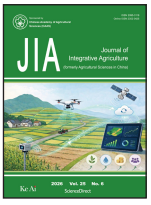
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RESEARCH ARTICLE

Digital technology knowledge and farmer's e-commerce valuation in Nigeria

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Highlights

- Fewer than half of rural farming households demonstrated knowledge of digital technology, with test scores exceeding 40%.
- At least 88% of rural farming households were willing to pay 19% of the sale price to use digital marketing platforms' services.
- Digital knowledge increases e-commerce valuation, mostly among male and young adults.

Abstract

The growth of digital marketing platforms is reshaping the food systems and offers a potential solution to farmers' output market access problem. However, the digital transformation also leads to a growing digital divide, driven by disparities in digital literacy, which may hinder rural farmers from exploiting opportunities in the digital market. This paper investigates the relationship between e-commerce valuation and digital technology knowledge in rural Nigeria. We used contingent valuation questions to measure farmers' willingness to pay for digital platform services in commercializing their agricultural products. We performed a basic digital technology knowledge test to assess farmers' proficiency in using digital tools, focusing on practical digital skills. Using the treatment effects framework associated with panel data, we found significant positive and heterogeneous effects of digital technology knowledge on e-commerce valuation in rural Nigeria. To fully realize the potential of rural e-commerce, urgent policy interventions are needed to enhance digital literacy and make internet access more affordable for rural farming households.

Keywords: rural e-commerce, digital technology, contingent valuation, Nigeria

1. Introduction

The advent of information and communication technologies – ICTs created the digital economy. Its importance and implication for development and economic and inclusive growth are now well recognized (Kouladoum 2023; Nayyar *et al.* 2024; World Bank 2024). Economic and commercial activities are increasingly taking place through digital technologies. Among many digital economy sectors are e-commerce and digital marketing, two complementary activities involving online businesses and transactions (Ferié 2020; Semerádová and Weinlich 2022). E-commerce implies the sale and purchase of products and services through the Internet. Digital marketing focuses on online advertising of products and services using digital channels. The United Nations Conference on Trade and Development (UNCTAD) statistics reveal that business e-commerce sales in 43 developed and developing economies, representing three-quarters of global GDP, grew by nearly 60% from 2016 to 2022. Between 2017 and 2021, the use of e-commerce in least-developed countries rose by 140% but represented only 5.8% of individuals online purchases, compared to 62% in developed countries (UNCTAD 2024).

Despite its potential for market widening and business

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growth, the adoption of e-commerce in developing countries is far behind that in developed countries, attributed in part to the digital divide (World Bank 2016; Murthy *et al.* 2021; Reardon *et al.* 2021). Possible challenges reported in the literature for adopting and using e-commerce in developing countries, mostly in rural areas, are literacy, infrastructural, and financial barriers such as inadequate logistical network connection, non-affordable cost, and lack of skills in using digital tools (Hendricks and Mwapwele 2024). Reducing the digital gap between countries involves thus removing these constraints, particularly in rural areas, which experience a lag in that matter (Richmond *et al.* 2017). However, there is an argument that infrastructural and financial interventions may be of limited scope for increasing e-commerce use in a context where potential users do not perceive its benefit (Hendricks and Mwapwele 2024).

In this study, we ask whether and how digital knowledge influences the valuation of e-commerce by farmers in Nigeria, a question from whom a positive answer may justify digital literacy interventions in rural areas. We argue that the lack of demand for digital marketing platforms would not compel public authorities to get involved in installing rural digital infrastructure, which necessitates significant investments (World Bank 2016). Also, rural demand for e-commerce would not be effective in the context of poor or a lack of digital skills or knowledge (Meijer *et al.* 2015). Even whenever investments for infrastructure installation are made, there would be no efficient use if farmers do not have adequate training or skills to make good use of it for their benefit (Lynn *et al.* 2022).

Economists have identified the importance of digital innovations and technologies in agricultural and rural markets (Muto and Yamano 2009; Aker 2010; Deichmann *et al.* 2016). In Sub-Saharan Africa, the rapid digital transformation and expansion of mobile network coverage and internet access present an opportunity to link farmers to markets through e-commerce amidst existing and emerging constraints (Aker *et al.* 2016; Van Campenhout 2017). Over the years, cooperatives and contract farming schemes have been targeted at linking farmers to markets (Bingen *et al.* 2003; Barrett *et al.* 2012). The tendency to shift to online trading brings potential opportunities for farming households and highlight that digital technologies help overcome information problems and inefficiencies that hinder smallholder farmers' market access (Jensen 2007; Deichmann *et al.* 2016). For example, using technologies like mobile phones extends smallholder market reach in Uganda (Muto and Yamano 2009). E-commerce platforms like mobile phone trading applications and websites help reduce transaction and search costs, facilitate communications, and open up opportunities in both local and international markets (Van Campenhout 2017; Couture *et al.* 2021).

Empirical literature on rural e-commerce in Africa, primarily related to digital technology knowledge is rare. We contribute to this strand of the literature, which examined the role of farmers' digital technology knowledge in terms of internet use, receiving e-training, and smartphone use experience, which are self-assessment measures used by previous studies. We used objective measures, which are answers from basic digital knowledge tests administered to farmers to assess their knowledge or ability in digital technology. Abate *et al.* (2023) highlight the importance of digital literacy and discuss the need for interventions in this area within developing country contexts. The authors further note that despite the development in digital innovations in African agricultural markets, progress has been limited and note that the gap in digital literacy is a major limiting factor. Caldarola *et al.* (2023) also emphasize the important role of digital literacy in the successful adoption and scaling of digital tools and technologies in developing countries. Recent literature linking digital skills and tools to agricultural outcomes has been concentrated in China, with little to no evidence on sub-Saharan Africa despite the importance of agriculture in the region. Zhang *et al.* (2023, 2024) note that internet access significantly reduces the rural income gap, with increased non-farm employment acting as important mechanism of effect. Chandio *et al.* (2023, 2024) also underscore the substantial positive impact of internet access and computer utilization on grain production, particularly in rice production.

Some studies assess the effect of e-commerce on farmers (Couture *et al.* 2021; Liu *et al.* 2021). We have an acquaintance with a few studies examining the determinants of adopting e-commerce. Studies assessing determinants highlighted positive factors such as delivery time and risk aversion (Fecke *et al.* 2018), internet use and e-training (Ma *et al.* 2020), control and behavioral beliefs (Alavion and Taghdisi 2021), experience of using smartphones (Liu *et al.* 2021), performance and effort expectancy (Cimino *et al.* 2024) which significantly affects farmers' willingness to accept e-commerce or their behavioral intention in adopting digital platforms. We also add to the literature on ICT adoption that estimates farmers' willingness to adopt e-commerce. E-commerce adoption may take two forms: whether farmers use freely digital-based social media networks such as WhatsApp or Facebook to advertise and sell their products or utilize costly services from digital marketing platforms to do so. We used contingent valuation questions to assess the farmers' interest in commercializing agricultural products through a digital marketing platform, which helps understand the demand for digital marketing platforms from the farmer's or seller's perspective. The willingness to pay for e-commerce services may be linked to the perceived value of these services. Farmers who understand the benefits of e-commerce, such as increased market access, reduced transaction costs, and higher income potential, are more likely to value and invest in these platforms (Montealegre *et al.* 2007; Li 2019). Similarly, behavioral economic perspectives suggest that farmers' decisions are influenced by their knowledge and understanding of digital technologies. For instance, as seen in the case of the e-wallet initiative in Rwanda, farmers who receive information and training in their local language are more likely to adopt e-commerce solutions (Grossman and Tarazi 2014; Schroeder *et al.* 2021).

Finally, our study contributed to the literature on rural development in Nigeria, providing empirically insight into rural digital knowledge and valuation of digital marketing. New and emerging challenges like the COVID-19 crisis

have led policymakers to recognize the importance of digital transformation and innovations in the agricultural food system.

Using the treatment effects framework applied to panel data, the study analyzed the relationship between e-commerce valuation and digital technology knowledge and assessed the heterogeneous effects. The results revealed that farmers have yet to utilize the potential opportunities mobile phones offer fully. Many still lack knowledge or ability in open applications. Nevertheless, they were ready to pay an average of 19% of their sale price for using digital marketing platforms' services. The effect of digital technology knowledge on e-commerce valuation varies across age and gender.

2. Nigeria's digital transformation

Nigeria has undergone a significant digital transformation, particularly in mobile internet connectivity. According to country-level data from the GSMA Mobile Connectivity Index, a single composite indicator that measures a country's enabling environment for mobile internet adoption, country-level data reveals a steady growth in Nigeria's mobile internet connectivity over the past decade, positioning the country ahead of its eastern and western neighbours (Fig. 1). The index comprises four 'levels', with each level scored between 0 and 100, and a higher score is associated with a more enabling environment for delivering mobile internet connectivity. Indicators are used to compute the Mobile Connectivity Index, and weightings are applied to aggregate the indicators into dimensions, the dimensions into enablers, and the enablers into the overall index score (GSMA 2021). Nigeria has a higher mobile penetration rate compared to the average in SSA. In 2018, 49% of the population owned mobile phones, slightly higher than the 45% mobile penetration rate in SSA. Though, there is considerable variation in digital adoption and use across African countries, largely driven by differences in firm size and income levels. Middle-income countries like Ghana, Kenya, and Senegal generally have higher adoption rates of digital tools compared to low-income countries such as Burkina Faso, Ethiopia, and Malawi. But generally, both SSA and Nigeria have made significant improvements in digital inclusion, with policies focusing on mobile and internet penetration, digitization of payments, and digital credit (Nair and Varghese 2020).

The African Union's 2020–2030 Digital Transformation Strategy and the World Bank's Digital Economy for Africa (DE4A) Initiative indicate an increasing recognition of the importance of strengthening the foundations necessary for Africa's digital economy, with digital agriculture identified as an important sector. For example, many African governments like Ethiopia and Nigeria are actively driving the agri-technology agenda (like digital soil map) to improve agricultural outcomes (Kim *et al.* 2020; Cruz 2024).

However, Nigeria stands out with its higher mobile penetration rate and thriving digital agriculture ecosystem. The growth is particularly noteworthy given the Nigeria's limited fixed-line infrastructure, leading to mobile broadband becoming the primary means of internet access in Nigeria, with

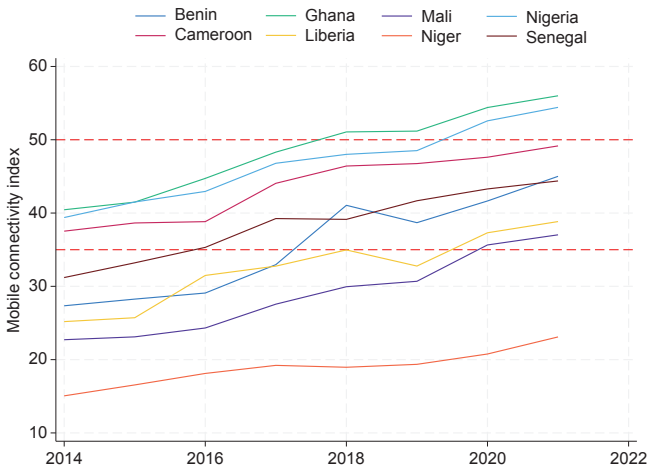


Fig. 1 Countries' enabling environment for mobile internet adoption. A composite indicator is derived from four key enablers: infrastructure, affordability, consumer readiness, and content and services. This indicator is normalized to a scale ranging from 0 to 100. Countries classified as 'Emerging' (with scores exceeding 35) demonstrate satisfactory performance in one or two enablers, yet exhibit potential for enhancement in others. 'Transitioners' (with scores above 50) exhibit strong performance in at least two enablers. 'Advanced' countries (with scores above 65) perform well in three enablers and typically possess high penetration rates. See www.mobileconnectivityindex.com. Source: Calculations based on data from GSMA 2021.

3G coverage reaching 54% of the population (Lixi *et al.* 2019). Despite its growth, mobile device ownership trends in Nigeria reveal significant disparities between urban and rural areas. Statistics from EFInA (Enhancing Financial Innovation and Access) surveys show that about 58% of urban residents own smartphones, while only 32% have access to smartphones in rural areas (EFInA 2023).

The online market is progressively developing along with the digital transformation occurring in Nigeria. Available statistics from 2023 indicate that mobile e-commerce dominates, with 70% of online transactions operating on mobile devices and 89% of internet users buying online. Also, Nigeria is ranked as the 38th largest market for e-commerce (GO-Globe 2025). Digital commerce in the country is supported by 87 Nigerian platforms, employing 2.9 million people (Lixi *et al.* 2019). The grocery sector remains a small part of the online market, accounting for 5.5% of the total e-commerce market, and the online share of the food retail market amounts to 0.1% (ECDB 2025).

The rural areas where primary food production occurs are at risk of being left behind by the digital transformation. Rural farming in Nigeria has yet to fully benefit from this opportunity the digital transformation offers to link to markets through e-commerce. Statistics on agricultural commercialization from the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) show that farming households' access to the output market during the 2018/2019 agricultural season was essentially through local traditional markets, irrespective of the crops sold (Fig. 2). Farmers may not be willing to adopt online trading because of their limited (or lack of) understanding of digital technologies. In this study,

we assume that basic digital technology knowledge helps build self-reliance and equip farmers with the capacity to evaluate better the opportunities that may result from using e-commerce.

3. Data and methods

3.1. Study area and data collection

The data we use in this study stems from the baseline and the follow-up surveys that are part of a randomization research project designed to evaluate digital literacy interventions aimed at increasing farming households' access to output markets. The surveys took place between July and September 2022 (baseline) and in September 2023 (follow-up). We focused on farming communities in three states in Western Nigeria — Kwara, Osun, and Oyo, due to the relative peace, shared local language, higher educational levels, and rapid mobile network expansion in the region compared to other areas considering that all parts of the country have rural farming communities (Oluwatayo 2013).

The study's Primary Sampling Units are local government areas (LGAs) within the three states. We conducted community and household listing surveys to map the communities and households within them. Then, rural farming communities within LGAs with mobile phone coverage and internet access were selected. Finally, farming households were sampled in 255 eligible rural communities across the three states.

3.2. Sample and unit of analysis of the study

A total of 3,513 farming households were surveyed during the baseline phase. The same households were visited during the follow-up survey with an attrition rate of 2.16 %. We used a household survey instrument to collect data on household characteristics, asset ownership, phone ownership and access, digital knowledge, access to financial services, group membership, willingness to pay for a digital marketing platform, and livestock holding. We developed the instrument with questions adapted from existing questionnaires such as LSMS-ISA or IFPRI questionnaires. Of importance in this study are the modules related to digital technology accessibility and usage, digital knowledge, and the valuation of e-commerce. As such, the primary unit of analysis in the study is an individual household member respondent, mainly the head of the household, who took the digital knowledge test we performed during the baseline and the follow-up surveys. This resulted in a sample of 2,228 household heads per survey for the analysis.

3.3. Digital technology accessibility and usage

All the households in the sample have access to a mobile phone at baseline, as shown by the statistics on mobile phone ownership in Fig. 3-A. Over half of the surveyed households (80%) owned feature phones or smartphones (including a camera, internet access, and an operating system allowing users to add applications) at baseline, with an increase in the percentage in the subsequent year. Mobile phones were regularly used among rural households, as indicated by the recharge frequency. At least 59% of the sampled households purchased airtime for their mobile phones daily or weekly, with average monthly expense and time on airtime purchases in the household amounting to 1,194 Naira and 11 times, respectively. Rural households are yet to fully utilize mobile phones' potential opportunities, as shown in Fig. 4. Indeed, in addition to receiving and making phone calls, only a few use their phones for essential farming-related activities, such as weather or climate information, financial transactions, social media (e.g., WhatsApp/Facebook), and buying and selling goods. Internet accessibility may partly explain this

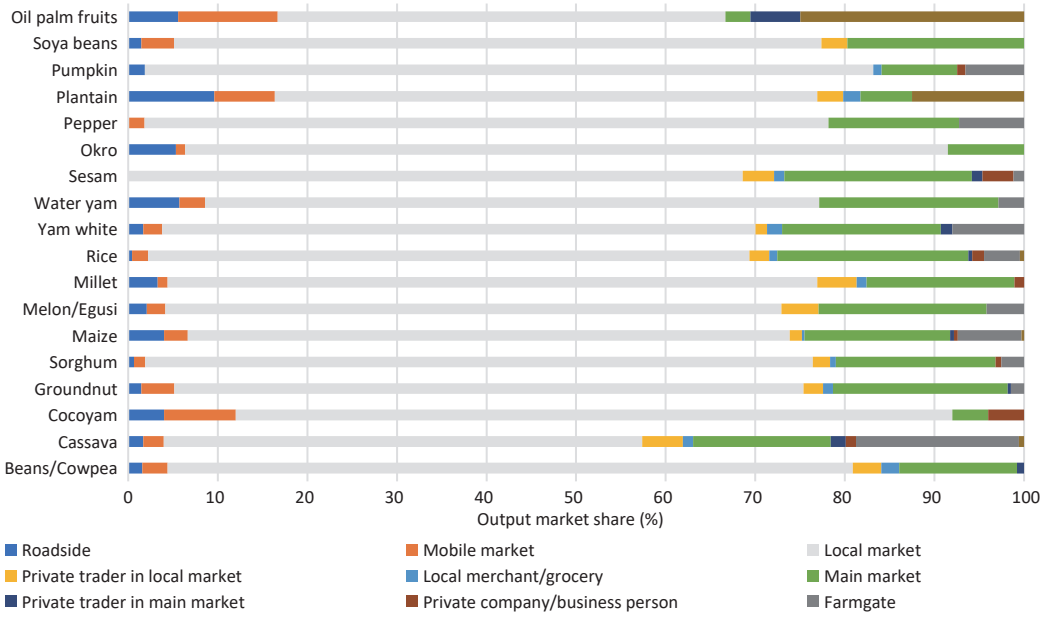


Fig. 2 Market channels for selected crops in Nigeria. Output market share (%) of harvested crops sold during the 2018/2019 agricultural season. Source: Calculations based on data from LSMS-ISA 2018/2019.

trend, particularly for the latter two mobile phone usage purposes (Fig. 3-B). Although 95% of the rural households were exposed to 4G LTE or 3G or H or H+ mobile internet networks in the communities (Fig. 3-C), very few of them may enjoy a better or a higher internet connection provided by telecommunication operators (Fig. 3-D). Lesser or a lack of knowledge of digital technology or skill may be another reason for most rural households not to use digital platforms, as depicted in Fig. 5.

3.4. Digital technology ability

During the data collection, we administered a basic digital knowledge test to assess household head knowledge or ability in digital technology. Using their mobile data collection platform, the enumerators displayed to the respondents the same picture of a mobile phone along with five alphabetical capital letters that indicated (A) where to take a picture, (B) the front camera, (C) the home button, (D) the open App, and (E) the back button. The enumerators then asked the respondents to select the correct letter corresponding to each function. The results of the digital technology knowledge test are displayed in Fig. 5. At least half of the respondents surveyed still lack knowledge or ability in digital technology, mainly on open applications (Fig. 5-A). Less than half of the respondents' household heads presented digital technology knowledge with a test score exceeding 40% (Fig. 5-B), indicating a significant need for improved digital literacy among rural farming households, especially among women (Fig. 5-C) and adults (Fig. 5-D). This is important as the basic digital technology knowledge test was performed on some elementary mobile phone features necessary for digital platform transactions.

3.5. Valuation of e-commerce

We assessed the respondents' interest in commercializing agricultural products through a digital marketing platform. We used contingent valuation questions. Though with this method, respondents may overstate their WTP in hypothetical scenarios, leading to inaccurate valuations. Hence, we reduce the bias by developing recruiting experts to develop the questions, hiring and training professional enumerators to administer the questions and piloting the questionnaires before the main survey. We prefer the CV method for eliciting WTP because it is a relatively simple and flexible and particularly useful for valuing benefits of e-commerce that are not directly reflected in market prices.

The contingent valuation questions are structured thus (1) Enumerators first explained to the respondent what everything was about in his native language, Yoruba. This is summarized as follows: "A digital marketing platform is an online platform that directly connects farmers to buyers and consumers. The platform allows farmers to register and list their products for sale before/after harvest. Let's assume you have a product for sale, and the value is 1,000 Naira. Depending on the commodity type, the farmer pays a certain amount of the total commodity value for every transaction. Farmers receive payment *via* their registered bank account once the product is delivered to the customer". (2) The enumerators then asked: "Will you or any household member be willing to use a digital marketing platform to sell

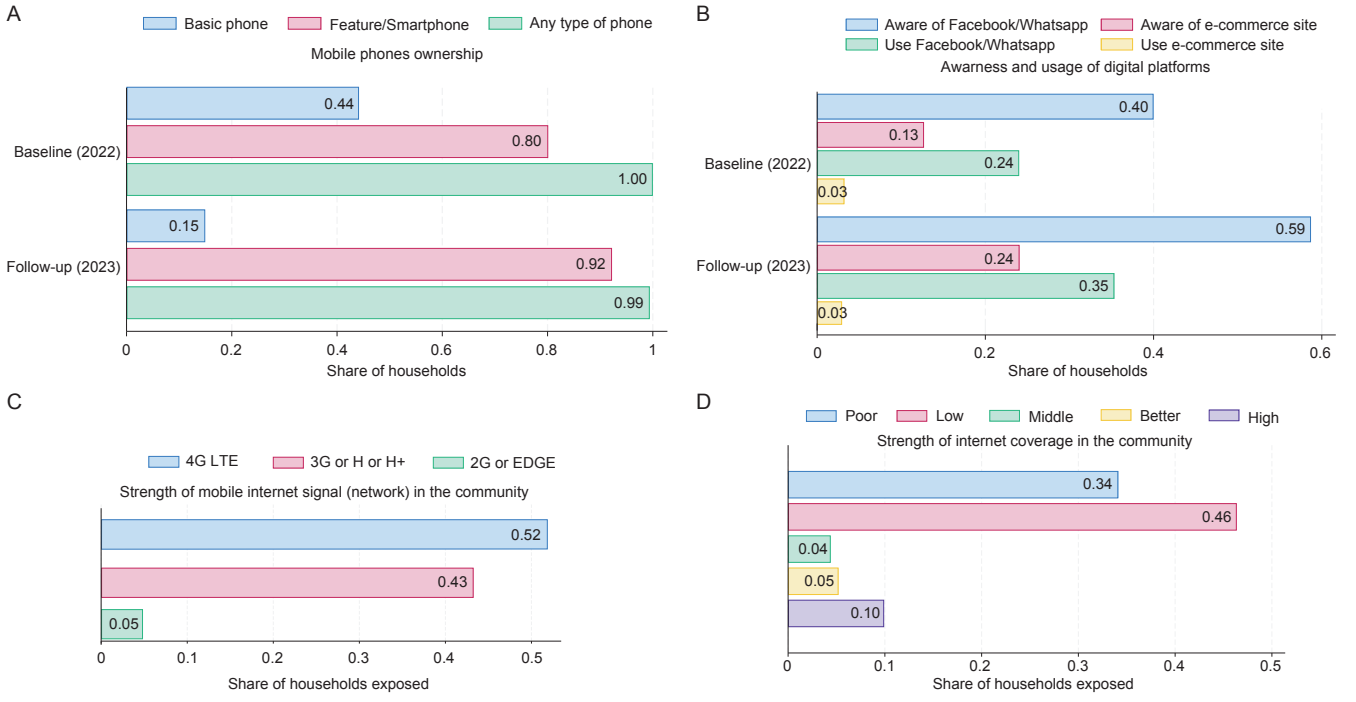


Fig. 3 Digital technology accessibility and usage. A, the share of households owning a type of phone. Basic phones include voice calls and SMS. Feature phones include a camera and the internet. B, the share of households that were aware of and used digital platforms such as WhatsApp, Facebook, or e-commerce sites. C and D, the share of households exposed to any Internet network and quality in the communities. Source: Own calculations with survey data for 2022 and 2023.

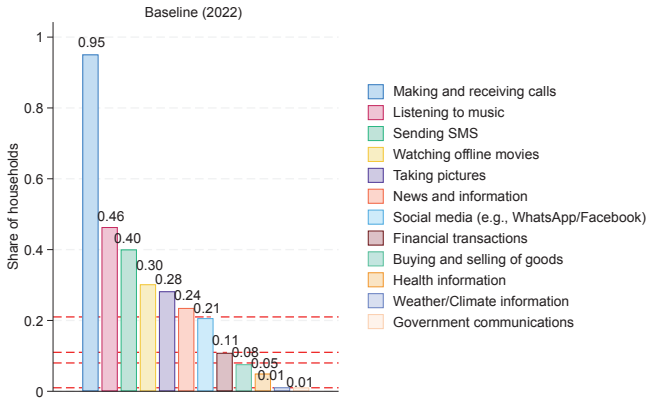


Fig. 4 Mobile phone usage purposes. It indicates the share of households using mobile phones for any listed activities. Source: Own calculations with survey data for 2022 and 2023.

your products if you have an opportunity to do so?" And (3) After a positive answer from the respondent, enumerators asked the second question: "What maximum amount are you or any household member willing to pay for using the digital marketing platform service to sell your farm product for 1,000 Naira? Remember: this maximum amount to be paid is meant to be deducted from the 1,000 Naira the product was sold *via* the digital marketing platform".

Overall, farmers are generally interested in using e-commerce, even when it involves a cost. At least 88% of the household heads sampled were willing to use the services of digital marketing platforms. They were ready to pay an average maximum of 174 Naira, 19% of the sale price, for these services. This unit price is above the interval of 3 to 10% of prices practiced by Agriple, a Nigerian online trading platform that directly connects farmers to buyers and consumers in Nigeria. Fig. 6 illustrates that more than half of the surveyed household heads were willing to pay 20% of their sale price to use an e-commerce service, with more skilled respondents in digital technology above the average having a higher probability of doing so at a given percentage of the sale price and the follow-up.

3.6. Respondents' and households' characteristics

Descriptive statistics on the sociodemographic variables of the respondents and the households are presented in Table 1. We conducted a mean difference test on the digital technology knowledge test scores. We divided the respondents into two groups, with the more digitally skilled respondents having test scores that were above average. Table 1 shows that most of the household head respondents in the sample are men. Significant differences between the two groups of respondents are observed in terms of human, financial, and social capital. More digitally skilled respondents

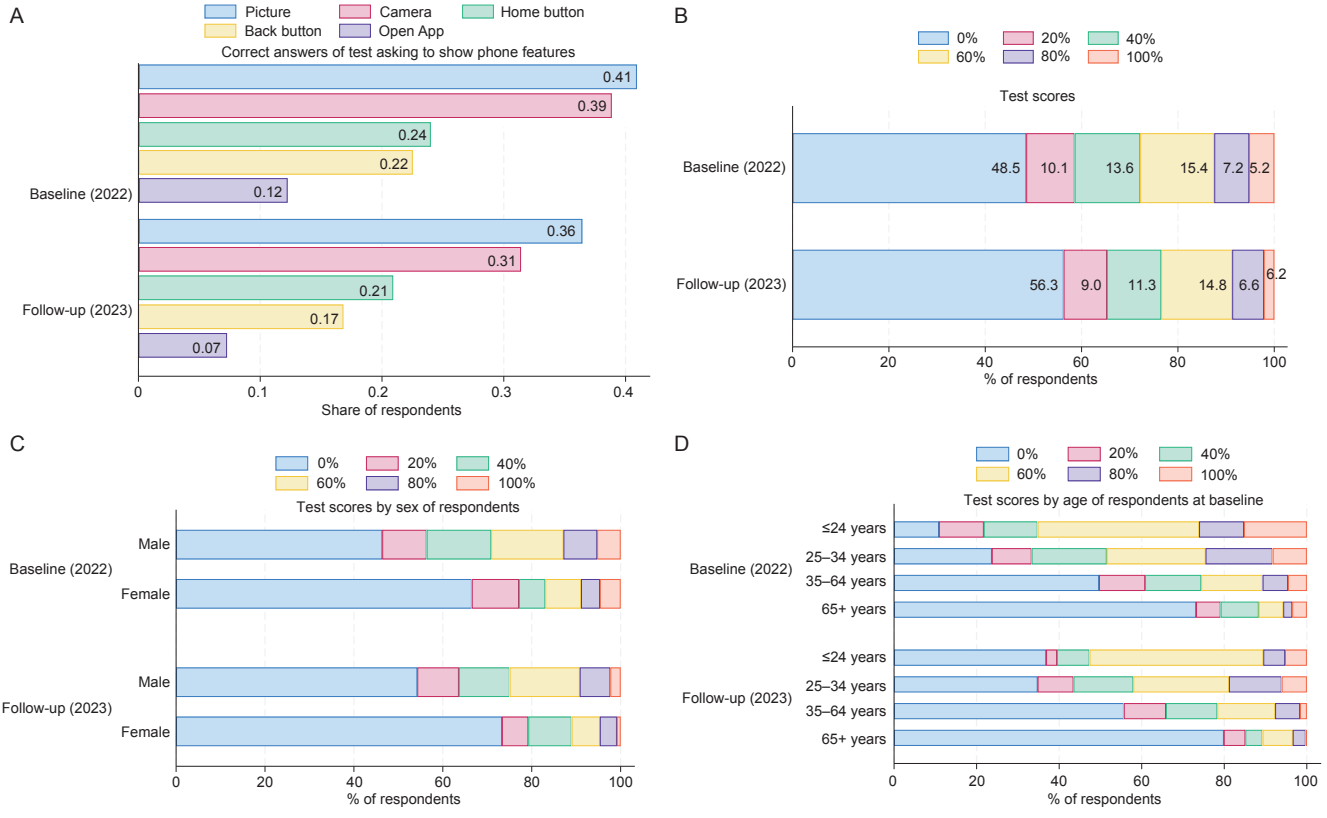


Fig. 5 Basic test on digital technology knowledge. A, the share of respondents who gave correct answers on questions asking them to show these features on a smartphone: picture button, front camera, home button, open App, back button. B, the share of respondents with the corresponding average test scores. C and D, the distribution of the scores according to sex and age of respondents. Source: Own calculations with survey data for 2022 and 2023.

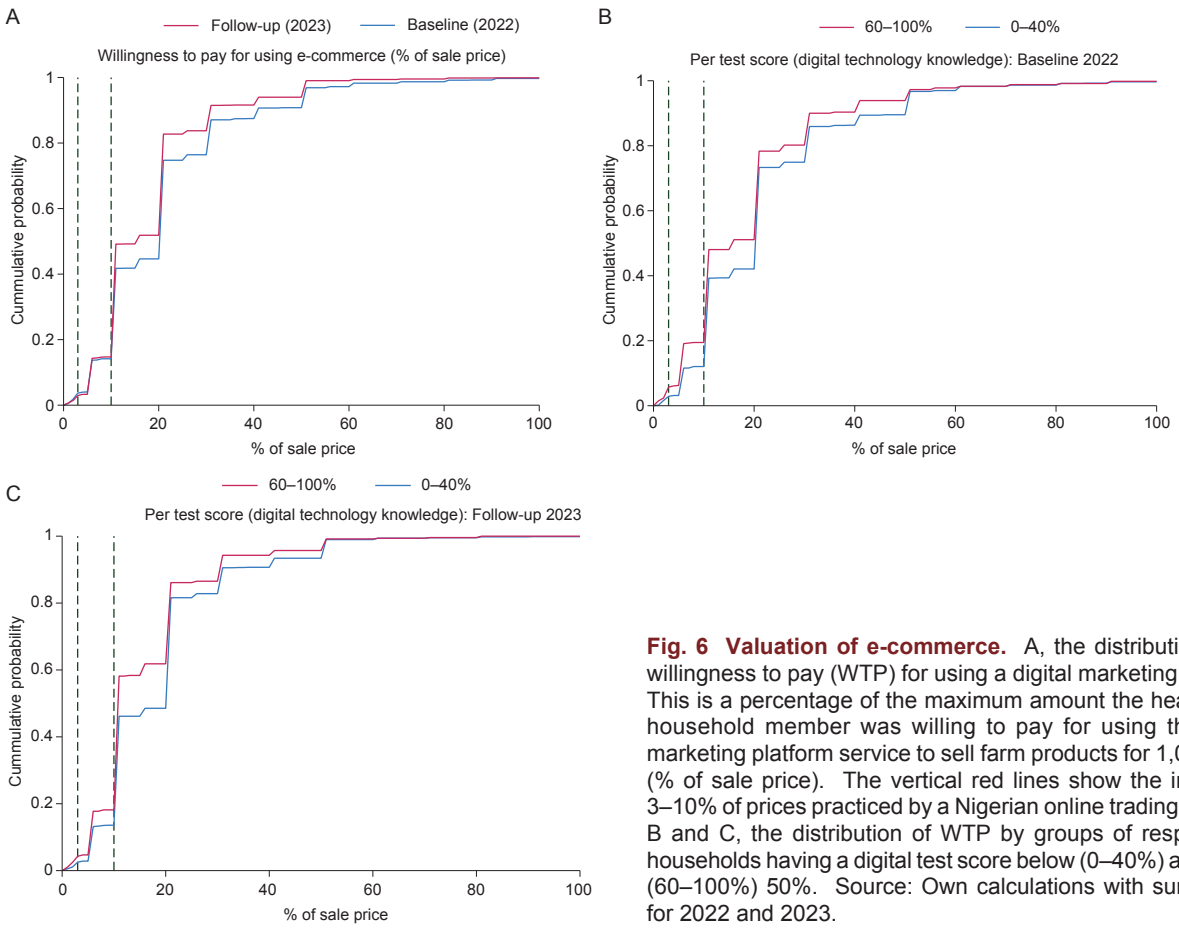


Fig. 6 Valuation of e-commerce. A, the distribution of the willingness to pay (WTP) for using a digital marketing platform. This is a percentage of the maximum amount the head or any household member was willing to pay for using the digital marketing platform service to sell farm products for 1,000 Naira (% of sale price). The vertical red lines show the interval of 3–10% of prices practiced by a Nigerian online trading platform. B and C, the distribution of WTP by groups of respondents' households having a digital test score below (0–40%) and above (60–100%) 50%. Source: Own calculations with survey data for 2022 and 2023.

Table 1 Differences in characteristics: More versus less knowledgeable respondents in digital technology

	All Sample (4,456)		Digital test Score=0–40% (3,313)		Digital test Score=60–100% (1,143)		*t*-test[1)]	
	Mean	SD	Mean	SD	Mean	SD	*t*-value	*P*-value
Is female	0.106	0.308	0.123	0.328	0.058	0.233	6.150	0.000
No education	0.184	0.388	0.223	0.416	0.073	0.260	11.450	0.000
Primary education	0.285	0.451	0.314	0.464	0.199	0.399	7.500	0.000
Secondary education	0.400	0.490	0.358	0.479	0.521	0.500	–9.850	0.000
Tertiary education	0.103	0.304	0.072	0.259	0.193	0.395	–11.800	0.000
Quranic/Adult education	0.028	0.164	0.033	0.178	0.014	0.118	3.300	0.001
Is from Yoruba ethnicity	0.870	0.337	0.868	0.338	0.875	0.331	–0.600	0.556
Adult equivalent	2.447	2.671	2.421	2.691	2.520	2.611	–1.100	0.282
≤24 years	0.019	0.136	0.010	0.101	0.044	0.205	–7.200	0.000
25–34 years	0.159	0.366	0.117	0.321	0.281	0.450	–13.350	0.000
35–64 years	0.654	0.476	0.671	0.470	0.602	0.490	4.250	0.000
65+ years	0.169	0.375	0.202	0.401	0.073	0.261	10.100	0.000
Has a bank account	0.633	0.482	0.578	0.494	0.792	0.406	–13.150	0.000
Access to credit (HH)	0.185	0.388	0.170	0.376	0.227	0.419	–4.350	0.000
Savings (HH)	0.791	0.407	0.759	0.428	0.885	0.320	–9.100	0.000
Belongs to group (HH member)	0.491	0.500	0.473	0.499	0.542	0.498	–4.050	0.000
Livestock units (TLU) (HH)	4.033	49.723	3.750	53.089	4.855	38.340	–0.650	0.517
Wealth index (HH)	0.022	1.141	–0.031	0.702	0.175	1.903	–5.250	0.000

[1)] *t*-test is a mean difference test.
Source: Own calculations with survey data for 2022 and 2023.

generally have more significant human capital. They were younger and more educated, suggesting a predisposition for acquiring knowledge in digital technology. They mainly belong to a social group and households that were more financially included, as shown by the statistics on financial accessibility. Physical capital is homogeneously distributed within surveyed households. The two groups were similar regarding livestock units.

3.7. Empirical analysis

We estimate the relationship between e-commerce valuation (willingness to pay for using a digital marketing platform) and digital technology knowledge within the framework of treatment effects modeling. The treatment variable, digital technology knowledge, is likely endogenous. Because of some unobserved factors such as innate ability, more capable or intelligent respondents may be quickly acquainted with digital technology and capable of navigating easily through the Internet. Because of this innate capability, they may also value the utility of digital marketing platform services. They may as well value less the utility of using the services as they can advertise and sell themselves through social media platforms. We account for these unobserved factors that may influence both the outcome and the treatment variables by jointly estimating the following models:

$$\text{Valuation of e-commerce}_i = \alpha \text{Digital technology knowledge}_i + \beta X_{1i} + u_{1i} > 0 \quad (1)$$

$$\text{Digital technology knowledge}_i = \begin{cases} 1, \text{ if } \lambda X_{2i} + \gamma Z_{1i} + u_{2i} > 0 \\ 0, \text{ otherwise} \end{cases} \quad (2)$$

where X is the vector of control variables, Z_1 represents the exclusion restrictions, and α, β, λ, and γ are the parameters to be estimated. The unobserved error terms are normal with mean zero and have the following correlation structure: corr (u_1, u_2)=ρ_{12}. The treatment variable is endogenous if the estimated correlation $\rho_{12}\neq 0$. The outcome model is estimated through a linear regression, and the treatment model is estimated through a probit regression.

The estimated parameter α is the average effect of digital technology knowledge on e-commerce valuation. α_1 is also interpreted as the average treatment effect of the treatment variable. We use the number of household members with at least one feature mobile phone and the maximum number of months ago a household member bought a new phone, as instruments in the endogenous treatment eq. (2). Both variables are assumed to be correlated to digital technology knowledge but not directly to the valuation of e-commerce, except through the treatment variable. The assumption here is that the mere ownership of feature phones should not directly affect how e-commerce is valued, except through the increased digital knowledge it brings or that the recency of phone purchases affects the valuation of e-commerce only through its impact on digital technology knowledge. However, we control for potential confounding factors that might violate the exogeneity assumption. For examples, households with more feature phones may be systematically different in ways that also affect their valuation of e-commerce, and the timing of phone purchases is correlated with unobserved factors that also affect e-commerce valuation. Keeping these in mind, the chosen IVs can be considered valid for addressing endogeneity in the model.

We additionally estimated two variants of the model represented by eqs. (1) and (2). The first variant accounts for sample selection bias because we did not observe the willingness to pay for a digital marketing platform service for the respondents who declared they were unwilling to use that service. We estimated the model (1–2) along with the following model (3), using the (Heckman 1979) two-step procedure:

$$\text{Willingness to use e-commerce}_i = \begin{cases} 1, \text{ if } \Phi X_{3i} + \varphi Z_{2i} + u_{3i} > 0 \\ 0, \text{ otherwise} \end{cases} \quad (3)$$

with the unobserved error terms u_3 having the following characteristics : $u_3 \sim N(0, 1)$ and corr (u_1, u_3)=ρ_{13}. X is the vector of control variables, Z_2 are the instruments, and Φ, and φ the parameters to be estimated.

We used two exclusion restrictions in the selection model (3): whether the respondent decides to sell the harvested agricultural products and whether he decides on the location to sell the harvested agricultural products. Both variables are assumed to be correlated to the willingness to use e-commerce but not directly to the valuation of e-commerce, except through the selection variable. We first estimated the selection model (3) using a probit regression and computed the inverse Mills ratio (IMR) as a correction term included as an additional regressor in the outcome model (1). The selection of willingness to use e-commerce is non-random if the estimated coefficient of IMR is different from zero, which means $\rho_{13}\neq 0$.

The second variant of the model, represented by eqs. (1) and (2), accounts for the panel structure of our data. We estimated a random-effects linear regression model that allows treatment effects and accounts for the correlation of observations within panels (StataCorp 2025).

4. Results and discussion

In Table 2, we report the estimated treatment effect of digital technology knowledge, the treatment variable, on the valuation of e-commerce, the outcome variable, accounting for the correction of the endogeneity of the treatment variable (Column A) and sample selection (Column B). At the bottom of Table 2, we report the correlation coefficients between the error terms of the endogenous treatment equation (eq. (2)) and the outcome equation (eq. (1)), testing endogeneity through the dependence between both equations. The significance of the estimated correlation coefficients, irrespective of the two specifications (A and B), shows that treatment endogeneity biases are likely. The negative sign of the estimated correlation coefficients indicates that unobserved factors that increase the likelihood of being digitally unknowledgeable or skilled tend to occur, along with unobserved factors that increase the willingness to pay for digital marketing services. Moreover, the exclusions restrictions are jointly statistically significant and thus correlated to the likelihood of having digital ability. The Di Falco *et al.* (2011) falsification test for instrument validity shows that the exclusion restrictions are not jointly statistically correlated to the outcome variable with the sample of farmers without a digital ability sample. There is no evidence that sample selection is an issue in the estimations. The estimated coefficients of the correction term (IMR) are insignificant in both specifications.

The estimation results in Table 2 indicate that having digital technology knowledge increases farmers' e-commerce valuation and Appendix A shows the comprehensive results. We find that the ability to use digital technology is positively associated with a higher willingness to pay for

digital marketing platform services. The expected amount digitally skilled farmers would be willing to pay for using e-commerce services is higher than what they would be willing to pay had they not possessed digital knowledge. Our result is consistent with other studies (Erjavec *et al.* 2021; Pesci *et al.* 2023; Cheng *et al.* 2024) that found that younger farmers with higher educational attainment were more likely to use digital tools to access markets. For example, In China, Cheng *et al.* (2024) note that digital skills have a statistically significant positive influence on farmers' agricultural entrepreneurship. We find that digital technology's knowledge increases the willingness to pay by at least 158 Naira, compared to the counterfactual case. The results remain consistent regarding sign and significance when accounting for the correlation of observations within panels (Table 3 and Appendix B). Digital technology knowledge increases the willingness to pay for digital marketing services by at least 154 Naira. Although the estimated treatment effects using panel data are slightly lower than those from the pooled data, the difference is minimal. However, our results are in line with emerging evidence in literature. For example, Palloni *et al.* (2018) and Townsend *et al.* (2019) note the importance of digital skills in improving access to digital services and markets and how such skills drive demand for digital agriculture and nutrition services.

We conduct a sensitivity analysis to check whether the results are robust to changes in sample and specification. First, we examined whether the specific characteristics of the respondents drive estimation results. Some survey questions were explicitly directed at individual respondents — the household head. This was the case of questions testing the digital technology knowledge of these respondents. However, for other variables, such as the valuation of e-commerce, the questions were asked as "Are you or any household member." As such, whether the respondent was the household head (likely involved in farming and making

Table 2 Treatment effect of digital knowledge on valuation of e-commerce (linear regression)[1)]

	Endogenous treatment correction (A)		Endogenous treatment and sample selection corrections (B)	
	Willingness to pay (WTP)	Has digital ability (DA)	Willingness to pay (WTP)	Has digital ability (DA)
Has digital ability (ATT)	159.402***		158.394***	
Awareness of digital (marketing) platform (HH)	13.459***		9.252	
Usage of Facebook or WhatsApp (HH)	10.434*		11.018**	
Own feature or smartphone	–42.943***	0.405***	–43.893***	0.405***
Monthly internet expenses (HH)	–0.001*	0.000*	–0.001*	0.000*
Monthly times of airtime purchase (HH)	–1.770***	0.015***	–1.802***	0.015***
Weekly expenses on recharge card (HH)	0.000	0.000***	0.000	0.000***
Time from buying a new phone in HH (months)		–0.000		–0.000
No. of features and smartphones (HH)		–0.068***		–0.068***
Controls	Yes	Yes	Yes	Yes
Chi2(2) test for joint significance of the IVs		17.23		17.28
Prob>chi2		0.0002		0.0002
IMR			–55.372	
Corr(e.DA, e.WTP)	–0.753***		–0.753***	
Constant	135.030***	–0.522***	149.947***	–0.526***
Observations	4,046	4,046	4,046	4,046

[1)] Appendix A shows the full result. State-fixed effects included. ***, $P<0.01$; **, $P<0.05$; *, $P<0.10$.
Source: Own calculations with survey data for 2022 and 2023.

Table 3 Treatment effect of digital knowledge on valuation of e-commerce (linear regression with random effects)[1)]

	Endogenous treatment correction (A)		Endogenous treatment and sample selection corrections (B)	
	Willingness to pay (WTP)	Has digital knowledge (DK)	Willingness to pay (WTP)	Has digital knowledge (DK)
Has digital ability (ATT)	154.604***		153.849***	
Awareness of digital (marketing) platform (HH)	14.343***		10.778*	
Usage of Facebook or WhatsApp (HH)	11.161**		11.574**	
Own feature or smartphone	–40.874***	0.429***	–41.656***	0.429***
Monthly internet expenses (HH)	–0.001	0.000*	–0.001*	0.000*
Monthly times of airtime purchase (HH)	–1.747***	0.018***	–1.777***	0.018***
Weekly expenses on recharge card (HH)	0.000	0.000***	0.001	0.000***
Time from buying a new phone in HH (months)		–0.000		–0.000
No. of features and smartphones (HH)		–0.074***		–0.074***
Control	Yes	Yes	Yes	Yes
Chi2(2) test for joint significance of the IVs		15.01		14.97
Prob>chi2		0.0005		0.0006
IMR			–49.294	
Corr(e.DK, e.WTP)	–0.781***		–0.781***	
Corr(DK[hhid], WTP[hhid])	–0.612***		–0.612***	
Constant	135.030***	–0.522***	149.947***	–0.526***
Observations	4,046	4,046	4,046	4,046
Number of hhid	2,196	2,196	2,196	2,196

[1)] Appendix B shows the full result. State-fixed effects included. ***, $P<0.01$; **, $P<0.05$; *, $P<0.10$.
Source: Own calculations with survey data for 2022 and 2023.

decisions about agricultural marketing) may influence their answer on the willingness to pay for using e-commerce services and thus the estimation results. We ran further regressions on the sample restricted only to the respondents who decided where to sell the crops cultivated. Table 4 shows that the estimated coefficients of the treatment variable are positive and significant. Digital technology knowledge still increases e-commerce valuation.

So far, we have defined e-commerce valuation as the willingness to pay for using digital marketing platform services for which a linear regression was employed. We used another definition of e-commerce valuation, responding to our belief that its values are unobserved but may fall within an interval with fixed endpoints. The fixed upper endpoints correspond to the maximum amount the respondents would be willing to pay for using digital marketing platform services to sell farm products. The fixed lower endpoints correspond to the amount the same respondents would be willing to pay for the same purpose, which may be equal to or less than the maximum amount declared.

Table 5 presents the interval regression estimation results using this definition of e-commerce valuation. The estimated average treatment effects still have the expected sign, although the magnitude has decreased compared to results obtained with the linear regression.

Overall, our results align with the literature showing that the experience of using smartphones, e-training acquisition, and the use of the Internet increases farmers' adoption of e-commerce (Ma *et al.* 2020; Liu *et al.* 2021), implying that digital technology knowledge is important in e-commerce valuation.

We extended our analysis to answer which e-commerce has more value among knowledgeable digital technology respondents. We examined the profiles of the estimated average treatment effects among the digitally skilled respondents for representative values of some characteristics of these respondents. We performed the heterogeneous effects analysis by allowing the interaction of the treatment variable with some control variables. These variables are the age and gender of the respondent, whether the respondent has been aware of or has used any social media digital platform (Facebook or WhatsApp), and whether the respondent's household was far or close to the nearest market. The farthest household is defined as living at a distance far more than the median. The average is 9 km for the distant group and 2 km for the close group.

Fig. 7 shows that the estimated average treatment effects among digitally

Table 4 Treatment effect of digital knowledge (DA) on the valuation of e-commerce (WTP): Sample restricted to decision-makers on sale of agriculture products[1)]

	Linear regression		Linear regression with random effects	
	Endogenous treatment correction	Endogenous treatment and sample selection corrections	Endogenous treatment correction	Endogenous treatment and sample selection corrections
Has digital ability (ATT)	156.205***	154.163***	151.981***	150.737***
	(9.756)	(9.675)	(10.122)	(10.021)
Corr (e.AD, e.WTP)	–0.741***	–0.740***	–0.774***	–0.774***
	(0.035)	(0.035)	(0.043)	(0.042)
Corr(AD[hhid], WTP[hhid])			–0.576***	–0.578***
			(0.093)	(0.093)
Observations	3,692	3,692	3,692	3,692
Number of hhid			2,127	2,127

[1)] State-fixed effects included. Control variables included but not reported. Robust standard errors in parentheses. ***, $P<0.01$; **, $P<0.05$; *, $P<0.10$. Source: Own calculations with survey data for 2022 and 2023.

Table 5 Treatment effect of digital knowledge on the valuation of e-commerce (interval regression)[1)]

	Endogenous treatment correction		Endogenous treatment and sample selection corrections	
	Willingness to pay (WTP)	Has digital knowledge (DK)	Willingness to pay (WTP)	Has digital knowledge (DK)
Has digital knowledge (ATT)	119.390***		117.551***	
Awareness of digital (marketing) platform (HH)	22.949***		14.871**	
Usage of Facebook or WhatsApp (HH)	8.032		9.161*	
Own feature or smartphone	–45.717***	0.457***	–47.536***	0.457***
Monthly internet expenses (HH)	–0.001*	0.000*	–0.001**	0.000*
Monthly times of airtime purchase (HH)	–1.810***	0.016***	–1.872***	0.016***
Weekly expenses on recharge card (HH)	–0.001	0.000***	–0.001	0.000***
Time from buying a new phone in HH (months)		–0.001		–0.001
No. of features and smartphones (HH)		–0.085***		–0.085***
Controls	Yes	Yes	Yes	Yes
Chi2(2) test for joint significance of the IVs		22.92		23.48
Prob>chi2		0.000		0.000
IMR			–105.628*	
Corr(e.DA, e.WTP)	–0.682***		–0.682***	
Constant	144.772***	–0.642***	173.174***	–0.649***
Observations	4,046	4,046	4,046	4,046

[1)] Appendix C shows the full result. State-fixed effects included. The interval regression with random effects was computationally time-consuming and difficult to implement. ***, $P<0.01$; **, $P<0.05$; *, $P<0.10$. Source: Own calculations with survey data for 2022 and 2023.

skilled respondents increase more significantly for those aged 25–34 years and 65+ years, especially when they have not been aware of digital platforms or have not used any social media digital platforms. The estimated average treatment effects increase more for digitally skilled male household heads. The result implies that young adults and retirees (or senior citizens) benefit more from digital skills in terms of their engagement with e-commerce, and it enhances ability of those who are new to digital technologies to engage in e-commerce. In addition, male household heads, when equipped with digital skills, show a greater increase in their demand for and valuation of e-commerce compared to the females suggesting that there may be gender-specific factors, such as socio norms and cultural barriers, driving the adoption and valuation of e-commerce (Roscoe and Ntim 2022; Sufian *et al.* 2023).

5. Conclusion and policy recommendations

Limited digital literacy may be a significant barrier to the demand for and use of digital marketing services. Yet, the link between digital literacy and the demand for digital marketing platforms remains an empirical question. Our study contributes new evidence on smallholder farmers' valuation of digital marketing tools (e-commerce). We provided evidence of the link between digital knowledge (information and ability) and willingness to pay to use digital marketing platform services.

We found that the farmers were willing to bear the cost of using an e-commerce service, a percentage of the sale price above that is demanded by a Nigerian online trading platform that directly connects farmers to buyers and consumers in Nigeria. The estimation results from treatment effects and panel data analysis revealed that knowledge of digital technology is associated with the willingness to pay for digital marketing platform services. The estimated average treatment effects among digitally skilled farmers vary according to age, gender awareness, and usage of social media platforms. Our results imply that having basic digital skills can incentivize the demand for e-commerce and provide valuable appeal for policy to focus on investing in rural digital infrastructure and digital literacy.

Also, by demonstrating that digital literacy is positively linked to the demand for digital marketing platforms, the study provides valuable insights for private sector strategies aimed at expanding rural digital markets. First, private companies, particularly those in the e-commerce sector, can collaborate with government and non-governmental organizations to develop and implement digital literacy programs tailored to rural communities and vulnerable groups. Second,

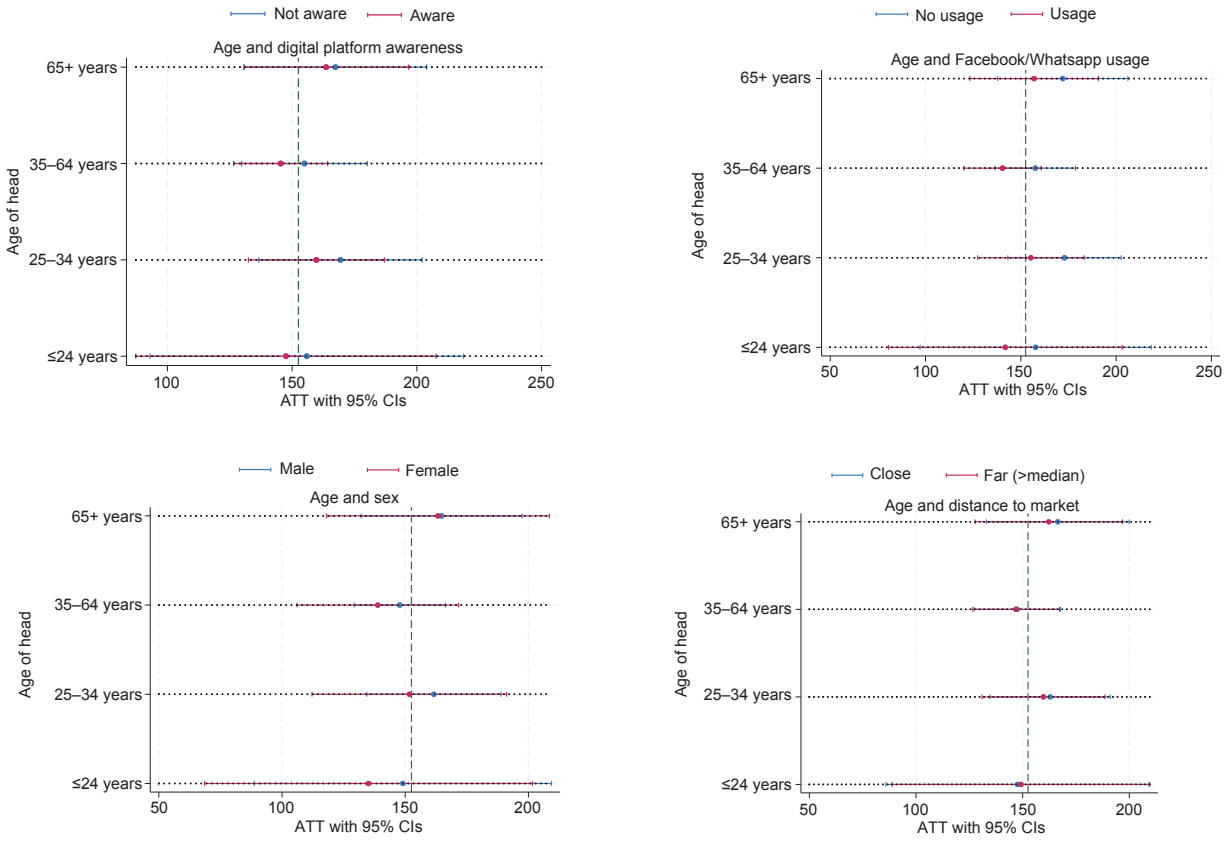


Fig. 7 Heterogeneous effects analysis: Average treatment effects (ATT) among digitally technology-knowledgeable farmers. ATTs are displayed for different groups of farming households, considering the age and sex of the head of household, whether the household has been aware of or has used any social media digital platform (Facebook or WhatsApp), and whether the household is far or close to the nearest market. The farthest distance is far more than the median. The vertical green line shows the overall ATT. Source: Own calculations with survey data for 2022 and 2023.

e-commerce platforms can design services that cater specifically to the needs and preferences of smallholder farmers and financial institutions can also design financial products that support the adoption of e-commerce among smallholder farmers. Third, agribusinesses can leverage the insights from this study to develop integrated digital solutions that connect farmers directly with buyers and offer real-time information on market prices.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Grammarly and Microsoft Copilot in order to improve the linguistic quality of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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