraham, M., Pingali, P., 2020. Transforming smallholder agriculture to achieve the SDGs. In The Role of Smallholder Farms in Food and Nutrition Security. Springer: Cham, Switzerland. pp. 173–209.
[5] Du, R.Y., Netzer, O., Schweidel, D.A., et al., 2021. Capturing marketing information to fuel growth. Journal of Marketing. 85(1), 163–183.
[6] Nchimbi, S.A., Kisangiri, M., Dida, M.A., et al., 2022. Design a services architecture for mobile-based agro-goods transport and commerce system. Mobile Information Systems. 2022(1), 6041197.
[7] Khidir, A.A., 2020. Awareness and use of mobile phone apps by farmers in North West Nigeria [PhD thesis]. North-West University (South Africa): Mafikeng, South Africa.
[8] Naika, M.B., Kudari, M., Devi, M.S., et al., 2021. Digital extension service: quick way to deliver agricultural information to the farmers. In Food Technology Disruptions. Academic Press: London, UK. pp. 285–323.
[9] Schroeder, K., Lampietti, J., Elabed, G., 2021. What's cooking: Digital transformation of the agrifood system. World Bank Publications: Washington, DC, USA.
[10] Mhlanga, D., 2024. Digital transformation of the agricultural industry in Africa. In Fostering Long-Term Sustainable Development in Africa: Overcoming Poverty, Inequality, and Unemployment. Springer Nature: Cham, Switzerland. pp. 441–464.
[11] Abate, G.T., Abay, K.A., Chamberlin, J., et al., 2023. Digital tools and agricultural market transformation in Africa: Why are they not at scale yet, and what will it take to get there? Food Policy. 116, 102439.
[12] Eze, S.C., Awa, H.O., Chinedu-Eze, V.C., et al., 2021. Demographic determinants of mobile marketing technology adoption by small and medium enterprises (SMEs) in Ekiti State, Nigeria. Humanities and Social Sciences Communications. 8(1), 1–11.
[13] Nan, W., Zhu, X., Markus, M.L., 2021. What we know and don't know about the socioeconomic impacts of mobile money in Sub-Saharan Africa: A systematic literature review. The Electronic Journal of Information Systems in Developing Countries. 87(2), e12155.
[14] Adam, I.O., Alhassan, M.D., 2021. The effect of mobile phone penetration on the quality of life. Telecommunications Policy. 45(4), 102109.
[15] Kumar, V.V., Devi, G.D., Ajay, U., et al., 2023. Enhancing smallholder farmer livelihoods through

AI-based e-commerce marketing for agricultural products. In Proceedings of the 2023 International Conference on Sustainable Computing and Data Communication Systems (ICSCDS), Erode, India, 23–25 March 2023; pp. 533–538.

[16] Sudha, M., Ramasundaram, P., 2021. An evaluation of e-commerce platform usage in agricultural marketing: Evidence from India. Journal of Agribusiness in Developing and Emerging Economies. 11(1), 75–94.

[17] Anand, N., Saxena, N., Jha, A., 2020. E-commerce platforms: A new paradigm for agriculture marketing in India. Agricultural Economics Research Review. 33(2), 267–273.

[18] Kariuki, L., Okumu, M., Nzui, D., 2020. E-commerce adoption in the Kenyan agricultural sector: opportunities and challenges. Journal of Entrepreneurship and Innovation in Emerging Economies. 6(2), 151–172.

[19] Adzimah, E.O., Amankwah, E.A., 2020. Mobile applications for enhancing smallholder farmers' access to agricultural information and markets in Ghana. Journal of Agribusiness in Developing and Emerging Economies. 10(2), 153–166.

[20] Dhinakaran, D., JoePrathap, P.M., 2022. Protection of data privacy from vulnerability using two-fish technique with Apriori algorithm in data mining. The Journal of Supercomputing. 78(16), 17559–17593.

[21] Jayalath, M.M., Perera, A.N., Ratnayake, R.C., et al., 2024. Towards digital transformation of vegetable supply chains in developing economies. In Proceedings of the Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering, Chiang Mai, Thailand, 24–27 January 2024; pp. 359–364. DOI: https://doi.org/10.1109/ECTIDAMTNCON60518.2024.10480012

[22] Rijswijk, K., Klerkx, L., Bacco, M., et al., 2021. Digital transformation of agriculture and rural areas: A socio-cyber-physical system framework to support responsibilization. Journal of Rural Studies. 85, 79–90.

[23] Correani, A., De Massis, A., Frattini, F., et al., 2020. Implementing a digital strategy: Learning from the experience of three digital transformation projects. California Management Review. 62(4), 37–56.

[24] Yadav, V.S., Singh, A.R., Gunasekaran, A., et al., 2022. A systematic literature review of the agro-food supply chain: Challenges, network design and performance measurement perspectives. Sustainable Production and Consumption. 29, 685–704.

[25] Lopez-Cueva, M., Apaza-Cutipa, R., Araujo-Cotacallpa, R.L., et al., 2024. Multi moving target localization in agricultural farmlands by employing optimized cooperative unmanned aerial vehicle swarm. Scalable Computing: Practice and Experience. 25(6), 4647–4660. DOI: https://doi.org/10.12694/scpe.v25i6.3130

[26] Ayasrah, F.T., Alsharafa, N.S., S, S., et al., 2024. Strategizing low-carbon urban planning through environmental impact assessment by artificial intelligence-driven carbon footprint forecasting. Journal of Machine and Computing. 4(4), 1140–1151. DOI: https://doi.org/10.53759/7669/jmc202404105

[27] Roque-Claros, R.E., Flores-Llanos, D.P., Maquera-Humpiri, A.R., et al., 2024. UAV path planning model leveraging machine learning and swarm intelligence for smart agriculture. Scalable Computing: Practice and Experience. 25(5), 3752–3765. DOI: https://doi.org/10.12694/scpe.v25i5.3131

[28] Ghanimi, H.M.A., R, S., Gloria Jeyaraj, J.P., et al., 2024. Smart fertilizing using IoT multi-sensor and variable rate sprayer integrated UAV. Scalable Computing: Practice and Experience. 25(5), 3766–3777. DOI: https://doi.org/10.12694/scpe.v25i5.3132

[29] Rahmani, M.K.I., Ghanimi, H.M.A., Jilani, S.F., et al., 2023. Early pathogen prediction in crops using nano biosensors and neural network-based feature extraction and classification. Big Data Research. 38, 100412. DOI: https://doi.org/10.1016/j.bdr.2023.100412

[30] Alsharafa, N.S., Sengan, S., Sri, S.T., et al., 2025. An edge-assisted Internet of Things model for renewable energy and cost-effective greenhouse crop management. Journal of Machine and Computing. 5(1), 576–588. DOI: https://doi.org/10.53759/7669/jmc202505045

[31] Ali, M.H., Deivasigamani, A., Karn, A.L., et al., 2024. The influence of direct market access on profit margins, supply chain efficiency, and economic resilience for small-scale dairy farmers of Asian country. Research on World Agricultural Economy. 6(1), 541–555. DOI: https://doi.org/10.36956/rwae.v6i1.1530

[32] Thiruvenkatasamy, V., Ghanimi, H.M.A., Sengan, S., et al., 2025. An online tool based on the Internet of Things and intelligent blockchain technology for data privacy and security in rural and agricultural development. Scientific Reports. 15, 27349. DOI: https://doi.org/10.1038/s41598-025-13231-9

[33] Hashim, N., Neo, T.G., Mohammed, M.N., et al., 2024. Toward sustainable smart cities: A new approach of solar and wind renewable energy in agriculture applications. In: Hamdan, A., Aldhaen, E.S. (Eds.). Artificial Intelligence and Transforming Digital Marketing. Springer: Cham, Switzerland. DOI: https://doi.org/10.1007/978-3-031-35828-9_47