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DIGITAL FINANCIAL DEVELOPMENT AND CORPORATE TECHNOLOGICAL INNOVATION: PROMOTION OR INHIBITION?¹

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ABSTRACT. *Digital finance not only drives the rebuilding of the traditional financing system but also considerably influences microscopic corporate technological innovation and even high-quality economic development. To explore the effects of digital financial development on corporate technological innovation, using panel data of A-share companies on Shanghai and Shenzhen Stock Exchanges in China from 2011 to 2019, and time-industry fixed effect models, according to resource allocation theory and information asymmetry theory, whether digital financial development can facilitate improvements of corporate technological*

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innovation was examined. Results show that: (1) Digital financial development can significantly promote corporate technological innovation. (2) Continuously deepening development of digital finance promotes technological innovation of non-state-owned corporates more clearly than that of state-owned corporates. (3) Digital finance can inhibit financing constraints and financial investment of corporates and plays an important mediating effect on the improvement of corporate technological innovation. (4) According to interaction processing, digital financial development can better drive the improvement of corporate technological innovation in regions with low economic development levels. The conclusions disclose that digital financial development not only promotes corporate technological innovation but also further facilitates high-quality economic progress, which can provide the government with powerful evidence to formulate relevant economic development policies.

KEYWORDS: corporate technological innovation, digital finance, high-quality development, financing constraints.

JEL classification: D80, G31, L80.

Introduction

Technological progress is not only a major source for the economic development momentum of a country, but also a major explanatory factor to describe its relevant laws and periodic economic fluctuations. Compared with developed countries, developing countries such as China still take technological innovation as the key momentum of high-quality development despite their low technological innovation ability (Gao *et al.*, 2020). However, these developing countries may have low output quality and insufficient corporate technological innovation, thus trapping them into the “low-end dilemma” of low yield and high input (Li *et al.*, 2016). How to solve the dilemma of copying and low-end technological innovation imperceptibly becomes a constraint against micro-corporate development. Corporate technological innovation needs the support of financial sources (Wang *et al.*, 2019). Financing pathways and innovation inputs are prerequisites of corporate technological innovation. The high costs for financing activities and innovation investments reveal that corporate technological innovation requires solutions to the mismatching problem of financing resources and improving the function of the financial market.

Improvement of the financing system can enhance the conversion rate between deposit and investment, increase effective investment, and stimulate entrepreneurship. In addition, resource allocation efficiency and corporate technological innovation development can likewise increase (King *et al.*, 1993; Laeven *et al.*, 2015). In view of the current developments of the traditional financial market, imperfect characteristics (e.g., imbalance and insufficiency) of the system all restrain the financing demands of the real economy (Huang *et al.*, 2018). First, financing sources prefer corporates with considerable contributions to the market. Second, corporates in industries with state support are also preferred. Finally, in terms of growth stages, mature corporates are commonly preferred. The above preferences of traditional finance in serving the real economy lead to a large structural imbalance of financial resource allocation, such that small and medium-sized corporates (SMEs) and innovative

businesses face difficulties in acquiring credit financing from banks. Financing constraints cause insufficient inputs, thus restricting corporate technological innovation. The emergence and development of digital finance have achieved great breakthroughs in traditional financial development and provided better support for the real economy, manifesting as information sharing, convenience, low cost, low access threshold, accurate user portrait, and user credit risk orientation (Demertzis *et al.*, 2018; Sliwa *et al.*, 2021). However, whether digital finance provides stronger support to corporate technological innovation needs further evidence (Tang *et al.*, 2020). The existing studies investigated the effects of corporate technological innovation mainly from perspectives of multi-department differences, financial structure, human capital (Seyoum *et al.*, 2015; Salem *et al.*, 2023; Wilfinger *et al.*, 2022), and financial investment behaviors. However, there is still a lack of studies on the influencing mechanism of digital finance on corporate technological innovation.

Innovation theory believed that innovation is the main source of economic development, and “innovation-driven” has become an important development strategy of countries around the world (Laeven *et al.*, 2015). According to the theory of resource allocation and information asymmetry, reducing market information asymmetry and improving the reasonable allocation of financial market resources are the needs of promoting high-quality economic development, and is also the premise of accelerating the construction of a new development pattern. Both the reduction of market information asymmetry and the reasonable allocation of financial resources are important research prerequisites for the promotion of technological innovation level of enterprises by digital finance. Thus, how to establish a balance among digital finance, corporate technological innovation, and high-quality economic development is still an issue that needs to be discussed. In this study, mediating effects in the relationship between digital finance and corporate technological innovation are investigated from the internal and external environments of corporates. Both internal financial investment (Duan *et al.*, 2021) and external financing constraint (Huang *et al.*, 2016; Fang *et al.*, 2022; Walle, 2023) have certain influence on corporate technological innovation. These two influencing pathways can be mediated by depth and breadth of digital finance, and can facilitate high-quality economic transformation.

This study presents several contributions. First, the influencing modes of digital financial development were expanded to depth-breadth-digitalization degree, and dynamic cumulated influences of dimension reducing of digital finance indexes on corporate technological innovation were analyzed. The effects of digital finance on corporate technological innovation are disclosed more accurately. Second, based on different influencing pathways of “financing constraints and financial investment behaviors”, this study reveals that digital finance promotes corporate technological innovation by regulating external financing constraints and financing investment ratios of corporates. Third, an analysis framework is built for digital finance, corporate technological innovation, and high-quality economic development. This framework proves for the first time that digital financial development facilitates corporate technological innovation in developing regions more than in developed regions. The findings further demonstrate that digital finance can promote high-quality economic development.

The remainder of this study is organized as follows: Section 1 reviews theories and associated literature. Section 2 introduces data source, variable definitions, and model construction, and presents the descriptive statistical analysis. Section 3 discusses the empirical results, heterogeneity, and mechanism effects thoroughly after reference regression analysis

and robustness test. Section 4 indicates the causes of empirical results. Section 5 presents a summary of conclusions and management implications.

1. Literature Review

Technological progress is a decisive factor of economic growth (Romer, 1990); that is, it is necessary to realize high-quality economic development and complete economic restructuring (Yu *et al.*, 2018). Studies on corporate technological innovation can mainly be divided into the following three parts: (1) from the government perspective, increased government support and budget (Miao, 2019) may facilitate micro-corporate technological innovation. (2) From the perspective of corporate development, increasing human capital levels can facilitate technological innovation output and improve the future development potentials of corporates (He *et al.*, 2019). Corporates receive financing needs through share pledge (Jiang *et al.*, 2020). Corporate property (state-owned or non-state-owned corporates) and cultural richness (Xu *et al.*, 2019) are both important factors that influence their technological innovation output. (3) From the perspective of external development environment of corporates, financing development structure (Jia *et al.*, 2016; Zhuang *et al.*, 2020; Tang *et al.*, 2019), competition degree of banking industry in traditional financial market, current situations of factor market, leverage ratio (Wang *et al.*, 2019), and market tax ratio all play decisive roles in corporate technological innovation. The literature review shows that traditional financial development cannot provide full use of factor endowment of corporates whereas a perfect financial market can provide more equitable financing environment.

At present, digital finance is rapidly developing in countries around the world, but its related literature remains limited. The early development of digital finance is mainly attributed to the slow progressive extension from “Internet finance” and “inclusive finance”. Moreover, studies on early Internet finance and subsequent ones on “inclusive” and digital finance focus on whether financial exclusion and friction (Li and Han, 2017) are reduced and whether financial resource allocation is optimized (He *et al.*, 2015). However, the rapid development of digital finance has caused important influences on the technological innovation of corporates. According to the theory of resource allocation, from the perspective of “smooth capital flow” in the financial market, capitals of various scattered small and middle-sized investors can be input as driven by multiple channels. However, the theory of information asymmetry also reveals digital financial development mainly improves information asymmetry in the market through digital technologies—such as big data, artificial intelligence, and cloud computing—transfers reasonable stock funds in financial market to financing demanders, and provides corporates with a fairer financing environment (Gomber *et al.*, 2018). With the deepening and generalization of digital finance, the “self-optimization of financial system,” transparency of information, and numerical values of indicators are realized. Both credit risk rating and future development evaluation of corporates can provide financial institutions with references for more reliable risk management (Norden *et al.*, 2014), thus improving capital allocation efficiency (Tang *et al.*, 2019). Second, in studies on internal corporate development that report rapid development of digital finance, corporates not only continuously innovate their product pursuit but also successively increase their investments in financial products (Duan *et al.*, 2021). Although increasing proportion of investment and fund embezzlement can inhibit the innovation inputs of corporates to a certain extent, the increased benefits from financial investment can promote patent application quantity of corporate

technological innovation and inputs. Moreover, corporate development has various factors influencing corporate technological innovation. Among them, an important factor is the proportion of corporate financial expenses in total benefits. Financial expenses may inhibit the output level of corporate technological innovation (Huang *et al.*, 2016). Digital finance not only overcomes the development bottlenecks of traditional financial market and perfects the external development environment of corporates (Huang *et al.*, 2018) but also mitigates the mismatch between corporate financing constraints and credit resources as well as perfects the internal development environment of corporates. Therefore, based on the theory of information asymmetry and resource allocation, as well as the above literature review, this study shows that the development of digital finance has improved the efficiency of resource allocation in the financial market environment and reduced the incidence of resource mismatch caused by information asymmetry. Several relationships between digital finance and corporate technological innovation are thus unknown.

Compared with economically developed countries, developing countries such as China still have a great gap in corporate technological innovation output and R&D inputs. For corporates, external financing constraints and internal financial expense ratio of corporates are important constraints against their technological innovation input. Therefore, developing countries have to overcome various difficulties to perfect financial market, improve corporate technological innovation ability, and promote high-quality economic development by using digital finance.

2. Methodology

2.1 Data Sources

Panel datasets of A-share companies on Shanghai and Shenzhen Stock Exchanges in 2011 and 2019 were collected and processed as follows: first, financial corporates were deleted because of the focus on non-financial corporates in this study. Second, missing values of listed companies were deleted from data processing to assure data accuracy. Moreover, several ST and delisted corporates were deleted. Finally, data were subjected to tail reduction by 1% and 99%. In the empirical test, a total of 13,018 observation sample data of “corporate-year” was collected. The data of listed corporates were mainly derived from CSMAR (China Stock Market & Accounting Research Database) and WIND database, while the digital finance index mainly was based on the Digital Finance and Inclusion Index of Peking University.

2.2 Variables

(1) Explained variables. With references to variable selection in previous studies concerning corporate technological innovation, the patent application quantity (*pat*) was first selected. In addition, corporate patent for invention (*Invpat*) was chosen, because innovation output of corporates could also represent innovation ability of corporates. Second, the R&D input ratio (*rda*) was used to represent innovation input intensity of corporates. In this study, the selected corporate technological innovation input and output indicators could represent corporate technological innovation ability.

(2) Explanatory variables. Data used in recent studies on digital finance index (*DIF*) were mainly based on the *Digital Finance and Inclusion Index* built by Peking University and

Ant Financial Services Group. *DIF* is mainly analyzed based on depth, breadth, and digitalization of provinces and quantizes the degree of digitalized financial development of provinces in China. In this study, provincial *DIF* was mainly chosen for analysis.

(3) Mediating variables. First, financing constraint index of corporates (*SA*) was chosen and mainly calculated by using the method of Hadlock *et al.* (2010). *SA* directly discloses the financing constraints of corporates in the financial market. Second, proportion of corporate financial investment (*fin*) was chosen and calculated according to the proportion of corporate financing investment proposed by Duan *et al.* (2021).

Table 1. Research variable design

Variable Properties	Variables	Meaning	Variable Description
Explained variables	<i>Inpat</i>	Total number of patent applications	Total number of patent applications filed by listed corporations
	<i>Lninvpnt</i>	Number of Invention Patent Applications	Total number of invention patents of listed corporations
	<i>rda</i>	R&D investment ratio	Research and development investment/operating income of the corporate
Explanatory variables	<i>DIF</i>	Digital Finance Index	General Digital Finance Index
	<i>DIF-B</i>	Digital Financial Broadening Indicators	Digital financial index
	<i>DIF-U</i>	Digital Financial Deepening Indicators	Digital financial index
	<i>DIF-D</i>	Digital Finance Digital Metrics	Digital financial index
Control variables	<i>Age</i>	Business Age	Number of years of establishment
	<i>lnProfit</i>	Natural logarithm of corporate profits	The net profit of the corporate is logarithmic.
	<i>lnTA</i>	Corporate asset size	Total assets of the corporate
	<i>Equity</i>	Shareholding Concentration	The first largest shareholder concentration
	<i>Capital</i>	Capital Intensity	Total assets/revenue from main business
	<i>State</i>	Whether it is a state-owned corporation	Is it a state-owned corporation
	<i>Merge</i>	The combination of two duties	Is the chairman and general manager the same person
Mediating variables	<i>SA</i>	Corporate financing constraint capability	<i>SA</i> reflects the degree of financing constraints faced by corporations.
	<i>fin</i>	Proportion of financial investment in corporations	Financial investment/total assets

Notes: (1) The Digital Finance Index was compiled by the Research Center for Digital Finance at Peking University, with reference to the specific calculation method. <https://idf.pku.edu.cn/index.htm>.

(2) $SA = -0.737 \times \ln TA + 0.43 \times \ln TA^2 - 0.04 \times Age$, (Hadlock *et al.*, 2010).

Source: own calculations.

(4) Control variables. To avoid influences of missing variables on empirical analysis results, we mainly referred to control variables related with corporate technological innovation proposed in the empirical study of Gu *et al.* (2018). In other words, seven control variables, including firm age (*age*), equity concentration (*lnProfit*), and corporate asset size (*lnTA*), were applied in the present study. The variables are explained in *Table 1*.

2.3 Modeling

To test the influencing mechanism of digital financial development on corporate technological innovation, we built the following models according to the hypotheses: *Pat*, *invpat*, and *rda* were chosen as the explained variables while *DIF* was used as the explanatory variable. Provincial data were used in the study. *CV* denoted all selected control variables and ε was the random error term of models. Given that effects of *DIF* on corporate technological innovation ability and corporate innovation inputs all have hysteresis, a one-phase delay treatment was performed in the empirical study. Moreover, the most conventional fixed effect models (industry-time) were observed. The constructed estimation models are introduced as follows.

$$pat_{i,t} = \alpha_0 + \alpha_1 DIF_{i,t-1} + \sum \phi CV + \sum year + \sum Ind + \varepsilon \tag{1}$$

2.4 Descriptive Statistical Analysis

Correlation coefficient analysis and VIF analysis are carried out to eliminate multicollinearity problems that may occur in variable selection. The results are shown in the appendix. According to the correlation analysis results shown in *Table 2*, the absolute values of correlation coefficients among the variables selected in this study are all lower than 0.8, and most of them are less than 0.1. Therefore, there is no multicollinearity problem among the variables selected in this study. VIF test results show that all individual factors and overall factors are less than 10, which also proves that there is no multicollinearity problem in variable selection in this study.

Table 2. Correlation analysis

	<i>hpat</i>	<i>hinvpat</i>	<i>rda</i>	<i>index</i>	<i>age</i>	<i>lnprofit</i>	<i>lnta</i>	<i>equity</i>	<i>capital</i>	<i>state</i>	<i>merge</i>	<i>sa</i>	<i>fin</i>
<i>hpat</i>	1												
<i>hinvpat</i>	0.638***	1											
<i>rda</i>	0.071***	0.067***	1										
<i>index</i>	0.098***	0.079***	0.125***	1									
<i>age</i>	0.067***	0.074***	0.081***	0.399***	1								
<i>lnprofit</i>	0.055***	0.059***	0.042***	0.050***	-0.024**	1							
<i>lnta</i>	0.042***	-0.021**	0.188***	0.254***	0.216***	0.128***	1						
<i>equity</i>	0.038***	0.021**	0.105***	0.124***	0.122***	0.100***	0.206***	1					
<i>capital</i>	0.059***	0.054***	0.181***	0.062***	-0.010	0.121***	0.038***	0.094***	1				
<i>state</i>	0.091***	0.036***	0.131***	0.101***	0.190***	0.007	0.371***	0.227***	0.098***	1			
<i>merge</i>	0.010	0.018*	0.093***	0.006	0.099***	0.003	0.189***	0.032***	0.050***	0.255***	1		
<i>sa</i>	0.068***	0.044***	0.009	0.368***	0.660***	0.034***	-0.016*	0.205***	0.033***	0.043***	0.066***	1	
<i>fin</i>	-0.004	0.013	0.163***	0.115***	0.097***	0.101***	0.213***	0.010	0.153***	0.089***	0.100***	0.092***	1
VIF Value				1.41	2.04	1.07	1.48	1.15	1.07	1.37	1.09	1.93	1.11

Source: own calculations.

Table 3. Descriptive statistics

Variable	obs	mean	S.D.	min	max
<i>Inpat</i>	13018	0.623	1.430	0	5.730
<i>lninvpat</i>	13018	0.383	0.999	0	4.625
<i>rda</i>	13018	0.021	0.018	0	0.096
<i>DIF</i>	13018	0.523	0.234	0.041	0.971
<i>DIF-B</i>	13018	0.528	0.237	0	1
<i>DIF-U</i>	13018	0.496	0.209	0	1
<i>DIF-D</i>	13018	0.607	0.267	0	1
<i>Age</i>	10355	16.548	5.782	2	52.670
<i>lnProfit</i>	13018	15.125	11.263	-21.163	22.874
<i>lnTA</i>	13018	22.183	1.271	19.946	26.175
<i>Equity</i>	13018	34.039	14.61	8.748	73.012
<i>Capital</i>	13018	2.261	1.562	0.413	9.809
<i>State</i>	13018	0.336	0.472	0	1
<i>Merge</i>	13018	0.264	0.441	0	1
<i>SA</i>	13018	-3.824	0.240	-4.494	-3.123
<i>fin</i>	13018	0.213	0.139	0.027	0.677

Source: own calculations.

Descriptive statistical results of major research variables are shown in *Table 3*. The mean of the logarithmic of patent application quantity (*Inpat*) was 0.623 and the standard deviation was 1.43. The mean of logarithmic of valid patent application quantity (*lninvpat*) was 0.383 and the standard deviation was 0.999. According to the proportion of corporate technological innovation input in total assets (*rda*), Chinese corporates have low input intensity to technological innovation. Moreover, *DIF* can be divided into general, deepening, generalization, and digitalization indices of digital finance. The means of these indexes were 0.523, 0.528, 0.496, and 0.607, and the corresponding standard deviations were 0.234, 0.237, 0.209, and 0.267, respectively. These results revealed that digital financial development caused different deepening degrees in terms of *pat*, *invpat* and *rda*.

3. Results Analysis

3.1 Reference Regression Analysis

A reference regression analysis is carried out on the influences of the general index of digital finance on corporate technological innovation output and input. The results are shown in *Table 4*, indicating that digital finance promotes corporate technological innovation. Digital finance (*L.DIF*) has positive driving effects on *Pat* and *Invpat*. Moreover, the regression coefficient of *rda* is positive. *Pat*, *Invpat*, and *rda* all pass the 1% statistical significance. Correlation results after relevant control variables are included and shown in M(4)–M(6), which agree with previous results that technological innovation ability of corporates improve continuously under digital finance. This proves to a certain extent that digital financial development facilitates the increase of practical conversion rate of corporate technological innovation ability, and reduces the R&D risks compared with early high inputs and low outputs in China. These findings further facilitate the independent R&D ability of China and thereby realize high-quality development.

Table 4. Reference regression result

Variable	M(1) <i>lnpat</i>	M(2) <i>lninypat</i>	M(3) <i>rda</i>	M(4) <i>lnpat</i>	M(5) <i>lninypat</i>	M(6) <i>rda</i>
<i>DIF</i>	0.298*** (3.69)	0.419*** (2.96)	0.047*** (12.56)	3.697*** (3.06)	2.376*** (3.64)	0.015*** (7.54)
<i>lnprofit</i>				0.002 (1.60)	0.003*** (4.07)	0.0001*** (2.93)
<i>lnta</i>				0.101* (1.93)	-0.008 (-0.21)	-0.003*** (-28.49)
<i>equity</i>				-0.004*** (-2.66)	-0.001 (-0.92)	-0.0001*** (-14.47)
<i>capital</i>				0.025** (2.27)	0.025*** (3.28)	-0.003*** (-15.58)
<i>state</i>				0.176** (2.00)	-0.009 (-0.18)	0.0005*** (4.69)
<i>age</i>				-0.445*** (-3.49)	-0.275*** (-3.86)	-0.0004*** (-6.40)
<i>merge</i>				0.035 (1.21)	0.048*** (2.95)	0.002*** (12.89)
<i>Constant</i>	-0.234*** (-3.70)	0.612 (1.07)	-0.013*** (-4.27)	4.062 (1.52)	3.969** (2.30)	0.096*** (56.39)
Observations	9,506	9,506	9,506	7,560	7,560	7,560
R-squared	0.045	0.071	0.035	0.054	0.040	0.125
Fixed effect of time and industry	Yes	Yes	Yes	Yes	Yes	Yes

Note: Figures in brackets are robust standard errors of regression coefficients; ***, ** and * represent the significance level of 1%, 5% and 10% respectively.

Source: own calculations.

Dimension reduction of digital finance indicators causes dynamic accumulated influences on corporate technological innovation, and allows for a more accurate analysis. Therefore, the influencing modes of rapid digital financial development are accordingly expanded to three levels: depth–breadth–digitalization degree. This approach further discloses aspects where digital finance promotes corporate technological innovation ability, that is, which aspects achieve the most significant empirical results can be determined (Table 5). According to empirical results, with the deepening of digital financial development, M(3) of corporates was influenced significantly but M(1) and M(2) are not. In the breadth development of digital finance, regression results of three variables are significant, and influenced M(2) more than M(1) and M(3). Regression results of digitalization degree of digital finance influences M(3) with only 10% of significance. Hence, deepening the development of digital finance alone cannot significantly influence corporate technological innovation. Rather, the continuous increasing coverage and deepening digitalization of digital finance is needed to facilitate long-term development of corporate technological innovation ability under comprehensive and multi-dimensional driving effects.

Table 5. The multi-dimensional driving effects of digital finance development on corporate technological innovation (depth-breadth-digitalization degree)

Panel A	Digital finance depth indicator	M(1) <i>lnpat</i>	M(2) <i>lninvpat</i>	M(3) <i>rda</i>
	<i>LI.DIF-B</i>	0.187*** (2.84)	0.372*** (3.76)	0.019*** (18.42)
	control variable	Yes	Yes	Yes
	Fixed effect of time and industry	Yes	Yes	Yes
Panel B	Digital financial breadth indicator	M(1) <i>lnpat</i>	M(2) <i>lninvpat</i>	M(3) <i>rda</i>
	<i>LI.DIF-U</i>	-0.756 (-0.63)	-0.431 (-0.61)	0.017*** (7.10)
	control variable	Yes	Yes	Yes
	Fixed effect of time and industry	Yes	Yes	Yes
Panel C	Digitalization degree indicator of digital financial	M(1) <i>lnpat</i>	M(2) <i>lninvpat</i>	M(3) <i>rda</i>
	<i>LI.DIF-D</i>	1.553*** (8.41)	0.819*** (4.92)	0.003* (1.66)
	control variable	Yes	Yes	Yes
	Fixed effect of time and industry	Yes	Yes	Yes

Note: Figures in brackets are robust standard errors of regression coefficients; ***, ** and * represent the significance level of 1%, 5% and 10% respectively.

Source: own calculations.

3.2 Robustness Test and Endogeneity Processing (GMM)

To address possible endogeneity of above estimation models caused by reverse causality or missing variables, a generalized method of moment (GMM) was applied for robustness analysis with references to Zhuang *et al.* (2020). The first-order lag and difference value of explanatory variables are used as instrumental variables for regression analysis of basic estimation models. In this study, the intersection items between *DIF* and several control variables are applied to investigate whether the influences of digital finance on corporate technological innovation output and input are significant. The results are consistent with those of the main reference regression test.

Table 6. Robustness test based on GMM regression

Variable	M(1)	M(2)	M(3)
	<i>lnpat</i>	<i>lninvpat</i>	<i>rda</i>
<i>L.lnpat</i>	0.204*** (5.73)		
<i>index</i>	2.914*** (4.87)	2.904*** (6.79)	0.015*** (4.58)
<i>L.lninvpat</i>		0.122*** (3.08)	
<i>L.rda</i>			0.550*** (9.74)
Control variable	YES	YES	YES
Observations	4,835	4,835	4,835

Note: Figures in brackets are robust standard errors of regression coefficients; ***, ** and * represent the significance level of 1%, 5% and 10% respectively.

Source: own calculations.

Table 6 shows the GMM regression test results. M(1), M(2), and M(3) are 0.204***, 2.904*** and 0.015***, respectively, and all are positively significant on 1% level. According to endogeneity regression based on instrumental variables, digital financial development still significantly promotes the regression results of M(1), M(2), and M(3). The regression coefficients are increased to a certain extent compared with the original reference regression. The above robustness and endogeneity processing results demonstrate that the core test in this study is stable.

3.3 Heterogeneity Analysis

Several resource mismatching and uneven allocations are observed in traditional financial market development. The heterogeneity in action mechanism of digital finance on corporate technological innovation is analyzed from the perspective of different corporate properties. Table 7 shows the results. Digital financial development promotes the technological innovation of state-owned and non-state-owned corporates to a certain extent. Although the regression results of M(1) show a positive promotion, the regression coefficient is only 3.877 and only passes the 5% statistical test. Comparatively, digital financial development significantly promotes patent for invention of non-state-owned corporates M(5) (regression coefficient is 2.246 and passes the 1% statistical test). Moreover, comparison of regression results of *rda* show that regression coefficient of non-state-owned corporates is 0.015***, which is higher than that of state-owned corporates (0.014***). Thus, digital finance drives technological innovation of non-state-owned corporates, which is consistent with the conclusions of Wei *et al.* (2017).

Table 7. Heterogeneity analysis based on corporate properties

Variable	M(1) <i>lnpat</i>	M(2) <i>lninvpat</i>	M(3) <i>rda</i>	M(4) <i>lnpat</i>	M(5) <i>lninvpat</i>	M(6) <i>rda</i>
<i>L.DIF</i>	3.877** (2.38)	2.691*** (2.77)	0.014*** (7.50)	3.750*** (2.86)	2.246*** (3.42)	0.015*** (6.74)
	state-owned corporates			non-state-owned corporates		
Control variable	YES	YES	YES	YES	YES	YES
Fixed effect of time and industry	YES	YES	YES	YES	YES	YES
N	2,206	2,206	2,206	5,354	5,354	5,354
adj. <i>R</i> ²	0.0414	0.0487	0.0279	0.0430	0.163	0.095

Note: Figures in brackets are robust standard errors of regression coefficients; ***, ** and * represent the significance level of 1%, 5% and 10% respectively.

Source: own calculations.

3.4 Mechanism Analysis: Mediating Effects of Financing Difficulty and Financialization

The above analysis shows that the deepening, generalization, and digitalization of digital finance can all promote corporate technological innovation. However, digital finance services must deepen continuously to improve corporate technological innovation. The above analysis focuses on the general influences of digital finance on corporate innovation, but has not distinguished major internal and external driving forces. For this reason, this study further

examines the specific influencing mechanism of the deepening development of digital finance on corporate technological innovation ability.

With considerations to mediating effects of mediating variables between corporate innovation ability (dependent variable) and digital financial development (independent variable), the following regression models are built:

$$pat_{i,t} = \alpha_1 + \delta DIF_{i,t-1} + \sum \mathcal{G}CV + \sum year + \sum Ind + \varepsilon \tag{2}$$

$$Mediator_{i,t} = \alpha_2 + \beta DIF_{i,t-1} + \sum \mathcal{G}CV + \sum year + \sum Ind + \varepsilon \tag{3}$$

$$pat_{i,t} = \alpha_1 + \beta_1 Mediator_{i,t} + \sum \mathcal{G}CV + \sum year + \sum Ind + \varepsilon \tag{4}$$

In this study, the proportion of corporate financial investment (*fin*) and corporate financing constraints (*SA*) are chosen as mediating variables. Control variables, disturbance term, and other settings are the same as in Section 3. The above two mediating variables are selected for the following considerations: First, the proportion of financial investment to real economy is gradually increasing in China, which has an incremental effect on the financial reserves of corporates and indirectly promotes corporate technological innovation. Second, the direct influences of digital financial development on micro-corporate are mainly caused by the relieved external financing constraints. If financing difficulties and high financing cost of corporates are relieved, corporate R&D inputs to technological innovation can be increased.

Table 8. The effect mechanism of digital financial development on corporate technological innovation

Panel A	M(1) <i>lnpat</i>	M(2) <i>Fin</i>	M(3) <i>lnpat</i>	M(4) <i>lninvpat</i>	M(5) <i>lninvpat</i>	M(6) <i>rda</i>	M(7) <i>rda</i>
<i>L.DIF</i>	3.697 *** (3.07)	-0.189*** (-4.73)	3.715*** (3.05)	2.376*** (3.65)	2.379*** (3.56)	-0.007** (-2.51)	-0.007** (-2.42)
<i>Fin</i>			0.094** (0.71)		0.013* (0.11)		0.001* (1.90)
Control variable	YES	YES	YES	YES	YES	YES	YES
Fixed effect of time and industry	YES	YES	YES	YES	YES	YES	YES
<i>N</i>	7,560	7,560	7,560	7,560	7,560	7,560	7,560
adj. <i>R</i> ²	0.054	0.039	0.054	0.040	0.040	0.123	0.123
Panel B	M(1) <i>lnpat</i>	M(2) <i>SA</i>	M(3) <i>lnpat</i>	M(4) <i>lninvpat</i>	M(5) <i>lninvpat</i>	M(6) <i>rda</i>	M(7) <i>rda</i>
<i>L.DIF</i>	3.697*** (3.07)	-0.064*** (-4.68)	3.632*** (3.06)	2.376*** (3.65)	2.339*** (3.57)	-0.007** (-2.51)	-0.007** (-2.39)
<i>SA</i>			-1.011*** (-7.72)		-0.573* (-1.92)		-0.007** (1.98)
Control variable	YES	YES	YES	YES	YES	YES	YES
Fixed effect of time and industry	YES	YES	YES	YES	YES	YES	YES
<i>N</i>	7,560	7,560	7,560	7,560	7,560	7,560	7,560
adj. <i>R</i> ²	0.0539	0.828	0.0552	0.0403	0.0411	0.123	0.124

Note: Figures in brackets are robust standard errors of regression coefficients; ***, ** and * represent the significance level of 1%, 5% and 10% respectively.

Source: own calculations.

According to the empirical results in *Table 8*, both increasing financial investment and decreasing financing constraints promote technological innovation input and output. In the table, Panel A shows a positive correlation between digital financial development and the mediating variable *M(3) (fin)*. In other words, digital financial development facilitates the increase of proportion of corporate financial investment to a certain extent. Effects of *fin* are significant on 5% level to *M(3)* and on 10% level to *M(5)* and *M(7)*. This result reveals that benefits from corporate financial investment indeed increase their R&D inputs, and thereby facilitate corporate technological innovation. Panel B shows a highly negative correlation of *DIF* with corporate financing constraints.

3.5 Further Analysis: Regression Test of Promoting High Quality Economic Development

Digital financial development integrates finance with technological means, such as big data and cloud computing. Digital finance not only perfects the traditional market mechanism, but also promotes technological innovations of micro-corporates. Moreover, technological progress is an important research topic to enable high-quality economic development. To further confirm the endogenous mechanism that digital financial development facilitates high-quality economic development by promoting corporate technological innovation ability, we further add economic growth factor into the research model of “digital finance–corporate technological innovation”. *lnGDP* is used as a proxy variable. In addition, China is divided into economically developed and developing zones. First, the study area is grouped according to economic development level and the regression test is carried out. Second, to assure robustness and accuracy of research results, this study applies the intersection items of *DIF*, economic development level (*GDP*), and *fin* in an empirical test to analyze the driving effect of digital finance on corporate technological innovation ability under different economic development levels.

$$pat_{i,t} = \beta_0 + \beta_1 DIF_{i,t-1} + \beta_2 (DIF_{i,t-1} \times GDP_{i,t-1}) + \beta_3 GDP_{i,t-1} + \sum \phi CV + \sum year + \sum Ind + \varepsilon \quad (5)$$

Table 9. Digital finance, economic development level and corporate technological innovation

Variable	M(1) <i>lnpat</i>	M(2) <i>lninvpat</i>	M(3) <i>rda</i>	M(4) <i>lnpat</i>	M(5) <i>lninvpat</i>	M(6) <i>rda</i>	M(7) <i>lnpat</i>	M(8) <i>lninvpat</i>	M(9) <i>rda</i>
<i>L.DIF</i>	3.630** (2.45)	2.352*** (3.03)	0.012*** (6.38)	3.973*** (5.09)	2.609*** (5.06)	0.016*** (5.94)	3.875*** (3.08)	2.603*** (3.69)	0.010*** (3.48)
<i>L.DIF</i> × <i>L.GDP</i>							-0.19*** (-4.36)	0.241*** (-5.76)	0.005*** (2.99)
	economically developed zones			economically developing zones			interaction item processing		
Control variable	YES	YES	YES	YES	YES	YES	YES	YES	YES
Fixed effect of time and industry	YES	YES	YES	YES	YES	YES	YES	YES	YES
N	5,047	5,047	5,047	2,513	2,513	2,513	7,560	7,560	7,560
adj. <i>R</i> ²	0.054	0.044	0.115	0.056	0.038	0.121	0.054	0.041	0.128

Note: Figures in brackets are robust standard errors of regression coefficients; ***, ** and * represent the significance level of 1%, 5% and 10% respectively.

Source: own calculations.

In Eq. (5), *DIF* and *GDP* are intersected ($DIF \times GDP$). In this regression model, the control variable (*CV*) and random error term (ε) are both consistent with the setting of the above reference regression model. The empirical test results mainly analyze the intersection term. If the regression coefficient of $DIF \times GDP$ is significantly positive, then digital finance promotes corporate technological innovation more significantly in economically developed zones. If the regression coefficient is negative, then digital finance promotes corporate technological innovation more significantly in economically developing zones.

Table 9 shows the results. Effects of digital financial development on corporate technological innovation all pass the 1% positive significance in both economically developed (M(1)–M(3)) and economically developing zones (M(4)–M(6)). This finding is consistent with the main conclusions and further verifies that continuous deepening of digital finance can promote corporate technological innovation. Moreover, digital financial development indeed provides financial inclusive effects under different economic development levels. The *DIF* and *GDP* are intersected for further robustness test (M(7)–M(9)). Empirical test results show that M(7) (*Pat* coefficient: -0.190) and M(8) (*invpat* coefficient: -0.241) are negatively significant on 1% level, indicating that digital finance promotes corporate technological innovation in economically developing zones more significantly. However, the results of M(9) (*rda* coefficient: 0.010) are positively significant and the coefficient passes the 1% significance level. This result proves that digital finance promotes corporate technological innovation inputs in economically developed zones more significantly.

4. Discussion

The scientific weight and rigorousness of this study were supported by empirical results, while also verifying the veracity of the proposed hypothesis. This paper means that digital finance has a promoting effect on enterprise technological innovation, and the index dimensionality reduction of digital finance has a dynamic superposition impact on enterprise technological innovation, specifically as follows:

First, the development of digital finance promotes the actual conversion rate of enterprises' technological innovation ability, which will further promote the ability of national independent research and development and achieve the goal of high-quality development. The reasons are as follows: Firstly, the application of digital finance to big data and cloud computing inhibits the occurrence of information asymmetry and improves the financial market system (Huang, 2018). It mainly provides relevant information of enterprises to fund providers more transparently (Huang, 2018), provides a fairer financing environment for financing demander, and further prevents credit risks caused by information asymmetry between credit parties (Tang *et al.*, 2020). Secondly, to a certain extent, the development of digital finance promotes the system perfection of the traditional financial market and improves the effectiveness of financial resource allocation. It not only stimulates the diversity of financial products and financing instruments in the market, but also provides more abundant financing resources for the development of micro-enterprises. It is not limited to the capital flow of investors originally existing in the traditional financial market, but absorbs the participation of a large number of investors who are displaced from the outside of the financial market, making the resource allocation of the financial market more rational and standardized, and filling the defects of the development of the traditional financial industry (Xie, Zhu, 2021).

Second, digital finance drives technological innovation of non-state-owned corporates, which is consistent with the findings of Wei *et al.* (2017). The possible reasons are as follows. Firstly, non-state-owned corporates and SMEs, which are the main driving force of China's economic development, have far higher productivity than the average and have far faster speeds of technological innovation improvement than large-sized state-owned corporates. Nevertheless, limited by self-development conditions, SMEs have short development histories, insufficient mortgage, and other issues. Therefore, they cannot obtain sufficient financing demands from the financial market. In other words, "credit discrimination" restricts the momentum of SMEs in technological innovation (Cao *et al.*, 2020). The continuous deepening and generalization of digital financial development not only repair and perfect the development system of traditional financial market, but also relieve external financing constraints of corporates and provide credit supports to their technological innovation (Yang *et al.*, 2021). Secondly, non-state-owned corporates have a smaller investment size in innovation compared with state-owned corporates that have sufficient capitals. The returns on investment of non-state-owned corporates are still rising. Once non-state-owned corporates gain financial support, they can achieve rapid innovation development (Cao, Zhang, 2022). Thirdly, digital financial development relieves financial exclusion and improves information transparency in the traditional financial market, where most corporates that suffer from financial exclusion and information asymmetry are non-state-owned.

Third, digital financial index DIF is highly negatively correlated with corporate financing constraints, and the development of digital finance inhibits the degree of corporate financing constraints, which also agree with the conclusions of Tang *et al.* (2020). This finding can be explained from two aspects. Firstly, digital financial development has one major feature, that is, it relieves corporate financing constraints and increases financial reserves in the capital market. Secondly, digital finance is the product of integrating finance and technology, and its development facilitates diversified financing tools in the market. How to reflect the positive promotion of digital finance on corporate financial investment thus requires further study in the future.

Finally, digital finance promotes corporate technological innovation inputs in economically developed zones more significantly. The main reasons are analyzed as follows. Firstly, digital finance can better promote patent application in economically developing zones, that is, digital financial development provides a more reasonable and fair financing environment (Tao *et al.*, 2022). Secondly, digital finance more significantly promotes R&D inputs of corporates in economically developing zones, because corporates pay more attention to the importance of technological innovation. Finally, corporate technological innovation is the key to rapid economic development and high-quality economic transformation in both economically developing and developed zones. The promotion effect of digital financial development on corporate technological innovation provides the most apparent references to improve economic levels.

Conclusions and Implications

Main Findings

Data from A-share companies on the Shanghai and Shenzhen Stock Exchanges in 2011 and 2019 were used in this study to build provincial deepening, generalization, and digitalization indexes of digital finance. An empirical analysis was carried out on the promotion effect of digital financial development on corporate technological innovation.

Several major conclusions are drawn as follows: (1) the deepening, generalization, and digitalization of digital finance can all promote corporate technological innovation ability to a certain extent. Digital financial development significantly increases the technological innovation ability of corporates. (2) Heterogeneity analysis of corporate properties shows that digital financial development promotes technological innovation of non-state-owned corporates more than that of state-owned corporates. (3) Digital financial development decreases the uneven resource allocation efficiency in traditional financial markets, inhibits increase of financial investment, and relieves financing constraints against corporates. (4) Finally, the positive driving effect of digital financial development on corporate technological innovation is stronger in regions with low economic development levels.

Managerial Implications

Based on conclusions, several management implications are proposed: (1) In the critical stage of economic transformation and high-quality economic development, digital financial development not only perfects the financing system but also promotes the economy to a certain extent. The main reason is that digital finance realizes information transparency by using technological means and decreases potential risks during credit loan processing for corporates; (2) Realizing independent technological innovation of corporates has become an important development means and factor in China. A perfect financial system is an essential prerequisite for corporates to improve their technological innovation ability. Improving the “financing difficulty” and “expensive financing” and repairing the defects in traditional financial system development based on digital finance are conducive to improving corporate technological innovation ability. Combining the experiences of developed countries with strong technological innovation abilities, sunk cost and output risks in the innovation stage are major constraints. Digital financial development inhibits the increase of sunk cost and output risks, and thus facilitates the improvement of corporate technological innovation ability; (3) Technological innovation is the primary means to realize high-quality economic development in the double circular economic development pattern. For micro-corporates, technological progress is mainly used to improve corporate technological innovation ability. According to the current test results, digital financial development can significantly promote corporate technological innovation. The discussion model of “digital finance—corporate technological innovation—high-quality economic development” shows that both digital financial development and improvement of corporate technological innovation play important roles in China to realize high-quality economic development.

Limitations and Future Directions

This study has certain limitations. For example, although heterogeneity of property rights is analyzed, the industrial and regional heterogeneities have not been further verified due to limited space. With respect to the selection of empirical data, only Chinese microscopic data is applied due to limitations of data accessibility, thus resulting in poor generalization of results. Thus, the conclusions may be more applicable to developing countries. In the future, studies based on countries with relatively mature digital financial development can be a very valuable direction to provide a prospective reference to policy implementation in other countries and regions.

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SKAITMENINĖ FINANSINĖ PLĖTRA IR ĮMONĖS TECHNOLOGIJOS NAUJOVĖS: SKATINTI AR DRAUSTI?

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SANTRAUKA

Skaitmeniniai finansai ne tik skatina tradicinės finansavimo sistemos atkūrimą, bet ir itin veikia mikroskopines įmonių technologines naujoves ir net kokybišką ekonomikos plėtrą. Siekiama iširti skaitmeninės finansinės plėtros poveikį įmonių technologinėms naujovėms naudojant Šanchajaus ir Šendženo vertybinių popierių biržose Kinijoje 2011–2019 m. A-share bendrovių skydinius duomenis ir laiko pramonės fiksuoto efekto modelius, remiantis išteklių paskirstymo teorija ir informacijos asimetrija. Išnagrinėta teorija, ar skaitmeninė finansinė plėtra gali padėti tobulinti įmonių technologines inovacijas. Rezultatai rodo, kad, pirma, skaitmeninė finansinė plėtra gali labai skatinti įmonių technologines naujoves. Antra, nuolat gilėjanti skaitmeninių finansų plėtra nevalstybinių įmonių technologines naujoves skatina aiškiau nei valstybinių įmonių. Trečia, skaitmeninis finansavimas gali stabdyti finansavimo suvaržymus ir įmonių finansines investicijas ir yra svarbus tarpininkas gerinant įmonių technologines naujoves. Ketvirta, atsižvelgiant į sąveikos apdorojimą, skaitmeninis finansinis vystymasis gali geriau paskatinti įmonių technologinių naujovių tobulinimą regionuose, kuriuose žemas ekonominio išsivystymo lygis. Išvadose atskleidžiama, kad skaitmeninė finansinė plėtra ne tik skatina įmonių technologines naujoves, bet ir toliau skatina kokybišką ekonominę pažangą, o tai gali suteikti vyriausybei svarių įrodymų formuoti atitinkamą ekonominės plėtros politiką.

REIKŠMINIAI ŽODŽIAI: įmonių technologinės inovacijos; skaitmeniniai finansai; kokybiška plėtra; finansavimo suvaržymai.

Appendix

Correlation Analysis

	<i>lnpat</i>	<i>lninpat</i>	<i>rda</i>	<i>index</i>	<i>age</i>	<i>lnprofit</i>	<i>lnta</i>	<i>equity</i>	<i>capital</i>	<i>state</i>	<i>merge</i>	<i>sa</i>	<i>fin</i>
<i>lnpat</i>	1												
<i>lninpat</i>	0.638***	1											
<i>rda</i>	0.071***	0.067***	1										
<i>index</i>	-0.098***	-0.079***	0.125***	1									
<i>age</i>	-0.067***	-0.074***	-0.081***	0.399***	1								
<i>lnprofit</i>	0.055***	0.059***	0.042***	-0.050***	-0.024**	1							
<i>lnta</i>	0.042***	-0.021**	-0.188***	0.254***	0.216***	0.128***	1						
<i>equity</i>	0.038***	0.021**	-0.105***	-0.124***	-0.122***	0.100***	0.206***	1					
<i>capital</i>	-0.059***	-0.054***	-0.181***	0.062***	-0.010	-0.121***	-0.038***	-0.094***	1				
<i>state</i>	0.091***	0.036***	-0.131***	-0.101***	0.190***	0.007	0.371***	0.227***	-0.098***	1			
<i>merge</i>	0.010	0.018*	0.093***	0.006	-0.099***	0.003	-0.189***	-0.032***	0.050***	-0.255***	1		
<i>sa</i>	0.068***	0.044***	0.009	-0.368***	-0.660***	0.034***	-0.016*	0.205***	0.033***	-0.043***	0.066***	1	
<i>fin</i>	-0.004	0.013	0.163***	-0.115***	-0.097***	0.101***	-0.213***	0.010	0.153***	-0.089***	0.100***	0.092***	1
VIF Value				1.41	2.04	1.07	1.48	1.15	1.07	1.37	1.09	1.93	1.11

Source: own calculations.