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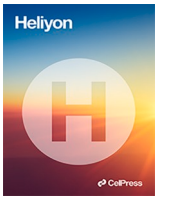

Digital Adoption levels and income generation in rural households in China

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ABSTRACT

With the increasing digital transformation of rural industries, the digital economy is considered a new driving force for consolidating the achievements of eradicating poverty and comprehensively promoting rural revitalization. This study constructs a multidimensional index to measure the digital application level of rural households based on microsurvey data and empirically investigates the economic returns and mechanism of its effects. The results show that digital application significantly improves the economic situation of households. For every 1 unit increase in the level of digital application, per capita net income of households will increase by 0.427 units, and the relative poverty incidence will decrease by 0.421 units. Mechanism analysis shows that the level of digital application in rural households can significantly improve the technical abilities of household members, promote non-agricultural employment, and increase the share of agricultural and sideline business operations, thus improving the economic situation of households. Further research shows that the economic returns obtained from digitization in rural households exhibit significant regional differences. This study provides research support on how to better examine the role of the digital economy for rural households to generate wealth and increase income.

1. Introduction

Relying on modern information technologies, such as artificial intelligence, big data, blockchain, and cloud computing, the digital economy has gained powerful advantages, including massive data processing, extremely fast information search, and accurate demand and supply matching. Thus, it is able to bring new impetus and opportunities to the economic and social system operation and has become a new engine for economic transformation and income growth. The integration and expansion of the digital economy has led to unprecedented changes in various fields of economic development, and the rural economy—traditionally understood as "off the land but not in the countryside"—is also compelled to undergo numerous changes. "Smart agriculture," "digital agriculture," and "Internet + agricultural products platform" have brought new models and ways to increase agricultural development and farmers' income. Thus, the digital economy has become an important support for agricultural and rural transformation. In May 2019, the General Office of the Central Committee of the Communist Party of China and the General Office of the State Council issued the Outline of the Digital

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Countryside Development Strategy. The document delineates that "the development of rural digital economy is both a strategic direction for rural revitalization and an important element in building digital China." In this context, how to release the supporting role of the digital economy in rural development and farmers' income increases and promote the connection between consolidating and expanding poverty eradication and rural revitalization achievements is widely discussed by management departments and academia.

The issue of the digital economy development and its role in agricultural and rural development has attracted the attention of numeorus scholars, and several insightful results have emerged. The literature directly related to this study focuses on the following two aspects: on one hand, research has been conducted on the factors influencing rural household income. First, Household characteristics, such as the level of household labor, material capital, and social network relationships, can have an impact on the income status of rural households. Studies by Cheng et al. (2016) [1] have shown that the health level, education level, skill training, and work experience of household labor have a significant positive effect on improving household income. Mao and Xu (2015) [2] pointed out that material capital, especially land, can effectively increase the income level of households by accelerating its circulation speed. Furthermore, the research by Gao and Yao (2006) [3] found that labor level contributes more to income improvement than material capital level. As China has always been a typical society focused on interpersonal relationships, social network relationships also have an impact on resource acquisition and income for rural households. Second, the external environment also affects household income. Infrastructure, public services, and financial support are all necessary conditions for improving household income. On the other hand, with the gradual digitization of agriculture and digital village construction, studies focusing on the digital and rural economy integration and development have gradually increased. Scholars have analyzed and demonstrated the effect of the digital economy on the increase in income of agricultural households from the perspectives of internet popularization, digital inclusive finance, rural e-commerce, and big data precision poverty alleviation management [4,5,6]. They confirm that the digital and rural economy integration and development can not only effectively ease the problems of insufficient innovation capacity and low production efficiency in rural areas owing to insufficient information but also enhance the risk control of agricultural production efficiency, reduce transaction costs, and innovate production service models [7,8]. Thus, it introduces the economies of scale effect of agricultural production, improves farmers' income, enhances farmers' happiness, reduces poverty, grows agricultural economic development, and promotes the transformation and upgrading of rural modernization [9,10]. This forms a more systematic lineage of literature. Existing scholars have argued from the typical practice model with Chinese characteristics that the digital and rural agricultural economy integration can promote agricultural upgrading and farmers' development in multiple directions [11]. However, with poverty eradication and continuous development of rural revitalization in China, there exists scarce literature on how to further merge and expand the achievements of poverty eradication and development of the new situation of rural revitalization. Therefore, using the 2018 China Family Panel Studies (CFPS) microdata, this study empirically explores the effects of the digital economy on agricultural households' income enrichment, considering regional and group heterogeneity.

Compared with extant literature, the contributions of this study are: first, the research perspective, based on household income heterogeneity, systematically analyzes the impact mechanism and performance characteristics of the digital economy on agricultural households' income increase. Thus, it broadens the research scope of agricultural and farmers' issues and creates a new dimension of the digital economy and rural income enrichment research. Second, this study uses the 2018 CFPS data and constructs digital application indexes based on microsamples to measure the application level of rural households in four dimensions: digital environment, digital services, digital usage frequency, and digital penetration. It refines the comprehensive evaluation and portrayal criteria of the rural digital economy development and provides more direct correlation factors for analyzing rural households' wealth and income increases. Finally, the analysis of the channels, theoretical mechanisms, and economic effects of the digital economy on rural households' income and prosperity in China's rural development practices can provide research support in understanding the effective interface between the digital economy and promoting poverty alleviation and rural revitalization in the new development stage.

2. Theoretical mechanism analysis

Digital economy refers to a series of economic activities that use digital knowledge and information as key production factors, modern information networks as important carriers, and the effective use of ICT information communications technology as a crucial driving force for improving efficiency and optimizing economic structure. "Digital changes life," digital, networked, and intelligent information and communication technologies have changed the traditional way of social interaction and made modern economic activities more flexible, agile, and intelligent. The widespread application of the digital economy to other economic fields has engendered unprecedented changes in various fields of economic development [12,13,14]. In particular, the rural economy is being driven to undergo many changes. Existing research shows that integrating the digital and rural economies can significantly promote the optimal allocation of agricultural production resources, improve agricultural labor productivity, and cultivate new industries and business models in rural areas. Furthermore, it can innovate agricultural business models, realize agricultural development and increase farmers' income, and help the rural economy successfully "overtake" the urban economy [15,16]. For rural families, the popular application of digitalization will significantly affect their production decisions, labor force skills improvement, and employment changes, which will engender a series of changes in the family economic income.

Throughout human history, the development of productivity often stems from the accumulation of knowledge and improvement of skills. Whether it is the Industrial Revolution or the era of the Electrical Revolution, knowledge and skills have been the driving force behind the liberation and development of productivity. For a considerable period of time, due to the lack of digital facilities in rural areas, farmers' access to information, education, and knowledge accumulation has been limited to basic education in fixed forms. As a result, the timeliness of information and the conversion rate of knowledge and skills for farmers have been low. With the improvement

of digital infrastructure in rural areas and the popularity of mobile internet, digital technology is increasingly integrating with rural life and farmers. With its advantages of being unrestricted by time and space and being inclusive to the masses, digital technology is gradually becoming the main channel for agricultural households to access important information technology resources. The application of digital technology can enhance the production skills of family members. On the one hand, digital applications represented by the internet bring a large amount of information resources and drive the dissemination of advanced technologies. Family members with strong learning abilities can identify and explore information resources, integrate and filter the acquired information resources, quickly grasp complex key technologies, improve their own agricultural technical capabilities, and subsequently improve the production efficiency of the family [17,18,19]. On the other hand, once a farmer takes the lead in boarding the "convenient express train" of digital applications, it will serve as a demonstration template for others and further drive other farmers to learn and use new digital production technologies through the collective effect. This will transform previous production and business methods, eliminate outdated production capacity, more efficiently use existing resources, and adopt advanced technologies. It will promote an innovative transformation of production methods, fundamentally improve the quality and grade of agricultural products, and increase farmers' operating income [20,21]. Based on the above analysis, we propose the following hypothesis.

Hypothesis 1. The improvement of household digital application level promotes income growth and wealth accumulation by enhancing the technical skills of household members.

The integration of digital applications and traditional agriculture has further given rise to new industries and business models in rural areas, fostering the cultivation of new agricultural production drivers and innovative farming models, which in turn provide diversified pathways for farmers to increase their income. Firstly, digital applications have brought about a transformation in the production and business models of rural households. Business models such as "crowdfunding agriculture", "order-based agriculture" and "customized agriculture" that are based on internet big data have helped cultivate new types of business entities, improving the scale efficiency of agricultural production activities and subsequently increasing farmers' operating income and property income [20]. Secondly, the further integration of digital applications and rural industries promotes the diversified development of agricultural production and business activities, expanding channels for farmers to increase their income [22,11]. In traditional agricultural production, individual farmers, positioned at the bottom of the production chain, cannot benefit from the added value in the processing and circulation stages of agricultural products. By utilizing internet technology, an agricultural big data platform can be effectively established, elevating the status of farmers in the agricultural industry chain and increasing their opportunities to participate in marketing activities. This allows farmers' sources of income to surpass the limitations of cultivation and animal husbandry, enabling them to enjoy more production dividends. Taking the thriving leisure agriculture as an example, innovative business methods such as running rural guesthouses and establishing experiential farms have been adopted to develop characteristic agriculture based on local conditions, achieving direct connection between production and sales. This transformation enables farmers to shift from "earning income once a year" to "earning income throughout the year", improving their income level and realizing the desirable goal of increasing income and becoming prosperous [4,23,24]. Based on this, we propose research hypothesis 2.

Hypothesis 2. By improving the digital application level in households, it can promote income growth and wealth accumulation by increasing the share of production and business activities.

Research has shown that the widespread application of digital technology will have a certain impact on employment. However, due to the nature of creative destruction, its promotion effect on employment and activation effect on entrepreneurship will be greater than the reduction effect. On the one hand, as the level of mechanization in household production continues to increase, the demand for human capital in the production process will decrease. As a result, surplus labor in households will continuously shift to other non-agricultural production activities, such as marketing. Digital technology has provided agricultural households with a broader platform, and online marketing through platforms like Taobao and JD.com has opened up new paths for agricultural households to explore non-agricultural employment. This widens employment channels and increases job opportunities, helping to improve the income level of rural households [25,26]. On the other hand, information barriers and lack of funds have always been obstacles to rural

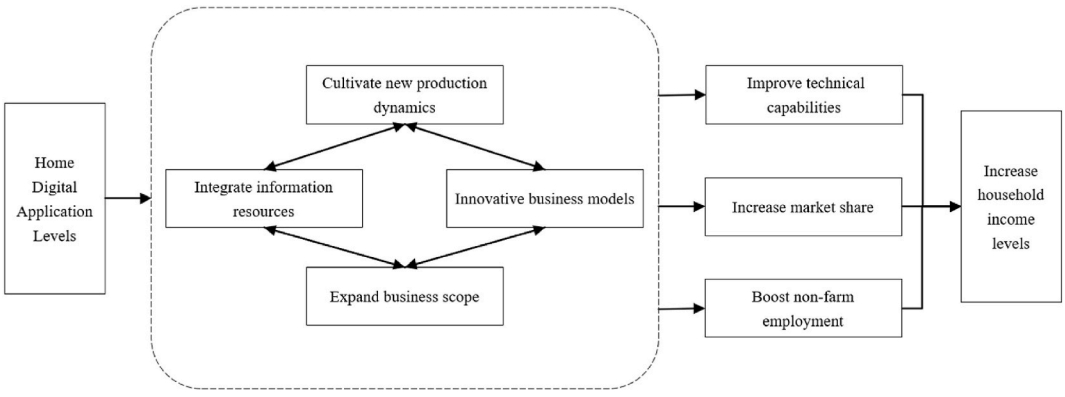

Fig. 1. Diagram of the economic return mechanism of digital applications.

entrepreneurship. The continuous improvement of digital applications can to a large extent compensate for these deficiencies. The mobile internet provides rural entrepreneurs with a wealth of information resources, greatly improving the efficiency of accessing effective information. At the same time, as the level of digital applications continues to improve, rural entrepreneurs are gradually exposed to channels such as digital inclusive finance and internet microloans. This effectively alleviates the problem of fund shortage in the entrepreneurial process and stimulates entrepreneurial activities based on digital technology and new business models. It helps to increase the property income and operating income of rural households [27,28]. Based on this, we propose the third research hypothesis.

Hypothesis 3. By improving the digital application level in households, it can promote income growth and wealth accumulation by facilitating non-agricultural employment (see Fig. 1).

3. Research design

3.1. Model setting

This study aims to analyze the impact of digital applications on rural households' income enrichment and provides empirical evidence from two aspects based on the mechanism explored in earlier studies. First, to examine the impact of digital applications on the economic status of rural households, we constructed a dichotomous choice model with the dependent variable of poverty alleviation. Second, from the perspective of continuous changes in rural household income, we construct a linear regression model with the net income of rural households as the dependent variable to investigate the effect of digital applications on wealth and income generation.

For the poverty status of rural households, there are only two states, poverty and nonpoverty. Referring to extant literature, we chose the Probit model in the binary choice model to examine the impact of digital applications and the probability of rural poverty occurrence by establishing the following measurement functions:

$$P(Y_i = 1|X_i) = f(\beta_0 + \beta_1 dedi_i + \beta_2 x_{i1} + \beta_3 x_{i2}) \tag{1}$$

In Model (1), i denotes different rural households, $Y_i=1$ represents poor households, $P(Y_i=1|X_i)$ denotes the probability of household i falling into poverty, X_i indicates the core explanatory variable $dedi_i$, and X_{i1} and X_{i2} denote all control variables, where X_{i1} is a household head characteristic variable, and X_{i2} is a household characteristic variable.

The income level is the most widely used and important measure in the current academic research on rural living conditions. Referring to existing literature, we employed the natural logarithm of net household income per capita ($\ln perinc_i$) to study the actual impact of numerical applications on absolute rural poverty status. The scatter plot was used to visualize the relationship between digital applications and net household income per capita, and the results showed that net household income per capita showed a significant positive linear correlation with the level of digital applications in households; as the level of digital applications in households increased, net household income per capita also increased. Accordingly, we established the following multiple regression model to examine the relationship between the level of household digital application and net income per capita:

$$\ln perinc_i = \alpha_0 + \alpha_1 dedi_i + \alpha_2 x_{i1} + \alpha_3 x_{i2} + \varepsilon_i \tag{2}$$

In Model (2), the explanatory variable $\ln perinc_i$ denotes the natural logarithm of net household income per capita, $dedi_i$ represnts the core explanatory variable rural household digital application index, X_{i1} denotes the household head characteristics variable, and X_{i2} indicates the household characteristics variable.

In light of the theoretical mechanism analysis in the second part, digital application may impact household income through channels such as improving the technical capabilities of household members, increasing the share of agricultural and sideline business operations, and promoting non-agricultural employment. Following the approach of existing literature, we establish the following model to examine the hypothesis 1-3:

$$channel_i = \beta_0 + \beta_1 dedi + \beta_2 x_{i1} + \beta_3 x_{i2} + \varepsilon_i \tag{3}$$

$$\ln perinc_i = \beta_0 + \beta_1 dedi + \beta_2 dedi \times channel_i + \beta_3 channel_i + \beta_4 x_{i1} + \beta_5 x_{i2} + \varepsilon_i \tag{4}$$

In Model (3) and (4), "$channel_i$" represents the channels, which are represented by "*business_share*", "*skills_upgrading*", and "*non-farm_employment*" in the regression.

3.2. Data sources

The microdata used in this study were obtained from the CFPS database, and the 2018 sample was selected for analysis. The CFPS is a national, large-scale, multidisciplinary, and comprehensive social tracking survey project that reflects the social, economic, demographic, educational, and health changes in China. It stores data at three levels—individual, household, and community—to provide a database for academic research and public policy analysis. The CFPS focuses on the economic and noneconomic welfare of Chinese residents. Its data sample covers 25 provinces/municipalities/autonomous regions, covering 95 % of China's population. The CFPS 2018 data sample comprises a total of 14,218 urban and rural households. Because this study focuses on the digital economy's impact on agricultural households' income and wealth, only data on rural households were retained. After screening the relevant data

from the child and adult pools and excluding missing value samples, the final valid study sample of 5937 was obtained.

3.3. Variable settings and descriptions

3.3.1. Explained variables

This study focuses on the impact of digital application level on the wealth status of rural households and sets two explanatory variables: rural household poverty status and economic income. The most representative indicators in existing studies are the probability of poverty occurrence and net income per capita of rural households. Based on data availability, we used annual net per capita household income as a proxy variable for economic income and determined the poverty status of rural households based on this corresponding to poverty criteria and formed a dichotomous variable. On the one hand, based on the household income, we studied the income-increasing effect of digital applications using the natural logarithm of household net income per capita (ln*perinc*) as the explanatory variable; On the other hand, regarding the impact of digital application on the incidence of relative poverty in rural areas, due to the unavailability of specific city information for households in the CFPS database, it is not possible to obtain median income data for different cities or urban-rural areas. Therefore, this study chooses to use the calculated median income of the CFPS sample data as a proxy. By calculation, the skewness coefficient of rural household income in the CFPS 2018 sample dataset is 6.25, indicating a significant right-skewed distribution. Therefore, it is reasonable to use the median income to measure relative poverty. Furthermore, based on the EU standards, setting the threshold at 60 % of the median income is chosen as the measure of relative poverty.

3.3.2. Core explanatory variables

The core explanatory variable of this study is the household digital application index. Based on the basic meaning of digital life, we constructed the rural household digital application index based on four dimensions: digital coverage, digital usage intensity, digital importance, and digital penetration, using data from the CFPS database. Further, we used factor analysis to calculate this index. Before conducting the factor analysis, we conducted KMO and Bartlett's sphericity tests to examine the indicators of the four dimensions of household digital application level. The results showed a KMO value of 0.821 and a P-value of 0 in the Bartlett's sphericity test, indicating that the data is suitable for factor analysis. Using Stata software, we further calculated the non-negative eigenvalues using the correlation coefficient matrix. The results showed that the eigenvalues of the first four factor variables were all greater than 1. After performing a varimax rotation, the cumulative variance contribution rate reached 73.67 %(as shown in Table 1), therefore, we ultimately selected four common factors (primary indicators).

The comprehensive factor scores are calculated using the proportion of each factor's variance to the cumulative variance as weights. Simultaneously, the final indicators are constructed based on the corresponding original variables reflected by each factor (as shown in Table 2).The factor score is a relative value, that is, the extent to which the digital application level of a single rural household deviates from the overall sample mean. If the positive is greater, the household's digital application level is relatively higher; conversely, if the negative value is greater, the household's digital application level is below the average level.

3.3.3. Other explanatory variables

(1) Mediating variables. Based on the available data, we have selected the following proxy variables to examine the effects of increasing agricultural and non-agricultural activities: *business_share*, this variable represents whether the household engages in non-agricultural activities, such as business, forestry, fisheries, etc. It is a binary variable where households not engaged in these activities are assigned a value of 1, and households engaged in these activities are assigned a value of 0. *Skills_upgrading*, this variable represents whether the household members use the internet for business activities, indicating their level of technical abilities. It is a binary variable where households using the internet for business activities are assigned a value of 1, and households not using the internet for business activities are assigned a value of 0. *Nonfarm_employment*, this variable represents whether the household has wage income from non-agricultural employment, indicating their participation in non-farm employment. It is a binary variable where households with wage income from non-agricultural employment are assigned a value of 1, and households without wage income from non-agricultural employment are assigned a value of 0. To further strengthen the validity of this mechanism, we will construct interaction terms between the household digital economic development index and *business_share*, *skills_upgrading*, and *nonfarm_employment* in the regression model, denoted as *dedi*$\times$*business_share*, *dedi*$\times$*skills_upgrading*, and *dedi*$\times$*nonfarm_employment*, respectively.

(2) Household head characteristics variables. Because this study takes rural households as the perspective of research entry; it is necessary to define the virtual household head to control for relevant variables. In other words, the financial respondents in the

Table 1
Factor analysis results.

	Initial eigenvalues			After orthogonal rotation		
	Eigenvalue	Variance contribution	Cumulative contribution	Eigenvalue	Variance contribution	Cumulative contribution
Factor 1	6.075	43.390	43.390	4.659	33.280	33.280
Factor 2	2.111	15.080	58.480	3.290	23.500	56.780
Factor 3	1.125	8.040	66.510	1.351	9.650	66.430
Factor 4	1.002	7.160	73.670	1.013	7.230	73.670

Table 2
Construction of home digital application index indicators.

Overall layer	Objective layer	Indicator layer	Note description
Home Digital Application Index	Digital Environment	Whether mobile Internet access, whether computer Internet access, whether sending and receiving e-mail	Yes = 1 No = 0
	Digital Services	Frequency of using the Internet for study, frequency of using the Internet for work, frequency of using Internet for socializing, frequency of using Internet for business activities	Assign a value of 0–6 according to CFPS questionnaire
	Frequency usage frequency	Time spent on the Internet in spare time	Hours
		Monthly cell phone bill	Yuan
		How many days a week you log in to your mailbox	Day
	Digital penetration	Importance of Internet for study, importance of Internet for work, importance of Internet for social interaction, importance of Internet for recreational activities, importance of Internet for business activities	Assign a value of 0–7 according to CFPS questionnaire
		Importance of TV as an information channel, importance of Internet as an information channel, importance of SMS as an information channel	Assign a value of 0–5 according to CFPS questionnaire

Table 3
Description of variables and descriptive statistics.

variable	Variable name	Variable description	Mean	Standard deviation
dedi	Household digital application index	The indicators obtained by using factor analysis method	−0.001	0.453
ln*perinc*	Logarithm of household net income per capita	Taking the natural logarithm of net household income per capita	7.024	1.353
poor	Household economic status	Dummy variables generated based on net household income per capita and poverty line criteria	0.330	0.470
age	Age of household head	Year of survey - year of birth of household head	51.437	14.154
age^2	Square of the age of the head of household	Square of the age of the household head/100	28.46	14.499
gender	Gender of household head	Male head of household = 1, female head of household = 0	0.570	0.495
healthy	Health of the head of household	Very healthy = 1; healthy = 2; Relatively healthy = 3; Generally healthy = 4; Unhealthy = 5	3.191	1.282
edu	Number of years of education of the head of household	Adults converted according to the education level of the head of household	6.094	4.425
familysize	Total household size	Number of household members living together	4.012	1.978
work	Nature of household work	No work = 0; working in agriculture = 1; working in non-agricultural work = 2	1.101	0.613
young	Percentage of children under 16 years old in the household	Number of children under 16 years old in the household/total household size × 100	15.418	18.615
elder	Percentage of elderly people over 65 years old in the household	Number of elderly people in the household over 65 years old/total household size × 100	17.993	31.431
social	Social network relationship	Portion of total household expenditures spent on human expenses (million yuan)	0.363	0.535
houseasset	Household net property	Household net property = total household property - property loan amount (million dollar)	21.550	92.321

CFPS 2018 database were used as the household heads, and the *age*, *gender*, health status (*healthy*), and years of education (*edu*) of the household heads were selected as control variables. Using locally weighted regression scatterplot smoothing, we found that the household head's age is associated with the probability of household poverty in a "U" shape; therefore, the squared term of age was included in the regression. As the problem of "difficult and expensive medical care" has become increasingly prominent recently, the number of people returning to poverty owint to illness has been rising. Hence, poverty owing to illness has become the primary cause of extremely impoverished groups returning to poverty [29]. Therefore, the health degree of the household head was selected as the control variable and assigned a value ranging 1–5 according to the CFPS questionnaire. "1" means "very healthy," "2" means "healthy," "3" means "relatively healthy; " "4" means "generally healthy," "5" means "unhealthy."

(3) Household characteristics variables. Family-size, the proportion of children under 16 years old (*young*), the proportion of elderly people over 65 years old (*eld*), whether the household is engaged in nonfarm work (*work*), household social expenditure (*social*), and household net property (*houseasset*) in the CFPS 2018 household database were selected as control variables. Children and elderly people have difficulty obtaining income owing to their lack of working ability; therefore, poverty mainly occurs at the stages of childhood and old age. The presence or absence of nonfarm business is a dichotomous variable, with the presence of nonfarm business assigned a value of 1, and the absence of nonfarm business assigned a value of 0. The presence of nonfarm business can increase the nonfarm income of the household and broaden the source of income, which can contribute to income increase to a certain extent.

3.3.4. Descriptive statistics

(1) Descriptive statistics of the rural household digital application index. The mean value of the rural household digital application index is −0.001, indicating that there are still many rural households with digital application levels below the average level. At the same time, it also reflects the huge potential for digital development in rural areas, which still needs to be further explored. Moreover, the variable has a large standard deviation, indicating that there is still a significant difference in the level of digital application among households. From the distribution of the rural household digital application index, it is obvious that the digital application level of most rural households is lower than the average level of the sample population. Building a digital countryside is an important strategic direction for rural revitalization, as well as a necessary path. However, in the current reality of China, the construction of digital villages is still constrained by factors such as low digital penetration in rural areas, lagging construction of digital talent teams, and imperfect market system. In addition, as a new product of the era, digitalization is still in the development stage in terms of academic research on the digital economy, and there is no consensus on the measurement method of digital application index. Therefore, to prevent potential errors in the measurement method of the core explanatory variable, digital application, this study will attempt to use a different measurement method for the core explanatory variable in robustness tests.

(2) Descriptive statistics of other variables. The results of descriptive statistics of other variables are presented in Table 3. Among the valid samples, some households are still in a state of relative poverty, based on the relative poverty standard calculated by dividing the median per capita income of households by 60 % according to the equivalent family size. Relative poverty remains a challenging issue that hinders rural revitalization. From the perspective of household head characteristics, the ratio of male to female household heads is roughly 11:9, and their health conditions are relatively good. The average years of education for household heads is around 6 years, which indirectly reflects the insufficient education quality and resources in rural areas. From the perspective of household characteristics, the population size of surveyed households is around 4 people. From the descriptive statistics of the indicator of whether they engage in agricultural work, it can be seen that rural households are still primarily engaged in agricultural-related work. In addition, looking at the proportion of children under 16 years old and elderly people over 65 years old in the household, rural areas are still facing a serious problem of population aging.

4. Empirical results and analysis

4.1. Baseline regression analysis

1.The impact of digital economic development on the likelihood of relative poverty and economic income in households is explored. Table 4 presents the regression results of the digital household index on the probability of relative poverty, per capita income, and various income components. Firstly, as indicated in the first column of Table 4, the coefficient of the digital household index is significantly negative, suggesting a pronounced inhibitory effect of digitalization on the probability of relative poverty in households. Specifically, for every 1% point increase in the digital household index, the likelihood of relative poverty in rural households decreases by 0.4205% points.Secondly, the regression results in columns (3) to (6), with various income components as dependent variables, demonstrate that the digital household index exhibits a significant promoting effect on household income. However, the impact on each income component varies. For every 1 % increase in the digital household index, the various income components increase by 0.5771 %, 0.3782 %, 0.4528 % and 0.2450 % respectively.On one hand, with the widespread dissemination of advanced digital technologies, the competitiveness of production and business markets in rural areas intensifies. This prompts rural households to utilize existing resources more efficiently and adopt advanced technologies. Technological progress enhances production efficiency, thereby improving the comparative benefits of agricultural production and livestock farming. Consequently, rural households can obtain greater profits from agricultural business markets, as demonstrated in column 3 of Table 4.On the other hand, in order to encourage the development of digital rural areas, the national and local governments have implemented a series of preferential policies to support the development of relevant emerging digital industries. Subsidies are provided to individuals involved, which to some extent, stimulate the enthusiasm of rural residents to engage in agricultural cultivation and animal husbandry. The probability of rural households obtaining transfer income also significantly increases, as evidenced from another aspect in column 6 of Table 4. Simultaneously, the integration and extension of digital industries compel innovation in traditional agricultural models. This, to a certain degree, drives the non-agricultural employment of rural labor force. For example, the “Internet + Agriculture” initiative not only stimulates employment and entrepreneurial activities in the agricultural product marketing industry, but also encourages non-agricultural activities related to agricultural trade. This attracts a continuous influx of labor force into the agricultural product market. The increase in the digital household index in column 4 of Table 4 significantly promotes the improvement of rural households’ wage income, further confirming this factor. Lastly, under the combined influence of these four factors, as shown in column 2 of Table 4, the impact of the digital household index on per capita income in rural households is observed to have a significant positive promoting effect. For every 1 % increase in the level of household digitalization, per capita income in the household increases by 0.4273 % [30,31].

2.The impact of various control variables on the probability of relative poverty occurrence and economic income in households is analyzed. From the results obtained by only introducing household head characteristic variables, the variable “age^2” shows a negative correlation with the probability of relative poverty occurrence and a positive correlation with various types of household income. This indicates a “U-shaped” nonlinear relationship between the age of the household head and household poverty. When the household head is young, with increasing age, the level of education and years of work experience of the household head also increase, which is

Table 4
Regression results of household digital application level on their relative poverty incidence probability, per capita income and each income.

	relative poverty incidence	log income per capita	log business income	log wage income	log property income	log transfer income
	(1)	(2)	(3)	(4)	(5)	(6)
dedi	−0.4205***	0.4273***	0.5771***	0.3782***	0.4528***	0.2450**
	(-7.1587)	(8.6322)	(4.7306)	(3.0294)	(6.1920)	(2.5459)
age	−0.0166*	0.0151*	0.0516**	0.2101***	0.0239*	0.1158***
	(-1.7414)	(1.7388)	(2.4128)	(9.5758)	(1.8618)	(6.8488)
age^2	0.0166*	−0.0107	−0.0666***	−0.1976***	−0.0094	−0.0660***
	(1.7537)	(-1.2238)	(-3.1117)	(-8.9973)	(-0.7323)	(-3.9002)
healthy	0.0470***	−0.0179	−0.1155***	−0.1124***	0.0414**	0.0560**
	(3.1995)	(-1.2753)	(-3.3491)	(-3.1765)	(2.0037)	(2.0591)
gender	0.1050***	−0.0470	−0.6160***	0.6028***	−0.0221	0.4093***
	(2.6388)	(-1.2664)	(-6.7503)	(6.4369)	(-0.4045)	(5.6885)
edu	−0.0438***	0.0444***	0.0800***	−0.0081	0.0066	0.0161*
	(-8.5444)	(9.1308)	(6.6831)	(-0.6609)	(0.9247)	(1.7068)
familysize	−0.0718***	−0.0330***	0.5657***	0.2806***	0.0127	0.2217***
	(-6.3304)	(-3.1117)	(21.8728)	(10.5257)	(0.8177)	(10.8270)
work	−0.3289***	0.2974***	0.8514***	−0.0760	0.0612	−0.2730***
	(-9.7348)	(9.6624)	(11.2516)	(-0.9788)	(1.3482)	(-4.5764)
young	0.0051***	−0.0082***	−0.0186***	−0.0080***	−0.0014	−0.0049**
	(4.0541)	(-6.9563)	(-6.4196)	(-2.6742)	(-0.8303)	(-2.1437)
elder	0.0053***	−0.0050***	−0.0219***	−0.0081***	0.0010	0.0148***
	(6.5029)	(-6.2502)	(-11.2690)	(-4.0574)	(0.8800)	(9.6473)
social	−0.2556***	0.2040***	0.3017***	0.3409***	0.1262**	0.1158*
	(-5.7041)	(5.8050)	(3.4908)	(3.8475)	(2.4358)	(1.6952)
houseasset	−0.0001	0.0003*	0.0010**	−0.0002	0.0013***	0.0002
	(-0.5267)	(1.9475)	(2.3050)	(-0.5066)	(5.0177)	(0.6565)
_cons	0.4044	6.8616***	3.8955***	−4.0077***	−0.1749	−3.0959***
	(0.7301)	(16.9979)	(3.9650)	(-3.9981)	(-0.2970)	(-3.9268)
Control Province	Yes	Yes	Yes	Yes	Yes	Yes
Control individual	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R^2	0.1504	0.1698	0.2858	0.0973	0.0541	0.1978
N	5937	5937	5937	5937	5937	5937

Note: t-values in parentheses; *, **, and *** indicate significant at the 10 %, 5 %, and 1 % levels, respectively, as follows.

beneficial for increasing the household head's income. However, as they enter the middle-aged and elderly stage, with increasing age, the household head's income gradually decreases and they can only rely on monthly pension insurance. Additionally, the health condition of the household head also shows a significant positive relationship with the probability of relative poverty occurrence [29].

Table 5
Intermediation effect test.

	Skills upgrading	Net household income per capita	Business share	Net household income per capita	Non-farm employment	Net household income per capita
	(1)	(2)	(3)	(4)	(5)	(6)
dedi	0.4733***	0.5330***	0.0717***	0.5821***	0.1051***	0.2260*
	(35.3717)	(7.1085)	(3.3362)	(7.6058)	(5.2292)	(1.9379)
dedi × *skills upgrading*		0.3450***				
		(3.6805)				
skills upgrading		0.1433*				
		(1.9437)				
dedi × *business share*				0.5513***		
				(5.5606)		
business share				0.2767***		
				(6.5911)		
dedi × *non-farm employment*						0.3380***
						(3.0698)
non-farm employment						1.7152***
						(42.9284)
Other control variables	Yes	Yes	Yes	Yes	Yes	Yes
_cons	1.5411***	5.9838***	0.8401***	6.3890***	0.4899***	5.7191***
	(22.4149)	(25.7130)	(19.6316)	(27.8568)	(7.6215)	(29.2871)
Pseudo R^2	0.1594	0.1372	0.4160	0.1293	0.2135	0.3432
N	5937	5937	5937	5937	5937	5937

Undoubtedly, health is a support for obtaining economic income and a guarantee for households to avoid falling into poverty. Secondly, for every additional year of education for the household head, the probability of relative poverty occurrence decreases by around 0.0438% points, and household income increases by 0.0444% points. The greater the number of elderly people and children, the higher the probability of relative poverty in the household. Since children and elderly people lack labor capacity, they represent low-income or zero-income individuals in the household, but expenses are inevitable. Therefore, an increase in the number of children and elderly people will inevitably lead to greater poverty in the household. Moreover, compared to agricultural work, non-agricultural work may be more conducive to increasing household income. Non-agricultural work can to some extent avoid losses caused by natural disasters and market fluctuations in agricultural production, thereby reducing the probability of relative poverty occurrence.

4.2. Mechanism Testing

The results of the mechanism test are presented in Table 5. The coefficients of the core explanatory variable, the household digital application index, in columns (1) (3) and (5) are significantly positive, indicating that digital application can significantly promote the growth of rural households' share of production and business activities, improvement of household members' skills, and increase in non-agricultural employment. Furthermore, the coefficients of the interaction terms in columns (2) (4) and (6) are also significantly positive, indicating that digital application does promote rural household income growth through the aforementioned channels. The regression results for the first channel, the improvement of household members' skills, are shown in columns (1) and (2). The results indicate that digital application has a significant promoting effect on the improvement of household members' skills, thereby increasing rural household income levels. One possible reason for this is that after the improvement of digital application level, the technical capabilities of household members are quickly enhanced through the group effect, leading to more efficient and low-cost production and sales models. This, in turn, enhances the value and efficiency of agricultural production, thereby increasing rural household income. This result is consistent with the theoretical analysis in the previous section, where the application of digital technology accelerates the spread of advanced technology, improves production efficiency, promotes increased production and income in households, and thus verifies hypothesis 1. The regression results for the second channel, the increase in the share of production and business activities, are shown in columns (3) and (4). The results show that a 1 % increase in the household digital application level leads to a 0.0717 % increase in their share of production and business activities. Compared to the baseline regression results, the estimated coefficient and t-value of the core explanatory variable, the household digital application index, decrease after introducing the channel variable. This suggests that improving the technical capabilities of household members is indeed a channel through which digital application promotes income growth in rural households. The main reason for this is that the digital industry has strong penetration capabilities and can accelerate the reform of traditional industries such as manufacturing and agriculture. It can also timely eliminate declining industries that hinder economic development, thereby optimizing the production and business structure. Additionally, emerging digital industries such as big data and e-commerce have greatly diversified the forms of production and business activities, which partly confirms hypothesis 2. And the regression results for the third channel, non-agricultural employment, are shown in columns (5) and (6). The results demonstrate that the improvement of digital application level can promote income growth in rural households by expanding non-agricultural employment opportunities. On the one hand, the booming development of emerging industries represented by the Internet of Things and e-commerce has created a large number of new job demands. On the other hand, the combination of emerging industries with traditional industries has also resulted in many job vacancies. Additionally, the younger generation in rural areas tends to engage in non-agricultural industries. Therefore, it can be seen that promoting non-agricultural employment is another important channel through which digital application enhances income growth in rural households, validating hypothesis 3.

4.3. Robustness tests

The paper further conducts robustness tests using three methods. Firstly, considering the possibility of measurement error in the core explanatory variable, the digital application index, an alternative method of calculation is used. Following the approach used by Tian et al. (2021) [32] in measuring the efficiency of agricultural modernization, the entropy method is employed to calculate the family digital application index, replacing the factor analysis method. The results are shown in columns (1) and (2) of Table 6. Secondly, despite controlling for variables that may affect household economic conditions from multiple perspectives, there may still be omitted variables. To address this concern, the study follows the method proposed by Joseph et al. (2005) [33] and evaluates the measurement bias of omitted variables by observing the changes in regression coefficient estimates (σ)[1] after introducing different control variables. In this study, three variables are included: the proportion of government subsidies to total household income (*gov*), whether there is compensation from relatives or private borrowing (*ft*), and the total value of cash and savings of the household (*lnsaving*). The results are reported in columns (3)–(6) of the table.Thirdly, the selection of the poverty threshold is considered. Sun and Xia (2019) [34] suggest that the weight of the median per capita income should range from 30 % to 60 %. Therefore, this study further regresses using the 40 % threshold of the median household income as a measure of poverty, as shown in column (7) of the table.The

[1] According to the approach proposed by Altonji et al. (2005), $\sigma = \left|\frac{\beta^F}{\beta^R - \beta^F}\right|$, where β^F represents the parameter estimate of the core explanatory variable in the original model, and β^R represents the parameter estimate of the core explanatory variable after adding new control variables. The larger the value of σ, the smaller the impact of omitted explanatory variables on the parameter estimate of the core explanatory variable.

Table 6
Robustness tests.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	relative poverty incidence	log income per capita	relative poverty incidence	relative poverty incidence	log income per capita	log income per capita	relative poverty incidence (bounded by 40 % of the median)
dedi(by entropy method)	−0.0472**	0.0382**					
	(-2.1790)	(2.4407)					
dedi			−0.2241***	−0.1944***	0.2577***	0.2246***	−0.3575***
			(-5.1201)	(-4.3586)	(6.4055)	(5.6401)	(-4.1989)
σ			7.55		7.79		
Other control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control individuals and provinces	Yes	Yes	Yes	Yes	Yes	Yes	Yes
_cons	0.6378	6.1763***	0.1094	0.3320	7.2038***	6.9439***	0.2106
	(1.2551)	(13.9881)	(0.1999)	(0.5965)	(17.9676)	(17.4992)	(0.4700)
Pseudo R^2	0.1266	0.1413	0.1468	0.1780	0.1649	0.1858	0.1277
N	5937	5937	5937	5937	5937	5937	5937

regression results in Table 6 are consistent with the baseline regression results in Table 4, demonstrating the robustness of the findings.

4.4. Endogeneity treatment

Due to the digital application's certain threshold, poverty may limit a household's ability to improve its level of digital application, thus affecting the income-generating effect of digital applications. Therefore, the baseline regression model may face endogeneity issues caused by reverse causality between variables. To avoid inconsistent estimates due to endogeneity problems, this study chooses to use instrumental variable (IV) approach to mitigate the endogeneity issues in the model. The choice of instrumental variables should meet the criteria of not being an included explanatory variable in the model, while also satisfying exogeneity and relevance conditions. Following the approach of Sun and Liu (2022) [35], this study selects telecommunication infrastructure (the ratio of fixed telephone lines per hundred people to mobile telephone lines per hundred people in the area where the household is located) as the instrumental variable to test the model. The rationale for this choice is as follows: first, telecommunication infrastructure is a prerequisite and foundation for rural households to enjoy digital benefits, and from this perspective, this instrumental variable satisfies the relevance condition with the endogenous variable in this paper. Second, telecommunication infrastructure does not directly affect the economic conditions of households, but can influence their economic conditions through its impact on the level of digitization, thus both the instrumental variable and the endogenous variable satisfy the exogeneity condition. The two-stage regression results using telecommunication infrastructure as the instrumental variable are presented in Table 7. According to the results of the first-stage regression in columns (1) of Table 7, telecommunication infrastructure has a significant positive impact on the level of household digitization. This conclusion is consistent with the findings of Sun and Liu (2022) [35], indicating that using telecommunication infrastructure as an instrumental variable effectively addresses endogeneity in the model. Columns (2) (3) of Table 7 present the second-stage regression results using telecommunication infrastructure as the instrumental variable. The results of the second-stage regression show that the relationship between digital applications and rural household economic conditions remains significant in the IV-Probit model and also significant in the 2SLS estimation with respect to rural household absolute income. Furthermore, these results pass the tests for endogeneity, indicating the robustness of the estimates. Overall, these findings suggest that the income-generating effect of releasing digital applications is a crucial path to consolidate poverty alleviation achievements and promote comprehensive rural revitalization.

Table 7
Regression results for instrumental variables.

	First Stage Regression	Second Stage Regression	
	(1)	(2)	(3)
	dedi	Relative poverty incidence	Log income per capita
Telecommunications infrastructure	0.0037***		
	(8.1630)		
dedi		−1.3749**	1.7861***
		(-2.4637)	(5.0349)
Other control variables	Yes	Yes	Yes
One-stage F-statistic values	29.99		
P-value		0.0000	0.0000
N	5937	5937	5937

5. Extended analysis

5.1. Further analysis considering the livelihood well-being of rural households

Previous research has indicated that using only per capita income and the relative poverty standard to measure the welfare of a population from the perspective of monetary poverty is not comprehensive enough. Therefore, this study further selects residents' consumption, which is directly related to well-being, as the dependent variable for multidimensional measurement, and uses it to analyze the impact of digital application levels on the living conditions of rural households. Based on the CFPS 2018 database, this study selects cooking fuel, food expenditure, household assets, and household consumption to reflect the living conditions of households. The regression results of the impact of digital application levels on household living conditions are shown in Table 8. The results indicate the following: first, the improvement in digital application levels has led to the upgrading of rural infrastructure, which may significantly affect the use of cooking fuel in rural households. This significantly improves the fuel welfare of agricultural households (by 0.1058% points), transitioning from traditional fuels such as firewood and straw to more advanced options such as electricity and natural gas. At the same time, there is a significant negative correlation between the Engel coefficient of households and digital application levels. This means that as digital application levels further improve, the Engel coefficient gradually decreases (by 0.0024% points), indicating a further improvement in household living standards. Additionally, even after including the variable of per capita income, the welfare effects brought about by digital application remain significant at the 1 % level. This suggests that household income may be the main channel through which digital application improves living facilities. Second, digital application has a significant positive impact on per capita assets and per capita consumption levels of rural households. Furthermore, after introducing the variable of per capita income, the consumption growth effect brought about by digital application remains significant at the 1 % level. However, the regression coefficient for per capita consumption of rural households has decreased compared to before, indicating that the improvement in digital application levels has to some extent transformed part of the income into consumption.

5.2. Further analysis considering the regional differences

Despite the gradual reduction in development disparities between China's eastern and central-western regions, there still exists a significant gap in agricultural and rural development [36]. Particularly, the digital industry as a new development area may exhibit regional differences. Therefore, this study divides households into eastern and central-western regions to examine the impact of digital application levels, and the results of the grouped regression are shown in Table 9. Overall, the digital application level has a significant positive effect on per capita income of rural households in both the eastern and central-western regions. However, the income growth effect of digital application is slightly stronger in the eastern region. Furthermore, the differential income effect of digital application on rural households in the eastern and central-western regions is reflected in different channels and mechanisms.From the regression results in Table 9, the income effects of digital application on rural households in the eastern region can be achieved through promoting skill improvement of household members, while this channel is not significant in the central-western region. Currently, digital applications have more extensive usage scenarios in eastern cities, and the level of urban-rural integration in the eastern region is significantly higher than that in the central-western region. Benefiting from economies of scale in cities, rural households in the eastern region have more opportunities to access digital applications and higher convenience in obtaining information technology. Farmers can access timely production information, update their knowledge, improve their agricultural technical capabilities, thereby improving their production efficiency and increasing household income.In contrast, in the central-western region, the income effects of digital application are achieved by increasing the share of household production and operation. According to the China Industrial Information Network's report on the in-depth research and investment prospects of rural land circulation industry in China from 2015 to 2020, the cultivated area in eastern China is 26.297 million hectares, accounting for 19.4 % of the national total, while the central-western region accounts for 80.6 %. Combined with the theoretical mechanism analysis above, the increase in the share of rural household production and operation through digital application mainly revolves around the extension of the industrial chain based on traditional agricultural production and the transformation of the role of farmers in production. In this sense, the income effects of digital application on rural households in the central-western region can be significantly achieved by increasing the share of production and operation, while in the eastern region, it shows as a non-significant positive impact.Furthermore, whether in the eastern or

Table 8
Impact of digital application level on living conditions of rural households.

	fuel for cooking (0 for firewood, 1 for other)	engel coefficient (food expenditure/ total expenditure)	log assets per capita	log consumption per capita	log consumption per capita
	(1)	(2)	(3)	(4)	(5)
dedi	0.1058***	−0.0024***	0.4146***	0.2930***	0.2023***
	(6.3270)	(-4.0551)	(10.4340)	(10.2474)	(7.3085)
_cons	0.6610***	0.0409***	9.8132***	8.3592***	5.6524***
	(4.9053)	(8.4872)	(31.3779)	(36.3472)	(22.4692)
Control Province	Yes	Yes	Yes	Yes	Yes
Pseudo R^2	0.1689	0.0960	0.3434	0.2928	0.3517
N	5937	5937	5937	5937	5937

Table 9
Regression results by region.

	Eastern Region				Central and Western Region			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	log income per capita	log income per capita	log income per capita	log income per capita	log income per capita	log income per capita	log income per capita	log income per capita
dedi	0.3992***	0.3006***	0.3456***	0.1504*	0.2939***	0.2232***	0.2363***	0.2155**
	(5.7022)	(3.8973)	(4.6161)	(1.8658)	(6.1620)	(4.4522)	(4.6594)	(2.4666)
dedi × *business share*		0.3110***				0.5662***		
		(2.7873)				(4.5122)		
dedi × *skills upgrading*			0.3492**				0.1869	
			(2.3520)				(1.5607)	
dedi × *non-farm employment*				0.2984***				0.2426**
				(2.9869)				(2.1366)
_cons	7.8500***	7.4275***	7.5765***	6.2739***	7.1278***	6.2235***	6.8057***	6.0870***
	(16.6966)	(14.9706)	(15.6481)	(17.6912)	(17.1133)	(14.2664)	(15.9814)	(16.5584)
Pseudo R^2	0.1751	0.1784	0.1778	0.3646	0.1360	0.1460	0.1386	0.3474
N	2223	2223	2223	2223	3701	3701	3701	3701

central-western region, digital applications can also achieve income growth through promoting non-agricultural employment in households.

6. Conclusion and policy implications

The digital economy has brought new models and approaches to rural development and increased incomes for farmers. It is seen as an important support for agricultural and rural transformation and a key driver for consolidating poverty alleviation achievements and promoting comprehensive rural revitalization. This study constructs a digital application index for rural households based on micro-level survey data, focusing on four dimensions: digital coverage, digital usage intensity, digital importance, and digital penetration. It investigates the economic returns and mechanisms of digital application levels in rural households. After using telecommunication infrastructure as an instrumental variable to address endogeneity issues, the research confirms that rural households can indeed obtain corresponding economic returns from digital applications. Specifically, digital applications significantly promote the growth of operating income, wage income, property income, and transfer income in rural households, leading to a significant increase in per capita income and per capita consumption while significantly reducing the probability of relative poverty occurrence. In other words, controlling for household and household head characteristics and mitigating endogeneity issues, higher levels of digital application are associated with a lower probability of rural households falling into relative poverty. Taking into account regional heterogeneity and extended analyses of mediating mechanisms, the study further finds that digital applications can further support rural development and increased incomes through channels such as increasing the share of agricultural and sideline business operations, improving the technical skills of household members, and promoting non-agricultural employment. Moreover, the results of regional differences show heterogeneous effects of digital application on the probability of relative poverty occurrence and per capita income in eastern and central-western regions. It is worth mentioning that, in addition to promoting income growth through non-agricultural employment channels, the income effect for rural households in eastern regions can be achieved by promoting the improvement of household members' skills, while the income effect for rural households in central-western regions can be achieved by increasing the share of production and business operations.

As a new economic form leading the future, digital economy is not only a "springboard" for the transformation and upgrading of traditional economy but also a "blue ocean" for future high-quality economic development. Recently, with the development of "webcasting" and "rural e-commerce," digitalization has brought new opportunities for the development of rural economy. However, the effect of the digital application level on the income enrichment of rural households in different regions and with different incomes showed heterogeneity, especially in the central and western regions and among low-income rural households. It is important to prevent the blindness characteristics that may appear in the construction of digital villages. In this context, the study provides rich policy implications: first, considering the differences in regional digitalization levels, the state should actively promote the construction of digital infrastructure in rural areas to eliminate the hindering effect of the "digital divide" as much as possible. Concurrently, it should actively conduct training activities for rural households on special internet usage skills, improve the digital literacy of low-income groups, ensure that every household enjoys digital dividends, and expand the audience of digital benefits. The state should ensure that villages are connected to broadband and that everyone can use smartphones. Second, to avoid the blind development of digital economy, the government needs to reasonably guide the planning of digital industries in each region, to develop digital economy according to local economic development level and pillar industries and other factors, to gradually promote the digital transformation and upgrading of traditional industries, and to realize the integration and development of the digital and rural economy. The overall welfare level of society can only be improved when the traditional and digital economies compete freely. Third, to make the foundation of poverty eradication more solid and the results more sustainable, local governments should increase the popularization of the digital information technology. They should prompt farmers to change their traditional and obsolete concepts and help farmers to understand that vegetables planted in the ground and poultry raised in pens can be sold nationwide through the

internet as a platform. Further, this will digitally empower the improvement of production efficiency in rural areas, thus creating favorable conditions for the effective integration of poverty eradication and rural revitalization and effective linkage between poverty alleviation and rural revitalization.

The limitations of this study are as follows: Due to the difficulty of obtaining detailed codes for the counties or cities where the households in the CFPS database are located, it was not possible to match the households with their corresponding counties or cities. Therefore, only household heads and relevant variables within the households were controlled for. In fact, the CFPS database officials have mentioned that it is possible to further apply for the use of county-level databases. County-level databases provide data such as county sequence codes, GDP, per capita GDP, population, employment rate, average years of education, proportion of working-age population, proportion of elderly population, gender ratio of underage population, and non-agricultural household population ratio, which were obtained through the fuzzification of the 2010 Statistical Yearbook. Therefore, in the future, it is possible to apply for the use of additional databases and establish a more rigorous empirical analysis by linking the county sequence codes with the publicly available CFPS data.

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Ethical statements

This work does not contain any studies with human participants performed by any of the authors.

Data availability statement

The original data for this study was obtained from the Peking University Chinese Family Tracking Survey (CFPS) database, downloaded from http://www.isss.pku.edu.cn/cfps/.

CRediT authorship contribution statement

Jiaqi Han: Methodology, Resources, Software, Visualization, Conceptualization, Writing - original draft, Writing - review & editing. **Jiayin Wang:** Writing – review & editing, Writing – original draft, Visualization, Data curation, Conceptualization. **Wenwu Zhang:** Conceptualization, Formal analysis, Funding acquisition, Software, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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