



Digital inclusive finance and the development of rural logistics in China

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ABSTRACT

The precarious production environment in rural areas limits the services of traditional finance and rural logistics. Digital inclusive finance is expected to alleviate some major drawbacks enabling financial services to contribute to rural logistics development. Using panel data from 31 provinces in China from 2013 to 2020, this paper constructed an indicator system to measure the development level of rural logistics. Furthermore, this paper investigates the mechanism enabling digital inclusive finance influences to enhance rural logistics development. We found that financial inclusion and digital finance have a positive and significant impact on the development level of rural logistics. Moreover, we found a nonlinear relationship with a diminishing marginal effect between digital inclusive finance and the development level of rural logistics. Furthermore, it was highlighted that the promotion efficiency of digital inclusive finance on the development level of rural logistics varies according to the region and economic development. This paper provides a theoretical basis for digital inclusive finance to promote rural logistics development. It also contributes to enhancing the role of financial services enabling good development of rural logistics.

1. Introduction

Digital inclusive finance is a step forward to solve financial issues in rural areas [1,2]. During the past decades, digital inclusive finance services have achieved great advancement in China, as of 2020, the digital inclusive finance index increased tenfold (334.8) compared to that of 2013 (33.6). The same pattern was observed at the provincial level with an average annual growth of 29.1% [3]. This continuous improvement is the result of initiatives from the Chinese authorities to enhance digital inclusive finance in rural areas at the cities and counties level.¹ The initiative aims to ensure good transmission of information between cities, counties, and regions;

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¹ The “No. 1 document” of the Central Committee in 2021 and the “Opinions of the CPC Central Committee and the State Council on Comprehensively Promoting Rural Revitalization and Accelerating Agricultural and Rural Modernization” was adopted for this effect; http://www.gov.cn/zhengce/2021-02/21/content_5588098.htm.

facilitate farmers' credit loans, and promote rural revitalization that is expected to speed up the development of rural logistics express distribution network ("Express to the village" project).² Ultimately, the massive investment in rural logistics is expected to facilitate trade within rural areas and the urban-rural trade [4]. For instance, in China, all organized villages have access to direct post services with a coverage rate of about 80.00%.³ In 2021, a total of 37 billion parcels estimated at around 1.85 trillion yuan (around 260 billion USD) were received and sent to rural areas accounting for 34.00% of the total annual express delivery volume. However, the development of rural logistics is a complex system involving a long-term project and requiring strong financial support and services, etc. [5,6]. Therefore, we expect that digital inclusive finance enhances the financial services in rural areas by facilitating credit access, providing adequate services, and focusing on services that support the links between rural economic and social development, hence, rural logistics.

Digital inclusive finance, when providing affordable, safe, and convenient financial services has great potential to support the development of rural logistics [7]. For instance, digital inclusive finance contributes to the upgrade of rural logistics by supporting and providing guarantees to industry capital flow and enhancing continuous innovation [8]. With the rapid transition of society toward a digital one, traditional finance is now shifting gradually toward digital finance even in the rural area. However, digital inclusive finance in rural areas faces serious challenges such as lack of infrastructure, digital divide, financial literacy, connectivity, etc [9]. Furthermore, digital inclusive finance in rural China is still in the initial stage and adequate strategies to use digital finance to develop rural logistics are still lacking [10]. Therefore, investigating the pathway enabling digital inclusive finance to ensure the "last mile" and promote the development of rural logistics is of utmost importance.

Most of the studies on digital inclusive finance and rural areas focus on determining the impact of digital inclusive finance on agricultural transformation in rural areas [11–13]. Limited literature investigates the relationship between digital inclusive finance and the development of rural logistics. Existing studies investigated more on the factors that transformed the traditional financial system into a digital one. For instance, the literature agreed that digital inclusive finance is the result of unprecedented growth in technology use and innovation in the financial sector [14–18]. Regarding the field of rural logistics, the literature focuses on e-commerce logistics service satisfaction, logistics optimization, and performance [19–21]. Few and far between were interested in the importance of digital inclusive finance when elaborating strategies to develop rural logistics. Among these, Balasubramanian et al. [22] studies brought evidence of the multidimensional impact of digital inclusive finance on the development of the logistics industries through payment methods, credit structures, and settlement methods. However, empirical research provides low interest in computing a quantitative measurement of the development level of rural logistics. Thus, the literature overlooked the importance of agricultural mechanization and rural logistics in enhancing the development strategies of a country. This research intends to fill these gaps by providing a theoretical analysis of the influence and action mechanism of digital inclusive finance on the development level of rural logistics. To achieve this goal, we used panel data from 31 provinces in China from 2013 to 2020 to elaborate a comprehensive evaluation index system and measure for rural logistics development level. Furthermore, we assessed the different effects of digital inclusive finance on the development level of rural logistics according to their province geographic localization.

The remainder of this paper is organized as follows. In Section 2, we present a general overview of the financial services and rural logistics in China. In Section 3 we presented the threshold model used to achieve the objective of this study. We report the results in Section 4. In Section 5, we propose some recommendations and conclude the research.

2. Background

2.1. Rural logistics in China

In 2022, the 20th National Congress of the Communist Party of China (CPC) put considerable effort to improve the access to rural areas. The "last mile" of rural consumption and the "first mile" of agricultural products entering cities are being sped up which had strengthened the urban-rural economics exchange.⁴ Besides this urban-rural exchange, rural logistics ensure the supply of agricultural input and output in rural areas and support the expansion of new activities (besides agriculture) in rural areas [23]. Therefore, developing rural logistics is believed to be one major component to alleviate poverty and support rural revitalization. However, the gap between rural-urban logistics in China still prevails [19,24]. To enhance rural logistics, investment and a strong understanding of the rural logistics system are required. Rural logistics encompass relevant services provided for agricultural activities and rural residents' daily life such as materials and products packaging, loading, and unloading, transportation, warehousing, etc [25]. With the continuous modernization in rural areas, traditional logistics systems can no longer meet the growing demand for high-quality logistics systems in rural areas. Consequently, upgrading the logistic systems toward a more efficient one is required to manage and optimize the use of rural logistics infrastructure, facilitate, speed up and increase the volume of freight in rural areas, and optimize the use of agricultural resources [26]. Furthermore, such a system will improve the horizontal coverage of rural logistics at the most

² The "No. 1 document" of the Central Committee in 2022 and the "Opinions of the Central Committee of the Communist Party of China and the State Council on the key work of comprehensively promoting rural revitalization" was adopted for this effect; http://www.gov.cn/xinwen/2022-02/22/content_5675041.htm.

³ State Post Office of the People's Republic of China in 2022, <https://www.spb.gov.cn/gjyzj/index.shtml>.

⁴ The 20th National Congress of the Communist Party of China (CPC) in 2022 and the "Hold high the great banner of socialism with Chinese characteristics and work together to build a socialist modern country in an all-round way" put considerable efforts to make enhance the accessibility of rural areas: http://www.gov.cn/xinwen/2022-10/25/content_5721685.htm.

decentralized level and enhance the scale effect of rural logistics transportation [27]. To build an efficient logistics system, traditional rural logistics can lean on the rapid growth and increasing penetration rate of the Internet, big data, Internet of Things, etc. In rural areas [28]. However, as digital rural logistics are more complex than traditional rural logistics, higher-skilled labor is required to scale up rural logistics services [29].

2.2. Digital inclusive finance and rural logistic

The financial system in Chinese rural areas is still underdeveloped making the construction of rural logistics challenging due to a shortage of capital [25]. Scholars suggested that the current rural financial system in China can no longer meet the needs of rural logistics construction, and the insufficient supply of logistics finance has seriously hindered the construction of modern rural logistics in China. However, it is believed that digital inclusive finance contributes to opening up rural areas [30–32]. The integration of new technology and the use of internet in the traditional finance services sensitized the researcher to dig deeper into the field of digital inclusive finance [33]. In China, the digitalization of traditional finance is now undergoing a massive investment that continuously improves the financial environment. For instance, digital inclusive finance in China is using disruptive technologies such as big data, cloud computing, artificial intelligence, and blockchain [34]. Tay et al. [35] defines digital inclusion as the digital access and utilization of various financial services by all populations, especially those excluded or underserved by the formal financial sector. From this definition, digital inclusive financial services are expected to address the needs of users, efficient, affordable, easy to use, and, and achieve sustainability for providers [36]. Indeed, the digital financial services platform has broken regional barriers, blurred geographical restrictions, intensified inter-regional competition, and coordinated the development of the logistics industry [37]. Digital inclusive finance overcomes the challenges of physical connectivity and information asymmetry providing financial services at a lower cost and higher effectiveness in the rural area [38]. Moreover, digital finance provides capital to support the development of rural logistics and economic development in rural areas [39]. Furthermore, digital inclusive finance has a spatial spillover effect on the development of rural logistics [40]. Scholars found that the impact of the digital economy on logistics is highest in the central region of China, while it weakens in the western and northeastern [39,41]. Finally, research analyzing the mechanism of digital finance in enhancing logistics found that technological innovation and factor allocation efficiency are possible pathways allowing digital finance to improve the logistics industry. Huang and Wang [42] found that an increasing number of farmers and agricultural operators in rural areas are using e-commerce platforms and live streaming as a new channel of marketing. This is expected to promote the development of rural logistics. Furthermore, Chen and Li [43] found that the development of rural finance has promoted the development of agricultural products logistics.

2.3. Conceptual framework and research hypothesis

2.3.1. Digital inclusive finance promotes the development level of rural logistics

The precarity of the production environment in rural areas presents a big challenge for traditional financial institutions [44]. Indeed, traditional financial institutions fail to support rural producers due to the low development of rural logistics, risk aversion, etc. However, digital inclusive finance can reduce the risk of financial uncertainty and help rural logistics to achieve balanced development with a lower cost and wider coverage contributing to sustainable development [45]. It was found that the capital flow of the rural logistics system cannot be separated from the strong support of the financial industry and the logistics industry [46]. Furthermore, digital inclusive finance can take advantage of big data to reduce uncertainty, provide more insurance support, and promote the prosperity of rural industries [41]. Finally, digital inclusive finance can support the development of modern rural logistics. Digital inclusive finance enables low-cost and large-scale credit funds to penetrate rural areas and provide convenient financial support for modern rural industrial operators [47]. Meanwhile, relying on big data and Internet technology, digital inclusive finance can broaden the service breadth and depth of traditional finance, change the supply mode of traditional finance, and improve the service efficiency of traditional finance [1]. Investigating the relationship between digital inclusive finance and rural logistics development is therefore encouraged [48]. Therefore, this paper wants to verify if digital inclusive finance promotes the development of rural logistics.

2.3.2. Nonlinear characteristics of digital inclusive finance on the development of rural logistics

As a combination of digital technology and inclusive finance, the impact of digital inclusive finance on the development of rural logistics is expected to have nonlinear characteristics. First, the literature showed that massive investment in the financial sector can harm the real sector economy [49]. For instance, once the financial service provided exceeds the demand for capital, the relationship between finance and growth is not efficient anymore. Furthermore, the rapid growth of digitally inclusive finances and digital financial services is adversely affected by a relatively high share of unskilled labor which slow down the increasing effect of digital inclusive finance on the development on the development of rural logistics. As proposed by Lee et al. [50] studies, such adverse effects can slow down the increasing effect of digital inclusive finance on growth. Moreover, the growth rate of the digital inclusive finance index has slowed down in recent years [3]. With the in-depth promotion of digital inclusive finance in rural areas, the marginal cost of capital for rural logistics operators decreases, thus increasing the operating income [5]. At the same time, the reduction of the financing threshold benefits rural logistics [51]. According to the law of diminishing marginal effects, production factors such as data used in digital inclusive finance have economies of scale characteristics. When the development level of digital inclusive finance exceeds a certain threshold, the marginal cost of financial products and services approaches infinity. That is, the promotion effect on the development level of rural logistics shows a marginal decreasing trend. Digital inclusive finance impact on rural logistics development may also have a certain dynamic nonlinear characteristic defined by the reduction of rural logistics operating costs, the efficient agricultural

input-output system, and the increase of the nonlinear characteristic of the rural logistics node number, etc [21]. Therefore, this paper proposes the following hypothesis. The impact of digital inclusive finance on the development of rural logistics has dynamic nonlinear characteristics, which will become more and more obvious with the improvement of the development level of digital inclusive finance.

3. Materials and methods

3.1. Model construction

Equation (1) was used to analyze the impact of digital inclusive finance on the development level of rural logistics.

$$\text{Log}_{i,t} = \alpha_0 + \alpha_1 \text{Dif}_{i,t} + \alpha_c X_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (1)$$

Where: $\text{Log}_{i,t}$ is the rural logistics development level index of province i at year t ; $\text{Dif}_{i,t}$ is the digital inclusive finance index of province i at year t ; $X_{i,t}$ is a series of control variables that may affect the development level of rural logistics of province i at year t ; μ_i indicates the fixed effect of provinces i ; δ_t represents the time fix effect at year t , $\varepsilon_{i,t}$ represents random disturbance term, α_1 is the expected impact of digital inclusive finance on the development level of rural logistics.

Equation (2) expresses the nonlinear characteristics of the impact of digital inclusive finance on the development of rural logistics using the threshold model of Hansen [52]. Threshold regression methods are developed for non-dynamic panels with individual-specific fixed effects.

$$\text{Log}_{i,t} = \varphi_0 + \varphi_1 \text{Dif}_{i,t} \times I(\text{Adj}_{i,t} \leq \theta) + \varphi_2 \text{Dif}_{i,t} \times I(\text{Adj}_{i,t} > \theta) + \varphi_c X_{i,t} + \mu_i + \varepsilon_{i,t} \quad (2)$$

$\text{Adj}_{i,t}$ is the threshold variable, $I()$ is the indicator function equal to 1 if the condition in the bracket is respected, and 0 otherwise. φ are parameters to be estimated. θ is the threshold value.

The threshold model is used to identify the non-linear impact of digital of rural logistics. First, the two basic assumptions of the threshold regression model are tested. A bootstrap self-sampling method (300 times) was used to test for the existence of a panel threshold and a likelihood ratio approach (LR) was used to test for the authenticity of the threshold.

3.2. Heterogeneity and robustness test

The regional gap in the Chinese economic development model implies a regional heterogeneity in the development level of digital inclusive finance and rural logistics [53]. Based on the benchmark regression, this paper analyzed the specific impact of digital inclusive finance on the rural logistics development level. The 31 provinces were regrouped according to two methods: clustered into five groups according to their economic development and regrouped according to their geographical localization (eastern, western, and central). To test for the robustness of the results, an endogeneity test was performed using instrumental variables and the lagged method. This paper refers to Zhang et al. [54] to solve possible endogenous problems. We took the spherical distance between provincial capital cities and Hangzhou (the capital of digital finance) because Hangzhou's digital financial development will produce spatial spillover effects [53]. It is expected that the closer the city is to Hangzhou, the greater the spillover effects will be. We further tested the robustness of the results following two approaches. First, we replaced the explained variable. The principal component method was used to re-calculate the development level index of rural logistics and perform regression. Second, we took out from the sample municipalities that are directly under the central government control or with a special status and policies of management. Thus Beijing, Shanghai, Tianjin, and Chongqing were excluded.

3.3. Empirical implementation

3.3.1. Data sources

Inclusive finance was proposed as a National strategy in China in 2013⁵ to enhance financial services. Therefore, we retrieved indicators related to the digital financial variable from Peking University as measured by Guo et al. [3]. The remaining data are from China Statistical Yearbook and China Rural Statistical Yearbook from 2013 to 2020. It is worth noting that for consistency purposes, we used the province or city identifier from Ref. [3] as a unique identifier and get panel data 31 provinces, autonomous regions, and municipalities from 2013 to 2020. The missing values were supplemented by the interpolation method, thus forming the balanced panel data of 31 provinces, autonomous regions, and municipalities in China.

3.3.2. Measurement of the development level of rural logistics

To proxy the development level of rural logistics, this paper used rural logistics infrastructure, information level, the level of demand, and the number of rural labor (Table 1) [55–57].

⁵ The Third Plenary Session of the 18th CPC Central Committee adopted the "Decision of the CPC Central Committee on Several Major Issues Concerning Comprehensively Deepening Reform", http://www.gov.cn/jrzq/2013-11/19/content_2530509.htm.

Table 1
Index system of rural logistics development level.

| Level indicators | The secondary indicators | Unit | Weight |
|--|---|------------------------------|--------|
| Rural logistics infrastructure level | Rural delivery route | Km | 0.103 |
| | Post office branch | Unit of office | 0.107 |
| | Investment in fixed assets of rural residents' transportation, storage, and postal services | Hundred million Yuan | 0.117 |
| Informatization level of rural logistics | Rural broadband access users | Thousands of families | 0.115 |
| | Telephone penetration | Department/one hundred | 0.100 |
| Rural logistics demand level | Delivery quantity | Thousands of parcels | 0.141 |
| | freight | Ten thousand tons of parcels | 0.104 |
| Rural labor level | Number of rural workers | Unit of labor | 0.109 |
| | Postal Service employment | Unit of labor | 0.106 |

Note that to avoid the problems of subjective weighting and overlapping of multi-index data, this paper used the entropy weight method to weigh the rural logistics development level index.

3.3.3. Digital inclusive finance index

To capture the digital financial variables, this paper used the digital inclusion index, coverage breadth, use depth, and digitalization degree from the Peking University database [3]. The database uses a non-dimensional method and analytic hierarchy process to calculate the score of the digital inclusive finance index and the scores of each dimension of each province according to the digital inclusive finance index system. Finally, all indices were divided by 100 for a better presentation of the regression coefficient.

3.3.4. Control variables

The selection of control variables was based on the processing methods of Lee et al. [50]. Seven control variables are selected in this paper (Table 2).

4. Results and discussions

4.1. Descriptive statistics

Table 3 displays the descriptive statistics of the variables used in this study. The average value of the digital inclusive financial development index is 5.493, the maximum value is 6.017, and the minimum value is 4.798. There is a large gap between the maximum value and the minimum value, indicating that there is a large regional difference in China's digital inclusive financial development level. From the control variables Agriculture, Enterprise, and Consumption index, the SD value is large, indicating a gap in China's regional economic development. The normality test performed on the variable shows that they were not normally distributed (p-value from Table 3 are less than 0.05). Therefore, the characteristic of the data suggests the presence of extreme values and gaps between the region in China.

4.2. Benchmark regression analysis

Digital inclusive finance has a positive and significant ($\alpha = 0.693$; $p = 0.007$) effect in promoting the development of rural logistics (Model (1) - Table 4). For instance, digital inclusive finance increases the availability and access to capital in rural areas, which in turn supports the development of rural logistics. More specifically, digital inclusive finance supports the construction of a digital platform that promotes the development of rural industries. Results from previous literature supported this evidence as they highlighted the importance of access to capital to promote the development of rural industries [58] and rural logistics [59]. Furthermore, the Chinese digital inclusive financial loan service platform (Huabei platform, cash loan, etc) has improved individual digital skills and lowered the rural financing threshold. The platform supports farmers to access financial services which in turn is expected to increase rural logistics development.

Among control variables, only the digital inclusive finance breadth score has a positive and significant effect ($\alpha = 0.491$; $p = 0.002$) on the development of rural logistics (Models (2) to (4)-Table 4). This shows that the coverage breadth of digital inclusive finance is the main factor to promote the development of rural logistics. For instance, the coverage breadth of digital inclusive finance has a positive effect on accumulating rural human capital. Thereby, accumulating human capital in rural areas facilitates the development process of rural [60]. Finally, the economic development level, social security level, enterprise development level, government support level, and social consumption level have a significant impact on the development of rural logistics. Among them, the level of government support has the highest magnitude ($\alpha = 0.269$; $p = 0.000$), while the economic level has a negative effect ($\alpha = -0.157$; $p = 0.000$) in promoting the development of rural logistics (Models (1) -Table 4).

4.3. Threshold effect analysis

There is an obvious single threshold feature in the impact of digital inclusive finance on rural physical development (Table 5).

Table 2
Variable used in the study.

| | Variables | Variable definition | Data sources |
|---------------------|---|---|--|
| Dependent variables | Log | Logarithmic expression of the Variables from Section 3.2.2, such as rural logistics infrastructure level, informatization level of rural logistics, rural logistics demand level, rural labor level | 《China Statistical Yearbook》《China Rural Statistical Yearbook》 |
| | Independent variables | Dif | Digital inclusive finance Index score |
| Range | | Digital inclusive finance breadth score | |
| Depth | | Digital inclusive finance depth score | |
| Control variables | Dig | The score of digitization degree of digital inclusive finance | 《China Rural Statistical Yearbook》 Report on China's Regional Innovation Capacity 《China Rural Statistical Yearbook》 《China Rural Statistical Yearbook》 《China Statistical Yearbook》 《China Rural Statistical Yearbook》 《China Rural Statistical Yearbook》 |
| | Agriculture | Total power of agricultural machinery (kW) | |
| | Innovation | The innovation ability | |
| | Economic | Per capita Disposable Income of rural residents (Yuan/person) | |
| | Nursing | Social endowment insurance fund for urban and rural residents/Per capita income (Yuan/person) | |
| | Enterprise | Total profits of industrial enterprises above designated size (100 million yuan) | |
| | Government | Transportation expenditure of local finance (100 million yuan) | |
| Consumption | Rural per capita Total retail sales of consumer goods (Yuan/person) | | |

Table 3
Descriptive statistics.

| Variables | Mean | SD | min | max | Normality test | | |
|-------------|-------|-------|-------|-------|----------------|----------|-------|
| | | | | | skewness | kurtosis | joint |
| Log | 0.226 | 0.135 | 0.041 | 0.674 | 0.000 | 0.051 | 0.000 |
| Dif | 5.493 | 0.286 | 4.798 | 6.017 | 0.009 | 0.003 | 0.001 |
| Range | 5.390 | 0.344 | 4.495 | 5.952 | 0.000 | 0.354 | 0.001 |
| Depth | 5.439 | 0.341 | 4.689 | 6.087 | 0.052 | 0.000 | 0.000 |
| Dig | 5.811 | 0.198 | 5.404 | 6.109 | 0.000 | 0.000 | 0.000 |
| Agriculture | 12.20 | 1.877 | 7.652 | 16.25 | 0.018 | 0.137 | 0.026 |
| Innovation | 4.501 | 0.927 | 1.099 | 5.476 | 0.000 | 0.000 | 0.000 |
| Economic | 9.456 | 0.351 | 8.745 | 10.37 | 0.006 | 0.947 | 0.029 |
| Nursing | 4.272 | 0.954 | 1.872 | 6.081 | 0.003 | 0.775 | 0.017 |
| Enterprise | 7.053 | 1.425 | 1.993 | 9.179 | 0.000 | 0.000 | 0.000 |
| Government | 5.649 | 0.509 | 4.291 | 6.783 | 0.000 | 0.051 | 0.000 |
| Consumption | 6.753 | 1.160 | 4.119 | 8.732 | 0.009 | 0.003 | 0.005 |

Table 4
Benchmark regression results of the impact of digital inclusive finance on the development level of rural logistics.

| VARIABLES | Model (1) | Model (2) | Model (3) | Model (4) |
|-------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Dif | 0.693*** (0.256) | | | |
| Range | | 0.491*** (0.160) | | |
| Depth | | | 0.114 (0.146) | |
| Dig | | | | -0.088 (0.202) |
| Agriculture | 0.003 (0.006) | 0.005 (0.006) | -0.000 (0.006) | -0.000 (0.006) |
| Innovation | -0.008 (0.021) | -0.002 (0.020) | 0.010 (0.021) | 0.017 (0.020) |
| Economic | -0.157* (0.087) | -0.108 (0.068) | -0.017 (0.085) | 0.037 (0.051) |
| Nursing | 0.167*** (0.034) | 0.172*** (0.034) | 0.158*** (0.034) | 0.160*** (0.034) |
| Enterprise | 0.042** (0.017) | 0.034* (0.018) | 0.041** (0.019) | 0.037** (0.019) |
| Government | 0.269*** (0.030) | 0.277*** (0.029) | 0.284*** (0.031) | 0.291*** (0.030) |
| Consumption | 0.273*** (0.024) | 0.276*** (0.024) | 0.271*** (0.024) | 0.272*** (0.024) |
| _cons | -8.375*** (0.830) | -7.755*** (0.614) | -6.582*** (0.478) | -6.015*** (1.227) |
| N | 248 | 248 | 248 | 248 |
| R-sq | 0.939 | 0.939 | 0.937 | 0.937 |
| adj. R-sq | 0.939 | 0.939 | 0.937 | 0.937 |

Bold value are significant variables; Value in parentheses are t statistics; *p < 0.1, **p < 0.05, ***p < 0.01.

Fig. 1 shows the likelihood ratio function used to estimate the threshold value of digital inclusive finance. The threshold value is defined by the intersection between the estimator of LR (solid line) and the interval of the threshold (dot line). According to Fig. 1, there is a single threshold for digital inclusive finance and the value of the threshold is consistent with the one displayed in Table 5 (5.158).

The red dot line is the interval of the threshold, and the solid line represents the estimator of the LR.

The coefficient of the digital inclusive finance index under the single threshold model (Table 6) is positive and significant in each

Table 5
Threshold effect test of digital inclusive finance.

| | Digital inclusive finance | |
|-----------------------|---------------------------|-------|
| Variable model | F | P |
| A single threshold | 13.906 | 0.087 |
| Double threshold | 6.172 | 0.447 |
| Triple threshold | 3.873 | 0.778 |
| The threshold number | A single threshold | |
| The threshold value q | 5.158 | |

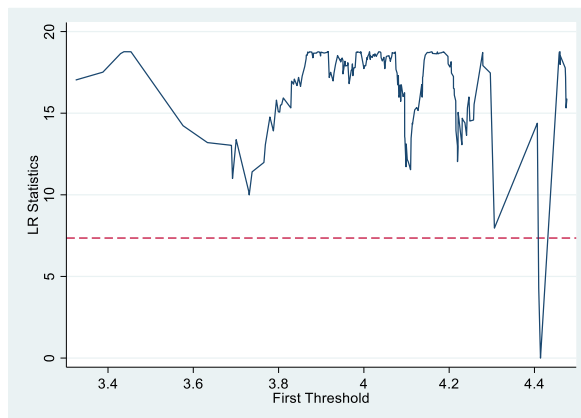


Fig. 1. LR graph of digital inclusive finance threshold.

Table 6
Regression results of the threshold model of digital inclusive finance affecting rural logistics development level.

| Variable | Adjust the variable Dif |
|-----------------------|-------------------------|
| The threshold value q | 5.158 |
| Dif × I (Adj ≤ q) | 0.946***(0.129) |
| Dif × I (Adj ≥ q) | 0.929***(0.127) |
| C | -16.734***(0.765) |
| Control variables | Yes |
| N | 248 |
| adj. R-sq | 0.835 |
| F | 56.020 |

Table 7
Regression results of heterogeneity discussion.

| | Cluster-1 | Cluster-2 | Cluster-3 | Cluster-4 | Cluster-5 | Not yet determined |
|-------------|--------------------|--------------------|-------------------|-------------------|-------------------|--------------------|
| Index | -0.034 (0.137) | 0.116*** (0.202) | 0.008 (0.137) | 0.548*** (0.332) | 0.142*** (0.341) | -0.049*** (0.322) |
| Agriculture | 0.007 (0.883) | 0.004 (0.088) | 0.005 (0.156) | -0.006 (0.038) | -0.022 (0.143) | 0.005 (0.199) |
| Innovation | 0.004 (0.066) | 0.003 (0.068) | 0.004 (0.096) | 0.002 (0.029) | 0.026* (0.179) | 0.003 (0.069) |
| Economic | 0.152*** (0.133) | 0.130*** (0.785) | 0.115*** (0.593) | 0.518*** (0.556) | 0.557*** (0.697) | 0.149*** (0.475) |
| Nursing | -0.004 (0.65) | 0.006 (0.176) | 0.004 (0.414) | -0.000 (0.003) | 0.025 (0.091) | -0.001 (0.103) |
| Enterprise | 0.004 (0.031) | 0.005 (0.090) | 0.004 (0.179) | -0.007 (0.011) | 0.002 (0.113) | 0.005 (0.085) |
| Government | -0.024*** (-0.235) | -0.017** (0.025) | -0.027 (0.093) | -0.007 (0.051) | -0.020 (0.169) | -0.021** (0.325) |
| Consumptio | -0.019** (0.134) | -0.010 (0.141) | -0.019*** (0.042) | -0.030** (0.023) | -0.51* (0.190) | -0.014** (0.033) |
| _cons | -1.060*** (-0.182) | -6.522*** (-0.762) | -1.055*** (0.603) | -3.928*** (0.317) | -6.459*** (0.786) | -1.036*** (0.816) |
| R-sq | 0.990 | 0.996 | 0.997 | 0.997 | 0.998 | 0.979 |
| adj. R-sq | 0.987 | 0.996 | 0.999 | 0.987 | 0.997 | 0.959 |

Note: Cluster are elaborated based on the economic level. Cluster-1: Beijing, Shanghai; Cluster-2: Tianjin, Jiangsu, Zhejiang, Guangdong; Cluster-3: Liaoning, Fujian, Shandong; Cluster-4: Hebei, Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, Hainan; Cluster-5: Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Not yet determined: Inner Mongolia Autonomous Region, Guangxi Zhuang Autonomous Region, Tibet Autonomous Region, Xinjiang Uygur Autonomous Region and Ningxia Hui Autonomous Region.

interval but gradually decreases. More specifically, when the value of the digital inclusive finance index is higher than the threshold value (5.158), the magnitude of its effect on rural logistics starts to decrease (from 0.946 to 0.929). This verifies the non-linear relationship between digital inclusive finance and the development level of rural logistics. Furthermore, we found that beyond a certain level of the digital inclusive finance index (5.158), an additional increase in the digital inclusive finance index will have a lower effect on the development of rural industries.

4.4. Heterogeneity test

First, the influence of digital inclusive finance on rural logistics development in the Cluster-4 ($\alpha = 0.548$; $p = 0.000$) is higher than that in Cluster-2 ($\alpha = 0.116$; $p = 0.000$) and Cluster-5 ($\alpha = 0.142$; $p = 0.000$) (Table 7). Since Clusters 4 are regions that have a higher economic development environment and human capital. This is expected to facilitate digital integration and digital transformation. Second, for Cluster-1, the impact of digital inclusive finance on the development of rural logistics has no significant promoting effect ($\alpha = -0.034$; $p = 0.622$) (Table 7). Cluster-1 regroups regions with high urbanization levels, rapid urbanization growth, abundant financial capital, and relatively good logistics facilities system like Beijing and Shanghai. Therefore, investment effort and labor are less oriented toward the rural area reducing the effect of digital inclusive finance on the development of rural logistics. Third, for Cluster-3, the results are similar to those of Cluster-1 ($\alpha = 0.008$; $p = 0.463$) (Table 7). The regions in this cluster are in the factor-driven stage, their economic model depends on natural resources and faces constant pressure from economic structural transformation and upgrade [61]. Therefore, they fail to take advantage of digital transformation. Finally, the not yet determined cluster has a large territory and disaggregated population. Moreover, its economy is still underdeveloped limiting the services of digital finance.

The financial development level, resource endowment, and development stage of China's eastern, central, and western regions are different inducing a regional heterogeneity. Table 8 returns the results from the regional heterogeneity analysis. It was found that digital inclusive finance in eastern, central, and western China ($\alpha = 2.987$; $p = 0.000$, $\alpha = 0.932$; $p = 0.000$, $\alpha = 1.408$; $p = 0.107$ respectively) has a positive and significant effect on the development level of rural logistics. However, the magnitude is the highest in the eastern region, followed by the western region and the central region (Table 8). Thus, there is a regional heterogeneity in the influence of digital inclusion finance on the development level of rural logistics. First, the production environment in the eastern region enhances the promotion effect of digital inclusion on the development of rural logistics. For instance, the eastern region has the highest level of digital inclusive finance and its population is relatively skilled, compared to other regions, which enhances the full release of the dividend of financial services [62]. Second, the challenging production environment in the western region [48] inhibits the impact of digital inclusive finance on the development of rural logistics is inhibited. Finally, the low application level of digital technology and financial services in the central region has not fully released the digital inclusive financial dividend in the central region [63].

4.5. Robustness test

4.5.1. Endogeneity problem

Column (1) of Table 9 shows that after controlling the endogeneity problem with the instrumental variable method, the effect of digital inclusive finance on promoting the development level of rural logistics is still valid, and the results are all significant at the 1% level. To overcome the effect of reverse causality, this paper selects one lag period of the digital inclusive finance index as the explanatory variable for re-estimation. The results are shown in column (2) of Table 9, and the coefficient of digital inclusive finance is still significantly positive, which is consistent with the benchmark regression results (Table 4).

4.5.2. Other robustness tests

The robustness test results (Columns (3) to (4) - Table 9) show that the regression coefficients of digital inclusive finance are significantly positive at the level of 1%. This is consistent with the benchmark regression results in Table 4, indicating that the regression results obtained in this paper are robust. This indicates that the development of digital inclusive finance in China has promoted the development of rural logistics significantly.

5. Conclusions and policy implications

In the context of the rapid development of the digital economy, the development of digital inclusive finance contributes to improving the rural logistics system and access to financial services in rural areas. It was assessed that digital inclusive finance contributes to the development of rural logistics with a nonlinear feature of decreasing marginal effect. Furthermore, the effect of digital inclusive finance on the development level of rural logistics follows the economic development level of provinces. Evidence was found that this effect is strongest in the eastern region and weaker in the western and central regions.

To promote the coordinated development of digital inclusive finance and rural logistics, this paper provides the following recommendations to policymakers. First, adequate strategies are required to promote the construction of rural digital infrastructure and accelerate the development of digital inclusive finance. For instance, the threshold impends policymakers to allocate effectively their capital. To this end, more investment is needed to construct new digital infrastructures such as rural broadband communication networks, digital TV networks, cloud computing technologies, public information platforms, and market data centers. This will facilitate digital transformation in rural areas and support the development of rural logistics. Second, more effort should be given to region-specific policies to develop digital inclusive finance and its coordination with rural logistics. Indeed, the non-linear

Table 8
Regression results of heterogeneity discussion.

| | The eastern region (1) | The central region (2) | In the western region (3) |
|--------------------------|------------------------|------------------------|---------------------------|
| <i>DIF</i> | 2.987*** (0.513) | 0.932*** (0.068) | 1.408 (0.726) |
| <i>Control variables</i> | Yes | Yes | Yes |
| <i>_cons</i> | -18.40*** (1.851) | -7.834* (1.873) | -17.53*** (1.845) |
| <i>N</i> | 88 | 64 | 96 |
| <i>R-sq</i> | 0.943 | 0.976 | 0.978 |
| <i>Adj. R-sq</i> | 0.935 | 0.955 | 0.968 |

To sum up, the effect of digital inclusive finance on the development of rural industries depends on the economic development level, the production environment, and human capital.

Table 9
Regression results of robustness test.

| variable | <i>Instrumental variable (1)</i> | <i>A phase lag (2)</i> | <i>The principal components method (3)</i> | <i>Excluded municipality model (4)</i> |
|--------------------|----------------------------------|------------------------|--|--|
| <i>Dif</i> | 0.076* (0.14) | 2.039*** (0.370) | 2.008*** (0.363) | 1.122** (0.353) |
| <i>Agriculture</i> | 0.005 (0.056) | 0.015 (0.009) | 0.016 (0.009) | 0.018* (0.008) |
| <i>Innovation</i> | 0.176*** (0.99) | 0.082** (0.031) | 0.101** (0.031) | 0.094*** (0.0275) |
| <i>Economic</i> | 0.487*** (0.061) | -0.227 (0.125) | -0.167 (0.123) | -0.020 (0.127) |
| <i>Nursing</i> | 0.046 (0.091) | 0.064 (0.055) | 0.055 (0.048) | 0.109* (0.046) |
| <i>Enterprise</i> | 0.096*** (0.049) | 0.123*** (0.027) | 0.112*** (0.026) | 0.118*** (0.022) |
| <i>Government</i> | 0.442*** (0.092) | 0.369*** (0.043) | 0.396*** (0.043) | 0.286*** (0.043) |
| <i>Consumption</i> | 0.333*** (0.109) | 0.316*** (0.036) | 0.320*** (0.034) | 0.336*** (0.040) |
| <i>_cons</i> | -11.93*** (0.125) | -15.17*** (1.184) | -15.86*** (1.178) | -12.14*** (1.200) |
| <i>N</i> | 248 | 217 | 248 | 216 |
| <i>R-sq</i> | 0.936 | 0.941 | 0.949 | 0.968 |
| <i>adj. R-sq</i> | 0.936 | 0.941 | 0.936 | 0.967 |

characteristics of the single-threshold effect of digital inclusive finance on rural logistics impend governments at all levels to consider the specific context of each region during the elaboration of policies. This will contribute to narrowing the “digital financial gap” in rural logistics development, and give full play to the role of digital inclusive finance in promoting rural logistics. Third, policymakers should focus more on less developed regions and provide specific supporting measures for digital transformation. Digital inclusive finance can be used to promote the innovative supply chain finance model of “finance and logistics”. Moreover, local authorities in these regions should provide integrated services for rural logistics to enhance the positive promotion of digital inclusive finance for rural logistics. Finally, policymakers should introduce relevant laws and regulations on digital inclusive finance to effectively protect the privacy of rural logistics data and the digital financial system. More specifically, by proposing digital inclusive finance-related laws and regulations to effectively protect the privacy of rural logistics data and the rights and interests of digital finance consumers.

This research contributes to the literature by providing evidence of the importance of the digital economy in providing strategic development opportunities for agricultural mechanization. Furthermore, we highlighted the contribution of digital finance in providing a new approach to developing rural logistics. Finally, we provided a baseline for policymakers to develop an efficient rural logistics system focusing on digital inclusive finance. However, our research was limited by data availability limiting our analysis and the construction of the indicators to a provincial level. However, the results provided by this research can be used as a baseline to foster more research in the field and to provide general guidance to sustainably develop rural areas. With the increasing concern for environmental sustainability, future research can investigate the relationship between digital inclusive finance and green logistics. Furthermore, more research can be done using more micro-level data.

Author contribution statement

Qin Zhaohui: Conceived and designed the analysis; Analyzed and interpreted the data; Contributed analysis data; Wrote the paper. Pei Xueke: Conceived and designed the analysis; Analyzed and interpreted the data; Contributed analysis data; Wrote the paper. Mihasina Harinaivo Andrianarimanana: Analyzed and interpreted the data; Contributed analysis data; Wrote the paper. Wen Shizhou: Contributed analysis data; Wrote the paper.

Data availability statement

Data will be made available on request.

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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