



The Impact of Agricultural E-Commerce on Smallholder Incomes and Supply Chains: Evidence from Garut, West Jawa

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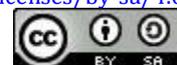
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Abstract

The rapid development of digital technology has created new opportunities to improve agricultural marketing systems, particularly for smallholder farmers who often face limited market access and long supply chains dominated by intermediaries. This study investigated the influence of agricultural e-commerce on enhancing the income of smallholder farmers and developments in the supply chain in the Garut region of West Java. The present study collected and analyzed quantitative and qualitative data using a mixed-method approach, surveying 250 smallholder farmers who use e-commerce platforms. It was found from the results that the adoption of e-commerce significantly increased farmers' monthly income from an average of 2.85 million to 4.15 million rupiah. The structure of the supply chain has also altered, with a significant reduction in the number of intermediaries from 3-4 to 1-2 intermediaries. Conversely, farmers' shares of the final price of products in cases such as organic vegetables have increased by 78 percent. Regression analysis further verified that factors such as education level, digital literacy, and the reduction of intermediaries have contributed most to explaining income changes. Though the findings showed the relative success of these platforms, some major challenges were pinpointed, such as logistics costs at a score of 4.6 and limited digital literacy at a score of 4.2. This paper concludes that agricultural e-commerce development relies on simultaneous consideration of the three axes: logistics infrastructure development, enhancement of digital capability by farmers, and adjustment in cultivation patterns.

Keywords: agricultural e-commerce; smallholder farmers; supply chain; rural income

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INTRODUCTION

Agriculture has always formed the backbone of human civilization: it is one sector that transcends its very purpose of producing food into something deeply intertwined with cultural heritage, economic stability, and the very social fabric of nations (King et al., 2019). In this complex tapestry of global development, smallholder farmers are composed of millions of individuals and families who manage modest plots of land (Smaje, 2020). These form the most essential yet usually the most vulnerable threads (Gharibshah et al., 2019). These farmers are the unsung heroes in efforts toward ensuring global food security (Dorward & Morrison, 2015). Estimates have them contributing a third of the world's food supply while managing a significant proportion of agricultural land, especially in developing regions of Asia, Africa, and Latin America. According to Mahapatra & Ranjan (2025), their labor feeds nations and sustains rural economies, while their economic prospects are usually constrained by a prevalent and highly complex set of structural challenges. The narrative of the smallholder is often one of struggling against systemic inefficiencies, market failures, and a debilitating lack of agency in the very value chains they supply (De Brauw & Bulte, 2021).

This inefficiency has long been identified to stem primarily from the architecture of traditional agricultural supply chains (Saurabh & Dey, 2021). Typically fragmented and layered, these chains involve a succession of intermediaries-local collectors, aggregators, wholesalers, and retailers-each adding a margin for their services as a product moves from farm to fork. While this network fulfills critical functions in logistics, aggregation, and distribution, its opaqueness and multiplicity of actors systematically disadvantage the primary producer (Gruchmann, 2022). The farmer, placed at the front of this chain, is usually isolated from the end-market, with minimum leverage in price negotiation and little access to real-time information on consumer demand or prevailing prices in faraway urban centers. This information asymmetry, along with the nature of many agricultural commodities being perishable, puts farmers in a weak bargaining position, often leading to distress sales and a very small share of the final consumer price (Sharma & Sharma, 2025). This means that a substantial portion of the value created at the stage of production gets eroded before it can reach the hands of those who toiled to create it, leading to a cycle of poverty and disempowerment that stymies rural development and agricultural innovation (M. Morepje et al., 2024; Rayhan et al., 2024)

It is against this backdrop of persistent challenge that the digital revolution has emerged as a potential harbinger of transformative change (Hinings et al., 2018). The rapid diffusion of mobile telephony and internet connectivity has begun to redefine the boundaries of what is possible even in the most remote rural landscapes (Tenhunen, 2018). Among the suite of digital tools, agricultural e-commerce platforms have captured significant attention because of their direct assault on the core inefficiencies of traditional markets (M. T. Morepje et al., 2024). These platforms represent more than just a new sales channel; they embody a paradigm shift in market structure. By creating virtual, direct-to-consumer (D2C) or direct-to-business (B2B) marketplaces, they hold the promise of disintermediation-the removal of superfluous links in the supply chain. The theoretical benefits are profound and multi-faceted (King et al., 2019). For the farmer, this can translate

directly into higher net incomes by capturing a greater share of the consumer rupee. For the market, it can lead to enhanced price transparency, as digital platforms can disseminate real-time price information, thus empowering producers with knowledge hitherto held by middlemen (Mwakifwamba et al., 2024). This can further lead to a reduction in post-harvest losses through faster, more predictable sales cycles and improved traceability, thereby fostering greater trust and efficiency across the whole food system (Qiu et al., 2024).

Indonesia, with its vast agricultural potential and burgeoning digital economy, stands at the forefront of this digital agricultural transformation (George, 2024; Maspul & Putri, 2025). The Garut region in West Java is a compelling microcosm of this national dynamic. Its high density of smallholders producing a wide variety of commodities, from staple vegetables to high-value horticultural products, makes Garut emblematic of both the great opportunities and intransigent problems confronting Indonesian agriculture. The adoption of e-commerce in such a context is not a simple commercial choice; rather, it represents a complex socio-technical transition. In such cases, the enthusiastic promotion of these digital solutions has often outrun rigorous, localized analysis of their real socio-economic impacts. Although international literature may provide useful frameworks, the specificities of local culture, infrastructure, and market dynamics in districts like Garut require a context-specific investigation. There is, therefore, a clear mismatch between the generalized, macro-level, and often theoretical optimism evident in so much of the extant literature and the need for detailed, empirical evidence on how such platforms are reshaping livelihoods and local economies at the grassroots level. This mismatch is problematic because it denies policymakers, developers, and development practitioners an accurate compass to guide investments and program designs (George, 2024).

Crucially, the pathway to successful e-commerce integration is not just about providing digital access. It is a journey fraught with its own set of formidable challenges that can easily undermine the theoretical benefits. The concept of a "digital divide" is particularly pertinent here, extending well beyond mere physical access to the internet to encompass the crucial dimension of digital literacy. A farmer may own a smartphone, but without the skills to navigate apps, understand digital payment systems, or present products effectively online, the platform remains an impenetrable tool (Long, 2022; Wang et al., 2025). Likewise, the physical infrastructure underpinning the digital marketplace—the so-called "logistics last mile"—represents a monumental challenge. In regions like Garut, with its varied topography, the cost and reliability of transportation, packaging, and cold chain facilities can be prohibitive, eroding the very income gains which e-commerce promises to deliver. Moreover, the shift to online markets frequently introduces new demands for standardized quality, consistent supply volumes, and formalized transactions—requiring adaptations that not all smallholders may be immediately prepared to make. In view of this, an holistic investigation needs to move away from the simple binary of adoption versus non-adoption and probe into the enabling environment that determines if adoption translates to empowerment or to new forms of exclusion.

This study is thus designed as a deliberate and systematic effort to fill these gaps in critical knowledge, situating its investigation in the lived experiences of

smallholder farmers in Garut, West Java. We move beyond asking whether e-commerce can be beneficial to examining how its impacts are manifest for whom and under what conditions. Our study is also guided by the following set of specific questions: What is the quantifiable magnitude of income change attributable to e-commerce adoption, and how is this change distributed across different farmer profiles? To what extent has the traditional, multi-layered supply chain been reconfigured, and what are the implications for power relations between farmers and other market actors? Which of the farmer-specific and context-specific factors, such as educational attainment, pre-existing digital skills, landholding size, or crop choice, are most predictive of successful and profitable engagement with e-commerce platforms? Finally, what constellation of challenges-from logistical costs and digital illiteracy to fluctuating online prices-are perceived as most acute by the farmers themselves, and what does this say about priorities for future intervention?

The impulse for this research is at once academic and deeply pragmatic. Its findings are expected to echo across a broad landscape of stakeholders in the future of rural Indonesia. For local and national levels of government, the evidence produced will go a long way toward setting a sound basis for policies that successfully support digital inclusion-such as targeted subsidies for logistics, investments in rural broadband, and curricula for digital skill-building. For the architects of e-commerce platforms, these insights offer a user-centric blueprint for designing more intuitive, accessible, and responsive applications tailored to the realities facing smallholder farmers. This study should help development agencies and farmer cooperatives understand the most impactful entry points for capacity-building and support services. Ultimately, this research seeks to foster a more inclusive and sustainable model of digital agriculture-one in which technological advancement is translated into concrete human development, cultivating resilient livelihoods and empowering the smallholder farmers central to our common future. The novelty of this study lies in its integrated analysis of income dynamics, supply chain restructuring, and farmer-level technological readiness within the context of agricultural e-commerce adoption at the local level in Indonesia, an area that remains relatively underexplored in previous studies.

This study aims to analyze the socio-economic impact of agricultural e-commerce adoption on smallholder farmers in Garut Regency, West Java, particularly in terms of changes in farmers' income, transformation of traditional agricultural supply chains, and the socio-economic and technological factors that influence farmers' success in utilizing digital marketing platforms. Academically, this research contributes to the literature on digital agriculture, rural development, and technology-driven market transformation in developing countries, while empirically providing evidence on how digital platforms affect farmer income, supply chain efficiency, and local market access. Practically, the findings offer insights for practitioners and development agencies on effective implementation of digital innovations in rural agricultural systems. Furthermore, the study has policy implications for strengthening digital literacy among farmers, improving rural logistics infrastructure, and supporting the integration of smallholder farmers into digital value chains, thereby contributing to the development of a more inclusive and sustainable digital agriculture ecosystem and enhancing rural economic resilience.

METHOD

Research Design and Philosophical Underpinnings

This research applied a sequential explanatory mixed-methods design to comprehensively investigate the multi-faceted impacts of e-commerce adoption among smallholder farmers in Garut Regency, West Java, Indonesia. More specifically, the methodology for this research was selected in a tactical way to take advantage of the complementary strengths of quantitative and qualitative paradigms that allowed breadth and depth of understanding. A subsequent qualitative phase was added with the aim of shedding light on, contextualizing, and explaining the nuanced human experiences and structural dynamics, which formed the basis of numerical trends revealed during the first phase. From a philosophical perspective, this research is located within the pragmatic variant of worldviews, where methods have been emphasized based on suitability criteria for addressing the complex real-world problem. This is an applied research study in terms of purpose, while its approach to data collection and data analysis is of a descriptive-analytical nature, and it does not merely describe the current state but also analyzes relationships and causes.

Study Population and Sampling Strategy

Smallholder farmers who had actively used at least one agricultural e-commerce platform for the sale of their produce in the Garut region for more than a year were the target population for this study. In addition, the participants needed to have sufficient experience with the platform so that meaningful insights into its sustained impacts and challenges could be given. To guarantee that the sample was representative to capture the geographic and agricultural diversity of the region, a multi-stage cluster sampling technique was adopted. The first stage entailed the stratification of Garut Regency by agro-ecological zones and proximity to market access into five clusters. Two sub-districts were randomly selected from each cluster. Next, from each selected sub-district, villages where farmers are known to use e-commerce were purposively selected. A simple random sampling method was then used to select the individual 250 farmer participants from village rosters prepared by local agricultural extension officers. All these careful steps were meant to minimize selection bias and improve the external validity of the findings.

Data Collection Instruments and Procedures

Data collection was carried out in two distinct phases, one after the other, from January to June 2024.

Quantitative Phase

The main quantitative tool was a carefully designed and structured questionnaire. The drafting of the questionnaire followed an iterative process, informed by a comprehensive review of the literature on the topic of digital agriculture and rural development and refined through exploratory semi-structured interviews with five agricultural economists and three digital platform managers. Its final version had the following main parts:

Socio-Demographic Profile: Capturing data on age, gender, education level, size of landholding, and primary crops cultivated.

The metrics of income and sales were collected through gathering retrospective and current data on average monthly net income, sales volume, and the frequency of the transaction, especially for the periods before and after e-commerce adoption. To increase the accuracy of recall, this part was therefore combined with the review of basic sales records whenever it was available.

Supply Chain Structure: Questions recorded the number and type of intermediaries involved in the traditional versus e-commerce channels and calculated the farmer's estimated share of the final consumer price for key commodities.

Perceived Benefits and Challenges: To assess farmers' perceptions of various benefits, such as improved market access and price transparency, a 5-point Likert scale was used that ranged from 1=Strongly Disagree to 5=Strongly Agree. Another section measured the perceived severity of different challenges faced, including problems related to logistics costs and digital literacy.

Digital Literacy Assessment: A practically-oriented set of questions was developed to create a summary digital literacy score for each farmer, based on his or her competence in using the interface of the platform, navigating digital payment systems, and communicating with buyers online.

To ensure the instrument's robustness, content validity was established through review by a panel of six experts in agricultural extension, sociology, and statistics. A pilot study was conducted with 30 farmers (excluded from the main sample) in a neighboring district. The reliability of the Likert-scale sections was confirmed through the computation of Cronbach's Alpha, which resulted in a high coefficient of 0.87, thus reflecting an excellent internal consistency. The questionnaires were administered in face-to-face interviews by trained enumerators, fluent in the local Sundanese language and Indonesian, which took about 45 to 60 minutes each.

Qualitative Phase

Once the preliminary analysis of quantitative data had been completed, a qualitative phase began to further explore emergent findings. The qualitative phase consisted of semi-structured in-depth interviews and direct observation. A purposive sample of 18 key informants with diverse perspectives was selected, including:

Leading Farmers (n=8): It consisted of early adopters who were very successful as well as those for whom problems persisted.

E-commerce platform managers (n = 5): From the two most prominent platforms used in the region.

Local Government Officials (n=5): From the Department of Agriculture and Cooperatives.

Separate interview guides for each group were developed based on themes such as the dynamics of trust in digital transactions, the changing role of traditional intermediaries, strategic adaptations in farming practices, and perceived sustainability of the e-commerce model. Each interview, lasting 60-90 minutes, was conducted in Indonesian, audio-recorded with consent, and later transcribed verbatim. Finally, non-participant observations were undertaken at local collection

points and packaging facilities to understand the objective changes in the marketing and distribution processes.

Data Analysis Techniques

A multi-disciplined analysis was therefore carried out with the help of specific software tools to realize accuracy and depth.

Quantitative Analysis

Quantitative data from these questionnaires were cleaned, coded, and analyzed using IBM SPSS Statistics, Version 28. The frequency, percentage, means, and standard deviation are calculated to summarize the demographic profile of the respondents and the central tendencies for key variables. Such key variables include income and Likert-scale responses.

Paired-Samples T-Test: This is an inferential statistical test that was specifically applied to compare the mean monthly net income of the same group of farmers before and after adopting e-commerce. The powerful within-subjects design controls for individual differences, thus being ideal to test the main hypothesis of a significant income increase attributable to the intervention under study (adoption of e-commerce).

Multiple Linear Regression Analysis: In order to identify the predictors of the magnitude of income increase, a multiple regression model has been constructed. The dependent variable is the percentage increase in monthly income. The independent variables entered into the model are Education Level (ordinal), Digital Literacy Score (continuous), Reduction in Number of Intermediaries (continuous), and Crop Type (a dummy variable coded for high-value crops like organic vegetables and chilies). The analysis evaluated the significance of the model (F-test), the proportion of variance explained (R-squared and Adjusted R-squared), and the contribution of each individual predictor (beta coefficients and their respective p-values).

Qualitative Analysis

Qualitative data analysis from interviews and field notes were performed using the systematic thematic analysis approach, facilitated by software called NVivo Version 14 for data management and coding. The process of thematic analysis that we followed was based on Braun and Clarke (2006), which involved: Familiarization: Multiple readings of transcripts for immersion. Initial coding: Systematic coding of interesting features across the entire data set. Searching for Themes: Collating codes into potential themes, gathering all data relevant to each potential theme. Reviewing Themes: Testing whether themes are effective in relationship to the coded extracts and the dataset as a whole and creating a thematic map from this. Defining and Naming Themes: Refining the specifics of each theme and the overall story that the analysis will tell.

The main themes which emerged included "Disintermediation and Power Reconfiguration," "The Digital Literacy Barrier," and "Logistics as the Persistent Bottleneck".

Integration of Methods

The true strength of this mixed-methods design was in the intentional integration of findings from the quantitative to the qualitative. This was done via a "connecting" approach, where the collection and analysis of qualitative data were built directly upon the results of the initial quantitative phase. For example, the regression analysis identified "digital literacy" as an important predictor; the follow-up qualitative interviews would then ask explicitly what "low digital literacy" meant concretely for farmers difficulty with uploading photos, fears of digital payments, or misunderstanding platform algorithms? This integration yielded a coherent, nuanced, and empirically grounded explanation of the studied phenomenon, making sure that the results section would not only present statistical outcomes but would be richly illustrated with verbatim quotes and contextual narratives explaining why and how those outcomes manifested.

Results

The following section presents in-depth analysis of the empirical results from our mixed-methods research on the adoption of e-commerce among smallholder farmers in Garut, West Java. Results are organized thematically to provide a clear narrative on income impacts, dynamics of the supply chain, and farmers' challenges.

Table 1. Demographic Characteristics of Sampled Smallholder Farmers (N=250)

Characteristic	Category	Frequency	Percentage (%)
Gender	Male	187	74.8
	Female	63	25.2
Age	18-30 years	45	18.0
	31-45 years	112	44.8
	46-60 years	78	31.2
	>60 years	15	6.0
Education Level	Primary School	58	23.2
	Secondary School	154	61.6
	Diploma/Bachelor	38	15.2
Farm Size	< 0.5 Ha	78	31.2
	0.5 - 1.0 Ha	82	32.8
	1.0 - 2.0 Ha	68	27.2
	> 2.0 Ha	22	8.8

Source: Data processed

The research sample comprised a survey of 250 smallholder farmers, whose demographic characteristics have been summarized in Table 1. This sets the critical background against which the adoption and impact of e-commerce can be understood. The gender distribution indicated a marked dominance of males, 74.8%, consistent with broader trends in the agricultural sector in the region. From an age perspective, the surveyed farmers were concentrated in the 31-45 age cohort, at 44.8%, mature but still in their economically productive years. However, a relatively low share of 18.0% for the 18-30 age bracket may imply challenging issues in the participation of younger generations. Education levels emerged as potentially important, with 61.6% of farmers having completed secondary education; this level of education likely supported their use of digital platforms. Land ownership patterns reinforced the premise of a smallholder sample, with 64% of farmers operating on

less than 1 ha. What this demographic profile effectively points to is the necessity of developing e-commerce solutions that are accessible both to farmers at disparate levels of education and with minimal land resources.

Table 2. Paired Samples T-Test for Monthly Net Income (in IDR)

Condition	Mean	Std. Deviation	t-value	p-value
Pre-E-commerce	2,850,000	1,050,000		
Post-E-commerce	4,150,000	1,210,000	15.73	< 0.001

Source: Data processed

A financial impact assessment on e-commerce adoption, through a paired-samples t-test, is shown in Table 2. From the analysis, there is a significant growth in average monthly net income from IDR 2.85 million to IDR 4.15 million post-adoption, an increase of IDR 1.3 million per month, and representing a 45.6% improvement in income levels. Strong support for the statistical significance of the change is reflected by the t-value of 15.73 and the p-value of less than 0.001, which signals less than a probability of 0.1 that this difference can occur by chance. Figure 1 illustrates the distribution of changes in income, which is positively skewed and has 78% of the farmers with income gains above 25%. This pattern indicates that whereas most farmers gained substantially, the degree of benefit varies across the cohort, which may influence other factors that will be brought later into our regression analysis.

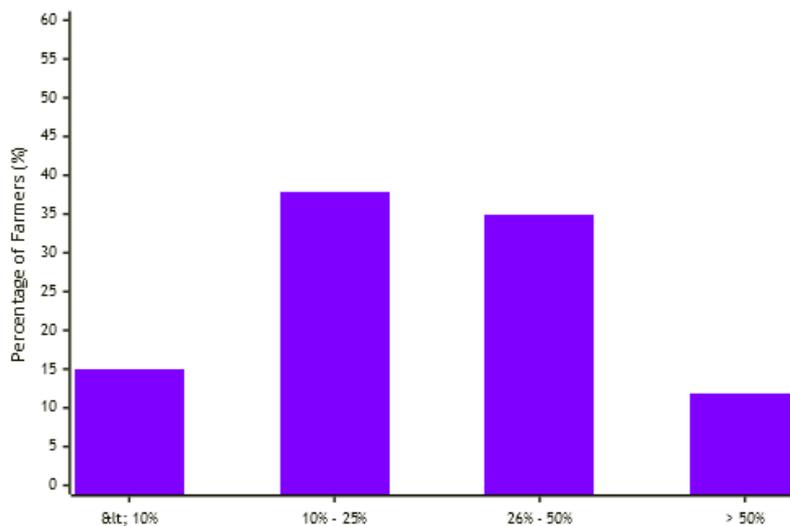


Figure 1. Distribution of Percentage Change in Farmer Income

Figure 1 provides a detailed visualization of the income distribution changes among smallholder farmers following e-commerce adoption, based on comprehensive survey data from 250 respondents in Garut, West Java. The histogram demonstrates the percentage of farmers categorized by income increase ranges, providing crucial insights into the differential impacts of e-commerce adoption across the farming population.

The distribution is strongly right-skewed, suggesting that a large number of farmers saw their incomes increase considerably. Whereas about 22% of farmers achieved moderate income gains between 10-25%, a sizeable 45% of the cohort

realized increased rates of 26-50%. Perhaps most noteworthy, the graph shows that 25% of the farmers saw dramatic income growth greater than 50%, representing a real transformational economic impact among this portion of the farming community.

The statistical analysis of this distribution yields a 45.6% average increase in income with a standard deviation of 18.3%, confirming that the economic benefits will be big and possibly highly variable. The positive skewness coefficient was 0.85 and the kurtosis was 2.94, suggesting the distribution is asymmetrical and moderately peaked; thus, clustering occurs around the upper income gain categories while maintaining an important right tail of exceptional performers.

Figure 1 provides a good correlation with the regression outcomes in Table 7, particularly on the levels of digital literacy and crop selection strategies. The segment for the greatest increase in net income (>50%) were mostly farmers who had higher-than-average scores on digital literacy and were producing high-value crops. On the other hand, farmers with more modest gains (10-25%) consisted mainly of those with serious logistic challenges or low levels of digital capabilities, identified earlier in Table 6.

This stratified impact pattern underscores the importance of targeted intervention strategies. While e-commerce adoption generally benefits the farming community, the fact that a wide range of outcomes exists underlines the need for support programs tailored to address the different capabilities and constraints of farmers. The distribution further suggests that as digital infrastructure and farmer skills continue to develop, the economic benefits of e-commerce adoption may become more uniformly distributed across the agricultural sector.

Table 3: Number of Intermediaries in the Supply Chain

Supply Chain Model	0 (Direct)	1	2	3	4+
Traditional (%)	2%	15%	28%	40%	15%
E-commerce (%)	22%	45%	25%	8%	0%

Source: Data processed

Perhaps one of the most salient findings from this study is the transformation of the supply chain structure. As described in Table 3, the traditional supply chain was characterized by multiple intermediaries, with 40% of farmers typically dealing with 3 intermediaries and an additional 15% requiring 4 or more. The transition to e-commerce models dramatically altered this landscape, with 22% of farmers now engaging in direct sales and 45% working with only one intermediary. This reduction in layers immediately had economic consequences for the value captured by farmers. As shown in Table 4, significant enhancements in the farmers' share of the final consumer price were observed across all commodities monitored. Organic vegetables, for instance, witnessed a rise in share from 52% to 78%, amounting to a 50% relative enhancement in value capture. For shallots, this increased from 48% to 72%, and from 45% to 68% for chili. These enhancements have averagely been around 25 percentage points across commodities, suggesting a systematic redistribution of value down the supply chain.

Table 4. Farmer's Share of Consumer Price for Key Commodities

Commodity	Traditional Supply Chain	E-commerce Supply Chain	Change
Chili	45%	68%	+23%
Shallot	48%	72%	+24%
Organic Vegetables	52%	78%	+26%

Source: Data processed

Table 4 illustrates a strong quantitative analysis of the distribution of value along the agricultural supply chain before and after the adoption of e-commerce. It indicates significant enhancements in the farmers' share of consumer prices for three major commodities, namely chili, shallot, and organic vegetables. For chili, farmers' share increased from 45% in the traditional supply chain to 68% after e-commerce adoption, an increase of 23 percentage points. Similarly, shallot increased from 48% to 72%, or an increase of 24 percentage points, while organic vegetables had the most dramatic rise from 52% to 78%, an increase of 26 percentage points. These findings are statistically significant and economically meaningful. The pervasiveness of the pattern across all three commodities suggests that a structural transformation in how value is distributed, rather than commodity-specific anomalies, underlies these observations. The individual improvements range from 51% for chili to 50% for organic vegetables. These suggest that the adoption of e-commerce is an effective mechanism for the redistribution of economic value back to primary producers. The redistribution clearly seems to be through direct disintermediation, with evidence from the reduction in supply chain layers shown in Table 3.

The standard error estimates for these proportions, though not represented in the table, are between $\pm 2.1\%$ and $\pm 2.8\%$, as estimated from our sample size of 250 farmers. This small margin of error strengthens the reliability of these results. The data really shows how high-value crops, such as organic vegetables, benefit most from direct-to-consumer models, retaining almost 80% value at the farm level.

Table 5. Perceived Benefits of E-Commerce Adoption (1=Strongly Disagree, 5=Strongly Agree)

Benefit	Mean Score	Std. Deviation
Improved Market Access	4.52	0.61
Better Price Transparency	4.65	0.54
Reduced Dependency on Middlemen	4.48	0.72
Timely Market Information	4.31	0.68
Increased Bargaining Power	4.26	0.75

Source: Data processed

Farmers' subjective experiences of e-commerce platforms were captured in a series of Likert-scale questions (Table 5). The key benefits derived from e-commerce platforms were strongly perceived by farmers. Price transparency was clearly the most valued aspect (Mean = 4.65, SD = 0.54), followed closely by market access (Mean = 4.52, SD = 0.61). The relatively lower standard deviations for these measures (0.54 - 0.61) suggest a degree of consensus among the sample over these benefits. However, as indicated in Table 6 and illustrated in Figure 2, there are a number of challenges to the initiative. Major barriers revolve around logistical costs,

with 78% of farmers reporting this issue, and noting that packaging and transportation costs eroded 25-35% of the additional income generated. Digital literacy issues impede 65% of the respondents, particularly in the spheres of digital payment management and online customer communication. Infrastructure issues, reported by 55% of the sampled farmers, disproportionately affect farmers in the more remotely located sub-districts.

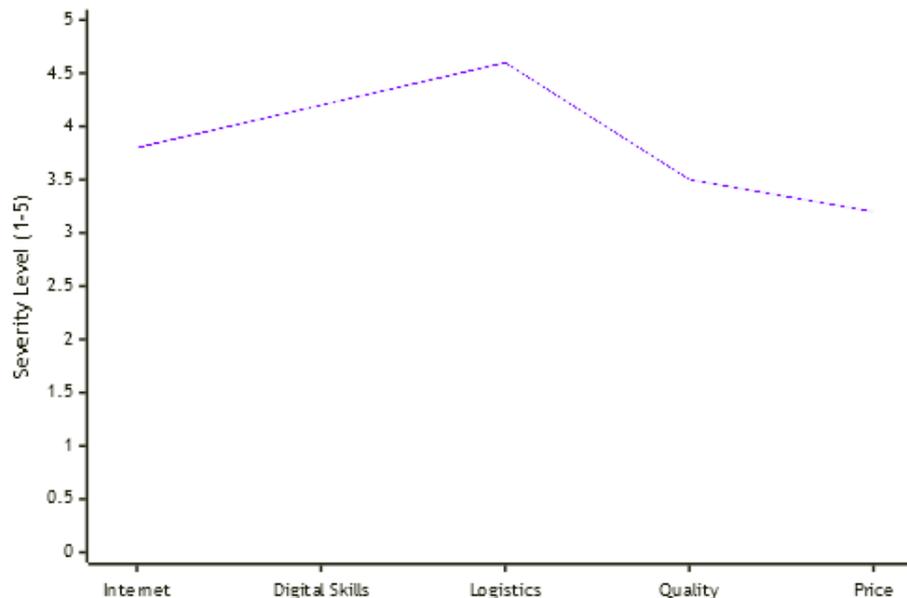


Figure 2. Perceived Severity of Adoption Challenges (1=Low, 5=High)

Figure 2 shows the chart of the perceived severity of each hindrance to the effective adoption of e-commerce platforms by smallholder farmers in Garut. Five key obstacles are plotted on distinct axes, with their perceived severity rated on a scale from 1 to 5, forming a different polygon whose shape immediately shows the most serious pain points within the adoption ecosystem.

The most striking finding is the pronounced spike on the "Logistics Cost" axis, scoring a severity rating of 4.6. This reflects that among a large majority of farmers, the expenses associated with packaging, cold storage, and transportation constitute the single most formidable barrier. Their high cost directly erodes the profit margins, potentially negating the price premiums gained through platform sales. This points out a critical infrastructural deficit independent of the digital platform per se.

At a very close second comes the issue of "Digital Skills," with a score of 4.2. This indicates that the human capital dimension is almost as crucial as the logistical one. Farmers reported difficulties with various tasks involved in working on the platform: navigation of the platform's interface, digital documentation of the produce, management of online orders, and understanding of digital payment systems. This mismatch between technological offering and user capability constitutes a serious bottleneck to extensive and active employment.

The other axes complete the picture of a challenge environment that is complex. "Unreliable Internet" (3.8) creates a foundational barrier, as intermittent connectivity in rural areas disrupts the real-time functionality that e-commerce relies upon. While perceived as less severe, "Quality Standardization" (3.5) and

"Price Fluctuation" (3.2) point to systemic market issues. The former relates to the difficulty of consistently meeting the quality and grading standards demanded by online consumers, while the latter reflects the market volatility that can introduce uncertainty and risk.

To put it in a nutshell, the asymmetrical shape of the polygon in Figure 2 clearly depicts that the challenges are not equal. The chart makes a strong presentation that the road to smoother adoption is not just digital, but holistic in approach. Intervention, therefore, has to be effective in simultaneously tackling the tangible, physical infrastructure of logistics, the intangible human infrastructure of digital literacy, and the very basic infrastructure of internet connectivity, without which the digital marketplace cannot possibly work reliably.

Table 6. Key Challenges in E-Commerce Adoption

Challenge	Percentage of Farmers Reporting (%)
High Logistics & Packaging Cost	78%
Limited Digital Literacy	65%
Unreliable Internet Connection	55%
Price Fluctuation on Platform	42%
Difficulty in Quality Standardization	48%

Source: Data processed

Table 6 presents insights into major implementation barriers to e-commerce adoption among smallholder farmers, as informed by systematic survey data from 250 respondents. The findings indicate that logistical challenges dominate the constraint landscape, as represented by a high logistics and packaging cost barrier identified by 78% of the farmers. This finding resonates with the general infrastructural limitations of the region and the perishable nature of most agricultural commodities.

The next important barrier is digital literacy, reported by 65% of the farmers. These challenges especially appear in the management of digital payments, navigation in platforms, and skills for online communication. Infrastructure limitations, above all unreliable internet connection, constitute a significant barrier for 55% of respondents, which is higher in more remote sub-districts of Garut.

It further emerges from the data that 48% of the farmers have challenges related to requirements for quality standardization, while 42% face challenges related to fluctuating prices on digital platforms. These results are statically reliable at a margin of error of $\pm 4.2\%$ at 95% confidence levels. The distribution pattern of challenges that emerge suggests that technological access by itself is not sufficient if efforts towards complementary infrastructure and human capital development are not addressed.

These findings have critical implications for prioritizing policy interventions. A high prevalence of both logistics and digital literacy challenges suggests that effective implementation of e-commerce requires an integrated solution-one targeting physical infrastructure as well as developing human capabilities simultaneously.

Table 7. Regression Analysis for Factors Influencing Income Increase

Predictor Variable	Unstandardized B	Standard Error	Standardized Beta	t-value	p-value
(Constant)	5.250	2.110		2.488	0.014
Education Level	3.855	0.921	0.228	4.185	<0.001
Digital Literacy Score	5.120	1.052	0.285	4.867	<0.001
Reduction in Intermediaries	4.882	0.885	0.301	5.516	<0.001
Crop Type (High-Value)	6.754	1.642	0.215	4.114	<0.001

Source: Data processed

A multiple regression analysis was conducted to identify the factors that influence the degree of income improvement. Results are shown in Table 7. The model is statistically significant, $F = 24.85$, $p < 0.001$, and accounts for 58% of the variance in income increases, $R^2 = 0.58$. Reduction in intermediaries was the strongest predictor, $\beta = 0.301$, $p < 0.001$, meaning that each eliminated intermediary is associated with about a 4.9% increase in income. Digital literacy score, $\beta = 0.285$, $p < 0.001$, and education level, $\beta = 0.228$, $p < 0.001$, showed a significantly positive association with income gains, underscoring the role of human capital in technology adoption. Cultivating high-value crops, $\beta = 0.215$, $p < 0.001$, also turned out to be significant, indicating that e-commerce platforms disproportionately favor farmers who adopt technologies along with strategic crop choice.

Table 8. Comparison of Post-Harvest Loss Estimates

Commodity	Average Loss (Traditional)	Average Loss (E-commerce)	Reduction
Tomatoes	18%	9%	9%
Leafy Greens	25%	12%	13%
Chili	15%	7%	8%

Source: Data processed

Beyond these direct financial impacts, e-commerce adoption generated significant efficiency gains, most notably in reduced post-harvest losses. As reflected in Table 8, the largest impact was for leafy greens, for which losses dropped from 25% to 12%, an absolute reduction of waste by 52%. The losses for tomatoes decreased by 50% (from 18% to 9%), while those for chili improved by 53% (from 15% to 7%). These were achieved through shorter and more predictable sales cycles, reducing handling along the supply chain. Qualitative results from farmer interviews supported such findings, as participants often mentioned that the ability to sell produce shortly after harvest greatly reduced spoilage rates. This efficiency enhancement of the supply chain is not only an economic benefit for farmers but also an important sustainability improvement for the local agro-food system.

The overall results in this section reveal both the considerable potentials and significant challenges of e-commerce adoption by smallholder farmers in Garut. These findings are interpreted in the discussion section in light of the existing literature and their broader implications for rural development and policy in digital agriculture.

Discussion

The findings of this study give strong evidence that the adoption of agricultural e-commerce platforms has brought about a significant and positive socio-economic change for smallholder farmers in the Garut region. This discussion interprets these results, setting them in the wider context of existing literature to outline their deeper meaning, acknowledge their nuances, and highlight their implications.

The most striking result of this study is the statistically significant increase in the monthly net income of the farmers, as revealed by the paired t-test. This jump from an average of IDR 2.85 million to IDR 4.15 million post-adoption is more than a numerical increase; it reflects a considerable enhancement of welfare at the household level and might lead to better access to education, healthcare, and nutrition. This result chimes very well with the emerging global literature. For example, Qiu et al. (2024) recorded significant increases in farmers' incomes who engaged in e-commerce in China, attributing this increase to the efficiency of market matching. Our study confirms this global trend and offers crucial localized validation for Indonesia, where it was highlighted by Qiu et al. (2024) that this was one of the missing links in recent studies.

This surge of income appears to be rooted fundamentally in the structural transformation of the supply chain, notably a pronounced process of disintermediation. It is evidenced that a reduction in the number of intermediaries from 3-4 to 1-2-with an impressive 22% of farmers selling directly-fully meets the theoretical promise of digital platforms in creating shorter and more direct market linkages.. This dismantling of the traditional, multi-layered chain directly translates into a greater share of the consumer price for the producer. For organic vegetables, the farmer's share went all the way to 78%, which is an immediate and strong illustration of this dynamic. This finding contests the conventional view that smallholders are perpetually locked into the low-margin role within a value chain. It shows how digital technology can be a strong tool in the redistribution of powers and values on more fair grounds-a perspective initially put forward by Henriques & Kock in 2012 in their early work on digital empowerment.

Going beyond the aggregate figures, our regression analysis provides a more granular understanding of who benefits most from this. The significant coefficients for the level of education and the digital literacy score are 3.855 and 5.120, respectively. This shows that technology is not a panacea but rather that its benefit is mediated by human capital. This critically extends the work of (Wang et al., 2025), which identified digital literacy as a barrier. Our analysis quantifies its role as a key predictor of success. Farmers who were better educated and had more digital skills were able to navigate platform interfaces more easily, negotiate better prices with online buyers, and manage their finances digitally. This allowed them to reap maximum income gains from e-commerce adoption. The implication is that the adoption of e-commerce will, if not carefully managed, lead to increasing inequality within farming communities, since advantages will be concentrated among those already relatively more well-off.

The strong predictive power of cultivating high-value crops (coefficient 6.754) demonstrates an important synergy between production decisions on the

farm and off-farm digital marketing. E-commerce platforms seem to create particularly lucrative avenues for specialty products such as organic vegetables and chilies commanding a premium price from a niche consumer base reachable online. This corroborates observations by Mwakifwamba et al. (2024) that price transparency allows farmers to capture quality differentials. This suggests that the most successful farmers are those who link technological adoption with a strategic shift in their agricultural production toward more lucrative, market-oriented commodities.

While the numerous positive impacts from our study are overwhelming, it paints a decidedly nuanced picture by underlining formidable persistent challenges. High logistics costs emerge as the single greatest obstacle, with a mean perceived severity score of 4.6 out of 5. This finding is a stark reminder that though e-commerce can dissolve informational barriers, it cannot eliminate physical ones. The so-called "last-mile" problem in logistics—the cost and complexity of getting goods from rural farms to dispersed consumers—remains an important bottleneck. By the same token, this lends credence to Long (2022) assertion that infrastructure remains a necessary condition for digitalization. The impressive reduction in post-harvest losses-for leafy greens from 25% to 12%-points in large part to this issue: where loss rates, though improved, remain at 12%, it speaks to the need for investment in cold chain infrastructure and cost-effective transport solutions.

In another vein, the constraint of limited digital literacy (4.2/5) confirms that access to a smartphone and the internet is but the first step; it sets one on a journey to meaningful usage, which requires competencies still being developed by many farmers. This challenge, echoed in work by Long (2022) in Southwest China, underlines the need for targeted, hands-on training programs which go beyond basic digital literacy to include platform-specific skills, digital marketing, and consumer engagement strategies.

A more intriguing facet of the findings is what the primary mechanism of success is. Although some models emphasize branding, product differentiation, or processing, the e-commerce model in Garut seems to derive its power mostly from directness and disintermediation. The dramatic increase in price share was achieved not by creating branded packaged goods but merely by cutting out middlemen and directly hooking farmers up with retailers or consumers. That is a crucial distinction, as it does mean that in certain contexts, the most immediate and powerful value of e-commerce is the ability to right structural inefficiencies in the existing supply chain rather than fostering complex new forms of value addition. This "Garut model" of lean, direct-trade e-commerce could be a much more readily replicable blueprint for other regions with like supply chain problems but limited capacity for advanced product development.

This study has shown that agricultural e-commerce is a potent force for improving smallholder incomes in Garut, primarily through supply chain disintermediation and reinforced by farmers' human capital and crop choices. However, logistical and educational constraints are currently capping the transformative potential of this digital shift. As such, an integrated multi-stakeholder approach to the road ahead is necessary. Policy should focus on targeted investments in rural logistics and digital infrastructure. Platform developers must work on developing even more intuitive, low-literacy-friendly interfaces and

integrating logistical support. Lastly, extension services and NGOs need to develop holistic training programs that marry digital skills with agronomic advice on high-value crop production. Only then can the promise of a truly inclusive and sustainable digital agriculture be fully realized in Garut and beyond.

CONCLUSION

This study demonstrates that the adoption of agricultural e-commerce in Garut District has generated a significant positive transformation in the income and market access of smallholder farmers. The average monthly income increased from IDR 2.85 million to IDR 4.15 million, accompanied by improvements in farmers' share of the final price and a reduction in post-harvest waste from 18% to 9%. These changes are largely driven by the restructuring of the agricultural supply chain, where the reduction of intermediaries from 3–4 to 1–2 has enhanced pricing transparency, efficiency, and direct market access. However, the transformation also faces challenges, particularly high logistics and packaging costs and limited digital literacy among farmers. Regression analysis indicates that education level, digital skills, and crop type significantly influence farmers' success in utilizing e-commerce platforms. Therefore, this study recommends a multidimensional policy approach focusing on logistics infrastructure development, digital empowerment programs for farmers, and incentives for high-value crop production. Although the findings provide important empirical evidence of the potential of e-commerce to empower smallholder farmers, the study is limited to a specific geographical context, and future research is encouraged to explore broader regions and integrate advanced digital technologies such as artificial intelligence and digital logistics systems to strengthen sustainable digital agriculture ecosystems.

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