Research article

Can digital financial inclusion effectively stimulate technological Innovation of agricultural enterprises?—A case study on China

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Abstract: Digital financial inclusion is a new product of traditional finance through digitalization and technologization. This paper uses the data of China's A-share listed agricultural companies from 2015 to 2020 to explore the impact of digital financial inclusion on the technological innovation efficiency of agricultural enterprises and answer the question of whether digital financial inclusion can solve the financing problems of agricultural enterprises and provide them the necessary support to stimulate their technological innovation effectively. Firstly, the data envelopment analysis (DEA) is used to measure the technological innovation efficiency of agricultural enterprises, and the Tobit model is adopted to analyze the impact of digital financial inclusion on the technological innovation efficiency of agricultural enterprises. Secondly, the influence mechanism of digital financial inclusion is explored. Thirdly, the heterogeneity test is conducted for enterprises with different characteristics. Finally, we discuss how the marginal effect of digital financial inclusion changes. The empirical results show that: first, digital financial inclusion has a significant promoting effect on the technological innovation efficiency of agricultural enterprises, and the impact is prominent in a wide range; second, digital financial inclusion can promote technological innovation through the mechanism of enterprise digitization, financing constraints and market efficiency; third, non-state-owned enterprises with high financing level are more suitable to encourage innovation through digital financial inclusion; fourth, the promoting effect of digital financial inclusion has structural characteristics, and it shows an increasing trend with the improvement of enterprise innovation level.

Keywords: digital financial inclusion; technological innovation efficiency; agricultural enterprise; mechanism analysis; innovation incentive effect

JEL Codes: C67, C80, O30, Q10

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1. Introduction and literature review

1.1. Research background

Technological innovation is a major strategic action with high costs, high risks and high returns for enterprises. It is considered to be one of the essential means to improve the economic level and comprehensive strength of enterprises. As an important driving force of long-term economic growth, technological innovation determines the long-term development trend of enterprises and even the advantages of national competitive strategy (Aghion and Howitt, 1992). In particular, agricultural enterprises, as an enterprise organization of national advanced productive forces, undertake the critical mission of promoting the industrialization of agricultural science and technology and agricultural development through technological innovation (Juríčková et al., 2020). However, technological innovation can't help agricultural enterprises obtain short-term profits due to great uncertainties in research, testing and sales. In this process, technological innovation requires sustained, stable and high capital investment (Liao and Drakeford, 2019), which has caused tremendous pressure on the short-term financial objectives of agricultural enterprises, so it is highly dependent on the financial level of enterprises. However, there are many problems in the development of the traditional financial system, which is hard to meet the financial needs of enterprises (Tripathy, 2019; Xu and Li, 2020).

In response to a large number of problems in the traditional financial system, various countries and enterprises are committed to developing financial technologies to solve them. For example, the booming development of digital financial systems such as Internet technology, big data technology and artificial intelligence has greatly compensated for the availability and convenience of traditional finance (Ezzahid and Elouaourti, 2021; Li et al., 2021; Li et al., 2021). Digital finance generally refers to the realization of financing, payment, investment and other new financial services by traditional financial institutions and enterprises using digital technology (Li et al., 2020). By improving the quality of financial infrastructures such as payment and settlement systems, digital finance can stimulate residents' consumption, improve the level of enterprise operation and promote the technological innovation of the physical business model. With the development of digital finance, the financial inclusion system, which shows a strong correlation with it, has also been vigorously developed by various countries. Financial inclusion can be defined as a financial system that effectively and comprehensively serves all classes and groups of society. In order to solve the difficulties which are caused by traditional finance and promote the development of digital finance and financial inclusion, countries have combined them to establish a system of digital financial inclusion.

For example, taking mobile payment as a critical breakthrough in development, China's digital financial inclusion has shown obvious competitive advantages compared with the development of digital finance worldwide (Zhong and Li, 2020). Digital financial inclusion is a financial inclusion with the digital financial mode as an essential source and growth point. As a product of digital technology and financial innovation, digital financial inclusion has the unique characteristic of information sharing. It can not only solve the problem of information asymmetry which causes the financing constraints between enterprises and financial institutions, but also can deepen the digitization degree of enterprises. Therefore, it has spillover effects on enterprises' technological innovation (Wen et al., 2021). With the strong

support of policies, China's digital financial inclusion provides a steady stream of economic support for agricultural enterprises, enriching the available resources of enterprises and intensifying the competition between enterprises (Chao et al., 2021). This competitive effect also enables enterprises to obtain new competitive advantages in technological innovation. The development of digital financial inclusion has also led to investment in the virtual economy, reducing the flow of idle funds in society. Agricultural enterprises are more likely to achieve technological innovation and industrial upgrading with the help of digital financial inclusion. Therefore, their innovative products can better adapt to the market and improve market efficiency. Based on this, the technology spillover effect (Li et al., 2019), competition effect, and industrial optimization effect of digital financial inclusion directly affect agricultural enterprises' technological innovation.

1.2. Literature review and marginal contribution

With the vigorous development of digital finance, the research on the relationship between digital finance and enterprise technology innovation has gradually attracted great attention. Based on previous studies, this paper concludes that digital finance can promote the technological innovation of enterprises from the following three aspects. First, the development of digital finance has improved the shortcomings of traditional financial models, providing convenient financial services to small and medium-sized enterprises and enterprises in underdeveloped areas, and promoting the technological innovation of enterprises in poor conditions. Armendariza and Morduch (2005) found that traditional financial institutions preferred enterprises with large scale, strong profitability and particular political background, and discriminated against small and medium-sized enterprises with specific potential but still in the stage of development, and they also found that the allocation of financial resources among enterprises was unbalanced. In addition, the problem of information asymmetry in the traditional financial system makes traditional financial institutions more inclined to provide services to state-owned enterprises [1], reducing the market risks faced by state-owned enterprises, making it difficult for companies without political affiliations to raise sufficient funds for technological innovation. The traditional financial system is also geographically constrained from expanding further. Therefore, it does not provide sufficient support for enterprises in underdeveloped areas, which cannot enjoy convenient financial services. Without the support of financial services, enterprise innovation cannot be carried out (Aghion et al., 2007; Li et al., 2020). Digital finance realizes the functions of lending, investment and payment through digital technologies such as the Internet, providing high-quality services for the technological innovation of these enterprises. Xie et al. (2020) concluded that digital finance improved the deficiencies of traditional finance from the following two aspects. On the one hand, digital financial inclusion provides formal financial services for small and medium-sized enterprises through digital technology, alleviates the problem of information asymmetry and reduces the financing cost of enterprises. On the other hand, digital financial inclusion extends the range of financial services. Remote areas that cannot be served by traditional finance can also enjoy complete financial services, effectively making up for traditional finance deficiencies and promoting the technological innovation of enterprises (Aziz and Naima, 2021).

Second, relying on big data, digital finance reduces corporate financing costs. The financing difficulty of enterprises is the main obstacle to the development of technological innovation. Due to the singleness of corporate financing channels, and the traditional financial system is difficult to judge

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[1] State-owned enterprises in China are those that are invested in or hold more than 50% of state-owned assets.

the integrity of enterprises, it is difficult for enterprises to obtain sufficient financial support. Hall (2010) et al. explored why corporate technological innovation would produce a capital gap, that is, the reason for insufficient capital investment in the traditional financial market. They found that investors view technological innovation as a risky activity that does not yield short-term gains. Therefore, enterprises have a poor level of financing in technological innovation. Moreover, the risk assessment model of the traditional financial system focuses on the rigid indicators of enterprises, and the risk level of emerging enterprises cannot be effectively evaluated. The risk assessment model of digital finance is more inclined to the soft information of enterprises, such as the Internet behavioral data. Duarte (2012) built a credit evaluation model for small and medium-sized enterprises through big data analysis, which alleviated the problem of insufficient rigid indicators for small and medium-sized enterprises. The financial model based on digital finance reduces the cost of risk assessment and helps enterprises obtain adequate financing. Shahrokhi (2008) believes that digital finance can reduce costs for enterprises and expand the scope of financial services, enable non-bank institutions and capital markets to access more borrowers and provide more opportunities for technological innovation for enterprises. Fuster (2019) believes that the traditional financial system has complicated procedures and low efficiency in financing. Digital finance reduces investors' information cost and transaction cost through digital technology while reducing enterprises' credit risk premium and financing cost. The development of digital finance has enriched the types of financial services, made it easier for enterprises to obtain financing channels, and increased the opportunities for technological innovation of enterprises.

Third, as a new financial system, digital finance provides a foundation for enterprise innovation and increases technological innovation opportunities. As the core product of current financial innovation, digital finance provides a steady stream of power for economic growth and provides better conditions for enterprise technological innovation (Usman et al., 2021). Laeven (2015) studied the necessity of financial innovation to maintain economic growth. The results show that enterprises earn profits and alleviate the constraints of traditional finance through technological innovation. They believe that enterprises can avoid the stagnation of economic development and promote the development of innovation through continuous technological innovation. Teece (2010) discussed the connection between digital finance and enterprise innovation. They analyzed how enterprises rely on the reform of financial modes to obtain profits and actively innovate. Digital finance has had a significant impact on business development in the two dimensions of enterprise delivery and realization. It makes online transactions possible, changes the business model under the traditional financial system, and promotes enterprise technological innovation. Hsu (2014) believes that finance is the core component of enterprise technological innovation, directly affecting technological innovation. The development of digital finance has effectively absorbed financial resources and provided adequate supply for technological innovation of enterprises. More importantly, digital finance can provide high-quality information technology analysis tools and screen the optimal results of technological innovation for enterprises, helping them make reasonable and practical technological innovation decisions. Moreover, in order to expand the business of traditional financial services, digital finance can drive the reshaping of the traditional financial system to a certain extent.

To sum up, scholars have mainly explored whether digital finance can promote enterprise technological innovation, but there is still a lack of in-depth research on the promoting effect of digital finance, especially digital financial inclusion. Digital financial inclusion is an inclusive financial service which are achieved by banks, other traditional financial institutions and Internet enterprises using digital technology to carry out financial business. Its impact on technological innovation depends

on the path of digital finance. Then, how digital financial inclusion with extensive, low-cost and personalized services can more efficiently drive the technological innovation of agricultural enterprises has become a thought-provoking topic. Based on the existing research, this paper uses the data of China's A-share agricultural listed companies from 2015 to 2020 to explore how digital financial inclusion can effectively promote the technological innovation of enterprises. Compared with previous studies, the marginal contributions of this paper are as follows. First, this paper adopts the data envelopment analysis (DEA) to calculate the technological innovation efficiency of agricultural enterprises, which can more effectively estimate the technological innovation level of agricultural enterprises. Tobit method we use is also applicable to the results of DEA calculation, and the empirical results are comparatively more accurate. Second, this paper selects a variety of variables related to digital financial inclusion as mechanism variables by referring to relevant literature. Through mechanism analysis, this paper determines how to promote the technological innovation of agricultural enterprises more efficiently. Third, by distinguishing the nature of enterprises and the financing level, this paper studies the characteristics of agricultural enterprises that are more suitable for digital financial inclusion. Most studies only explore the promoting effect of digital financial inclusion by classifying enterprises according to their size. However, the classification standard is vague and can't get accurate conclusions. Therefore, based on a large number of previous studies, this paper redefines the classification standard. Fourth, this paper explores whether the innovation-promoting effect of digital financial inclusion has "structural" characteristics. This paper discusses how the marginal effect of digital financial inclusion on the technological innovation of agricultural enterprises changes with the improvement of their technological innovation level and determines the optimal technological innovation level of agricultural enterprises in developing digital financial inclusion.

The rest of this paper is arranged as follows. Section 2 is the research design, including the basic theory analysis, the hypotheses, model specification and variable description. Section 3 carries out the basic empirical analysis, namely Tobit regression and the robustness test. Section 4 is the further discussion, including mechanism analysis, heterogeneity test and marginal effect analysis. The fifth section draws the conclusion and provides enlightenment of digital financial inclusion promoting the technological innovation of agricultural enterprises.

2. Research design

2.1. Theoretical analysis and research hypotheses

China's digital financial inclusion has a significant incentive effect on the technological innovation of agricultural enterprises. Due to the defects of China's traditional financial system and the limitations of enterprises, China's traditional finance does not significantly promote the technological innovation of agricultural enterprises. On the one hand, China's traditional financial system, which is dominated by banks, has problems such as single financing mode, lack of financing channels and conservative risk assessment. Therefore, it cannot provide sufficient support to the development of agricultural enterprises' technological innovation with a great demand for capital, long term and high uncertainty. On the other hand, some agricultural enterprises have fewer mortgage assets and low credit, which are seriously inconsistent with the credit preferences of banks. Banks, worried about the risks, consistently refuse to provide adequate financial support to rural enterprises. As an emerging financial model in China, digital financial inclusion provides an effective solution for the

technological innovation of agricultural enterprises. Digital financial inclusion can stimulate the technological innovation of agricultural enterprises from three aspects: increasing the liquidity, reducing the financing cost and improving the operating income of agricultural enterprises (Galvez-Sanchez et al., 2021; Lu et al., 2020; Yang and Zhang, 2020). Allen et al. (2014) analyzed the help of mobile banking to enterprise financing and concluded that digital finance could provide enterprises with more convenient financial services. Based on the above analysis, this paper proposes the following hypothesis:

Hypothesis 1: Digital financial inclusion can promote the technological innovation efficiency of agricultural enterprises.

The promoting effect of digital financial inclusion on technological innovation of agricultural enterprises is influenced by financing constraints, market efficiency and enterprise digitalization. In the technological innovation stage, agricultural enterprises need a large amount of human capital and fixed capital investment to support the R&D and experimentation of new technologies or new products (Escobar et al., 2020). However, this stage is full of technical risks, and investors are faced with severe information asymmetry. The digital financial inclusion system relies on data mining, artificial intelligence, machine learning and other methods to timely and efficiently collect and analyze massive data of enterprises. The third-party credit evaluation system can implement accurate risk pricing for enterprises, reduce credit risk premium and enterprise financing constraints, thus affecting the technological innovation of agricultural enterprises. Gibbert (2014) discussed the impact of financing constraints on technological innovation. Moreover, digital financial inclusion supports new products and sales services through digital technology, increasing their marketization efficiency. In this way, enterprises can reduce marketing costs, improve sales efficiency and promote enterprise innovation. Brancati and Emanuele (2015) found that an enterprise's market share and past sales growth had a pronounced promoting effect on enterprise innovation. In the process of the development of digital financial inclusion, agricultural enterprises themselves are undergoing digital transformation, that is, the process of industrial upgrading and transformation using emerging technologies. Digital transformation originates from the interaction between technological innovation and operational needs of enterprises, and it is the core force to promote technological innovation of enterprises. It can be used as an external motivation to promote enterprise technological innovation, which is an internal demand for enterprises to realize digital transformation. In the process of digital financial inclusion, enterprises upgrade and transform the industry through digital technology to promote enterprises to carry out technological innovation more effectively making enterprises change from the traditional innovation mode to the new innovation mode of digital-driven development. Therefore, enterprise digitization can change the original business model of enterprises and have an essential impact on their technological innovation. Verhoef et al. (2021) divided the digital transformation of enterprises into three stages, where the second and third stages were combined with digital finance to optimize the operation mode of enterprises, which will also promote the technological innovation of enterprises to a certain extent. Based on the above analysis, this paper proposes the following hypothesis:

Hypothesis 2: Digital financial inclusion can affect the technological innovation efficiency of agricultural enterprises through financing constraints and market efficiency.

Hypothesis 3: Enterprise digitization can affect the process in which digital financial inclusion influences the technological innovation efficiency of agricultural enterprises.

There is heterogeneity in the impact of digital financial inclusion on the technological innovation of enterprises with different attributes and financing levels. Especially for non-state-owned enterprises

with high financing levels, the innovation incentive effect of digital financial inclusion is more significant. In terms of financing level, digital financial inclusion has a significant driving effect on enterprise technological innovation for enterprises with high financing levels. This is because enterprises have a strong dependence on external financing and weak internal financing, resulting in a more significant influence of digital financial inclusion. In terms of the nature of enterprises, there is heterogeneity in the impact of digital financial inclusion on the technological innovation of state-owned and non-state-owned agricultural enterprises. Under the traditional financial system, non-state-owned enterprises face strong financial exclusion and discrimination in the financial market, which deepens the information asymmetry between non-state-owned enterprises and traditional financial institutions. With the help of digital financial inclusion, it is easier for non-state-owned enterprises to obtain financial support. Moreover, the system and mechanism of non-state-owned enterprises are more flexible and can be adjusted rapidly with the development of digital financial inclusion, which makes the innovation incentive effect of digital financial inclusion more obvious. Based on the above analysis, this paper puts forward the following hypotheses:

Hypothesis 4: The impact of digital financial inclusion on the technological innovation efficiency of agricultural enterprises is different in terms of financing level and enterprise nature.

At different innovation levels, the marginal impact of digital financial inclusion on the technological innovation of agricultural enterprises is different. Due to different corporate technological innovation levels, the constraint degree of the external financial environment of enterprises is also different, and the impact of digital financial inclusion on enterprises is also different. The innovation incentive effect of digital financial inclusion will vary with the change of technological innovation level of agricultural enterprises. Demir et al. (2020) used the quantile regression method to study the relationship between digital finance and income inequality. Referring to Demir's empirical method, this paper discusses the relationship between digital financial inclusion and agricultural enterprises' technological innovation at different innovation levels. Based on the above analysis, this paper proposes the following hypothesis:

Hypothesis 5: With the improvement of the innovation level of agricultural enterprises, the impact of digital financial inclusion on the technological innovation efficiency of agricultural enterprises varies.

2.2. Model specification

In order to accurately explore the impact of China's digital financial inclusion on the technological innovation efficiency of agricultural enterprises, this paper adopts DEA to measure the technological innovation efficiency and then uses the panel Tobit regression to make an empirical analysis. DEA was proposed by Charnes et al. (1978) in 1978 to evaluate the relative effectiveness of decision-making units in the "multi-input & multi-output" mode. By referring to the research of Tone (2001), this paper uses a non-radial DEA-SBM model based on slack variable measurement to better avoid the deviation caused by traditional DEA. The advantage of DEA-SBM is to expand output on the premise of relatively stable existing input, so as to obtain more accurate measurement of efficiency. The specific model is as follows:

$$min\rho^* = \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}}{1-\frac{1}{s}\sum_{r=1}^{s}\frac{s_r^+}{y_{r0}}} \tag{1}$$

$$s.t.\, x_{i0} = \sum_{j=1}^{n}\theta_j x_{ij} + s_i^- \,(i = 1,2,\dots,m) \tag{2}$$

$$y_{r0} = \sum_{j=1}^{n}\theta_j y_{rj} + s_r^+ \,(r = 1,2,\dots,s) \tag{3}$$

$$\sum_{j=1}^{n}\theta_j = 1; \theta_j, s_i^-, s_r^+ 0 \tag{4}$$

As shown in the model, suppose there are n decision-making units DMU, denoted as $DMU_j (j = 1,2,\dots,n)$. ρ is the efficiency evaluation indicator; x_{ij} is the i-th input variable of the j-th DMU; y_{rj} is the r-th output variable of the j-th DMU; θ_j represents the weight of each element in the reference set. The MaxDEA software is employed to measure the technological innovation efficiency of agricultural enterprises. The results of DEA calculation belong to truncated data, the data range is $0 < DEA < 1$. When we use the results of DEA which is the efficiency score as the explanatory variable of regression model, we must solve the problem which the efficiency score is less than or equal to 0 and greater than 1. In this case, the estimation results of the ordinary least square method (OLS) are biased and inconsistent. In order to avoid the errors caused by OLS estimation, the restricted dependent variable model, that is, Tobit model, is usually used for estimation. Tobit model is set as follows:

$$Patent_{it} = \alpha_0 + \alpha_1 * Dfin_{it} + \sum_{j=2}^{6}\alpha_j * Control_{it} + \varepsilon_{it} \tag{5}$$

$$Patent_{it} = \begin{cases} Patent_{it}, & 0 < Patent_{it} < 1 \\ 0 & , Patent_{it} \le 0 \\ 1 & , Patenty_{it} \ge 1 \end{cases} \tag{6}$$

Patent represents the technological innovation efficiency of agricultural enterprises measured by DEA; Dfin is the digital financial inclusion index; Control represents the control variable; i represents the number of enterprises; t represents the year; ε represents the random disturbance term; α_0 is a constant term, and $\alpha_1 - \alpha_6$ are the coefficients of the variables.

Referring to the research of Baron et al. (M, Baron, A, personality, & psychology, 1986; Toothaker, 1994), this paper tested Hypothesis 2 and Hypothesis 3 by establishing a mediating effect model and a moderating effect model. The models are as follows:

$$Med_{it} = \beta_0 + \beta_1 * Dfin_{it} + \sum_{j=2}^{6}\beta_j * Control_{it} + \varepsilon_{it} \tag{7}$$

$$Patent_{it} = \beta_0' + \beta_1' * Dfin_{it} + \beta_2' * Med_{it} + \sum_{j=3}^{7}\beta_j' * Control_{it} + \varepsilon_{it} \tag{8}$$

$$Patent_{it} = \gamma_0 + \gamma_1 * Dfin_{it} + \gamma_2 * Dig_{it} + \gamma_3 * Dfin_{it} * Dig_{it} + \sum_{j=4}^{8}\gamma_j * Control_{it} + \varepsilon_{it} \tag{9}$$

Model (7) and Model (8) are mediating effect models, and Model (9) is the moderating effect model, where Med represents the mediating variable; Dig represents the moderating variable, and the rest are consistent with those in Model (5).

In order to test Hypothesis 4, this paper classifies agricultural enterprises according to their financing levels and attributes. The heterogeneity of the data is tested according to the classification results, and the model set is shown in Model (5).

As for the marginal effect analysis, this paper uses the quantile regression method to carry out regression analysis under the quantiles of 5%, 25%, 50%, 75% and 95% of the technological innovation efficiency of agricultural enterprises. The model setting is shown in Model (5).

2.3. Variable selection and data sources

2.3.1. Explained variables

This paper uses DEA to measure the corporate technological innovation efficiency to evaluate the technological innovation ability of agricultural enterprises. Because DEA measures a wide range of indicators, it can more accurately evaluate the technological innovation ability of agricultural enterprises. Considering the characteristics of technological innovation of agricultural enterprises and the availability of data, this paper selects the following indicators to measure the technological innovation efficiency (Patent) of agricultural enterprises. The input indicators are the amount of R&D investment and the number of R&D personnel, which are used to reflect the input of capital and human resources in the technological innovation of enterprises. Output indicators include the number of patent applications authorized, main business income and profitability. The number of patent applications can reflect the technological innovation level of agricultural enterprises. The main business income determines subsequent investment in technological innovation. Profitability has an impact on technological innovation. Therefore, the above indicators are selected for calculation in this paper, and the specific descriptions are shown in Table 1.

Table 1. The measurement indicators of technological innovation efficiency.

First-level indicator	Second-level indicator	Description
Input indicator	the amount of R&D investment	The amount of R&D expenditure in annual reports of listed companies
	the number of R&D personnel	The number of R&D personnel in annual reports of listed companies
Output indicator	the number of patent applications	The number of authorized invention patents of listed companies

2.3.2. Explanatory variable

In this paper, the Digital Financial Inclusion Index of China (DFIIC), released by the Institute of Digital Finance Research Center of Peking University, is used as the measurement index of digital financial inclusion. This paper uses the DFIIC at the county and city level to represent the development level of digital financial inclusion where the enterprise is located. DFIIC measures the development of digital financial inclusion from multiple dimensions such as breadth and usage depth. Therefore, this

paper uses the data of the breadth and depth of the DFIIC to explore the impact of digital financial inclusion on the technological innovation efficiency of agricultural enterprises in these two dimensions.

2.3.3.   Control variable

Based on previous studies, this paper selects government support, enterprise size, enterprise debt ratio, enterprise profitability and equity concentration as control variables (Hill and Snell, 2010; Huang et al., 2019; Cohen and Klepper, 1996; Tapver, 2019; Williamson, 1988). Government support refers to a policy aimed at encouraging enterprise innovation. Technological innovation investment is subject to enterprise size. The greater the debt ratio of enterprises, the more reluctant enterprises are to support technological innovation activities. Enterprise profitability can provide power for technological innovation. The stronger the degree of equity concentration, the more vulnerable the enterprise's technological innovation ability is to the behavior of major shareholders.

2.3.4.   Moderating variables and mediating variables

In this paper, financing constraints, market efficiency and enterprise digitization are selected as the mediating and moderating variables. By referring to Hadlock (Hadlock and Pierce, 2010), this paper calculates the SA (Size and Age) index to measure the financing constraints of enterprises and how digital financial inclusion affects the technological innovation of agricultural enterprises through financing constraints. The SA index is calculated by the formula: $-0.737 \times Size + 0.043 \times Size^2 - 0.04 \times Age$, where Size represents the size of the enterprise and Age represents the age of the enterprise. For measuring market efficiency, referring to Lee (2020), this paper selects the sales expense rate of enterprises as the mediating variable to measure market efficiency. Referring to the research of Ghosh (2014), this paper uses the proportion of intangible assets related to digitization to measure the level of enterprise digitization and studies how enterprise digitization affects the process of technological innovation of agricultural enterprises through digital financial inclusion.

The research objects of this paper are China's A-share listed agricultural, forestry, animal husbandry and fishery companies from 2015 to 2020. After considering the availability and validity of the data, this paper excludes ST, *ST, PT companies and those with severely missing data and finally selects 31 listed companies as the research objects. Except for the data of the DFIIC, other data are from the CSMAR database. In order to avoid errors in research results caused by unit differences among variables, this paper conducts logarithmic processing on the enterprise size and government subsidies and supplements the missing data using average interpolation. The specific descriptions of the above variables are shown in Table 2, and the descriptive statistics of the variables are shown in Table 3.

Table 2. Variable selection and description.

Variable type	Variable name	Symbol	Variable description
Explained variable	Technological innovation efficiency	Patent	Calculating with the DEA model
Explanatory variable	Digital financial inclusion	Dfin	Digital Financial Inclusion Index
	Breadth of financial inclusion	Dfin_cov	Digital Financial Inclusion Index
	Usage depth of financial inclusion	Dfin_use	Digital Financial Inclusion Index
Control variable	Government support	Gov	Government subsidies for enterprise innovation
	Enterprise scale	Size	The total assets of the enterprise at the end of the year
	Enterprise debt ratio	Lev	The asset-liability ratio of the enterprise
	Enterprise profitability	Gain	Net profit of the enterprise
	Degree of equity concentration	Only1	Shareholding ratio of the largest shareholder
Mediating variable	Financing constraints	FC	SA index
	Market efficiency	Sale	Sales expense rate of the enterprise
Moderating variable	Enterprise digitization	Dig	The proportion of intangible assets of digitization

Table 3. Descriptive statistics.

VarName	Obs	Mean	SD	Min	Median	Max
Patent	186	0.273	0.384	0.000	0.065	1.000
Dfin	186	241.084	35.477	147.950	244.118	320.788
Dfin_cov	186	235.342	38.327	139.500	234.828	313.360
Dfin_use	186	231.923	44.447	114.410	240.081	339.017
Lev	186	0.443	0.187	0.059	0.408	0.980
Lnsize	186	22.236	1.012	20.320	22.063	25.535
Lngov	119	16.751	1.338	11.904	16.613	20.530
Only1	186	33.462	14.963	4.080	34.110	70.000
Gain	186	6.67e+08	2.88e+09	−4.15e+09	6.53e+07	3.04e+10
FC	186	4.234	1.229	1.931	3.926	8.459
Sale	186	0.057	0.056	0.002	0.034	0.347
Dig	186	0.013	0.021	0.000	0.002	0.150

3. Empirical analysis

3.1. Baseline regression

Because the technological innovation efficiency of agricultural enterprises is a relative value, between 0 and 1, it has a truncated characteristic. Therefore, software Stata16.0 is used in this paper to conduct an empirical test on Model (5) to verify the impact of digital financial inclusion on the technological innovation efficiency of agricultural enterprises. In addition, this paper explores the impact from two dimensions of digital financial inclusion. The empirical results are shown in Table 4.

Table 4. Baseline regression.

Variable	Tobit (1) Patent	Tobit (2) Patent	Tobit (3) Patent
Dfin	0.013***		
	(2.916)		
Dfin_cov		0.011***	
		(2.973)	
Dfin_use			0.007
			(1.309)
Lev	−0.232	−0.257	−0.123
	(−0.807)	(−0.893)	(−0.414)
Lnsize	−0.318***	−0.310***	−0.298***
	(−2.917)	(−2.846)	(−2.649)
Lngov	−0.099**	−0.095**	−0.096**
	(−2.246)	(−2.166)	(−2.068)
Only1	−0.018**	−0.017*	−0.020**
	(−2.024)	(−1.873)	(−2.176)
Gain	0.000	0.000	0.000
	(0.899)	(0.770)	(0.990)
Time Effect	YES	YES	YES
Individual Effect	YES	YES	YES
_Cons	6.684**	7.089***	8.080***
	(2.609)	(2.829)	(2.986)
N	119	119	119

Note: *, ** and *** represent passing the significance test of 10%, 5% and 1%, respectively.

The empirical results in Table 4 show that digital financial inclusion can promote the technological innovation efficiency of agricultural enterprises, and the influence of the breadth dimension is far greater than that of the usage depth dimension. By comparing Columns (1)–(3), it can be seen that the influence coefficient of digital financial inclusion on the technological innovation efficiency of agricultural enterprises is 0.013, which is significant at the significance level of 1%. The influence coefficient of the breadth of digital financial inclusion is 0.011, and it is significant at the significance level of 1%. However, the usage depth of digital financial inclusion has no significant impact on the technological innovation efficiency of agricultural enterprises. This shows that digital financial inclusion has a positive impact on the technological innovation of agricultural enterprises, and the impact of the breadth dimension is significant. Therefore, Hypothesis 1 is verified. Agricultural enterprises use digital financial inclusion to improve corporate liquidity, financing costs and operating income to improve the efficiency of technological innovation. In addition, the reason why the breadth of digital financial inclusion has a more significant impact may be that the development of digital financial inclusion has got rid of the traditional financial model, and its influence scope is broader, which provides suitable conditions for technological innovation of agricultural enterprises. The reason why the usage depth of digital financial inclusion has no significant impact on the technological innovation efficiency of agricultural enterprises may be that digital financial inclusion does not profoundly explore the diversity of its services. The expansion of digital financial inclusion to

traditional financial services has an insufficient influence on the technological innovation of agricultural enterprises. It is also possible that the breadth of digital financial inclusion is growing faster than the depth of its use, so its innovation incentive effect is more significant. Lorenz et al. (2021) explored the impact of enterprises' use of digital finance models on enterprise innovation. The results show that the use of the digital finance model reduces the financing constraints faced by enterprises and positively impacts enterprise innovation. Moreover, digital financial inclusion has a greater impact on the technological innovation of small and medium-sized enterprises than that of large enterprises.

In addition, the relationship between the control variables and the technological innovation of agricultural enterprises conforms to reality. At present, there is a significant negative relationship between enterprise size and technological innovation, which may be due to problems such as low management ability that impair innovation efficiency. Government support has a significant negative impact on the technological innovation efficiency of agricultural enterprises, which may be due to the conflict between the goals and interests of the government and enterprises. It may also be because of the crowding-out effect of government input on enterprise innovation input. The more concentrated the equity is, the more detrimental it is to the development of technological innovation. Shareholders pay more attention to short-term interests through relatively long-term technological innovation and development. Individuals do not want to risk too much of their gains.

3.2. Robustness test

In order to prevent the endogeneity problem from affecting the accuracy of the results, this paper conducts a robustness test on the empirical results. The reason for endogeneity maybe a reverse causal relationship between digital financial inclusion and the technical innovation efficiency of agricultural enterprises, or there is the problem of missing variables. Therefore, in this paper, the ratio of R&D expenditure to operating income (Cost) of agricultural enterprises is chosen to replace the technological innovation efficiency of enterprises for regression analysis. The ratio of R&D expenditure to operating income of agricultural enterprises measures the technological innovation level of agricultural enterprises from the perspectives of input and output. The development of digital financial inclusion impacts both the input and output of enterprises, and there is no reverse causal relationship between the two. In addition, fixed effect (Fe) and two stage least square (2SLS) methods are also used as the basis of robustness test to prevent missing variables from affecting the accuracy of research results. The results of robustness tests are shown in Table 5.

The results in Table 5 show that the positive impact of digital financial inclusion on the technological innovation efficiency of agricultural enterprises is robust. As shown in Column (1), the influence coefficient of digital financial inclusion on the proportion of R&D expenditure to the business income of enterprises is 0.021, which is significant at the significance level of 1%. This is similar to the empirical results in Table 4, and digital financial inclusion plays a promoting role to a certain extent. This may be because digital financial inclusion can help agricultural enterprises more easily access financial support, increase R&D expenditure, and improve the possibility of technological innovation. Moreover, Columns (2) and (3) show that digital financial inclusion has a significant promoting effect on the technological innovation efficiency of agricultural enterprises. Therefore, this paper believes that the empirical results are robust.

Table 5. Robustness test.

Variable	Tobit (1) Cost	Fe (2) Patent	2SLS (3) Patent
Dfin	0.021***	0.011**	0.011***
	(3.220)	(2.450)	(3.025)
Lev	0.090	−0.147	−0.147
	(0.378)	(−0.499)	(−0.429)
Lnsize	0.013	−0.283**	−0.283***
	(0.112)	(−2.527)	(−3.132)
Lngov	0.051	−0.081*	−0.081**
	(1.609)	(−1.833)	(−2.017)
Only1	0.032***	−0.014	−0.014
	(4.583)	(−1.619)	(−1.329)
Gain	−0.000	0.000	0.000*
	(−0.907)	(0.882)	(1.901)
Time Effect	YES	YES	YES
Individual Effect	YES	YES	YES
_Cons	−7.445**	5.704**	6.061***
	(−2.436)	(2.223)	(2.942)
N	119	119	119

Note: *, ** and *** represent passing the significance test of 10%, 5% and 1%, respectively.

4. Further discussion

4.1. Mechanism analysis

In order to discuss how digital financial inclusion can more effectively promote the technological innovation of agricultural enterprises, this paper conducts an empirical analysis on whether market efficiency and financing constraints have a mediating effect and whether enterprise digitalization has a moderating effect. The empirical results are shown in Table 6. Med represents the mediating effect, and Reg represents the moderating effect.

According to the results in Table 6, market efficiency and financing constraints play a mediating effect in the process of digital financial inclusion improving the technological innovation efficiency of agricultural enterprises, and enterprise digitalization can further improve the promoting effect. In Column (1), the influence coefficient of digital financial inclusion on sales expense rate is −0.001, significant at the significance level of 5%. In Column (2), under the influence of sales expense rate, the influence coefficient of digital financial inclusion is 0.003 and is significant at the significance level of 10%. The influence coefficient of sales expense rate on the technological innovation efficiency of agricultural enterprises is −1.669 and is significant at the significance level of 5%. This indicates that market efficiency plays a mediating effect in the process of digital financial inclusion improving the technological innovation efficiency of agricultural enterprises, and the change of sales expense rate will reduce the promoting effect. In Column (3), the influence coefficient of digital financial inclusion on financing constraints is −0.01 and is significant at the significance level of 1%. In Column (4), the influence coefficient of digital financial inclusion is 0.003 and is significant at the significance level

of 10%. The influence coefficient of financing constraints on the technological innovation efficiency of agricultural enterprises is −0.13, which is significant at the significance level of 1%. This shows that financing constraints have a mediating effect in the process of digital financial inclusion improving the technological innovation efficiency of agricultural enterprises, and the change of financing constraints will reduce the promotion effect. Therefore, Hypothesis 2 is verified. In Column (5), the influence coefficient is 0.013, significant at the significance level of 1%. In Column (6), the influence coefficient of digital financial inclusion on the technological innovation efficiency of agricultural enterprises under the effect of enterprise digitization is 0.016, which is significant at the significance level of 1%. The influence coefficient of the interaction between digital financial inclusion and enterprise digitization on the technological innovation efficiency of agricultural enterprises is 0.203, which is significant at the significance level of 5%. This indicates that enterprise digitization has a moderating effect on digital financial inclusion promoting the technological innovation efficiency of agricultural enterprises. Enterprise digitization can enhance the promoting effect. Therefore, Hypothesis 3 is verified.

Table 6. Empirical results of moderating effect and mediating effect.

Variable	Med (1) Sale	Med (2) Patent	Med (3) FC	Med (4) Patent	Reg (5) Patent	Reg (6) Patent
Dfin	−0.001**	0.003*	−0.010***	0.003**	0.013***	0.016***
	(−2.252)	(1.839)	(−2.851)	(2.081)	(2.767)	(3.307)
Sale		−1.669**				
		(−2.615)				
FC				−0.130***		
				(−3.297)		
Dig					−2.982**	−5.812***
					(−2.228)	(−3.021)
C_dd						0.203**
						(2.024)
Lev	−0.066***	−0.200	0.181	−0.066	−0.426	−0.566*
	(−2.684)	(−1.169)	(0.443)	(−0.389)	(−1.425)	(−1.874)
Lnsize	−0.039***	−0.211***				
	(−5.433)	(−3.949)				
Gain	0.000	0.000	0.000***	0.000	−0.000	−0.000
	(0.495)	(0.379)	(4.555)	(0.410)	(−0.871)	(−1.291)
Lngov	0.008	0.048	0.572***	0.037	−0.152***	−0.155***
	(1.501)	(1.329)	(8.629)	(1.037)	(−3.481)	(−3.613)
Only1	−0.001***	−0.000	0.002	0.002	−0.013	−0.013
	(−2.693)	(−0.149)	(0.422)	(0.707)	(−1.435)	(−1.467)
Time Effect	YES	YES	YES	YES	YES	YES
Individual Effect	YES	YES	YES	YES	YES	YES
_Cons	0.959***	3.758***	−3.146**	−0.530	0.592	−0.086
	(7.081)	(3.431)	(−2.409)	(−0.956)	(0.405)	(−0.058)
N	119	119	119	119	119	119

Note: *, ** and *** represent passing the significance test of 10%, 5% and 1%, respectively.

Agricultural enterprises can effectively stimulate enterprise innovation by improving market efficiency, alleviating financing constraints and enhancing enterprise digitalization. Firstly, the development of digital financial inclusion reduces the sales expense rate of agricultural enterprises; that is, by reducing the sales expense rate of enterprises, the marketization of technological innovation achievements is accelerated. This may be because the change of the financial mode leads to the reduction of marketing costs, and digital financial inclusion makes it easier for enterprises to market their technological innovation achievements. Yang et al. (2009) believe that a high degree of marketization helps enterprises pay attention to the input and output of technological innovation and has a significant effect on improving enterprises' technological innovation level. Therefore, by developing digital financial inclusion, agricultural enterprises can improve market efficiency and then effectively accelerate the efficiency of technological innovation of enterprises. Secondly, the development of digital financial inclusion reduces the financing constraints of agricultural enterprises, that is, by expanding the financing channels of enterprises, the financing level of technological innovation can be improved. The reason for this may be that digital financial inclusion can alleviate information asymmetry and increase the external financing of enterprises. Gorodnichenko et al. (2013) believe that the external financing environment limits the technological innovation activities of enterprises, and innovative enterprises are more susceptible to the impact of financing constraints. Therefore, agricultural enterprises can solve complex financing constraints by developing digital financial inclusion and effectively improving the efficiency of enterprises' technological innovation. Finally, enterprise digitization can increase the promotion effect of digital financial inclusion; that is, it can promote the technological progress of enterprise innovation through digitization. Digital facilities and technology accelerate enterprises' information flow, enhance the information transparency of enterprises, and reduce the information asymmetry of geographical distance and cultural distance existing in the traditional financial model. Ardito et al. (2021) examined the impact of digitalization on technological innovation in small and medium-sized enterprises. The results show that digitalization has a direct positive impact on the innovation performance of small and medium-sized enterprises. Therefore, agricultural enterprises can effectively enhance the impact of digital financial inclusion on their technological innovation efficiency by enhancing their digital level.

4.2. Heterogeneity test

This paper classifies agricultural enterprises according to the degree of financing constraint and the nature of enterprises and further studies the heterogeneous influence of digital financial inclusion on technological innovation efficiency of different enterprises. The degree of financing constraint affects the technological innovation level of agricultural enterprises, and the nature of enterprises determines their technological innovation environment. Therefore, this paper chooses these two influencing factors as classification criteria to explore the heterogeneous impact of digital financial inclusion on the technological innovation efficiency of agricultural enterprises. In this paper, the SA index is calculated to measure the financing constraints of agricultural enterprises, and the median of the overall SA index and the average of the SA index of each agricultural enterprise are calculated. If the average SA index of agricultural enterprises is greater than the median, this paper believes that these agricultural enterprises are enterprises with high financing constraints, namely enterprises with low financing level. The empirical results are shown in Table 7.

Table 7. Heterogeneity test results.

Variable	High financing level (1) Patent	Low financing level (2) Patent	State-owned enterprises (3) Patent	Non-state-owned enterprises (4) Patent
Dfin	0.014**	0.001	0.011	0.005**
	(2.199)	(0.136)	(1.161)	(2.037)
Lev	−0.010	0.423	0.769	−0.729
	(−0.021)	(1.234)	(1.020)	(−1.634)
Lnsize	−0.396**	−0.056	−0.454**	−0.249**
	(−2.134)	(−0.455)	(−2.261)	(−2.228)
Lngov	−0.118	−0.011	−0.157**	−0.016
	(−1.564)	(−0.182)	(−2.123)	(−0.232)
Only1	−0.020	0.024	−0.038***	0.012
	(−1.367)	(0.933)	(−4.309)	(1.630)
Gain	0.000	0.000	−0.000	0.000
	(1.623)	(1.036)	(−1.661)	(1.040)
Time Effect	YES	YES	YES	YES
Individual Effect	YES	YES	YES	YES
_Cons	8.441**	1.189	10.273*	5.246***
	(2.123)	(0.526)	(1.836)	(2.752)
N	63	56	47	72

Note: *, ** and *** represent passing the significance test of 10%, 5% and 1%, respectively.

Table 7 shows that the heterogeneous impact of digital financial inclusion on the technological innovation efficiency of agricultural enterprises is reflected in the financing level and the enterprise nature. On the one hand, digital financial inclusion has a heterogeneous impact on their technological innovation efficiency for agricultural enterprises with different financing levels. In Column (1), the influence coefficient of digital financial inclusion on the technological innovation efficiency of agricultural enterprises with high financing level is 0.014, which is significant at the significance level of 5%. In Column (2), the influence coefficient of digital financial inclusion on the technological innovation efficiency of agricultural enterprises with low financing level is 0.001 but not significant. This indicates that digital financial inclusion has different impacts on the technological innovation efficiency of agricultural enterprises with different financing levels. On the other hand, for agricultural enterprises of different natures, digital financial inclusion also has a heterogeneous impact on their technological innovation efficiency. In Column (3), the influence coefficient of digital financial inclusion on the technological innovation efficiency of state-owned agricultural enterprises is 0.011 but not significant. In Column (4), the influence coefficient of digital financial inclusion on the technological innovation efficiency of non-state-owned agricultural enterprises is 0.005, which is significant at the significance level of 5%. This indicates that digital financial inclusion has different impacts on the technological innovation efficiency of agricultural enterprises with different natures, and the enterprises that are more suitable to improve the technological innovation efficiency through digital financial inclusion are non-state-owned agricultural enterprises with high financing level. So Hypothesis 4 is verified.

Digital financial inclusion has a significant impact on non-state-owned agricultural enterprises with high financing level. The reason why digital financial inclusion plays a more significant role in promoting innovation of enterprises with high financing level may be that those enterprises are more likely to get financial support for technological innovation. Enterprise technology innovation needs an ample and stable fund supply, and financing is an important factor that restricts enterprise technology innovation and industrial structure upgrading. Although the insufficiency of traditional financial mode causes the financing difficulties of enterprises, digital financial inclusion expands the financing channels of enterprises and gives them much support for technological innovation. Song et al. (2015) used dynamic panel data from 2003 to 2008 to discuss the impact of financing constraints caused by different political backgrounds on the innovation efficiency of 269 firms. The empirical results show that enterprises with political background will face weaker financing constraints than those without political background, making it easier for enterprises with low financing constraints to develop technological innovation. To improve the innovation efficiency of Chinese enterprises, the government should initiate long-term change and provide strong, short-term supervision. Enterprises themselves should strengthen internal management, use funds appropriately, optimize resource allocation, and actively carry out production and research and development activities such as those involving innovation, which is beneficial to long-term development.

The reason why digital financial inclusion plays a more significant role in promoting innovation of non-state-owned enterprises maybe that non-state-owned enterprises can get similar financial services as state-owned enterprises under the mode of digital financial inclusion. As non-state-owned enterprises are not owned by the government, they are subject to strong financing constraints and less financial support in the traditional financial market, which eventually leads to the deepening of information asymmetry between traditional financial institutions and non-state-owned enterprises. In the development of digital financial inclusion, financial institutions can quickly assess the credit level and enterprise value of non-state-owned enterprises with the help of digital technology to improve the possibility of financing. In addition, the system and mechanism of non-state-owned enterprises are more flexible. According to the development of digital financial inclusion, non-state-owned enterprises can quickly adjust the decision-making of innovative financing, optimize the allocation of innovative resources, and finally make digital financial inclusion more effectively support their technological innovation. Huang et al. (2017) took the innovation efficiency of enterprises as the research object and analyzed the agglomeration features based on the panel data of 23 Chinese industrial sectors from 2001–2013. They classified four types of enterprises: state-owned enterprises, individual enterprises, foreign-owned enterprises and enterprises as a whole. The results show that although the R&D investment and R&D personnel of state-owned enterprises are much more than those of the other three types of enterprises, the innovation efficiency of state-owned enterprises is lower than that of individual enterprises. This shows that non-state-owned enterprises have relatively more vital technological innovation ability, so the development of digital financial inclusion is more suitable for non-state-owned enterprises.

4.3. Marginal effect analysis

Based on the distribution of technological innovation efficiency of agricultural enterprises, this paper selects the quartiles of 5%, 25%, 50%, 75% and 95% to conduct quantile regression to explore

how the impact of digital financial inclusion on technological innovation efficiency of agricultural enterprises changes at different innovation levels. The empirical results are shown in Table 8.

Table 8. Marginal effect of digital financial inclusion on promoting technological innovation at different levels of innovation.

Variable	5th Patent (1)	25th Patent (2)	50th Patent (3)	75th Patent (4)	95th Patent (5)
Dfin	0.001	0.002*	0.004***	0.010***	0.023
	(0.12)	(1.81)	(2.64)	(3.88)	(1.21)
Control	YES	YES	YES	YES	YES
Time Effect	YES	YES	YES	YES	YES
Individual Effect	YES	YES	YES	YES	YES
_cons	−0.324	−0.521*	−0.870**	−2.124***	−4.784
	(−0.16)	(−1.68)	(−2.36)	(−3.53)	(−1.22)
N	119	119	119	119	119

Note: *, ** and *** represent passing the significance test of 10%, 5% and 1%, respectively.

The results in Table 8 show that, with the continuous increase of innovation level, the promotion effect of digital financial inclusion on the technological innovation efficiency of agricultural enterprises shows an increasing trend. In Columns (1) to (5), the influence coefficients of digital financial inclusion on the technological innovation efficiency of agricultural enterprises are 0.001, 0.002, 0.004, 0.01 and 0.023, respectively, but they are not significant at the innovation levels of 0.05 and 0.95. This indicates that with the increase of technological innovation level of agricultural enterprises, the promoting effect of digital financial inclusion is different. Therefore, Hypothesis 5 is verified. This paper holds that agricultural enterprises whose innovation level has not reached an advanced level can improve their technological innovation efficiency through the development of digital financial inclusion. The reason for the above results may be that the influencing factors of technological innovation are different at different levels of innovation. When the technological innovation level of agricultural enterprises is low, technological innovation is mainly affected by the financial environment. The traditional financial system can't provide a better financial environment to help enterprises effectively improve technological innovation. However, the development of digital financial inclusion can better improve the financial environment and alleviate financing constraints for enterprises. Therefore, digital financial inclusion has a pronounced promotion effect on the technological innovation efficiency of agricultural enterprises. With the improvement of innovation level of agricultural enterprises, the difficulty of technological innovation also increases. At this time, the improvement of technological innovation efficiency is more dependent on the technical level of agricultural enterprises rather than the financial environment. Digital financial inclusion cannot effectively improve the technical level of agricultural enterprises, so the promotion effect of digital financial inclusion is not significant. Afrin et al. (2017) investigate the impact of financial inclusion on the enhancement of paddy farmers' technical efficiency (TE). They discussed the relationship between TE and digital finance using least squares method and quantile regression. The results show that the impact of digital finance is more significant when TE is low. They believe that the government should enact appropriate policies to promote the development of corporate technical efficiency according to its size.

5. Conclusions

Using the data of Chinese A-share agricultural listed companies from 2015 to 2020, this paper explores how digital financial inclusion can effectively support the technological innovation efficiency of agricultural enterprises under the premise of controlling a variety of other factors that may affect the technological innovation efficiency. Compared with theoretical analysis, this paper studies how to efficiently support the technological innovation efficiency of agricultural enterprises based on the results of empirical analysis, which is more targeted. In particular, the mechanism of digital financial inclusion promoting technological innovation and the characteristics of enterprises suitable for the development of digital financial inclusion are studied in depth from the perspective of the innovation stage. In this paper, the DEA-Tobit two-step method is used to calculate the technological innovation efficiency of agricultural enterprises, and the influence of digital financial inclusion on the technological innovation efficiency of agricultural enterprises is explored, and the source of such influence is discussed. On this basis, through mechanism analysis, heterogeneity test and marginal effect analysis, this paper studies how digital financial inclusion can effectively promote the technological innovation of agricultural enterprises. This paper draws the following conclusions.

(1) Digital financial inclusion plays a significant role in promoting the technological innovation efficiency of agricultural enterprises, and the influence of its breadth is greater than that of its usage depth. The empirical results also passed the robustness test. The reason why the breadth of digital financial inclusion has a greater impact may be that the breadth of digital financial inclusion is growing faster than the usage depth. This leads to a more significant promotion of the former in the sample period.

(2) Agricultural enterprises can enhance the promoting effect of digital financial inclusion on their technological innovation efficiency by improving market efficiency, easing financing constraints and improving the level of enterprise digitalization. This paper holds that financing constraints and market efficiency play a mediating effect between digital financial inclusion and the technological innovation efficiency of agricultural enterprises, and enterprise digitization plays a moderating effect in the process of digital financial inclusion promoting the technological innovation efficiency of agricultural enterprises.

(3) In terms of financing level and enterprise nature, the impact of digital financial inclusion on the technological innovation efficiency of agricultural enterprises is heterogeneous. This paper holds that non-state-owned agricultural enterprises with a high financing level are more suitable for improving technological innovation efficiency through the development of digital financial inclusion. On the one hand, a high financing level will help enterprises raise innovative funds faster and more stably. On the other hand, non-state-owned enterprises can effectively improve their technological innovation level through digital financial inclusion.

(4) The promoting effect of digital financial inclusion on the technological innovation efficiency of agricultural enterprises increases with the improvement of enterprise innovation level. This shows that at different levels of innovation, the promoting effect of digital financial inclusion is different; moreover, it also has structural characteristics and presents an increasing trend with the improvement of innovation level.

Based on the above research conclusions, this paper proposes the following policy implications. First, while expanding the breadth of digital financial inclusion, emphasis should be placed on developing its usage depth. Taking China's digital financial inclusion as an example, this paper finds out from the empirical results that the breadth has a significant role in promoting the technological

innovation of agricultural enterprises, while the effect of the usage depth is not significant. This paper holds that the development of digital financial inclusion should be carried out simultaneously in two dimensions: extending the usage breadth and improving the usage degree of digital financial inclusion for agricultural enterprises. In this way, the incentive effect of digital financial inclusion on the technological innovation of agricultural enterprises can be better brought into play. Second, digital financial inclusion can enhance the promotion of technological innovation in agricultural enterprises in a variety of ways. Encouraging enterprises to use digital technology to digitize innovative products and services can also reduce the financing constraints of enterprises and make their technological innovation more in line with market demand (Wen et al., 2021). Digital financial inclusion can not only alleviate the problem of information asymmetry between enterprises and financial institutions and enable financial institutions to have a better evaluation of enterprises with high financing constraints but innovation potential, but also broaden the financing channels of enterprises, which is conducive to improve the technological innovation efficiency. Thirdly, non-state-owned agricultural enterprises with high financing levels should focus on developing digital financial inclusion. Such enterprises have abundant financing channels, which provide continuous economic support for their technological innovation. In addition, non-state-owned enterprises are flexible, and they can better adapt to the development of digital financial inclusion driven by profit maximization, making the innovation incentive effect of digital financial inclusion more obvious. Fourth, the application strategy of digital financial inclusion by agricultural enterprises should be adjusted according to the corporate innovation level. For enterprises with high innovation levels, the development of digital financial inclusion can't effectively improve their technological innovation. Therefore, they should pay attention to improving their own technical level (He and Walheer, 2020). For enterprises with great room to improve their innovation level, the development of digital financial inclusion can improve their external financial environment and help them alleviate financing constraints. Therefore, such enterprises should strive to effectively improve the level of technological innovation through the development of digital financial inclusion.

Conflict of interest

All authors declare no conflicts of interest in this paper.

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