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Impact of Digital Finance on Technological Innovation in China's High-Tech Zones

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ABSTRACT

In this paper, we study the impact of digital finance on technological innovation in China's national high-tech development zones. We find that digital finance improves technological innovation in high-tech zones. Regarding digital financial coverage, usage, and support, the results still exist. Additional analysis suggests that when a high-tech zone faces severe financing constraints (in terms of higher local governmental debt and better development of credit markets), the impact of digital finance on technological innovation is more salient.

KEYWORDS

Digital Finance; High-Tech Development Zones; Technological Innovation; Financing Constraints

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1. Introduction

Technological innovation is essential to the competitiveness and long-term growth of enterprises. However, enterprise innovation involves a long-term and risky process that has a high likelihood of failure (Holmstrom, 1989). With the growth of entrepreneurial clusters and ecosystems, a series of national high-tech industrial development zones have emerged (Adler et al., 2019), which have become important forces for promoting high-quality economic development in China. Moreover, China's national high-tech development zones (CNHIDZ) gather a large number of innovative, high-growth, and start-up Small and Medium Enterprises (SMEs). Due to the limited scale of these companies and the lack of operating records, there are serious information asymmetries between them and the funding providers, making it difficult for them to finance innovative activities (Stiglitz and Weiss, 1981).

Inclusive finance, first mentioned in the 2005 International Year of Microfinance, refers to a financial system that can effectively and comprehensively provide services to all classes of society (Demirgüç-Kunt and Klapper, 2012). As a part of inclusive finance in developing countries and emerging economies, digital finance has significantly increased the enthusiasm of innovative activities for SMEs (Ozili, 2018; Trinugroho et al., 2021). The digital finance that was created disruptively by the Internet and digital technology not only has positive effects on corporate innovation and financial performance but also affects the business and competitiveness of enterprises (Rossi et al., 2020; Luo et al., 2021). Access to financing has been a long-term problem for SMEs attempt to develop through innovative activities, but the emergence of digital finance has widened the financing channels available to SMEs via relaxing conditions for obtaining funds (Nigam et al., 2020; Elisa et al., 2021; Fernandez, 2021). Meanwhile, there is a strong argument that digital finance can weaken traditional finance's exclusivity and decrease exclusion from investment and loan markets in traditional financial markets (Zhong and Jiang, 2021), and be conducive to inclusive development (Song et al., 2020). Although digital finance can bring many benefits, it is not yet clear how it affects the innovation of China's high-tech zones.

The objective of this paper is to examine the impact of digital finance on the innovation of CNHIDZ. We use a set of "Digital Financial Inclusive Index" (CDFII) compiled by the research team of Peking University Digital Finance Research Center, and document that digital finance improves technological innovation in high-tech zones. The findings are robust to alternative metrics of digital finance. Results from the additional analysis suggest that the impact of digital finance on the innovation of China's high-tech zones is more pronounced when the local government debt is higher and the credit market develops better in the high-tech, which is consistent with the notion that digital finance promoting innovation by alleviating financing constraints.

Our paper makes several contributions. First, we advance the literature on innovation by documenting digital financial matters for SMEs in high-tech zones. Second, we analyze how digital finance affects technological innovation in high-tech areas and help enterprises to better formulate relevant policies. Third, our research conclusions provide a reference for other countries to adopt Internet-converged digital finance.

The rest of this paper is structured as follows. Section 2 reviews the related literature. Section 3 outlines our hypotheses. Section 4 details the data source, sample selection process and model specifications. Section 5 presents the main empirical findings and robustness checks. Finally, Section 6 offers a conclusion.

2. Literature Review

In the context of technological innovation, micro-entities cannot detach from finance; effective financial provision directly influences the conduct of technological innovation activities (Jia Junsheng et al., 2017). Numerous studies have illustrated the significant impact of finance on the real economy and, specifically, technological innovation activities. Lim et al. (2010) proposed an equity-oriented financial system whose capital markets can assist economic entities in mitigating certain moral hazards and adverse selection issues by efficiently collecting,

organizing, and disclosing information, thereby benefiting corporate innovation and economic growth. In China's traditional financial system, where banks play a predominant role, the inefficiencies and resource misallocation in the banking system have been somewhat mitigated with enhanced competition within the sector, significantly fostering corporate innovation (Dai Jing et al., 2020). However, many imperfections still persist in China's financial system (Chen Binkai et al., 2012).

An increasing number of scholars are now focusing on the impact of digital finance on innovation. Digital finance broadly refers to new financial business models in financing, payment, investment, and others, implemented by traditional financial institutions and Internet companies using digital technologies (Huang Yiping et al., 2018). Huang Rui et al. (2020) found that the development of digital finance could alleviate corporate financing constraints. In terms of enterprise innovation, Sun Jiguo et al. (2015), from the perspective of policy effects, found that digital finance significantly enhances the technological innovation levels of small and medium-sized enterprises, with this promoting effect being more pronounced for private enterprises. Other scholars have integrated theories of dynamic capabilities and ambidextrous innovation to study this issue, likewise concluding that digital finance effectively promotes corporate technological innovation (Wang Xiao et al., 2021; Zheng Yuxi et al., 2022; Jia Junsheng, 2021; Nie Xiuhua, 2020). Chen Li et al. (2022) and Wan Jiayu et al. (2020) found that digital finance strengthens the market's role as the "invisible hand" in the allocation of resource elements, significantly promoting enterprise innovation investment. Wu Qingtian et al. (2021), Yu Ping et al. (2020), and Liang Bang et al. (2019) found that digital finance has a significant driving effect on enterprise technological innovation output. However, research on the impact of digital finance on China's high-tech development zones is relatively scarce. Due to the varying levels of economic development, policy environments, and technological conditions across Chinese provinces, digital inclusive finance shows imbalanced development across the provinces (Sun Yuhuan et al., 2021). Guo Feng et al. (2020), by compiling the "Peking University Digital Inclusive Finance Index," have deeply depicted the developmental trends of digital inclusive finance across regions in China, finding that digital finance development exhibits regional convergence, spatial agglomeration, and spatial heterogeneity. Other scholars have pointed out that as digital technologies continue to develop and proliferate, and as national policies progressively advance, the regional disparities in digital finance development across China are gradually narrowing (Jiao Yunxia, 2022).

In summarizing existing literature on the relationship between digital finance and technological innovation, it is found that there are areas for expansion: Firstly, most studies focus on the impact of traditional finance on technological innovation but overlook the role of digital finance, which as an emerging financing model, has more advantages and will be more beneficial for technological innovation, yet related research is relatively scarce. Secondly, existing research on digital finance and technological innovation mostly targets enterprises whose financing requirements can be met by the traditional financial system, hence the impact of digital finance on these enterprises is minimal. This paper, unlike previous studies, builds on existing research, optimizes the research subject by selecting high-tech zones in China as the study object, and analyzes the impact of digital finance on high-tech zones, addressing the deficiencies in existing research.

3. Hypothesis development

Digital finance has a direct effect on technological innovation. Firstly, digital finance platforms can provide easier and more efficient access to capital for high-tech enterprises, especially small and medium-sized enterprises (SMEs) that may find it challenging to secure funding through traditional financial institutions. By lowering the barriers to obtaining financial resources, digital finance can facilitate increased investment in research and development (R&D) and innovation activities. Secondly, high-tech zones are specialized areas designed to promote technological advancement and economic development through concentrated efforts in R&D, high-tech manufacturing, and the incubation of innovative startups. These special economic zones often require substantial

financial resources to support the development of new technologies, the commercialization of innovations, and the growth of high-tech enterprises. Thirdly, digital inclusive finance can enhance the flow of resources, improve the efficiency of capital utilization, optimize regional resource allocation, and strengthen regional economic regulation through precise data analysis and risk assessment. Finally, digital inclusive finance can support high-tech zones in achieving sustainable growth and entering new growth paths by fostering entrepreneurship, technological innovation, and the transformation and upgrading of industrial structures. Given these potential benefits, we hypothesize that:

H1. Digital finance has a direct positive effect on technological innovation in high-tech zones.

4. Research Design

4.1. Data source and sample Selection

Our data covers an unbalanced panel with 1,046 samples of 169 China national high-tech industrial development zones (CNHIDZ) located in 156 cities and established from 2011 to 2018, the data chosen from this period since the China digital financial inclusive index (CDFII) that publicly available is also between 2011 and 2018. Panel A of Table 1 shows the distribution of sample data by year. From 2011 to 2018, the sample size increased each year. In 2011, the sample size accounted for 8.51% of the total sample, while in 2018, it accounted for 16.16%. The total sample size over this period was 1,046. Panel B of Table 1 displays the distribution of sample data by city. The table lists the sample size for each city and its proportion of the total sample. For instance, Shanghai had a sample size of 16, representing 1.53% of the total sample, whereas Suzhou had a sample size of 28, representing 2.68% of the total sample. The sample covers various cities, with some having smaller sample sizes, such as Sanming (4 samples, 0.38%), and others having larger sample sizes, such as Suzhou (28 samples, 2.68%).

Table 1. Sample Distribution.

Panel A: Sample distribution by year		
year	Freq.	Percent
2011	89	8.510
2012	106	10.13
2013	115	10.99
2014	116	11.09
2015	147	14.05
2016	147	14.05
2017	157	15.01
2018	169	16.16
Total	1,046	100
Panel B: Sample distribution by city		
city	Freq.	Percent
Sanming	4	0.380
Shanghai	16	1.530
Dongguan	8	0.760
Dongying	4	0.380
Zhongshan	8	0.760
Linyi	8	0.760
Wulumuqi	8	0.760
Leshan	7	0.670
Jiujiang	1	0.100
Xiantao	4	0.380
Foshan	8	0.760
Baoding	8	0.760

Lanzhou	8	0.760
Neijiang	2	0.190
Baotou	8	0.760
Beijing	8	0.760
Beihai	4	0.380
Nanjing	8	0.760
Nanning	8	0.760
Nanchang	8	0.760
Nantong	6	0.570
Nanyang	8	0.760
Xiamen	8	0.760
Hefei	8	0.760
Ji'an	4	0.380
Jilin	8	0.760
Huhehaote	6	0.570
Xianning	2	0.190
Xianyang	15	1.430
Haerbin	8	0.760
Tangshan	8	0.760
Jiaxing	4	0.380
Daqing	8	0.760
Dalian	8	0.760
Tianjin	8	0.760
Taiyuan	8	0.760
Weihai	8	0.760
Xiaogan	7	0.670
Ningbo	8	0.760
Ankang	4	0.380
Anyang	8	0.760
Anshun	2	0.190
Yichang	8	0.760
Yichun	1	0.100
Baoji	8	0.760
Suqian	2	0.190
Changzhou	15	1.430
Changed	2	0.190
Pingdingshan	4	0.380
Guangzhou	8	0.760
Langfang	8	0.760
Yanbian	8	0.760
Xuzhou	7	0.670
Dezhou	4	0.380
Deyang	4	0.380
Huaihua	1	0.100
Huizhou	8	0.760
Chengdu	8	0.760
Yangzhou	4	0.380
Chengde	7	0.670
Fuzhou	4	0.380
Panzhihua	4	0.380
Xinxiang	7	0.670
Xinyu	8	0.760
Wuxi	16	1.530
Kunming	8	0.760
Jichang	8	0.760
Jingdezhen	8	0.760

Benxi	7	0.670
Hangzhou	12	1.150
Zaozhuang	4	0.380
Liuzhou	8	0.760
Zhuzhou	8	0.760
Guilin	8	0.760
Chuxiiong	1	0.100
Yulin	7	0.670
Wuhan	8	0.760
Shantou	2	0.190
Jiangmen	8	0.760
Shenyang	8	0.760
Heyuan	4	0.380
Quanzhou	8	0.760
Taian	7	0.670
Taizhou	8	0.760
Luzhou	4	0.380
Luoyang	8	0.760
Jinan	8	0.760
Jining	8	0.760
Haikou	8	0.760
Zibo	8	0.760
Huainan	1	0.100
Huai'an	2	0.190
Shenzhen	8	0.760
Qingyuan	4	0.380
Wenzhou	7	0.670
Weinan	8	0.760
Huzhou	4	0.380
Xiangtan	8	0.760
Zhanjiang	1	0.100
Zhangzhou	6	0.570
Weifang	8	0.760
Qianjiang	1	0.100
Yantai	8	0.760
Jiaozuo	4	0.380
Yuxi	7	0.670
Zhuhai	8	0.760
Baiyin	8	0.760
Yiyang	8	0.760
Yancheng	4	0.380
Shizuishan	6	0.570
Shijiazhuang	8	0.760
Shihezi	6	0.570
Fuzhou	8	0.760
Shaoxin	8	0.760
Mianyang	8	0.760
Zhaoqing	8	0.760
Zigong	8	0.760
Wuhu	8	0.760
Suzhou	28	2.680
Maoming	1	0.100
Jingzhou	1	0.100
Jingmen	6	0.570
Putian	7	0.670
Laiwu	4	0.380

Yingkou	8	0.760
Bengbu	8	0.760
Hengyang	7	0.670
Quzhou	6	0.570
Xiangyang	8	0.760
Xining	8	0.760
Xi'an	8	0.760
Guiyang	8	0.760
Ganzhou	4	0.380
Liaoyang	8	0.760
Lianyungang	4	0.380
Tonghua	6	0.570
Zhengzhou	8	0.760
Chenzhou	4	0.380
Ordos	2	0.190
Chongqing	14	1.340
Tonglin	2	0.190
Yinchuan	8	0.760
Jinzhou	4	0.380
Zhenjiang	5	0.480
Changchun	15	1.430
Changsha	8	0.760
Changzhi	4	0.380
Fuxin	6	0.570
Suizhou	4	0.380
Qingdao	8	0.760
An'shan	8	0.760
Ma'anshan	7	0.670
Yingtan	7	0.670
Huangang	2	0.190
Huangshi	1	0.100
Qiqihaer	8	0.760
Longyan	4	0.380
Total	1,046	10

The data of CNHIDZ are initially obtained from the China Torch Statistical Yearbook issued by Torch High Technology Industry Development Center of Science & Technology Ministry of China. Here we collect the basic information of each CNHIDZ, such as the performance of technological innovation, total assets, the total number of employees and enterprises, leverage (the ratio of debt/asset), R&D investment and employees. The CDFII provided by the Peking University Digital Finance Research Center portrays the development of digital finance in different regions of China. At the city level, we acquired the data on city characteristics from the Provincial Statistical Yearbook of the National Bureau of Statistics, including the proportion of students to the whole population, gross regional product per capita, average number of patents applicated per thousand people, population, registered unemployment rate and average wage.

4.2. Model Specifications

In order to investigate the relationship between digital finance and technological innovation, we employ the following regression, that is:

$$Tech_{Innovation_{i,t}} = \alpha_0 + \alpha_1 * DFIIC_{i,t-1} + \alpha_2 * X_{i,t-1} + \alpha_3 * Z_{i,t-1} + \sum City + \sum Year + \varepsilon_{i,t-1} \quad (1)$$

where subscripts i and t indicate the national high-tech industrial development zone and year, respectively. The dependent variable Technological $Innovation_{i,t}$ refers to the performance of technological innovation, which computed as the technology revenue to operating revenue for a certain national high-tech industrial development zone. The $DFIIC_{i, t-1}$ stands for the development of digital finance in the city of year *t-1* where the CNHIDZ is located. The $DFIIC_{i, t-1}$ includes four different dimensions of index, involve a first-level indicator (total index) and three second-level indicates (coverage breadth, the depth of use and the degree of digitization). And $X_{i, t-1}$ and $Z_{i, t-1}$ represent CNHIZE and city covariates. The CNHIZE characteristics include total assets, the ratio of debt to total assets, the number of employees and enterprises in each national high-tech industrial development zone, R&D investment and staff. City level characteristics include the gross regional product per capita that represents the economic status of the city, the percentage of students to the whole population, the average number of patents applicated per thousand people, the total population of the city, the registered unemployment rate, and the income per capita. ΣCity demonstrates the time-invariant city fixed effect, and ΣYear is the year effects. The dependent variable is ahead by one year. And all continuous variables are winsorized at the top and bottom 1%.

5. Empirical findings

5.1. Descriptive statistics

Table 2 represents summary statistics for all variables. The mean (median) value of *Tech_Innovation* is 0.047 (0.061). (We present the summary statistics of the sample in Table 2. The mean (median) of Tech_Innovation is 0.047 (0.061) and the standard deviation is 0.065. Hence, the extent of technological innovation among China national varies greatly.)

Table 2. Descriptive statistics.

Variables	N	Mean	S.D.	Min	P25	Median	P75	Max
$Tech\_Innovation_{i,t}$	1,046	0.047	0.065	0.000	0.003	0.016	0.067	0.277
$DFIIC_{i,t-1}$	1,046	5.098	0.410	3.834	4.889	5.209	5.405	5.642
$Coverage_{i, t-1}$	1,046	5.068	0.395	3.753	4.870	5.171	5.360	5.612
$Usage_{i, t-1}$	1,046	5.075	0.423	3.856	4.843	5.130	5.434	5.671
$Digitization_{i, t-1}$	1,046	5.173	0.581	3.130	5.026	5.454	5.571	5.733
$Size_{i, t-1}$	1,046	25.311	1.196	22.950	24.386	25.234	26.111	28.656
$Employees_{i,t-1}$	1,046	11.167	1.002	8.955	10.460	11.178	11.849	13.725
$Enterprises_{i,t-1}$	1,046	5.677	1.091	3.135	4.970	5.645	6.306	8.400
$Leverage_{i,t-1}$	1,046	0.549	0.101	0.231	0.494	0.556	0.614	0.757
$RD\_Funds_{i,t-1}$	1,046	20.775	1.616	16.570	19.568	20.822	21.952	24.494
$RD\_Staff_{i,t-1}$	1,046	9.017	1.390	5.513	7.989	8.981	9.976	12.535
$Education_{i,t-1}$	1,046	0.028	0.025	0.003	0.010	0.019	0.033	0.109
$GRP_{i,t-1}$	1,046	26.446	0.962	24.386	25.729	26.365	27.096	28.751
$Patent_{i,t-1}$	1,046	1.082	0.668	0.172	0.544	0.941	1.498	2.656
$Population_{i,t-1}$	1,046	15.388	0.697	13.596	14.902	15.391	15.858	17.214
$Unemployment_{i,t-1}$	1,046	0.029	0.008	0.013	0.023	0.030	0.035	0.043
$Wages_{i,t-1}$	1,046	10.953	0.273	10.312	10.760	10.960	11.140	11.625

5.2. Digital inclusive finance and high-tech industrial development zone innovation

We present the baseline results of Eq. (1) in Table 3. Column (1) shows that the coefficient of DFIIC is positive and significant at 1 percent level, suggesting that digital finance does really have a positive influence on the performance of technological innovation. Then, we use the other three indicators (Coverage, Usage, Digitization)

reflecting the different dimensions of digital finance to replace the previous independent variable and find that the result is still positive and significant at the 1 percent level. In addition, we include all control variables in Column (5) to Column (8), and find that the estimated coefficients are still significant and positively associated with the performance of technological innovation. In Column (9), we add three different dimension indicators to the regression at the same time, the variable *Coverage* is only significant at 10 percent level and the variable *Usage* is not significant, but the variable *Digitization* is significant at 1 percent level, suggesting that the degree of digitization of digital finance is a key factor in promoting the innovation efficiency of SMEs in high-tech zones.

Table 3. Digital inclusive finance and the innovation of high-tech industrial development zones.

Variables	Y= Tech_Innovation$_{i,t}$								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DFIIC$_{i,t-1}$	0.101***				0.094***				
	(4.24)				(4.31)				
Coverage$_{i,t-1}$		0.072***				0.063***			0.033*
		(3.37)				(3.40)			(1.76)
Usage$_{i,t-1}$			0.092***				0.079***		0.021
			(3.74)				(3.83)		(1.07)
Digitization$_{i,t-1}$				0.051***				0.046***	0.038***
				(4.47)				(4.64)	(3.93)
Size$_{i,t-1}$					-0.005	-0.004	-0.006	-0.006	-0.005
					(-1.12)	(-0.97)	(-1.30)	(-1.22)	(-1.21)
Employees$_{i,t-1}$					-0.032***	-0.034***	-0.031***	-0.033***	-0.032***
					(-4.46)	(-4.51)	(-4.19)	(-4.82)	(-4.46)
Enterprises$_{i,t-1}$					0.029***	0.030***	0.030***	0.034***	0.031***
					(4.42)	(4.40)	(4.58)	(5.16)	(4.69)
Leverage$_{i,t-1}$					-0.052**	-0.051**	-0.055**	-0.048**	-0.051**
					(-2.38)	(-2.30)	(-2.41)	(-2.12)	(-2.33)
RD_Funds$_{i,t-1}$					0.003	0.003	0.003	0.003	0.003
					(0.93)	(0.86)	(1.05)	(1.01)	(1.01)
RD_Staff$_{i,t-1}$					0.003	0.007	0.005	0.004	0.000
					(0.53)	(1.18)	(0.85)	(0.68)	(0.09)
Education$_{i,t-1}$					0.330	0.316	0.229	0.528*	0.447
					(1.18)	(1.12)	(0.81)	(1.72)	(1.55)
GRP$_{i,t-1}$					0.027***	0.027***	0.028***	0.025***	0.026***
					(2.85)	(2.82)	(2.89)	(2.80)	(2.82)
Patent$_{i,t-1}$					0.016**	0.015**	0.012*	0.012*	0.015**
					(2.32)	(2.25)	(1.71)	(1.79)	(2.23)
Population$_{i,t-1}$					0.044***	0.042***	0.035***	0.045***	0.046***
					(3.27)	(3.09)	(2.63)	(3.38)	(3.41)
Unemployment$_{i,t-1}$					-0.276	-0.288	-0.281	-0.060	-0.166
					(-0.70)	(-0.72)	(-0.69)	(-0.15)	(-0.43)
Wages$_{i,t-1}$					-0.031	-0.033	-0.024	-0.025	-0.028
					(-1.33)	(-1.38)	(-1.03)	(-1.09)	(-1.23)
Constant	-0.469***	-0.320***	-0.419***	-0.217***	-1.245***	-1.066***	-1.139***	-1.059***	-1.272***
	(-3.85)	(-2.93)	(-3.36)	(-3.67)	(-3.11)	(-2.69)	(-2.85)	(-2.86)	(-3.24)
City FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Adj. R^2	0.717	0.709	0.711	0.718	0.744	0.738	0.739	0.745	0.750
Observations	1,046	1,046	1,046	1,046	1,046	1,046	1,046	1,046	1,046

*Notes: The t-values are reported in the parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*

5.3. Additional analysis

Financing constraints will have a significant negative impact on corporate innovation (Aghion et al., 2012; Amore et al., 2013). SMEs often face severe financing constraints when engaging in innovative activities (Hall and Lerner, 2010). If the logic of inclusive finance improves technological innovation by alleviating financing constraints is established, we expect that inclusive finance is more pronounced for CNHIDZ where financing is harder.

5.3.1. Comparison of innovation with different local governmental debt

Prior studies (e.g., Teles and Mussolini, 2014) suggest local governmental debt can crowd out private investment and hinder economic development. Huang et al. (2020) find that the expansion of local governmental debt will crowd out corporate investment by increasing corporate financing costs. Local government debt increases the degree of financing constraints faced by enterprises by increasing the external financing costs of enterprises. We follow Wu (2014) and define local governmental debt (Debt) as the balance of urban construction investment bonds divided by the GDP. We interact the local governmental debt (Debt) with the DFIIC and include the interaction terms in the regression specification in Equation (1). The results are reported in Table 4, which show that the coefficients on DFIIC×Debt is positive and statistically significant, suggesting that the effect of inclusive finance on technological innovation is amplified for zones with higher local governmental debt, consistent with our expectation that inclusive finance is more pronounced for CNHIDZ where financing is harder. We use the other three indicators (Coverage, Usage, Digitization) to interact with debt respectively and find that the result is still positive and significant. Overall, the results in Table 4 are consistent with the financing constraint channels. (Wu, 2014)

Table 4. Interactions between digital inclusive finance and local governmental debt.

Variables	Y= Tech_Innovation$_{i,t}$			
	(1)	(2)	(3)	(4)
$DFIIC_{i,t-1}$	0.070***			
	(5.286)			
$DFIIC_{i,t-1}$×$Debt_{i,t-1}$	0.414***			
	(5.838)			
$Coverage_{i,t-1}$		0.042***		
		(3.628)		
$Coverage_{i,t-1}$×$Debt_{i,t-1}$		0.476***		
		(6.455)		
$Usage_{i,t-1}$			0.065***	
			(4.731)	
$Usage_{i,t-1}$×$Debt_{i,t-1}$			0.304***	
			(5.220)	
$Digitization_{i,t-1}$				0.030***
				(4.358)
$Digitization_{i,t-1}$×$Debt_{i,t-1}$				0.263***
				(4.557)
$Debt_{i,t-1}$	-2.224***	-2.564***	-1.592***	-1.459***
	(-5.695)	(-6.306)	(-5.052)	(-4.525)
Controls	YES	YES	YES	YES
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Adj. R^2	0.754	0.749	0.746	0.751
Observations	1,046	1,046	1,046	1,046

*Notes: The t-values are reported in the parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*

5.3.2. Comparison of innovation with different financial development

Hsu et al. (2014) find that the development of credit markets discourages innovation in industries that are more dependent on external finance. Because banks are excessively concerned with avoiding risky activities and failures, Berger and Udell (1990) find that companies usually need collateral to obtain debt financing, which is difficult for SMEs in CNHIDZ. At the same time, since banks are afraid that managers and equity holders of high-tech companies will overinvest afterwards, they will avoid providing funds to these companies. Therefore, for SMEs in CNHIDZ that are highly dependent on financing, the better the credit market develops, the more difficult it will be

to raise funds. We follow Hsu et al. (2014) and define credit market development (CREDIT) as the country's domestic credit provided by the banking sector divided by the GDP. We interact credit market development (CREDIT) with the DFIIC and include the interaction terms in the regression specification in Equation (1). The results are reported in Table 5, which show that the coefficients on DFIIC×CREDIT are positive and statistically significant, suggesting that the effect of inclusive finance on technological innovation is amplified for zones with better development of credit markets, consistent with our expectation that inclusive finance is more pronounced for CNHIDZ where financing is harder. We use the other three indicators (Coverage, Usage, Digitization) to interact with debt respectively and find that the result is still positive and significant. Overall, the results in Table 5 are consistent with the financing constraint channels.

Table 5. Interactions between digital inclusive finance and financial development scale.

Variables	Y= Tech_Innovation$_{i,t}$			
	(1)	(2)	(3)	(4)
$DFIIC_{i,t-1}$	0.075***			
	(3.67)			
$DFIIC_{i,t-1}$×$CREDIT_{i,t-1}$	0.012***			
	(4.57)			
$Coverage_{i,t-1}$		0.046***		
		(2.76)		
$Coverage_{i,t-1}$×$CREDIT_{i,t-1}$		0.014***		
		(4.60)		
$Usage_{i,t-1}$			0.054***	
			(2.68)	
$Usage_{i,t-1}$×$CREDIT_{i,t-1}$			0.009***	
			(4.03)	
$Digitization_{i,t-1}$				0.031***
				(3.17)
$Digitization_{i,t-1}$×$CREDIT_{i,t-1}$				0.005***
				(3.26)
$CREDIT_{i,t-1}$	-0.047***	-0.056***	-0.037***	-0.014
	(-3.42)	(-3.61)	(-2.85)	(-1.49)
Controls	YES	YES	YES	YES
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Adj. R^2	0.763	0.760	0.752	0.758
Observations	1,046	1,046	1,046	1,046

*Notes: The t-values are reported in the parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*

6. Conclusion

In this paper, we examine how enterprises' innovations are linked to the level of local development of digital finance, and we study how digital finance reduces financing constraints for enterprises.

First, we study the correlation between China's national high-tech industrial development zones' technology income and the Inclusion index for digital finance. We find that technology innovation is positively impacted by digital finance, in line with the literature. Then, we substitute three other independent variables reflecting different aspects of digital finance (coverage index, use index, support degree of digital finance), and find that the coefficient is still significant and continues to rise with technological innovation performance.

Furthermore, we examine the impact of a lack of adequate financing on technological innovation in high-tech zones. We find that local government debt increases financing constraints of enterprises by increasing the costs of

external financing, and we find that financial inclusion has an amplified impact on technological innovation in regions with high local government debt. Further, we look at how credit market developments impact technological innovation. It seems that the stronger the credit market develops, the more complicated it will be for SMEs in built-up areas that are highly dependent on financing. The impact of inclusive finance on technological innovation is greater in regions where the credit markets have developed well.

We had limited data sets and some questions remain to be answered in future studies. Future research should focus on the spillover effect of digital finance on technological innovation in high-tech zones, that is, the cooperation between enterprises and universities and between enterprises and cities. Furthermore, it is important to examine how technological innovation in high-tech zones affects enterprises in different industries in different ways. Policymakers should consider enhancing digital finance infrastructure and policies to support innovation, particularly in regions with high financing constraints. Future research could explore the spillover effects of digital finance on technological innovation across different industries and regions. Policymakers should enhance digital finance infrastructure and policies to support innovation, especially in regions with high financing constraints.

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Conflict of interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

Appendix

Appendix A. Variable Definition.

Variables	Definition
Dependent variables	
$Tech\_Innovation_{i,t}$	The percentage of technological revenue to operating revenue for CNHIDZ *i* in year *t*.
Independent variables	
$DFIIC_{i,t-1}$	An index that measures the overall development of digital finance for city *i* in year *t-1*.
$Coverage_{i,t-1}$	An index that measures the breadth of digital finance coverage for city *i* in year *t-1*.
$Usage_{i,t-1}$	An index that measures the depth of digital finance usage for city *i* in year *t-1*.
$Digitization_{i,t-1}$	An index that measures the degree of digital financial supporting for city *i* in year *t-1*.
CNHIDZ-level variables	
$Size_{i,t-1}$	Natural logarithm of total assets for CNHIDZ *i* in year *t-1*.
$Employees_{i,t-1}$	Natural logarithm of the number of employees for CNHIDZ *i* in year *t-1*.
$Enterprises_{i,t-1}$	Natural logarithm of the number of enterprises for CNHIDZ *i* in year *t-1*.
$Leverage_{i,t-1}$	Ratio of total liabilities divided by total assets for CNHIDZ *i* in year *t-1*.
$RD\_Funds_{i,t-1}$	Natural logarithm of research and development expenditure for CNHIDZ *i* in year *t-1*.
$RD\_Staff_{i,t-1}$	Natural logarithm of the number of employees engaged in research and development activities for CNHIDZ *i* in year *t-1*.
City-level variables	
$Education_{i,t-1}$	Percentage of students to total population for city *i* in year *t-1*.
$GRP_{i,t-1}$	Natural logarithm of gross regional product per capita for city *i* in year *t-1*.
$Patent_{i,t-1}$	Natural logarithm of patent applications per 1,000 inhabitants for city *i* in year *t-1*.
$Population_{i,t-1}$	Natural logarithm of population for city *i* in year *t-1*.
$Unemployment_{i,t-1}$	Unemployment rate for city *i* in year *t-1*.
$Wages_{i,t-1}$	Natural logarithm of average wage of employed workers for city *i* in year *t-1*.

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