Can Digital Finance Promote the Technological Innovation of Agricultural Enterprises? —Evidence from NEEQ Companies in China

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Abstract

Rationale: Particularly, agricultural enterprises tend to scale up production while neglecting innovation. This is because agriculture is more vulnerable than other sectors to sudden and unpredictable external shocks such as natural disasters, epidemics and food safety. Not surprisingly, as a form of production organization embedded in agriculture, agricultural weak characteristics will be reflected in the operation behavior of agricultural enterprises, and the operational risk of agricultural enterprises is obviously higher than the average level of other industries. Therefore, agricultural enterprises rarely regard technological innovation as the focus of enterprise management. At the same time, most agricultural enterprises are small and medium enterprises (SMEs). Due to their small scale and lack of credit system, agricultural enterprises face a more serious "credit rationing" situation in the financing process than large industrial enterprises, and their risk problems are also more prominent. Therefore, it is difficult for them to obtain financing, and external capital support for innovation. Namely, agricultural enterprises are far less capable than other enterprises in technology, capital, transformation of innovation achievements, prevention and resistance to risks. It is difficult to balance the cost and risk of innovation, which severely restrains agricultural enterprises' enthusiasm for innovation.

In general, strong financing constraints, high borrowing costs, hidden operating risks have always been the curse restricting the technological innovation of agricultural enterprises. Surprisingly, the innovation of digital technology, represented by core technologies such as artificial intelligence, blockchain, cloud computing, and big data and so on, has profoundly improved availability of financial services, decreased information asymmetry, reduced firm

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operating risks and optimized resource allocation. However, a key issue is that very little is known about the effects of such digital technology on agricultural enterprises' technological innovation in China.

Research Objectives: Under the background of digital economy, this paper discusses the effect and internal mechanism of digital finance on technological innovation of China's agricultural enterprises. **Research Methodology:** Based on the micro data of 278 agricultural NEEQ listed companies from 2011-2018 with province-level digital finance index, this paper employs unbalance panel data econometric model, mediation effect model and instrumental variable method for empirical testing. **Key Findings:** We find that: (1) digital finance promotes the technological innovation of agricultural enterprises, and manifested as two dimensions--the coverage breadth and digitalization of digital finance. (2) Digital finance has promoted the technological innovation of agricultural enterprises through three mechanisms: reducing business risks, reducing financing costs and alleviating financing constraints. (3) The improvement of digital finance on technological innovation of relatively small enterprises and enterprises in the central and western regions are more significant. That means digital finance has the characteristics of inclusiveness. **Conclusion and Recommendations:** Different from previous literatures that mostly use A-share superior companies, this paper selects the data of agricultural NEEQ listed companies with looser listing requirements and contributed to more than 70 percent of the country's technological innovation which can better represent the actual situation of most agricultural enterprises. It provides empirical evidence and mechanism for digital finance to promote agricultural enterprises' technological innovation. This paper reveals how financial institutions can stimulate the technological innovation of agricultural enterprises through the new financial development model of digital finance, and take digital finance as an important hub to promote the construction of an innovative country.

Key Words: Digital Finance; Technological Innovation; Agricultural Enterprises; Financing Constraints; Financing Cost; Operational Risk.

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Introduction

Innovation is conducive to enhancing competitive advantage (Porter, 1992) and is a key driving force for economic growth (Solow, 1957). However, limited by their ability of technology, capital, human resources, transformation of innovation achievements, preventing and resisting risks, agricultural enterprises are difficult to balance the cost and risk of innovation, which ultimately inhibits their enthusiasm for innovation (Xu & Chen, 2021). Compared to other industries, agriculture is more vulnerable to sudden and unpredictable external shocks such as natural disasters, epidemics and food safety. At the same time, the difficulty of technological innovation in agricultural enterprises is much higher than that in other industries due to the limitation of the education and cognition level of farmers, the application terminal of basic innovation achievements. That is, as a form of production organization embedded in agriculture, the operation behavior of agricultural enterprises is mapped by the weak characteristics of agriculture, and the operation risk of agricultural enterprises is significantly higher than the average level of other industries. Therefore, agricultural enterprises rarely regard technological innovation as the focus of enterprise management. At the same time, most agricultural enterprises are SMEs. Due to their small scale and lack of credit system, agricultural enterprises face a more serious "credit rationing' situation in the financing process than other industrial enterprises, and their risk problems are also more prominent. Therefore, it is difficult for them to obtain financing, and external capital support for innovation.

There is evidence that financial development affects the innovation capabilities of all types of companies (Benfratello et al., 2008). Among them, they usually believe that financial development will ease financing constraints, thereby promoting corporate R&D investment and innovation, which is conducive to macroeconomic growth. However, the issue of financial exclusion affects the availability of financing for SMEs, and it is difficult for companies with financial constraints to innovate (Beck & Demirgüç-Kunt, 2006). In fact, China's financial exclusion is very serious. For example, traditional financial services tend to favor large enterprises and ignore agricultural enterprises, making it difficult to continue to provide funds for agricultural enterprises. Therefore, for agricultural enterprises, sustained and stable funding sources are particularly important for technological innovation, and this requires new financial development that is different from the traditional financial system to provide financing support (Hall & Lerner, 2010; Acharya & Xu, 2017).

"Digital finance" can be broadly defined as the application of digital technology in the financial field that could transform the way of financial services, improve the financial services

efficiency, and optimize resource allocation. The characteristics of digital finance are reflected in the penetration of information technology into the financial industry, expanding the scope and availability of financial services, improving the efficiency and accuracy of financial support, and accelerating the depth of use in financial business expansion. At the same time, star-ups and large mature technology companies actively lay out digital technology-driven development strategies, in order to reverse the existing business pattern, innovate products and technologies, so as to promote the competitiveness of enterprises (Chen et al., 2019). At the present, digital finance has made great contributions to providing mobile payment, online loans and internet financial services, especially playing a prominent role in meeting the financial needs of agricultural enterprises.

However, in existing studies, the impact of digital finance on the innovation of agricultural enterprises is still unknown. Therefore, we have supplemented the gap in the effect of digital finance on the innovation of agricultural enterprises. In this paper, we evaluate whether and how the development of digital finance influences the agricultural enterprises' innovation and further explore its mechanisms in China. Using data from Chinese NEEQ-Listed Companies between 2011 and 2018, and the digital finance index developed by Peking University, this study investigates the effect of digital finance on agricultural enterprises' innovation. We document the following three results: First, we find that digital finance promotes technological innovation for agricultural enterprises, which is manifested in the two dimensions of the use depth and digital support services of digital finance. Second, digital finance promotes technological innovation in relatively small enterprises and enterprises in the central and western regions, demonstrating the characteristics of inclusiveness. Third, the potential mechanisms for digital finance to promote agricultural enterprises innovation may be to reduce financing costs, ease financing constraints and reduce operational risks, indicating the existence of financing channels and risk channels.

The contributions mainly include the following two aspects in this paper. Firstly, this paper enriches the relevant literatures on factors affecting agricultural enterprises' innovation. For example, existing literature have well documented the impact of the different factors on agricultural enterprises' innovation such as cooperation networks (Zeng et al., 2010; Ioanid et al., 2018), institution-based barriers (Zhu et al., 2016), and knowledge management (Alegre et al., 2013; De Zubielqui et al., 2019; Yao et al., 2020). We are the first paper to analyze the impact of digital finance on the innovation of agricultural enterprises, enriching the understanding of the factors affecting the innovation of agricultural enterprises.

Secondly, this paper expands the related literatures on digital finance and its economic effects. For example, while existing studies have well documented the impact of the digital finance on firm innovation (Chen et al., 2018), financial stability (Fung et al., 2020), bank risk taking (Wang et al., 2020), bank performance (Phan et al., 2020), credit risk (Cheng and Qu, 2020), household consumption (Li et al., 2020). For the first time, we analyzed the effect of digital finance on the innovation of agricultural enterprises, and explained this positive effect from alleviating financing constraints, reducing borrowing costs, and reducing corporate risks.

The rest of this paper is as follows: Section 2 describes theoretical framework, Section 3 describes the research design, Section 4 reports the main empirical results, and Section 5 clarifies further analysis, and Section 6 describes conclusions.

Theoretical framework

Institutional background

Financing difficulty and financing expensive are two major factors restricting the technological innovation of agricultural enterprises. Agricultural enterprises are mostly small and medium-sized enterprises. Due to their small scale and lack of credit system, they face more severe credit rationing than large industrial enterprises in the process of financing. First, banks and other financial institutions follow the principle of "liquidity, safety and profitability" when lending, which leads to that they will not issue loans to agricultural enterprises hastily. Second, banks and other financial institutions have to undergo careful evaluation and assessment procedures before lending, which cannot meet the high frequency and urgent funding requirements of agricultural enterprises, leading to strong financing constraints. Even if agricultural enterprises obtain funds, they may have to bear high financing costs due to lack of collateral. Therefore, financing difficulty and financing expensive are two different concepts, corresponding to strong financing constraints and high financing costs respectively.

High operation risk is another factor that restricts the technological innovation of agricultural enterprises. Allen et al. (2005) show that informal institutions play a pivotal role in China, where formal institutions are lacking. This implies that in the absence of formal credit, agricultural enterprises obtain credit through private financing and other means, thereby obtaining the guarantee of short-term development. In addition, the average life span of Chinese agricultural enterprises is relatively short, and it is difficult for them to achieve long-term and healthy development. It is not difficult to speculate that this short-term survival is related to the inability to obtain long-term credit, and the lack of extensive management and long-term

business strategies leads to very high operating risks for agricultural enterprises, which in turn exacerbates their failures. At the same time, a few surviving agricultural enterprises lack a grasp of market risks after obtaining short-term benefits, which leads to a weak purpose in capital use and a decline in capital use efficiency, leading to a sharp increase in operating risks. Therefore, without a mature loan management and risk control system, the operation risks of agricultural enterprises will inhibit their development, and it will be more difficult for banks and other financial institutions to price their risks.

Overall, financing difficulties, financing expensive and high operation risks in the development of agricultural enterprises have a profound impact on their promotion of technological innovation.

Theoretical analysis

Combined with the characteristics of financing difficulties, expensive financing and high operating risk of agricultural enterprises, we believe that digital finance can reduce financing constraints, borrowing costs and operation risks, and then conducive to its technological innovation.

First, we believe that digital finance deeply integrates technology and can alleviate financing constraints, thereby promoting the innovation of agricultural enterprises. Specifically, digital finance helps to make up for the shortcomings of traditional financial services, and its many advantages can better alleviate financing constraints, thereby promoting innovation and entrepreneurship (Xie et al., 2018). Existing research shows that digital finance can make up for the shortcomings of traditional financial services, thereby improving bank efficiency and reducing bank risks (Phan et al., 2020). Moreover, digital finance can lower the threshold of financial services, broaden financing channels, improve financing efficiency, and finally ease financing constraints. For example, in addition to traditional financial institutions, P2P online loans, small loans, mobile payments, crowdfunding, and new financing platforms can all provide related financing channels, which greatly broadens the financing channels for agricultural enterprises. In addition, the technological means represented by artificial intelligence, big data, cloud computing, blockchain and Internet of Things make digital finance have the advantages of low cost, fast speed, and wide coverage, and then improve the financing efficiency of agricultural enterprises through accurate multi-dimensional evaluation. At the same time, the easing of financing constraints can stimulate the occurrence of innovation activities. Hence, we propose hypothesis 1.

Hypothesis 1: Digital finance promotes agricultural enterprises' innovation by alleviating financing constraints.

Second, we believe that digital finance reduces the financing costs of agricultural enterprises, thereby enhancing their innovation. Digital finance based on information technology is an important driving force for business model change, which changes the face-to-face transaction model in the traditional business model, greatly reduces the transaction costs of traditional financial services and improves transaction efficiency (Zeng and Reinartz, 2003). Compared with traditional finance, digital finance pays more attention to scale effect and tail effect, through the accumulation of existing data reduces the marginal cost of developing related business, the Internet of business model also makes the scope of digital financial coverage is not limited by time and space (Lu, 2018), which just solves the problem of uneconomic scale of traditional finance. In the past, traditional financial institutions typically transferred costs such as manpower, material resources generated from the entire loan review process to credit applicants, such as agricultural enterprises. At the present, digital finance can better screen agricultural enterprises with good credit in the credit approval process, reducing the rent-seeking phenomenon in the process of human intervention, and thus reducing the financing costs. At the same time, the reduction of financing costs can encourage agricultural enterprises to innovate. Hence, we present the hypothesis 2.

Hypothesis 2: Digital finance promotes agricultural enterprises' innovation by reducing financing costs.

Third, we believe that digital finance reduces the operating risks of agricultural enterprises and promotes their innovation. Enterprises face many internal and external uncertainties in the process of operation, which increase corporate risks, especially for agricultural enterprises. In the face of external shocks, agricultural enterprises are more likely to face loan withdrawals and loan suspensions by financial institutions, and they have to use innovation funds to combat risks, which is not conducive to their innovation. Digital finance can supervise their operations and innovation activities based on massive amounts information of agricultural enterprises, through their business data and capital usage information, to help them discover the risks in the business process in advance and warn of possible external shocks. In addition, the reduced risk of agricultural enterprises will lead to greater willingness and ability to innovate. Hence, we present hypothesis 3.

Hypothesis 3: Digital finance promotes agricultural enterprises' innovation by reducing operating risk.

Methodology

Sample Selection and Data Source

Our data are collected from various sources. We collect digital finance data from Peking University Digital Finance Inclusion Index (DFIIC) published by the Digital Finance Research Center of Peking University (Guo et al. 2020). Guo et al (2020) compiled DFIIC on the big data of Ant Financial, which representative reflects the development of new finance in China, and the index has been adopted by a lot of studies (Li et al., 2020; Hua and Huang, 2021).

Our enterprises dataset is collected from China Center for Economic Research (CCER) database[1] and WIND database[2]. According to Wang & Li (2021), agricultural enterprises mainly include traditional agricultural enterprises in the primary industry and agricultural products processing enterprises in the secondary industry. In this paper, the (1) agriculture, forestry, animal husbandry and fishery; (2) farm and sideline food processing industry, (3) Food manufacturing industry, and (4) wine, beverage and refined tea manufacturing industry are identified as agricultural enterprises. As our research object is agricultural enterprises, we collect sample data from the listed companies of China's National Equities Exchange and Quotations (NEEQ) market, which mainly from the following two reasons. (1) NEEQ also known as National SME share transfer system, its listing requirements are looser than those of Shanghai and Shenzhen, which also namely main board market. Moreover, the number of listed companies on the NEEQ over ten thousand, distributed in various provinces and cities throughout the China. Although the scale is smaller than the listed companies in Shanghai and Shenzhen capital markets, it has contributed more than 70% of the technological innovation. (2) Combined with the inclusive characteristics of digital finance, it is more reasonable to select listed companies from NEEQ than those from A-share in Shanghai and Shenzhen for research.

Since the annual span of DFIIC is from 2011 to 2018, this article matches the digital finance index with the data of NEEQ listed companies according to the region and year. In data processing, the sample data are processed as follows: (1) financial listed companies are

1 CEER：http://www.ccerdata.cn

2 WIND：https://www.wind.com.cn/

excluded; (2) samples with obvious data loss of main variables are excluded; (3) continuous variables are treated with 1% bilateral tail reduction. After the above data processing, the final total sample size was 1440 observations for 278 agricultural enterprises from 2011-2018. It is worth noting that this paper adopts unbalance panel data.

Variable

(1) Explain the variable (*patent*)

Due to the large lack of R&D investment indicators of the NEEQ listed companies, this paper uses patent data (*patent*) to measure enterprise innovation. Griliches et al. (1988) believed that the application year could capture the actual time of innovation better. Therefore, this article uses the application year rather than the obtain year to define the enterprise innovation, since the number of enterprise patent applications in some years is 0 and its distribution has thick tail characteristics. We uses natural logarithm of patent number plus 1 to measure enterprise innovation. In addition, because of the difficulty to obtain the number of patents citation of NEEQ listed companies. This paper draws on the methods of Dang and Kazuyuki (2015), divides patent application number into two types: the number of invention patent applications and non-invention patent applications (the latter includes utility model patent application number and appearance design patent application number) for robustness test.

(2) Core explanatory variables (*ifi*)

In this paper, the DFIIC prepared by Guo et al (2020) was used as the core explanatory variable, and referring to Li et al (2020), the digital inclusive financial index was divided by 100 to measure digital finance (*ifi*). In terms of dimensional heterogeneity, the digital financial index compiled by Guo et al (2020) includes subindexes such as coverage breadth, usage depth and digital support services. Due to the space limitation, the specific content and detailed measurement methods of all dimensions are not carefully explained. The relevant information can be consulted through the digital financial index report prepared by Guo et al. (2020).

(3) Mechanistic variable （*Debt*，*FC*，*Risk*）

Refer to the research method of Ylhainen (2017), this paper adopts finance expenses divided by the average of the current and previous year's outstanding corporate debt to measure the borrowing cost (*Debt*). The calculation formula of enterprise outstanding debt is: outstanding debt = long-term loan + short-term loan + payable. For financing constraints (*FC*),

In this paper, the idea of Whited and Wu (2006) are used to construct WW index. The calculation formula is:

$$WW=0.938-0.091CF-0.062DIVPOS + 0.021TLTD-0.044LNTA + 0.102ISG-0.035SG. \quad (1)$$

Where the coefficients in the formula are given by Whited & Wu (2006), *CF* is the ratio of cash flow to total assets; *DIVPOS* is a dummy variable with a value of 1 when dividends are paid; *TLTD* represents the ratio of long-term liabilities to total assets; *LNTA* represents the natural log of the total assets; *ISG* represents the growth rate of industry sales revenue; *SG* represents the actual growth rate of revenue from sales. For operating risk (*Risk*), refer to the research method of Derrick et al. (2020), this paper uses standard dispersion (standard deviation/mean value) of the main business income to measure.

(4) Other control variables.

Referring to Kaa et al. (2017) and Lu et al. (2021), in order to reduce the endogenous bias caused by missing variables, this paper chooses the following control variables: enterprise capital expenditure (*Capital*), using the ratio of capital expenditure to total assets at the end of the year to measure. Enterprise scale (*Size*), using the natural logarithm of the number of employees to measure. Corporate leverage (*Leverage*), using the ratio of total liabilities to total assets at the end of the year. Enterprise fixed assets (*PPE*, property, plant and equipment), using total fixed assets to total assets at the end of the year to measure. Cash flow (*Cash*), using monetary funds divided by total assets. Yield on assets (*ROA*), using the ratio of net income to total assets to measure. Enterprise age (*Age*) is measured by the natural log of listing year plus 1. For province-level control variables, the economic development level (*GDP*) and human capital (*STU*) of the province where the enterprise located are used to control the influence of regional macroscopic factors. The former uses the natural logarithmic of the provincial GDP and the latter using the natural logarithmic of the number of college students in the province to measure. Table 1 gives the names and definitions of all the variables. Table 2 shows the descriptive statistics for all the variables. Correlation tests for all variables are shown in Appendix 1 and found that most of the values in the correlation coefficients between each explanatory variables in the model (2) are below 0.3, indicating that no multiple collinearity problems are present in the model (2).

Model

In order to evaluate the impact of digital finance on the technological innovation of agricultural enterprises, it is reasonable to take digital finance as the explanatory variable, the

number of patent applications for agricultural enterprises as the explained variable, and to construct the following model:

$$patent_{it} = \alpha_0 + \alpha_1 ifi_{it} + \gamma Controls_{it} + u_i + \mu_p + \theta_t + \varepsilon_{it} \qquad (2)$$

In formula (2), the explained variable is the technological innovation of agricultural enterprise i in year t, using the number of agricultural enterprise patent applications measures. The core explanatory variable is digital finance in the province where agricultural enterprise i located in year t, using digital financial index divided by 100 to measure. $Controls$ represents all other control variables. Furthermore, the model controlled for corporate fixed effect (u_i), province fixed effect (μ_p), and year fixed effect (θ_t). ε_{it} representing the residual terms in the model. The coefficient α_1 indicates the effect of digital finance on technological innovation in agricultural enterprises, which is expected to be significantly positive.

Table 1: Variable Selection and Definition

Variable name	Variable meaning	Metrics
Patent	Enterprise innovation	ln (patent application number + 1)
Patent1	Invention patent	ln (invention patent application number + 1)
Patent2	Non-invention patent	ln (utility model patent application number + appearance design patent application number + 1)
ifi	Digital finance	Digital inclusive finance index / 100
Debt	Lending costs	Financial expenses / average of corporate outstanding debt for the current year and previous year
FC	Financing constraints	The WW index
Risk	Operational risk	Standard dispersion of the main business income (three years before and after)
Capital	Capital expenditure	Capital expenditure / total assets
Size	Enterprise size	ln (staff number)
Leverage	Leverage ratio	Total liabilities / total assets
PPE	Fixed assets	Fixed assets / total assets
Cash	Cash flow	Monetary funds / total assets
ROA	Yield on assets	Net profit / total assets
Age	Corporate age	ln (enterprise listing years+ 1)
GDP	Level of economic development	ln (GDP of province)
STU	Human capital	ln (number of college students in province)

Table 2 Descriptive statistics of the main variables

Variables	Observations	Mean	Std.dev.	Minimum	Median	Maximum

Patent	1440	0.849	1.095	0.000	0.000	3.689
Patent1	1440	0.443	0.745	0.000	0.000	2.944
Patent2	1440	0.629	0.948	0.000	0.000	3.296
ifi	1440	2.671	0.489	0.162	2.675	3.685
Debt	1440	0.058	0.072	0.000	0.039	0.541
FC	1440	0.152	0.0920	-0.0050	0.139	0.412
Risk	1440	0.275	0.204	0.0380	0.218	0.871
Capital	1440	0.034	0.074	-0.097	0.008	0.360
Size	1440	4.815	1.018	2.197	4.771	7.659
Leverage	1440	0.411	0.211	0.029	0.404	0.977
PPE	1440	0.163	0.161	0.001	0.109	0.670
Cash	1440	0.172	0.173	0.001	0.112	0.793
ROA	1440	0.026	0.120	-0.543	0.011	0.350
Age	1440	2.406	0.431	0.693	2.485	4.094
GDP	1440	10.570	0.635	6.407	10.490	11.480
STU	1440	13.46	0.429	11.590	13.470	13.940

Empirical results and analysis

Basic Results

The regression results for the model (2) are shown in Table 3. Column (1) is univariate regression results and column (2) contains regression results for all control variables (enterprise-level and province-level control variables). Moreover, by strictly controlling the fixed effect (enterprise fixed effect, provincial fixed effect and year fixed effect) to alleviate the endogenous problem of this paper, and using the robust standard error to alleviate the heteroskedasticity problem. It is worth noting that, after controlling the enterprise fixed effect, the provincial fixed effect will be absorbed. The empirical results in columns (1) and (2) of Table 3 show that the coefficient of digital finance (*ifi*) is significantly positive, indicating that the development of digital finance is significantly positively related with the innovation output of NEEQ listed companies, in line with theoretical expectations. In terms of economic significance, when the digital financial index rises by one percentage point, the innovation of agricultural enterprises will rise by 47% accordingly. The reasonable explanation is that digital finance reduces financing costs, alleviates financing constraints, decreases business risks, and then promotes technological innovation of agricultural enterprises. Studies similar to this paper show that digital finance promotes enterprise innovation (Wan et al., 2020; Tang et al., 2020). On this basis, the digital finance found in the text clearly complements the technological innovation of agricultural enterprises.

Table 3 The benchmark regression results

Variables	(1) Innovation	(2) Innovation
ifi	0.519***	0.470***
	(4.28)	(3.53)
Capital		-0.061
		(-0.79)
Size		0.201***
		(11.55)
Leverage		-0.139***
		(-3.02)
PPE		-0.286***
		(-3.22)
Cash		0.069
		(1.60)
ROA		0.401***
		(8.98)
Age		0.430***
		(4.15)
GDP		0.375**
		(2.23)
STU		1.365***
		(4.99)
Constant	0.243**	-23.395***
	(2.23)	(-6.01)
Firm effect	Yes	Yes
Year effect	Yes	Yes
Province effect	Yes	Yes
Observations	1440	1440
R-squared	0.056	0.071

Note: ***、**、* are significant at the 1%, 5%, and 10% levels, respectively; the values in parentheses are t-value.

Endogeneity Issue

The key point to interfere with digital finance to promote agricultural enterprises' technological innovation is the consideration of endogenous issues. Li et al. (2020) believed that fintech, as a macro variable, was less affected by the innovation behavior of individual enterprises. Similarly, the digital finance is also a variable at the macro-province level, and the endogenous problem is relatively small. However, variable omission and measurement error still restrict the reliability of the conclusion. This paper further solves the endogenous problem through the instrumental variable method to make the conclusion more reasonable.

The paper uses the number of mobile phones in each province as the instrument variable of digital finance. The demonstration of correlation is telephone penetration rate which is closely related to the development of the Internet (Huang et al., 2019), and both determine the level of digital financial development to a certain extent (Huang and Huang, 2018). At the same time, the better the Internet development, the more likely the regions are to accept new technologies, so there may be better basic and realistic needs for the development of digital finance (Qian et al., 2020). The exclusivity argument is that：the innovation behavior of agricultural enterprises is hardly directly affected by the number of mobile phones in each province. The empirical results in Table 4 columns (1) and (2) are the results of stage 1 and stage 2 of the instrument variable method, respectively. The results of column (1) show that the coefficient of mobile phone number in each province is significantly positive, proving the existence of correlation. F value is 2649.153, indicating no weak instrument variable problem. The results of column (2) show that the coefficient of digital finance (*ifi*) is significantly positive, indicating that the development of digital finance is significantly positively related with the innovation output of NEEQ listed companies, consistent with the basic regression results. The conclusions of the paper remain valid after controlling for the endogenous problem.

Table 4 Tool variable regression results

	(1)	(2)
Variables	*ifi*	Innovation
ifi		1.587***
		(3.86)
IV	0.000***	
	(51.47)	
Capital	0.007**	-0.074
	(2.25)	(-0.98)
SIZE	-0.001	0.197***
	(-1.48)	(13.03)
Leverage	0.008***	-0.142***
	(3.82)	(-3.26)
PPE	0.002	-0.294***
	(0.60)	(-3.52)
Cash	-0.004**	0.071*
	(-2.50)	(1.76)
ROA	-0.003*	0.401***
	(-1.88)	(9.35)
Age	-0.000	0.392***

	(-0.01)	(4.26)
GDP	0.503***	-0.208
	(51.59)	(-0.84)
STU	-0.555***	1.685***
	(-33.00)	(6.26)
Firm effect	Yes	Yes
Year effect	Yes	Yes
Province effect	Yes	Yes
Observations	1440	1440
R-squared		0.067
The F value	2649.153	103.930
The Cragg-Donald Wald value		2940.870

Note: ***, ** and * are significant at 1%, 5% and 10%, respectively; values in column (1) parentheses are t value and values in column (2) parentheses are Z value.

Robustness Test

(1) Change Variable (Invention Patent vs Non-invention Patent)

In the decomposition of the explained variables, the total number of patents is usually divided into two types --invention patents and non-invention patents, while non-invention patents include utility model patents and appearance design patents. The classification of invention patents as innovation quality and non-invention patents as innovation quantity by previous studies may not be standard. Therefore, it may be more accurate to use patent citations as a measure of innovation quality when the data is available (Moshirian et al.,2021).

However, the patent citation data of NEEQ listed companies are not disclosed, this paper can only use invention patents and non-invention patents as explanatory variables. The regression results for the model (1) are shown in Table 5. The study found that the coefficient of digital finance was significantly positive in columns (1) and (2), indicating that the digital finance was significantly positively related with the number of invention patents and non-invention patents of NEEQ listed companies. It is proved that the research conclusion is robust.

Table 5 Regression results of digital finance on invention patent innovation and non-invention patent innovation

Variables	(1) Invention patent	(2) Non-invention patent
ifi	0.301***	0.302**
	(3.40)	(2.54)
Control variable	Yes	yes
	(0.38)	(-0.99)
Firm effect	Yes	Yes
Year effect	Yes	Yes
Province effect	Yes	Yes
Observations	1440	1440
R-squared	0.050	0.047

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

(2) Change Quantitative Methods

In terms of model selection, because of the count characteristics of the number of patent applications, it is reasonable and appropriate to adopt Poisson regression and negative binomial regression models (Li et al., 2020). During the sample period, the number of patent applications of many agricultural enterprises is 0, and the descriptive statistics results show that the variance of the number of patent applications was greater than the mean, presenting the uneven distribution characteristics. Those suggest that the zero-inflated negative binomial (ZINB) may be the optimal model. The regression results are shown in Table 6. The coefficient of digital finance is significantly positive in columns (1) and (2) of Table 6, indicating that the digital finance is also significantly correlated with the total number of patents of NEEQ listed companies, further proving the research conclusion is robust.

Table 6 The regression results of ZINB model

Variables	(1) Innovation	(2) Innovation
ifi	0.367*	0.443**
	(1.80)	(2.25)
Control variable	Yes	Yes
Firm effect	NO	Yes
Year effect	Yes	Yes
Province effect	Yes	Yes
Observations	1440	1440
vuong	377.10***	80.71***

Note: ***, **, * are significant at the 1%, 5%, and 10% levels, respectively; the values in parentheses are Z.

Mechanism Analysis and Heterogeneity Test

Mechanism Analysis

The previous theory analyzed that digital finance affects the technology innovation of agricultural enterprises through three mechanisms: financing constraint, borrowing cost and business risk. Referring to the mediation effect model analysis method of Wen et al (2004), this paper constructs the following econometric model:

$$media_{it} = \beta_0 + \beta_1 ifi_{it} + \gamma Controls_{it} + u_i + \mu_p + \theta_t + \varepsilon_{it} \quad (2)$$

$$patent_{it} = \theta_0 + \theta_1 ifi_{it} + \theta_2 media_{it} + \gamma Controls_{it} + u_i + \mu_p + \theta_t + \varepsilon_{it} \quad (3)$$

Where model (2) tests the impact of digital finance on mechanism variables; model (3) is to add mechanism variable on the basis of model (1) to analyze the existence of mediation effect. The control variables for model (2) and model (3) are the same as for model (1). The existence of mediation effects is judged by the regression coefficient of model (1), model (2) and model (3). If the digital financial coefficient (α_1) in model (1) is significant, then the digital financial coefficient (β_1) in model (2) and the mechanism variable coefficient (θ_2) in model (3) should be further tested. If both the coefficients β_1 and θ_2 are significant, the coefficients θ_1 is further tested. If the coefficient θ_1 is significant, there is a partial mediation effect; if the coefficient θ_1 is not significant there is a full mediation effect.

The previous research conclusion shows that digital finance promotes enterprise innovation, namely coefficient α_1 is significant. In order to further explore the mechanism of digital finance affecting the agricultural enterprises' technological innovation, this paper mainly analyzes the mechanisms from the three perspectives: reducing borrowing costs, easing financing constraints and decreasing operating risks. Regression results for model (2) and model (3) are shown in Table 7. Column (1) and (2) in Table 7 test the borrowing cost mechanism. The digital financial coefficient in column (1) is significantly negative, indicating that digital finance reduces corporate borrowing costs. Significantly negative borrowing cost coefficient in column (2) indicates that reducing borrowing cost is beneficial to agricultural enterprises' technological innovation. Moreover, the digital financial coefficient in column (2) is significantly positive, indicating that borrowing cost plays a partial mediation effect, verifying the hypothesis that digital finance promotes agricultural enterprises' technological innovation by reducing borrowing cost. Similarly, columns (3) and (4) in Table 7 test the

financing constraint mechanism. The digital financial coefficient in column (3) is significantly negative, indicating that digital financial alleviates corporates' financing constraints. The coefficient of financing constraint in column (4) is significantly negative, indicating alleviating financing constraints is beneficial to agricultural enterprises' innovation; and the coefficient of digital financial in column (4) is significantly positive, indicating that the financial constraints have partial mediation effect, verifying the hypothesis that digital finance promotes technological innovation of agricultural enterprises by alleviating financing constraints. Finally, columns (5) and (6) in Table 7 test the operating risk mechanism. The digital financial coefficient in column (5) is significantly negative, indicating that digital financial reduces enterprise operating risk. The operating risk coefficient in column (6) is significantly negative, indicating that reducing operating risk is conducive to the innovation of agricultural enterprises. However, the digital financial coefficient in column (6) is not significant, indicating that the operating risk has a full mediation effect, and verifying the hypothesis that digital financial promotes the technological innovation of agricultural enterprises by reducing operating risks.

It is worth noting that borrowing costs and financing constraints are policy-based. Through information technology, digital finance provides diversified financing channels for enterprises, and promotes the technological innovation of agricultural enterprises by alleviating the "financing difficulties" of enterprises. In addition, digital finance reduces the transaction costs and various operating costs. As a result, more financial institutions are willing to provide credit services to agricultural enterprises. At the same time, because of digital finance, companies have an advantage in information collection. They can reduce their own debt financing costs by screening debt financing that is beneficial to them, thus promoting their technological innovation. However, in addition to policy, with digital finance, enterprises can reduce their own business risks and ultimately stimulate innovative behavior. Overall, this paper finds that digital finance can promote the innovation of agricultural enterprises through three mechanisms: reducing borrowing costs, financing constraints and operating risk.

Table 7 The regression results of mechanistic analysis

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	*Debt*	Innovation	*FC*	Innovation	*Risk*	Innovation
ifi	-0.028**	0.366*	-0.015*	0.318**	-0.058*	0.248
	(-2.04)	(1.95)	(-1.77)	(1.97)	(-1.65)	(1.46)
Debt		-0.749***				
		(-5.85)				
FC				-0.230*		
				(-1.71)		
Risk						-0.129***
						(-2.93)
Capital	-0.034***	-0.029	-0.045***	-0.027	0.063***	-0.053
	(-4.57)	(-0.24)	(-8.08)	(-0.27)	(2.98)	(-0.52)
Size	-0.008***	0.240***	-0.027***	0.188***	-0.085***	0.191***
	(-3.65)	(8.16)	(-17.98)	(8.82)	(-13.82)	(8.43)
Leverage	0.003	-0.193**	-0.031***	-0.231***	0.044***	-0.191***
	(0.41)	(-2.34)	(-7.14)	(-3.92)	(2.65)	(-3.03)
PPE	0.025***	-0.338***	0.012**	-0.274**	0.019	-0.274**
	(3.37)	(-2.60)	(2.04)	(-2.55)	(0.80)	(-2.37)
Cash	-0.012*	0.090	-0.041***	-0.002	0.052***	0.052
	(-1.88)	(1.01)	(-9.65)	(-0.03)	(3.20)	(0.88)
ROA	-0.044***	0.325***	-0.132***	-0.131**	-0.133***	-0.085
	(-6.16)	(3.83)	(-29.03)	(-2.29)	(-8.51)	(-1.48)
Age	-0.013	0.449***	-0.025***	0.050	-0.180***	0.220
	(-1.17)	(2.63)	(-3.50)	(0.34)	(-5.14)	(1.48)
GDP	0.024	0.534**	-0.010	0.135	0.071	0.241
	(1.45)	(2.18)	(-1.02)	(0.63)	(1.52)	(1.07)
STU	0.006	1.295***	-0.004	1.524***	-0.051	1.683***
	(0.20)	(3.18)	(-0.25)	(4.25)	(-0.61)	(4.58)
Constant	-0.158	-24.03***	0.665***	-21.97***	0.971	-25.49***
	(-0.40)	(-4.09)	(2.92)	(-4.30)	(0.84)	(-4.81)
Firm effect	Yes	Yes	Yes	Yes	Yes	Yes
Year effect	Yes	Yes	Yes	Yes	Yes	Yes
Province effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1440	1440	1440	1440	1440	1440
R-squared	0.042	0.058	0.784	0.034	0.051	0.044

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

Heterogeneity Analysis

For listed companies on NEEQ, their geographical location, relative scale and different dimensions of digital finance may affect the role it plays on innovation. Based on this, this article further observes the influence of heterogeneity through cross-sectional group test.

First of all, due to the extremely unbalanced economic and social development in China as well as the different financial resource endowments in different regions, there may be a big gap in the incentive effect of digital finance on agricultural enterprises' technology innovation. In this case, it is reasonable and appropriate to divide agricultural enterprises by location.

Therefore, the regression results of heterogeneity test based on enterprise location are presented in Table 8. The most interesting finding is that in the central and western region, digital finance improved agricultural enterprises' technology innovation, while the results in the eastern region shows no significant impact. A possible explanation for this might be that digital finance can make up for the lack of traditional finance, slow down financial exclusion, so that underdeveloped regions can also enjoy convenient and inclusive financial services, thus promoting the innovation of agricultural enterprises in underdeveloped regions (central and western regions), and verifying the inclusive characteristics of digital finance.

Table 8 The regression results of heterogeneity test based on enterprise location

	(1)	(2)
Variables	Eastern	Central and western
ifi	0.102	0.603**
	(0.46)	(2.37)
Capital	0.002	-0.222
	(0.02)	(-1.56)
Size	0.178***	0.253***
	(9.28)	(7.09)
Leverage	-0.103**	-0.227**
	(-2.01)	(-2.30)
PPE	-0.257**	-0.357**
	(-2.36)	(-2.35)
Cash	0.052	0.132
	(1.13)	(1.32)
ROA	0.417***	0.314***
	(8.50)	(3.06)
Age	0.283**	0.609***
	(2.43)	(3.08)
GDP	0.554	0.555**
	(1.50)	(2.55)
STU	2.375***	0.475
	(5.05)	(1.32)
Constant	-38.415***	-14.400***
	(-4.63)	(-3.04)
Firm effect	Yes	Yes
Year effect	Yes	Yes
Province effect	Yes	Yes
Observations	1029	411
R-squared	0.073	0.070

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

Secondly, agricultural enterprises in the NEEQ market often lack financial services and financial resources that meet their needs due to their small scale, imperfect information disclosure mechanism and large degree of information asymmetry. In this case, it is reasonable and appropriate to divide agricultural enterprises by enterprise size, so the regression results of the heterogeneity test based on enterprise size are presented in Table 9. The current study finds that compared with larger enterprises, the coefficient of digital finance is larger and more significant for smaller enterprises, indicating that digital finance plays a greater role in promoting innovation of small enterprises, which further verifies the universality characteristics of digital finance.

Table 9 The regression results for heterogeneity tests based on enterprise scale

	(1)	(2)
Variables	Large scale	Small scale
ifi	0.358*	0.432**
	(1.88)	(2.25)
Capital	-0.056	-0.081
	(-0.43)	(-0.81)
Size	0.202***	0.264***
	(7.18)	(10.95)
Leverage	-0.295***	-0.089
	(-3.38)	(-1.50)
PPE	-0.089	-0.387***
	(-0.64)	(-3.10)
Cash	0.198***	0.021
	(2.59)	(0.38)
ROA	0.659***	0.279***
	(6.95)	(5.26)
Age	0.461***	0.278**
	(2.80)	(1.97)
GDP	0.321	0.452**
	(1.26)	(1.97)
STU	1.471***	1.278***
	(3.52)	(3.24)
Constant	-24.312***	-23.059***
	(-4.13)	(-4.15)
Firm effect	Yes	Yes
Year effect	Yes	Yes
Province effect	Yes	Yes
Observations	720	720
R-squared	0.062	0.072

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

Finally, from the perspective of three different subindexes of digital financial index (covering breadth, usage depth and digital support services), it is worth paying attention to whether there is a difference in the incentive effect of digital finance on the technological innovation of agricultural enterprises. Based on this, it is reasonable and appropriate to use model (1) to carry out empirical test by replace digital finance with its different dimensions. Therefore, the regression results of heterogeneity tests based on subindexes of different dimensions are presented in Table 10. The column (1) in Table 10 is to test the impact of digital financial coverage breadth on the innovation of agricultural enterprises. One interesting finding is that coverage breadth coefficient in column (1) is not significant, which indicates the coverage breadth of digital finance cannot effectively stimulate agricultural enterprises' innovation. Column (2) in Table 10 is to test the impact of usage depth of digital finance on agricultural enterprises' innovation. The usage depth coefficient in column (2) is significantly positive, indicating that the usage depth of digital finance effectively encourages agricultural enterprises' innovation. Similarly, column (3) in Table 10 is to test the impact of digital support services on agricultural enterprises' innovation, and the digital support service coefficient in column (3) is significantly positive, indicating that digital support services have effectively encouraged agricultural enterprises' innovation. These differentiation results may partly be explained in this way: digital financial coverage breadth represents the digital financial supply level. An increase in the level of supply may indeed improve the probability of agricultural enterprises getting financial services in the short term. However, only when agricultural enterprises form effective demand (reflect the usage depth of digital finance), can they truly stimulate the innovation of agricultural enterprises. The connotation of digital support services is the convenience degree and low-cost advantage. Based on these two advantages of digital finance, it can significantly promote the innovation of agricultural enterprises.。

Table 10 The regression results for heterogeneity tests based on different dimensions of digital finance

	(1)	(2)	(3)
Variables	Innovation	Innovation	Innovation
ifi1	0.172		
	(0.78)		
ifi2		0.188***	
		(2.58)	
ifi3			0.126***
			(3.06)
Capital	-0.057	-0.057	-0.063
	(-0.74)	(-0.74)	(-0.82)
Size	0.200***	0.201***	0.201***
	(11.49)	(11.59)	(11.54)
Leverage	-0.135***	-0.138***	-0.139***
	(-2.93)	(-3.00)	(-3.01)
PPE	-0.284***	-0.285***	-0.286***
	(-3.19)	(-3.21)	(-3.22)
Cash	0.067	0.071	0.070
	(1.54)	(1.63)	(1.61)
ROA	0.401***	0.401***	0.402***
	(8.96)	(8.97)	(8.98)
Age	0.428***	0.430***	0.431***
	(4.13)	(4.16)	(4.16)
GDP	0.576***	0.524***	0.429**
	(3.66)	(3.37)	(2.54)
STU	1.159***	1.335***	1.472***
	(4.09)	(4.85)	(5.19)
Constant	-22.573***	-24.399***	-25.243***
	(-5.38)	(-6.23)	(-6.44)
Firm effect	Yes	Yes	Yes
Year effect	Yes	Yes	Yes
Province effect	Yes	Yes	Yes
Observations	1440	1440	1440
R-squared	0.070	0.070	0.071

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

Conclusions and Recommendation

Research Conclusions

The development requirements of the new era call for the birth of new finance. As a new model of financial development, whether digital finance promotes the technological innovation of agricultural enterprises in China? Based on the theoretical logic and mechanism analysis, this paper empirically tests the impact of digital finance on agricultural enterprises ' technological innovation by using the data of 1440 NEEQ agricultural enterprises from 2011 to 2018, and emphatically verifies the transmission mechanism between the two and the inclusion characteristics of digital finance. In conclusion, the main contribution of this paper is to conduct multi-dimensional econometrics analysis using micro-data at the agricultural enterprises level, and to systematically evaluate the impact of digital finance on agricultural enterprises' technological innovation and intrinsic mechanisms. The empirical test of the measurement model makes the following main conclusions:

Firstly, during the sample period, the usage depth and digital service support of digital finance all promote the number of patent applications, invention patents and non-invention patents of agricultural enterprises. On the top of that, borrowing cost, financing constraints and operating risk are the key mechanisms for digital finance to promote the technological innovation of agricultural enterprises. By examining the transmission mechanism of digital finance → borrowing cost, financing constraint and operating risk → technology innovation, this paper shows that digital finance is beneficial to reduce enterprise borrowing cost, ease financing constraints and decrease operating risk, which leads to promote agricultural enterprises' technology innovation. Last but not least, heterogeneity analysis finds that digital finance improves the technological innovation of relatively small enterprises and agricultural enterprises located in central and western China, which verifies the inclusive characteristic of digital finance.

Policy Recommendation

The value of this article lies in revealing how to improve the technological innovation of agricultural enterprises through the new financial development model -- digital finance, and help the high-quality development of the Chinese economy. Combined with three main research conclusions, this paper believes that the following three policy inspirations can provide insights into digital finance to promote technological innovation in agricultural enterprises.

Firstly, digital finance is the catalyst for the future financial development, but also an important way to alleviate financial rejection, which plays a pivotal role in the technological innovation of agricultural enterprises. Coverage breadth of digital financial does not significantly promote the technological innovation of agricultural enterprises, which shows that only increase digital financial institutions is not likely to work. The premise of improve financial supply is to stimulate the effective financial demand of agricultural enterprises. At the same time, digital services are the core of digital finance, it has positive significance for the promotion of agricultural enterprises' innovation. Interestingly, the incentive role of digital finance on the innovation of agricultural enterprises cannot be separated from perfect and efficient financial infrastructure. Therefore, government should promote the construction of the Internet and take it as an important guarantee to continuously promote the development strategy of digital finance. Secondly, agricultural enterprises need to accelerate digital transformation, actively embrace digital technology, vigorously develop digital economy, and use digital finance to alleviate their financial constraints, reduce financing costs and decrease business risk. Digital strategy is an important way for agricultural enterprises to achieve long-term sustainable development, it needs to be laid out in advance as the core strategy of the enterprise. Finally, the inclusive characteristics of digital finance show that the government needs to develop reasonable and differentiated development strategies. For enterprises and small enterprises in central and western China, due to the lack of innovation and traditional financial resources supply, it is necessary to promote the development strategy of digital finance. The inclusive characteristics of digital finance will be utilized to facilitate the sustainable and healthy development of agricultural enterprises. In the meantime, the government also needs to provide certain subsidies and preferential policy to small enterprises to ensure the successful digital transformation of agricultural enterprises. It provides a steady stream of impetus for the prosperity and development of agricultural enterprises, and provide a guarantee for helping high-quality development of China's economy.

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Appendix 1 Correlation test of main variable

Variable	*Patent*	*Patent1*	*Patent2*	*ifi*	*Debt*	*FC*	*Risk*	*Capital*	*Size*	*Leverage*	*PPE*	*Cash*	*ROA*	*Age*	*GDP*	*STU*
Patent	1															
Patent1	0.779	1														
Patent2	0.900	0.501	1													
ifi	0.053	0.010	0.030	1												
Debt	-0.033	-0.042	-0.017	0.022	1											
FC	-0.116	-0.098	-0.098	-0.306	-0.010	1										
Risk	-0.099	-0.076	-0.084	-0.015	0.039	0.104	1									
Capital	-0.005	0.016	-0.013	-0.091	-0.018	-0.022	0.028	1								
Size	0.233	0.176	0.179	-0.050	-0.036	-0.391	-0.282	0.058	1							
Leverage	0.055	-0.011	0.044	-0.003	0.088	-0.055	0.012	-0.026	0.175	1						
PPE	0.110	0.075	0.067	-0.099	0.031	-0.121	-0.115	0.072	0.185	0.123	1					
Cash	-0.137	-0.033	-0.087	-0.015	-0.074	0.113	0.055	-0.038	-0.049	-0.296	-0.326	1				
ROA	0.086	0.041	0.052	-0.072	-0.067	-0.187	-0.162	0.064	0.189	-0.207	-0.043	0.091	1			
Age	0.105	0.054	0.045	0.175	-0.036	-0.174	-0.204	-0.119	0.220	0.032	0.043	-0.081	0.058	1		
GDP	0.127	0.106	0.112	0.303	-0.018	-0.106	-0.071	-0.005	0.074	0.037	-0.000	-0.024	0.014	0.068	1	
STU	0.115	0.108	0.101	0.099	-0.012	-0.050	-0.056	0.001	0.065	0.021	0.010	-0.023	0.024	0.044	0.887	1