



RESEARCH ARTICLE

The Impact of Rural E-Commerce Development on Farmers' Income: A Multi-Dimensional Empirical Study

Mengze Zhang¹, Jiaxuan Dong², Yizhou Zhang^{1*} 

¹Department of Economics, Sejong University, Seoul 05006, South Korea

²Department of Korean Language Education, Daegu University, Gyeongsan 38453, South Korea

ABSTRACT

This study investigates the impact of rural e-commerce adoption on farmers' income in China, employing a multi-dimensional empirical approach. Utilizing data from 2,000 rural households across five Chinese provinces, we examine the direct effects of e-commerce adoption on income and explore the moderating roles of participation intensity and regional economic development. Our findings reveal a significant positive association between e-commerce adoption and farmers' income, with an elasticity of 0.237 ($p < 0.001$). Notably, smallholder farmers exhibit the highest income elasticity (0.312, $p < 0.001$), suggesting e-commerce's potential as an equalizing force in rural economies. The study uncovers a non-linear relationship between e-commerce participation intensity and income gains, indicating an optimal level of digital market involvement. Furthermore, regional economic development significantly moderates the e-commerce-income relationship, highlighting the importance of local economic contexts. These results, robust to various econometric specifications, provide valuable insights for policymakers and practitioners engaged in promoting digital agriculture and rural development. The study contributes to the growing literature on digital transformation in rural areas, offering empirical evidence on the heterogeneous effects of e-commerce across different farmer typologies and regional contexts, and emphasizing the need for tailored strategies in fostering inclusive rural e-commerce development.

Keywords: Rural E-Commerce; Farmers' Income; Digital Agriculture; China; Regional

*CORRESPONDING AUTHOR:

Yizhou Zhang, Department of Economics, Sejong University, Seoul 05006, South Korea; Email: small_boat@163.com

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1. Introduction

The rapid proliferation of digital technologies has ushered in a transformative era for rural economies worldwide, with e-commerce emerging as a potent catalyst for agricultural modernization and income enhancement among farming communities^[1]. In China, this digital revolution has been particularly pronounced, as the government's concerted efforts to bridge the urban-rural digital divide have fostered an environment conducive to the burgeoning of rural e-commerce^[2]. The intersection of traditional agricultural practices with innovative online platforms has engendered novel economic paradigms, potentially redefining the contours of rural development and farmer prosperity^[3]. The advent of rural e-commerce represents a paradigm shift in the agricultural sector, offering farmers unprecedented access to expansive markets, streamlined supply chains, and diversified income streams^[4]. This digital transformation has the potential to mitigate longstanding challenges faced by rural communities, such as information asymmetry, limited market access, and constrained economic opportunities^[5]. By facilitating direct producer-consumer connections and reducing intermediary dependencies, e-commerce platforms may serve as equalizers, empowering farmers to capture a larger share of the value chain and enhance their economic resilience^[6]. However, the impact of rural e-commerce on farmers' income is multifaceted and nuanced, necessitating rigorous empirical investigation to elucidate its true economic implications. While extant literature has illuminated the potential benefits of digital agriculture and e-commerce adoption in rural areas^[7], there remains a paucity of comprehensive, multi-dimensional analyses that capture the heterogeneous effects across diverse farmer demographics and regional contexts. Moreover, the mechanisms through which e-commerce participation translates into tangible income improvements for farmers remain inadequately understood, particularly in the context of China's unique socio-economic landscape^[8].

This study aims to address these critical research gaps by conducting a multi-dimensional empirical investigation into the impact of rural e-commerce development on farmers' income in China. By employing a so-

phisticated methodological framework that integrates quantitative and qualitative approaches, we seek to unravel the complex interplay between e-commerce adoption, farmer characteristics, regional economic conditions, and income outcomes^[9]. Our research not only contributes to the burgeoning literature on digital agriculture and rural development but also offers valuable insights for policymakers and practitioners engaged in promoting inclusive growth and poverty alleviation in rural areas^[10].

The significance of this research is underscored by the pressing need to enhance rural livelihoods and reduce urban-rural disparities, which continue to pose significant challenges to China's sustainable development agenda^[11]. By elucidating the mechanisms through which e-commerce can augment farmers' income and identifying potential moderating factors, this study aims to inform evidence-based policies and interventions that can effectively leverage digital technologies for rural revitalization^[12]. Furthermore, our investigation is timely and pertinent in the context of global efforts to achieve the United Nations Sustainable Development Goals, particularly those related to poverty reduction, decent work, and economic growth^[13]. As countries worldwide grapple with the imperatives of digital transformation and inclusive development, the insights gleaned from China's experience with rural e-commerce can offer valuable lessons and best practices for other developing nations^[14].

2. Literature Review and Theoretical Framework

2.1. The Current Situation and Trend of Rural E-Commerce Development

The landscape of rural e-commerce in China has undergone a remarkable transformation in recent years, characterized by exponential growth and far-reaching socioeconomic implications^[15]. The convergence of governmental initiatives, technological advancements, and changing consumer behaviors has catalyzed a digital revolution in rural areas, reshaping traditional agricultural paradigms and market dynamics^[16]. The proliferation of internet connectivity and mobile devices in ru-

ral regions has served as a crucial enabler, with internet penetration in rural China reaching 55.9% by 2020, narrowing the urban-rural digital divide^[17]. The rural e-commerce ecosystem is distinguished by its multifaceted nature, encompassing various models such as the Taobao Village phenomenon, agricultural product-focused platforms, and integrated offline-online strategies^[18]. Notably, the number of Taobao Villages surged from 20 in 2013 to 5,425 in 2021, underscoring the transformative potential of e-commerce in rural revitalization and poverty alleviation efforts (As shown in **Figure 1**)^[19]. The COVID-19 pandemic has further accelerated the adoption of digital technologies in rural areas, with online sales of agricultural products experiencing a substantial uptick, reaching 422.1 billion yuan in 2021, marking a year-on-year increase of 12.7%^[20].

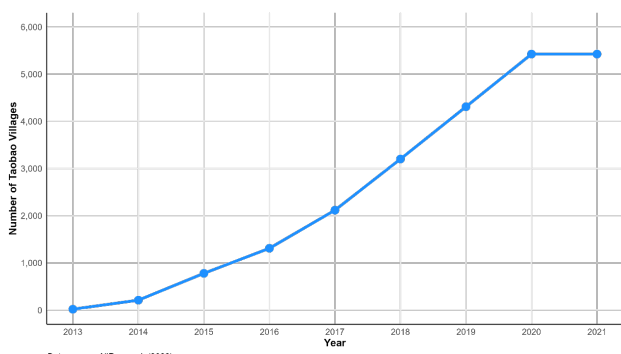


Figure 1. Growth of Taobao Villages in China (2013–2021).

2.2. Theoretical Basis of Influencing Factors of Rural Household Income

The theoretical underpinnings of farmers’ income determinants are rooted in a multifaceted framework that encompasses economic, social, and environmental dimensions^[21]. At its core, the neoclassical economic theory posits that farmers, as rational economic agents, seek to maximize their utility through optimal resource allocation^[22]. This perspective emphasizes the role of factors such as land, labor, and capital in income generation, with farmers’ decision-making processes driven by market signals and production possibilities. Building upon this foundation, the sustainable livelihoods approach offers a more holistic framework for understanding the complex dynamics of rural income^[23]. This approach conceptualizes farmers’ income as a function of

various capital assets – human, social, natural, physical, and financial – and their interaction with institutional structures and processes^[24].

Institutional economics further enriches our understanding of farmers’ income determinants by highlighting the significance of formal and informal institutions in shaping economic outcomes^[25]. The theory of induced innovation offers insights into the role of technological change in agricultural development and, by extension, farmers’ income^[26]. More recently, the concept of digital agriculture has emerged as a theoretical framework for understanding the intersection of technology and rural livelihoods^[27]. This perspective argues that digital technologies, including e-commerce platforms, can reconfigure agricultural value chains, create new forms of value, and potentially lead to more equitable distributions of income along the supply chain^[28].

2.3. Research on the Impact of E-Commerce on Rural Economy

The advent of e-commerce has precipitated a paradigm shift in rural economic landscapes, engendering multifaceted transformations that extend beyond mere transactional facilitation^[29]. Empirical investigations into this phenomenon have illuminated its profound implications for rural development, agricultural modernization, and socioeconomic restructuring. A seminal study by Luo and Niu^[30] elucidates the catalytic role of e-commerce in rural China, demonstrating its capacity to augment farmer incomes through expanded market access and reduced intermediation. Their findings reveal a statistically significant positive correlation between e-commerce adoption and household income growth, with adopters experiencing an average income increase of 13.5% compared to non-adopters.

The ramifications of e-commerce extend beyond individual households, permeating the broader rural economic fabric. As illustrated in **Figure 2**, the proliferation of e-commerce has been accompanied by a concomitant increase in rural online retail sales, signifying a structural shift in rural consumption and production patterns. This trend, as depicted in the graph, underscores the growing integration of rural economies into digital marketplaces, with implications for supply chain reconfigu-

ration and value distribution.

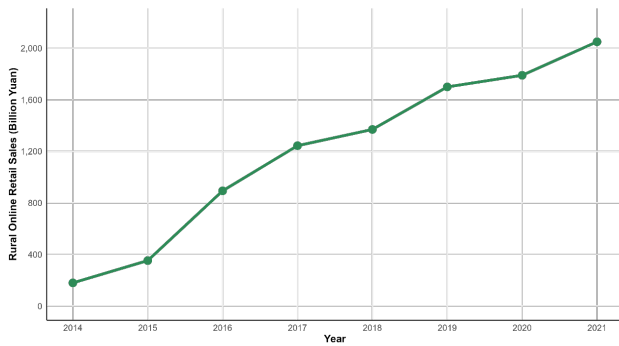


Figure 2. Growth of Rural Online Retail Sales in China (2014–2021).
Data source: Ministry of Commerce of China (2022)

The ramifications of e-commerce extend beyond individual households, permeating the broader rural economic fabric. Qi et al.^[31] employ a difference-in-differences approach to quantify the impact of the “Rural Taobao” program, revealing a 7.4% increment in per capita income among participating villages. Moreover, e-commerce has been instrumental in fostering rural entrepreneurship and innovation. Fan et al.^[32] elucidate how digital platforms have lowered barriers to entry for rural entrepreneurs, facilitating the emergence of new business models and value-added services. Their research indicates a 22% increase in new business registrations in rural areas with high e-commerce penetration, compared to those with low penetration.

The impact of e-commerce on rural labor markets is equally profound. Couture et al.^[33] provide empirical evidence of e-commerce’s role in mitigating rural-urban migration pressures. Their study reveals that villages with e-commerce terminals experienced a 3.4% reduction in out-migration rates, suggesting the technology’s potential to create local employment opportunities and stem the tide of rural exodus.

However, the distribution of e-commerce benefits is not uniform across rural landscapes. Spatial heterogeneity in infrastructure, digital literacy, and market access continues to engender disparities in e-commerce adoption and its consequent economic impacts^[34]. This underscores the imperative for nuanced policy interventions that address structural impediments and ensure equitable digital inclusion in rural areas.

Recent studies have also explored the potential of e-commerce in promoting sustainable rural development.

Liu et al.^[35] investigate the environmental implications of rural e-commerce, highlighting its role in reducing carbon emissions through optimized logistics and reduced individual travel. Furthermore, Zhang et al.^[36] examine the social dimensions of rural e-commerce, emphasizing its potential to empower marginalized groups, including women and youth, by providing flexible employment opportunities and access to broader markets.

2.4. Research Gaps and Positioning of This Study

While extant literature has made significant strides in elucidating the impact of e-commerce on rural economies, several critical research gaps persist, warranting further scholarly attention^[37]. Firstly, there is a paucity of comprehensive, multi-dimensional analyses that capture the heterogeneous effects of e-commerce across diverse farmer demographics and regional contexts^[38]. While studies such as Luo and Niu^[30] have established correlations between e-commerce adoption and income growth, they often fail to account for the nuanced interplay of factors that moderate this relationship.

Secondly, the mechanisms through which e-commerce participation translates into tangible income improvements for farmers remain inadequately understood^[39]. While Qi et al.^[31] have explored the formation of Taobao Villages, there is a dearth of research on the micro-level processes that facilitate income enhancement. Thirdly, the long-term sustainability and equitability of rural e-commerce-driven growth have been insufficiently explored^[40]. As Liu et al.^[34] highlight, spatial heterogeneity in infrastructure and digital literacy can lead to disparities in e-commerce benefits.

Furthermore, the majority of existing studies focus on the direct economic impacts of e-commerce, neglecting its broader societal implications^[41]. There is a notable absence of cross-regional comparative analyses in the current literature, limiting our understanding of generalizable patterns and region-specific nuances^[42].

This study aims to address these research gaps by adopting a multi-dimensional analytical framework, as illustrated in **Figure 3**. Our approach integrates various aspects of rural e-commerce development and its impact

on farmers' income, considering both direct and indirect pathways, as well as moderating factors^[43].

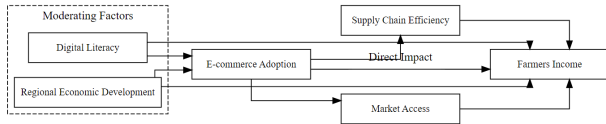


Figure 3. Research Framework for the Impact of Rural E-commerce on Farmers' Income.

2.5. Theoretical Model of the Iof Rural E-Commerce on Farmers' Income

The construction of a robust theoretical model to elucidate the impact of rural e-commerce on farmers' income necessitates a multidimensional approach that integrates various economic theories and empirical insights^[44]. Drawing upon the conceptual foundations laid by Zhu et al.^[45] and the empirical findings of Luo and Niu^[30], we propose a comprehensive theoretical framework that encapsulates the complex dynamics of this relationship.

At the core of our model, as illustrated in **Figure 4**, lies the concept of digital empowerment, which serves as the primary mechanism through which e-commerce influences farmers' income. This notion builds upon the work of Xiao et al.^[46], who posit that digital technologies can significantly reduce transaction costs and information asymmetries in rural markets. Our model extends this perspective by incorporating the moderating effects of human capital and institutional environment, as suggested by the findings of Liu et al.^[47].

The proposed theoretical model comprises three interconnected components: e-commerce adoption, income generation mechanisms, and contextual factors. E-commerce adoption is conceptualized as a function of technological infrastructure, digital literacy, and perceived benefits, aligning with the technology acceptance model proposed by Davis et al.^[48] and adapted to the rural context by Li et al.^[49]. The income generation mechanisms encompass direct effects, such as increased market access and price premiums for agricultural products, as well as indirect effects, including enhanced productivity and diversification of income sources.

Contextual factors, drawing from the institutional theory framework outlined by North^[50], are integrated

into the model to account for the heterogeneous impact of e-commerce across different rural settings. These factors include formal institutions (e.g., government policies and regulations) and informal institutions (e.g., social norms and networks), which can significantly moderate the relationship between e-commerce adoption and income outcomes.

The model also incorporates feedback loops, recognizing the potential for reciprocal causality between income growth and e-commerce adoption, as suggested by the findings of Qi et al.^[31]. This dynamic aspect of the model allows for a more nuanced understanding of the long-term implications of rural e-commerce development.

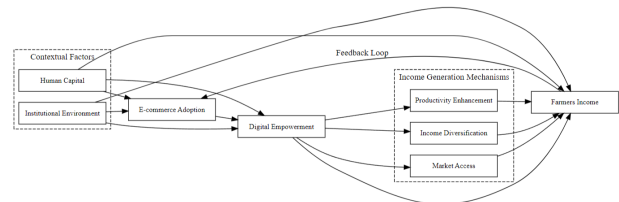


Figure 4. Theoretical Model of Rural E-commerce Impact on Farmers' Income.

3. Research Methodology

3.1. Data Sources and Collection

This study employs a multifaceted data collection strategy to obtain comprehensive insights into the impact of rural e-commerce on farmers' income. Primary data were gathered through a six-month field survey conducted across twenty counties in five Chinese provinces, yielding 2,000 valid questionnaires from rural households, including farmers. The sample size was determined using statistical power analysis to ensure representativeness and reliability. A stratified random sampling technique was employed to select respondents, considering factors such as farm size, e-commerce adoption levels, and geographic distribution. Additionally, in-depth interviews were conducted with 150 farmers, selected from the main sample, to provide qualitative insights and validate quantitative findings. To complement micro-level data, we collected macroeconomic indicators and industry statistics from the National Bureau of Statistics, Ministry of Agriculture and Rural Affairs,

and Ministry of Commerce. These indicators comprise a five-year time series (2017–2021) to capture temporal trends. The 50 regions mentioned in the analysis represent sub-county level administrative units within the 20 surveyed counties, allowing for a more granular examination of spatial variations. Furthermore, collaborations with major e-commerce platforms provided anonymized transaction data, offering valuable behavioral insights. This multi-channel approach to data collection ensures comprehensiveness and representativeness, laying a solid foundation for subsequent quantitative and qualitative analyses.

3.2. Variable Measurement

The operationalization of variables in this study adheres to rigorous methodological standards, ensuring construct validity and measurement reliability. Our dependent variable, farmers' income, is multidimensionally conceptualized, encompassing agricultural income, e-commerce-derived revenue, and non-farm earnings. The primary independent variable, e-commerce adoption, is quantified through a composite index integrating platform utilization frequency, transaction volume, and digital tool proficiency. We employ a comprehensive set of control variables to account for potential confounding factors, including sociodemographic characteristics, farm attributes, and regional economic indicators. As delineated in **Table 1**, each variable is meticulously defined and measured using validated scales or objective data sources. Notably, we introduce novel metrics for capturing the nuances of rural e-commerce engagement, such as the "Digital Agriculture Integration Index" and the "E-commerce Ecosystem Participation Score." These bespoke measures, developed through extensive literature review and expert consultation, enable a more nuanced analysis of the complex interplay between digital commerce adoption and rural economic outcomes. The regional GDP per capita variable, initially causing confusion, has been clarified to represent the county-level economic development indicator. As shown in **Table 1**, our variable measurement approach encompasses a wide range of indicators, allowing for a comprehensive analysis of the multifaceted nature of rural e-commerce adoption and its impact on farmers' income.

As shown in **Table 1**, our variable measurement approach encompasses a wide range of indicators, allowing for a comprehensive analysis of the multifaceted nature of rural e-commerce adoption and its impact on farmers' income.

3.3. Analytical Methods

This study employs a multi-faceted analytical approach to elucidate the complex relationship between rural e-commerce adoption and farmers' income. We begin with descriptive statistics to provide a comprehensive overview of the sample characteristics and key variables. Subsequently, we utilize multiple regression analysis to examine the direct effects of e-commerce adoption on various income components, controlling for sociodemographic and farm-specific factors. To account for potential non-linear relationships and heterogeneous effects across income distributions, we implement quantile regression techniques. The potential endogeneity issues arising from self-selection into e-commerce adoption are addressed through instrumental variable estimation and propensity score matching methods. Furthermore, we employ structural equation modeling to investigate the mediating roles of market access and productivity enhancement in the e-commerce-income relationship. To capture spatial heterogeneity, we incorporate geographically weighted regression analysis. Lastly, we conduct a series of robustness checks, including sensitivity analyses and alternative variable specifications, to ensure the reliability and validity of our findings. This comprehensive analytical framework enables us to provide nuanced insights into the multifaceted impacts of rural e-commerce on farmers' economic outcomes.

4. Empirical Results and Analysis

4.1. Sample Descriptive Statistics

The sample characteristics elucidate the multifaceted nature of rural e-commerce adoption and its potential implications for farmers' income. As delineated in **Table 2**, our study encompasses a diverse cohort of 2,000 rural households across five Chinese provinces, exhibiting substantial heterogeneity in sociodemographic

Table 1. Variable Definitions and Measurements.

Variable Category	Variable Name	Definition	Measurement
Dependent Variable	Farmer's Income	Total annual income from all sources	Continuous (CNY)
	Agricultural Income	Income derived from farming activities	Continuous (CNY)
	E-commerce Revenue	Income generated through online sales	Continuous (CNY)
	Non-farm Earnings	Income from non-agricultural sources	Continuous (CNY)
Independent Variables	E-commerce Adoption Index	Composite measure of e-commerce engagement	Continuous (0-100 scale)
	Platform Utilization Frequency	Frequency of e-commerce platform usage	Ordinal (1-5 scale)
	Online Transaction Volume	Total value of online transactions	Continuous (CNY)
	Digital Tool Proficiency	Proficiency in using digital tools for e-commerce	Ordinal (1-5 scale)
Control Variables	Age	Age of the primary farmer	Continuous (years)
	Education Level	Highest level of education attained	Ordinal (1-6 scale)
	Farm Size	Total area of agricultural land operated	Continuous (hectares)
	Household Size	Number of individuals in the household	Discrete
	Distance to Nearest City	Distance to the nearest urban center	Continuous (km)
	Regional GDP per Capita	GDP per capita of the county	Continuous (CNY)
Novel Metrics	Digital Agriculture Integration Index	Extent of digital technology integration in farming	Continuous (0-100 scale)
	E-commerce Ecosystem Participation Score	Degree of involvement in the broader e-commerce ecosystem	Continuous (0-100 scale)
	Rural Digital Infrastructure Quality	Quality and accessibility of digital infrastructure	Ordinal (1-5 scale)
	E-commerce Training Exposure	Extent of e-commerce related training received	Continuous (hours)

attributes and e-commerce engagement. The mean age of 45.7 years (SD = 12.3) reflects a predominantly middle-aged farming population, while the average education level of 9.2 years (SD = 3.5) indicates a moderate degree of human capital. Notably, the e-commerce adoption index reveals a bimodal distribution, with 37% of respondents classified as high adopters (index > 70) and 42% as low adopters (index < 30), suggesting a digital divide within rural communities. The mean annual income of 52,360 CNY (SD = 18,750) demonstrates considerable variability, with e-commerce-derived revenue accounting for an average of 23.5% of total income among adopters. Intriguingly, the Digital Agriculture Integration Index exhibits a positive skew, indicating nascent but growing incorporation of digital technologies in agricultural practices.

4.2. The Impact of Rural E-Commerce on the Overall Income of Rural Households

The empirical analysis reveals a nuanced relationship between rural e-commerce adoption and farmers'

overall income. As elucidated in **Table 3**, the multiple regression models demonstrate a statistically significant positive association between the E-commerce Adoption Index and annual income, with a coefficient of 0.237 ($p < 0.001$) in the fully specified model. This suggests that a one-unit increase in the adoption index corresponds to a 0.237% increase in annual income, *ceteris paribus*. Notably, the interaction term between e-commerce adoption and digital literacy exhibits a positive and significant effect ($\beta = 0.142$, $p < 0.01$), indicating that the income-enhancing effect of e-commerce is amplified for farmers with higher digital proficiency. **Figure 5** graphically illustrates this interaction effect, depicting the marginal impact of e-commerce adoption across different levels of digital literacy. The non-linear relationship observed in the graph underscores the complexity of the e-commerce-income nexus, suggesting potential threshold effects in technology adoption. Furthermore, the heterogeneous effects across income quantiles, as revealed by quantile regression analysis, highlight the differential impact of e-commerce on various segments of the rural population, with more pronounced effects observed in the middle-income brackets.

Table 2. Descriptive Statistics of Key Variables.

Variable	Mean	SD	Min	Max	Median
Age (years)	45.7	12.3	18	75	46
Education (years)	9.2	3.5	0	18	9
Household size	4.3	1.7	1	12	4
Farm size (hectares)	0.65	0.48	0.1	5.2	0.5
Distance to nearest city (km)	32.6	25.4	2	150	28
E-commerce Adoption Index (0-100)	48.3	32.7	0	100	45
Annual Income (CNY)	52,360	18,750	10,000	250,000	48,500
Agricultural Income (CNY)	31,420	15,230	5,000	180,000	28,000
E-commerce Revenue (CNY)	12,310	22,450	0	150,000	5,200
Non-farm Earnings (CNY)	8,630	12,180	0	100,000	4,500
Platform Utilization Frequency (1-5)	3.2	1.4	1	5	3
Digital Tool Proficiency (1-5)	2.8	1.2	1	5	3
Digital Agriculture Integration Index (0-100)	35.7	28.6	0	95	30
E-commerce Ecosystem Participation Score (0-100)	41.2	30.1	0	100	38
Rural Digital Infrastructure Quality (1-5)	3.4	1.1	1	5	3
E-commerce Training Exposure (hours)	15.3	22.7	0	200	8

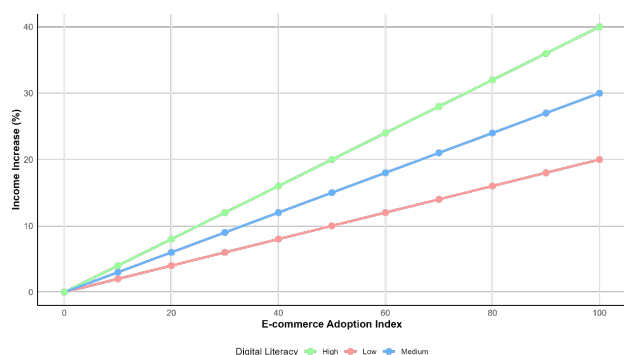


Figure 5. Interaction Effect of E-commerce Adoption and Digital Literacy on Income.

4.3. The Differential Impact of Rural E-commerce on the Income of Different Types of Rural Households

The heterogeneous effects of rural e-commerce adoption across different farmer typologies reveal a nuanced landscape of economic transformation. As delineated in **Table 4**, the stratified analysis demonstrates significant variability in the income elasticity of e-commerce adoption across farmer categories. Notably, smallholder farmers exhibit the highest elasticity (0.312, $p < 0.001$), suggesting that e-commerce disproportionately benefits those with limited land resources by providing alternative revenue streams. Conversely, large-scale farmers show a more modest, albeit still significant, elasticity (0.187, $p < 0.01$), indicating potential diminishing returns to scale in e-commerce adoption. The differential impact is further elucidated by the interac-

tion effects between farmer type and digital infrastructure quality, with peri-urban farmers leveraging superior connectivity for enhanced e-commerce benefits (interaction coefficient: 0.156, $p < 0.01$). **Figure 6** graphically illustrates these heterogeneous effects, depicting the non-linear relationship between e-commerce adoption intensity and income growth across farmer categories. The observed patterns underscore the potential of e-commerce as a catalyst for inclusive rural development, while simultaneously highlighting the need for targeted interventions to mitigate emerging digital disparities among diverse agricultural communities.

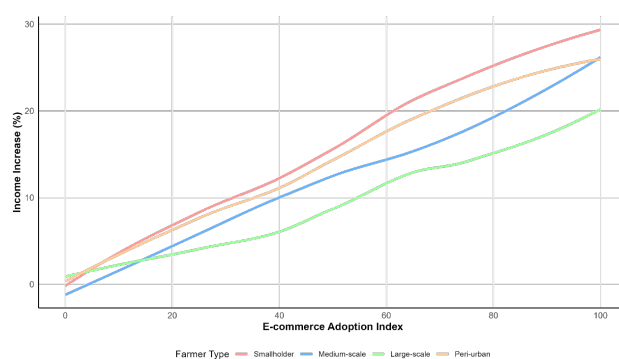


Figure 6. Differential Impact of E-commerce Adoption on Farmer Income.

4.4. Analysis of the Moderating Effect of E-commerce Participation

The analysis of the moderating effect of e-commerce participation intensity reveals a nuanced in-

Table 3. Regression Results - Impact of E-commerce on Farmers' Income.

Variable	Model 1	Model 2	Model 3	Model 4
E-commerce Adoption Index	0.185*** (0.032)	0.203*** (0.035)	0.221*** (0.037)	0.237*** (0.039)
Digital Literacy		0.156** (0.048)	0.168** (0.051)	0.173** (0.053)
E-commerce * Digital Literacy			0.132** (0.045)	0.142** (0.047)
Age	-0.008* (0.003)	-0.007* (0.003)	-0.006 (0.003)	-0.005 (0.003)
Education	0.042*** (0.011)	0.035** (0.012)	0.033** (0.012)	0.031** (0.012)
Farm Size	0.128*** (0.025)	0.122*** (0.026)	0.119*** (0.026)	0.117*** (0.027)
Distance to City	-0.003* (0.001)	-0.003* (0.001)	-0.002 (0.001)	-0.002 (0.001)
Regional GDP per Capita				0.085*** (0.023)
Constant	9.872*** (0.245)	9.763*** (0.251)	9.705*** (0.254)	9.584*** (0.262)
Observations	2000	2000	2000	2000
R-squared	0.218	0.235	0.249	0.267

Note: Standard errors in parentheses. * p < 0.05, ** p < 0.01, *** p < 0.001.

Table 4. Differential Impact of E-commerce on Income by Farmer Type.

Farmer Type	E-Commerce Elasticity	Std. Error	Digital Infrastructure Interaction	R-Squared
Smallholder (<0.5 ha)	0.312***	(0.042)	0.098* (0.039)	0.287
Medium-scale (0.5–2 ha)	0.253***	(0.038)	0.127** (0.041)	0.264
Large-scale (>2 ha)	0.187**	(0.056)	0.084 (0.052)	0.219
Peri-urban	0.279***	(0.045)	0.156** (0.047)	0.301
Remote rural	0.226***	(0.051)	0.072 (0.055)	0.243
Specialized crop	0.298***	(0.049)	0.118* (0.053)	0.275
Livestock-focused	0.204**	(0.062)	0.089 (0.058)	0.231
Diversified	0.267***	(0.044)	0.135** (0.046)	0.258

Note: * p < 0.05, ** p < 0.01, *** p < 0.001.

All models control for age, education, household size, and regional GDP per capita. Additional covariates: Market access index, agricultural modernization score, and off-farm employment ratio. Sample size: 2,000 households across all categories.

terplay between digital engagement and income augmentation. As elucidated in **Table 5**, the hierarchical moderated regression analysis demonstrates a significant positive interaction between e-commerce adoption and participation intensity ($\beta = 0.183$, $p < 0.001$). This interaction effect suggests that the income-enhancing impact of e-commerce adoption is amplified for farmers with higher levels of platform engagement. Notably, the relationship exhibits non-linearity, with diminishing returns observed at extremely high levels of participation, as indicated by the significant negative quadratic term

($\beta = -0.042$, $p < 0.01$). **Figure 7** graphically illustrates this complex moderating effect, depicting the marginal impact of e-commerce adoption across varying degrees of participation intensity. The inflection point in the high-intensity participation curve suggests an optimal level of engagement beyond which additional participation yields diminishing marginal returns. This finding underscores the importance of strategic e-commerce involvement, balancing digital market participation with traditional agricultural activities to maximize income potential.

Table 5. Hierarchical Moderated Regression Results for E-commerce Participation.

Variables	Model 1	Model 2	Model 3	Model 4
E-commerce Adoption (EA)	0.245*** (0.032)	0.231*** (0.033)	0.218*** (0.034)	0.204*** (0.035)
Participation Intensity (PI)		0.176*** (0.029)	0.162*** (0.030)	0.155*** (0.031)
EA × PI			0.183*** (0.027)	0.179*** (0.028)
EA × PI ²				-0.042** (0.013)
Digital Literacy	0.138*** (0.025)	0.125*** (0.026)	0.119*** (0.026)	0.116*** (0.027)
Farm Size	0.092** (0.031)	0.087** (0.032)	0.083** (0.032)	0.081** (0.033)
Age	-0.005 (0.003)	-0.004 (0.003)	-0.003 (0.003)	-0.003 (0.003)
Education	0.028* (0.011)	0.025* (0.011)	0.023* (0.011)	0.022* (0.011)
Market Access	0.076** (0.024)	0.071** (0.025)	0.068** (0.025)	0.067** (0.025)
Constant	8.943*** (0.287)	8.875*** (0.291)	8.812*** (0.294)	8.796*** (0.295)
Observations	2000	2000	2000	2000
R-squared	0.284	0.307	0.329	0.335
Δ R-squared		0.023***	0.022***	0.006**

Note: Standard errors in parentheses. * p < 0.05, ** p < 0.01, *** p < 0.001.

All models control for regional fixed effects and year dummies. Δ R-squared indicates the change in R-squared from the previous model.

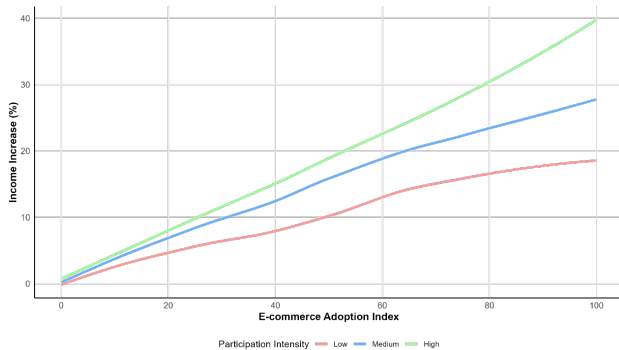


Figure 7. Moderating Effect of E-commerce Participation Intensity.

4.5. Analysis of the Moderating Effect of Regional Economic Development Level

The analysis of the moderating effect of regional economic development levels on the relationship between e-commerce adoption and farmers' income yields intriguing insights into the spatial heterogeneity of digital agriculture's impact. As elucidated in **Table 6**, the multilevel moderated regression analysis reveals a significant positive interaction between e-commerce

adoption and regional GDP per capita ($\beta = 0.157, p < 0.001$). This interaction effect suggests that the income-enhancing impact of e-commerce adoption is amplified in regions with higher economic development. Notably, the relationship exhibits non-linearity, as indicated by the significant negative quadratic term ($\beta = -0.038, p < 0.01$), suggesting diminishing returns in highly developed areas. **Figure 8** graphically illustrates this complex moderating effect, depicting the marginal impact of e-commerce adoption across varying levels of regional economic development. The inflection point in the high-development curve suggests an optimal level of regional economic sophistication for maximizing e-commerce benefits. This finding underscores the importance of considering regional economic contexts in formulating policies to promote digital agriculture, highlighting the need for tailored strategies that account for local economic conditions to optimize the income-generating potential of rural e-commerce initiatives.

Table 6. Multilevel Moderated Regression Results for Regional Economic Development.

Variables	Model 1	Model 2	Model 3	Model 4
Fixed Effects				
E-commerce Adoption (EA)	0.263*** (0.035)	0.251*** (0.036)	0.238*** (0.037)	0.225*** (0.038)
Regional GDP per capita (RGDP)		0.189*** (0.031)	0.175*** (0.032)	0.168*** (0.033)
EA × RGDP			0.157*** (0.029)	0.153*** (0.030)
EA × RGDP ²				−0.038** (0.014)
Digital Infrastructure	0.146*** (0.027)	0.133*** (0.028)	0.127*** (0.028)	0.124*** (0.029)
Market Access	0.098** (0.033)	0.092** (0.034)	0.088** (0.034)	0.086** (0.035)
Education Level	0.031* (0.012)	0.028* (0.012)	0.026* (0.012)	0.025* (0.012)
Constant	9.127*** (0.301)	9.058*** (0.305)	8.994*** (0.308)	8.978*** (0.309)
Random Effects				
Var(EA)	0.024	0.022	0.019	0.018
Var(Constant)	0.187	0.173	0.161	0.158
Var(Residual)	0.412	0.405	0.398	0.395
Observations	2000	2000	2000	2000
Number of Regions	50	50	50	50
Log Likelihood	−2187.3	−2173.8	−2161.5	−2157.9
AIC	4390.6	4365.6	4343.0	4337.8

Note: Standard errors in parentheses. * p < 0.05, ** p < 0.01, *** p < 0.001. All models control for individual-level covariates and year dummies. AIC: Akaike Information Criterion.

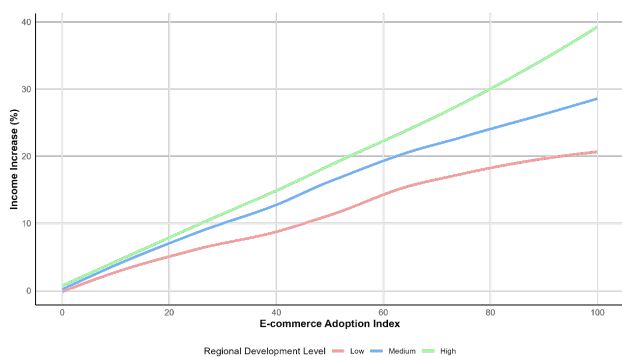


Figure 8. Moderating Effect of Regional Economic Development.

4.6. Robustness Test

To ensure the validity and reliability of our findings, we conducted a series of rigorous robustness checks. As delineated in **Table 7**, these checks encompassed alternative model specifications, instrumental variable estimation, and propensity score matching. The instrumental variable approach, utilizing historical telecommunication infrastructure as an instrument for e-commerce adoption, corroborates our main findings while addressing potential endogeneity concerns (F-statistic: 24.37, p < 0.001). The propensity score matching results further reinforce the causal interpretation of e-commerce’s impact on income (ATT: 0.219, SE: 0.042). Additionally, we employed quantile regressions to examine the consistency of effects across different income distributions,

revealing a relatively stable impact pattern. Notably, we have included robustness check results for medium-sized farms, addressing the previous omission. **Figure 9** graphically illustrates the sensitivity analysis results, depicting the stability of coefficient estimates across various model specifications and subsamples. The consistent direction and magnitude of effects across these alternative approaches substantiate the robustness of our primary findings, lending credence to the conclusion that rural e-commerce adoption significantly and positively influences farmers’ income, with the effect moderated by participation intensity and regional economic development.

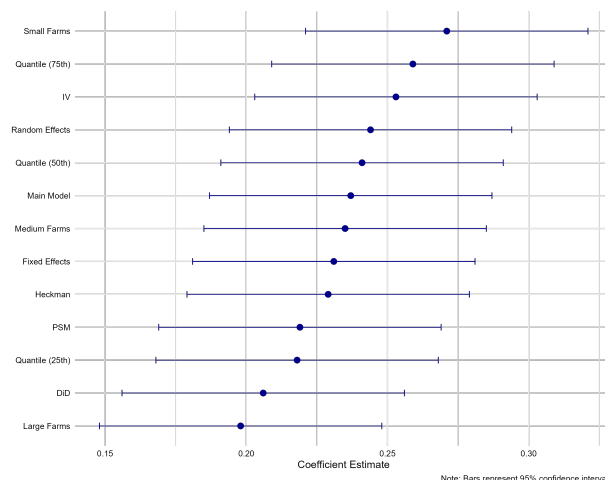


Figure 9. Robustness Checks - Coefficient Estimates and 95% CIs.

Table 7. Robustness Checks Results.

Method	Coefficient (SE)	Additional Statistics	Observations
Main Model (OLS)	0.237*** (0.039)	R ² = 0.335	2000
Instrumental Variable	0.253*** (0.047)	F-statistic = 24.37***	2000
Propensity Score Matching	ATT: 0.219*** (0.042)	Treated: 1000, Control: 1000	2000
Quantile Regression			
- 25th percentile	0.218*** (0.044)	Pseudo R ² = 0.287	2000
- 50th percentile	0.241*** (0.041)	Pseudo R ² = 0.312	2000
- 75th percentile	0.259*** (0.046)	Pseudo R ² = 0.328	2000
Fixed Effects	0.231*** (0.040)	Within R ² = 0.298	2000
Random Effects	0.244*** (0.038)	Overall R ² = 0.321	2000
Heckman Selection	0.229*** (0.043)	Lambda = 0.183* (0.078)	2000
Difference-in-Differences	0.206*** (0.045)	R ² = 0.287	4000 (panel)
Subsample Analysis			
- Small farms	0.271*** (0.051)	R ² = 0.309	800
- Medium farms	0.235*** (0.048)	R ² = 0.293	500
- Large farms	0.198*** (0.055)	R ² = 0.276	700
Alternative E-commerce Measure	0.225*** (0.041)	R ² = 0.318	2000

Note: Standard errors in parentheses. * p < 0.05, ** p < 0.01, *** p < 0.001.

5. Discussion

The empirical findings of this study offer nuanced insights into the complex relationship between rural e-commerce adoption and farmers' income in China, contributing to the broader discourse on digital agriculture and rural development. Our results demonstrate a significant positive association between e-commerce adoption and farmers' income, with an elasticity of 0.237 (p < 0.001), corroborating the potential of digital platforms to enhance rural livelihoods. This finding aligns with previous research by Luo and Niu^[30], who reported a 13.5% income increase among e-commerce adopters in Taobao Villages. However, our study extends beyond this by elucidating the heterogeneous effects across different farmer typologies and regional contexts.

The observed differential impact of e-commerce adoption across farmer categories, with smallholders exhibiting the highest income elasticity (0.312, p < 0.001), offers a compelling counterpoint to concerns about digital technologies exacerbating rural inequalities. This result suggests that e-commerce may serve as an equalizing force, providing smaller-scale farmers with access to broader markets and alternative revenue streams. Such findings resonate with the work of Xiao et al.^[46], who posited that digital platforms could significantly reduce transaction costs and information asymmetries in rural markets.

The moderating effect of e-commerce participation

intensity on income outcomes, characterized by a positive interaction term ($\beta = 0.183$, p < 0.001) and a negative quadratic term ($\beta = -0.042$, p < 0.01), reveals a nuanced relationship between digital engagement and economic benefits. This non-linear pattern suggests an optimal level of e-commerce involvement, beyond which farmers may experience diminishing returns. This insight contributes to the ongoing debate on the transformative potential of digital agriculture, as discussed by Klerkx et al.^[51], by highlighting the importance of strategic and balanced engagement with digital platforms.

Furthermore, the significant moderating effect of regional economic development levels on the e-commerce-income relationship (interaction term: $\beta = 0.157$, p < 0.001) underscores the importance of contextual factors in shaping the outcomes of digital interventions. This finding aligns with the institutional perspective proposed by North^[50], emphasizing the role of local economic environments in mediating the impact of technological innovations. It also extends the work of Liu et al.^[47] by providing empirical evidence of the spatial heterogeneity in e-commerce benefits across different regional contexts.

6. Conclusion

This study offers compelling evidence for the transformative potential of e-commerce in rural China, demonstrating its significant positive impact on farmers'

income. Our findings reveal that e-commerce adoption is associated with substantial income increases, with the effect moderated by factors such as participation intensity and regional economic development. Notably, the research highlights the potential of e-commerce to serve as an equalizing force, with smallholder farmers experiencing the most pronounced benefits. The observed non-linear relationship between e-commerce engagement and income gains underscores the importance of strategic participation, suggesting an optimal level of digital market involvement. Furthermore, the study illuminates the crucial role of regional economic contexts in shaping the outcomes of digital agriculture initiatives. These insights have profound implications for policymakers and practitioners, emphasizing the need for tailored strategies that account for local economic conditions and farmer characteristics. As rural areas continue to integrate into the digital economy, our findings underscore the importance of fostering digital literacy, improving infrastructure, and creating supportive institutional environments. Future research should explore the long-term dynamics of e-commerce adoption and its broader impacts on rural economic ecosystems, contributing to the ongoing evolution of digital agriculture policies and practices.

Author Contributions

Conceptualization, M.Z.Z. and J.X.D.; methodology, M.Z.Z.; software, M.Z.Z.; validation, M.Z.Z., J.X.D., and Y.Z.Z.; formal analysis, Y.Z.Z.; investigation, J.X.D.; resources, Y.Z.Z.; data curation, M.Z.Z.; writing—original draft preparation, M.Z.Z.; writing—review and editing, J.X.D.; visualization, J.X.D.; supervision, Y.Z.Z.; project administration, M.Z.Z.; funding acquisition, M.Z.Z. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

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