

Can Digital Inclusive Finance Promote High-Tech Manufacturing Enterprises Innovation? City-level Evidence from China

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Abstract: In the context of Industry 4.0, innovation in high-tech industries is crucial to promoting sustainable industrial development. Digital inclusive finance, supported by digital technology, provides new opportunities for innovation. In order to clarify the impact mechanism of digital inclusive finance on enterprise innovation, this paper selects high-tech manufacturing companies from 2015 to 2022 in A-shares. The results indicate that digital inclusive finance contributes to enhancing the innovation efficiency of high-tech manufacturing enterprises. This effect is achieved through alleviating financing constraints, controlling risk levels, and driving digital transformation. Therefore, the government should actively promote the development of digital inclusive finance and further enhance the role of digital transformation to drive innovation in high-tech manufacturing.

Keywords: Digital Inclusive Finance, High-tech Manufacturing Enterprises, Innovation Efficiency, Digital Transformation.

1. Introduction

In the current era marked by a global technological revolution and industrial transformation, high-tech manufacturing sectors such as electronic information, aerospace, and biomedicine stand out as vital drivers of industrial growth. In China, the investment in high-tech manufacturing increased by 9.9% compared to the previous year. Enterprises above designated size means all enterprises with annual main business revenue of 20 million RMB or above. In the first quarter of 2024, the added value of high-tech manufacturing enterprises above designated size increased by 7.5%, driving the added value of industries above designated size to increase by 1.1%. In the advancing era of global Industry 4.0, high-tech manufacturing represents a country's technological prowess and serves as crucial indicators of a nation's overall competitiveness.

However, their innovative endeavors typically entail characteristics of high investment, elevated risk, and protracted timelines[1]. Consequently, enterprises often grapple with the persistent challenge of insufficient resource allocation, with funding inadequacy emerging as one of the most pronounced concerns[2]. High-tech manufacturing enterprises frequently confront a trifecta of issues: a disparity between diverse capital requisites and available financing avenues, a mismatch between long-term capital necessities and financing tenures, and an incongruity between financial supply and demand dynamics[3]. The resultant repercussions, ranging from funding impediments to exorbitant financing costs and sluggish capital acquisition, serve to further impede the pace of technological advancement.

Digital inclusive finance is the product of the integration of financial technology and inclusive finance. Leveraging digital inclusive finance's cost-effectiveness, accessibility, and broad inclusivity[4], digital inclusive finance furnishes high-tech manufacturing enterprises with streamlined and adaptable financing modalities, thereby imbuing their innovation initiatives with renewed vigor. Within the Chinese landscape, the rapid maturation and deployment of digital technologies

such as cloud computing, blockchain, and big data have precipitated the swift ascension of digital inclusive finance. The exploration of how digital inclusive finance engenders impacts on innovation within high-tech manufacturing enterprises assumes paramount significance in effectuating qualitative and procedural transformations within the manufacturing realm. This inquiry not only holds substantial theoretical import but also bears tangible ramifications for practical applications.

Against above backgrounds, this paper first theoretically delineates the impact mechanism of digital inclusive finance on innovation efficiency in high-tech manufacturing enterprises. Subsequently, leveraging a dataset comprising 891 listed high-tech manufacturing enterprises in China from 2015 to 2022, we construct a new evaluation system for innovation efficiency based on the connotations of innovation efficiency and the characteristics of high-tech industries. Furthermore, we specifically juxtapose the development level of digital inclusive finance in prefecture-level cities with the innovation efficiency of high-tech manufacturing enterprises. We innovatively introduce degrees of digital transformation as mediating variables, systematically demonstrating the impact pathways of digital inclusive finance on the innovation efficiency of high-tech manufacturing enterprises.

2. Related Works

In recent years, there has been growing scholarly attention on the impact of digital inclusive finance on corporate innovation. A considerable body of literature affirms the direct influence of digital inclusive finance on corporate innovation. Demertzis et al. [5] highlighted the advantages of digital finance in terms of convenience, speed, and low entry barriers, which can facilitate technological innovation for enterprises. Zhao et al. [6] found that the development of digital finance not only promotes R&D investment by enterprises but also enhances both the quantity and quality of their innovation output. Moreover, the "expansion" and "deepening" of digital finance exhibit significant positive effects on enterprise innovation. Li et al. [7] empirically

discovered a significant positive role of digital finance development in fostering dual innovation within enterprises. Compared to exploitative innovation, digital finance demonstrates a greater promoting effect on exploratory innovation. Absorptive capacity exhibits a significant mediating role between digital finance and exploratory innovation. A nonlinear relationship exists between digital finance and dual innovation within enterprises.

Additionally, certain studies investigate how digital finance impacts enterprise innovation. Zhang et al. [8] pointed out that digital finance enhances enterprise innovation capabilities through increased interbank competition and credit supply, while simultaneously improving innovation levels by reducing financing constraints and costs. Zhao[9] examined the transmission effect of financing methods and found that digital finance promotes corporate innovation through the complete intermediary effect of internal financing and debt financing. Li et al. [10] figured out that digital finance can effectively correct the financial mismatch problem in the traditional financial model, thereby promoting the technological innovation capability of small and medium-sized enterprises. Zhang et al. [11] empirically suggested that reasonable financial regulation and adaptive government subsidies can strengthen the impact of digital finance on enterprise innovation. Li et al. [12] proposed that equity concentration can adjust the degree of innovation incentive provided by digital finance to enterprises.

For high-tech enterprises, there has been some research on the mechanisms through which digital inclusive finance impacts innovation. Han et al. [13] found a significant positive correlation between digital inclusive finance and the innovation performance of high-tech enterprises. The higher the level of debt financing, the stronger the role of digital financial inclusion in promoting innovation performance. Fan et al. [14] found that digital inclusive finance has a significant positive impact on the innovation resilience of high-tech manufacturing. R&D investment intensity shows a dual threshold effect in the impact of digital inclusive finance on the innovation resilience of high-tech manufacturing. Some studies have also examined the impact of digital inclusive finance on green innovation in manufacturing enterprises. Lu et al. [15] found that digital inclusive finance significantly improves the efficiency of capital supply and usage, eliminates financing constraints, and enhances the effectiveness of green innovation in manufacturing enterprises. Li et al. [16] used the Slack-Based Measure (SBM) efficiency model to measure the efficiency of regional manufacturing green transformation and analyzed the spatial impact of digital finance on transformation. The results show that the green transformation of manufacturing has positive spatial spillover effects.

A closely related category of literature in this study is innovation efficiency, which is assessed through three main methods. Firstly, single indicator method measures innovation output by indicators such as the growth in R&D investment, the number of patent applications or grants, and the quantity of trademark applications [17]. Secondly, the ratio approach, where specific parameters are adjusted according to practical considerations. Hirshleifer [18] evaluated innovation efficiency by the ratio of patent applications to R&D investment. Lastly, the frontier analysis method encompasses non-parametric DEA[19] and parametric Stochastic Frontier Analysis (SFA) [20]. DEA, a

non-parametric method based on linear programming, assesses efficiency levels by comparing the inputs and outputs of various enterprises without requiring a predefined function. SFA, on the other hand, is a parametric method based on an economic production function, assuming technical efficiency and random error terms, thereby measuring the capability of enterprises to produce outputs.

Specifically, the majority of scholars use the DEA method to measure enterprise innovation efficiency. Han et al. [21] evaluated the innovation efficiency of listed enterprises in the "Made in China 2025" initiative from five aspects: innovation efficiency, returns to scale, effectiveness, industry, and projection analysis. Qian et al. [22] utilized the parallel network DEA method to study the innovation efficiency of provincial high-tech enterprises from 2008 to 2014. Xu et al. [23] employed a three-stage DEA method to assess the innovation efficiency of 41 listed artificial intelligence companies. On the other hand, some scholars argue that SFA accounts for the impact of random factors on output, providing a stable measure. Deng et al. [24] applied the translog stochastic frontier model to estimate the technological innovation efficiency of 28 listed automobile enterprises in China from 2008 to 2012. Chao et al. [25] used the SFA method to analyze the technological innovation efficiency of sample enterprises, further dividing it into pure technological innovation efficiency and scale efficiency. Liu et al. [26] employed the stochastic frontier analysis method to measure and analyze the innovation efficiency of listed companies in China's strategic emerging industries from 2010 to 2020.

In summary, the current research findings on the micro-level innovation effects of digital inclusive finance on enterprises are abundant, but there is still room for improvement. Firstly, there is a need to consider factors except innovation inputs or outputs when measuring enterprise innovation. Since factors influencing enterprise innovation include inputs, outputs, and external environments. Thereby measuring innovation efficiency is more appropriate for assessing enterprise innovation capabilities. Current research has not reached a consensus on the evaluation of innovation efficiency in high-tech manufacturing enterprises. Secondly, the research on the impact of digital inclusive finance on enterprise innovation efficiency has not yet formed a relatively mature analytical framework. Current research only explores how digital inclusive finance influences enterprise innovation through channels such as easing financing restrictions and reducing financial mismatches. Therefore, there's a gap in understanding other channels like digital transformation.

3. Theoretical Analysis and Hypotheses

Innovation activities in high-tech manufacturing enterprises are characterized by high investment risk, significant capital input, and long return cycles, with financial exclusion and information asymmetry being important factors restricting the improvement of their innovation efficiency. Digital inclusive finance, relying on the "finance + technology" model, features inclusiveness, openness, and accessibility. On the one hand, digital finance utilizes new technologies to expand financial coverage, innovate financial service models, and simplify approval processes. It not only reducing financing costs but also enhancing financing efficiency, effectively addressing issues of scale and

ownership discrimination in financial resource allocation processes. On the other hand, the development of digital inclusive finance lowers the financing threshold and costs for enterprises [27]. Leveraging powerful data mining capabilities, digital inclusive finance accurately matches financial resources with the risks of innovative projects, thereby increasing the likelihood of financing for high-quality enterprises. Based on this, Hypothesis 1 is proposed.

H1: Digital inclusive finance has a positive impact on innovation efficiency of high-tech manufacturing enterprises.

The effect of alleviating financing constraints: Capital is a critical component of innovation factor for high-tech enterprises, and severe financing constraints can inhibit their innovation activities. Digital inclusive finance can transcend temporal and spatial limitations, utilizing its technological features to establish enterprise credit risk systems at lower costs. It also can analyze the credit and operational conditions of enterprises, thereby providing financial support to "long-tail users." Additionally, digital inclusive finance can alleviate adverse selection and moral hazard issues through digital technology, accelerating the turnover speed of financial assets. Furthermore, digital inclusive finance is able to correct the "attribute mismatch" caused by traditional finance effectively, thereby providing financial security for enterprise innovation activities.

The effect of controlling risk levels: The pecking order theory proposes that companies will follow a financing sequence of internal financing, debt financing, and equity financing. Digital inclusive finance can reduce capital consumption in financial transactions, thereby preventing companies from passively relying on leverage financing due to high costs [28], reducing the demand for external financing for companies. This mitigates financial risks and provides internal environmental protection for the long-term development of innovation activities. In addition, the technological nature of digital inclusive finance plays an information role, lowering information acquisition costs to inhibit managerial speculation behavior, alleviate operational risks for companies. Furthermore, digital inclusive finance exerts a risk level control effect in the process of enterprise innovation.

The effect of driving digital transformation: Digital inclusive finance has propelled the application of digital technology in the financial sector [29], accelerating the pace of enterprise digital transformation. Thanks to the digital characteristics of digital finance, companies can more conveniently access funds [30], thereby providing better support for the introduction of digital talents and equipment. Digital transformation promotes multi-dimensional improvements in enterprise production efficiency and total factor productivity. It achieves comprehensive transformation of production methods, business concepts, and marketing strategies [31]. The improvement in production efficiency and governance capacity brought about by digital transformation contributes to enhancing enterprise innovation efficiency. Based on this, hypothesis 2 is proposed.

H2: Digital inclusive finance affects innovation efficiency in high-tech manufacturing enterprises through the mechanisms of alleviating financing constraints, controlling risk levels, and driving digital transformation.

4. Theoretical Analysis and Hypotheses

4.1. Sample and Data Source

This paper selects high-tech manufacturing companies from 2015 to 2022 in A-shares as the research objects. The data is processed as follows: excluding companies that were delisted due to special treatment (ST) and *ST status, as well as those with severe data missingness during the sample period; performing winsorization on continuous variables at the top and bottom 1% levels. We finally obtain a conclusive sample comprising 891 companies. The data mainly comes from the Chinese Research Data Services (CNRDS) platform and statistical yearbooks of various provinces and cities.

4.2. Selection and Description of Variables

(1) Response Variable: Innovation efficiency of high-tech manufacturing enterprises (crste). The adjusted comprehensive efficiency value obtained using the three-stage DEA method is used as a representative variable for the innovation efficiency of high-tech manufacturing enterprises.

(2) Explanatory Variable: Level of development of digital inclusive finance (digfin). The Beijing University Digital Inclusive Finance Index is selected to measure the level of development of digital inclusive finance [32]. This index characterizes the development of digital inclusive finance from three dimensions: breadth of digital financial coverage, depth of usage, and degree of digitization.

(3) Mechanism Variables:

a. Financing constraint (fincon). The financial expense ratio [33] is used to measure financing constraints. The financial expense ratio is calculated by dividing financial expenses by operating income. If a company incurs significant financial expenses, this can result in decreased available capital, thereby increasing the demand for financing.

b. Risk level (risk). Return on Assets (ROA) [34] is an indicator used to assess a company's ability to generate profits or returns based on existing assets. In this paper, the standard deviation of the company's cash flow ROA (operating cash flow/total assets) from year t-2 to year t is used to measure risk.

c. Digital transformation (dct). The frequency of keywords such as artificial intelligence, blockchain, cloud computing, big data, and digital technology applications in annual reports of enterprises is counted. The total frequency of keywords is used to measure the degree of digital transformation of enterprises.

d. Control Variables. Control variables are selected from the perspectives of corporate financial characteristics and governance features. This paper selects six control variables containing financial characteristics of the companies. Debt is represented by the debt-to-assets ratio. Growth is represented by the growth rate of operating income. Liquidity is represented by the ratio of net cash flow from operating activities to total assets. Profitability is represented by return on assets (roa), return on equity (roe), and management expense ratio (mer). This paper selects two variables that represent the characteristics of corporate governance ownership. Concentration (top) is represented by the proportion of shares held by the largest shareholder to the total share capital. Board independence (indep) is represented by the proportion of independent directors to the total number of board members in the current year. Additionally, industry fixed effects (ind), time fixed effects (year), and regional fixed effects (pro) are controlled in this study.

4.3. Model Specification

To examine the relationship between digital inclusive finance and innovation efficiency, we construct Equation (1):

$$crste_{it} = \alpha_0 + \beta_1 digfin_{it} + \beta_n controls_{it} + year + ind + pro + \varepsilon_{it} \quad (1)$$

To examine the internal influence pathways of digital finance on enterprise innovation efficiency, we design the mediation mechanism Equation (2) and (3):

$$MV_{it} = \alpha_0 + \beta_1 digfin_{it} + \beta_n controls_{it} + year + ind + pro + \varepsilon_{it} \quad (2)$$

$$crste_{it} = \alpha_0 + \beta_1 digfin_{it} + \beta_2 MV_{it} + \beta_n controls_{it} + year + ind + pro + \varepsilon_{it} \quad (3)$$

5. Results of Main Effect Hypothesis Testing

5.1. Analysis of Baseline Regression Results

Based on the results of the Hausman test, we employ a fixed-effects model for regression analysis. Table 1 reports the effects of digital inclusive finance and its three sub-indices on the innovation efficiency of high-tech manufacturing enterprises.

Table 1. Baseline Regression Results

	(1)	(2)	(3)	(4)
digfin	0.1084*** (5.0123)			
dif_breadth		0.0915*** (6.2315)		
dif_depth			0.0723*** (2.8267)	
dif_digitalize				-0.0290 (-1.0744)
debt	0.2913*** (29.9510)	0.2906*** (29.9186)	0.2926*** (30.0326)	0.2926*** (30.0065)
growth	-0.0131*** (-5.5259)	-0.0132*** (-5.5325)	-0.0129*** (-5.4158)	-0.0124*** (-5.2292)
octa	0.0362*** (3.2800)	0.0365*** (3.3078)	0.0357*** (3.2393)	0.0358*** (3.2430)
indep	0.0649** (2.5380)	0.0643** (2.5180)	0.0661*** (2.5788)	0.0678*** (2.6408)
mer	-0.4353*** (-15.5101)	-0.4390*** (-15.5983)	-0.4297*** (-15.3994)	-0.4266*** (-15.3182)
top	0.1166*** (9.3997)	0.1162*** (9.3616)	0.1177*** (9.4910)	0.1193*** (9.6274)
roa	0.0866** (2.1067)	0.0848** (2.0680)	0.0896** (2.1650)	0.0903** (2.1797)
roe	0.1249*** (7.1763)	0.1248*** (7.1781)	0.1249*** (7.1385)	0.1247*** (7.1163)
cons	-0.6423*** (-5.3261)	-0.5462*** (-6.6730)	-0.4399*** (-3.1029)	0.1233 (0.8057)
fixed effect	Yes	Yes	Yes	Yes
N	7128.0000	7128.0000	7128.0000	7128.0000
Adj-R ²	0.3432	0.3440	0.3422	0.3417

In table 1, Column (1) shows that the coefficient of the core explanatory variable, digital inclusive finance (digfin), is significantly positive at the 1% level. It indicates that the development of digital inclusive finance promotes the innovation efficiency of high-tech manufacturing enterprises. This suggests that as the level of digital inclusive finance in the region where the enterprise is located increases, the enterprise is more likely to obtain innovative elements to conduct innovation activities and improve innovation

efficiency. Columns (2) to (4) further examine the effects of the various dimensions of digital inclusive finance on enterprise innovation efficiency. The results indicate that both the coverage breadth (dif_breadth) and depth of usage (dif_depth) of digital inclusive finance have a significantly positive impact on the innovation efficiency of high-tech manufacturing enterprises.

5.2. Mechanism Test and Analysis

The paper further investigates the intermediary mechanism through which digital inclusive finance influences the innovation efficiency. We replace the dependent variable in Equation 5 with alleviating financing constraints, reducing risk levels, and enhancing the degree of digital transformation.

As shown in Table 7, columns (2), (4), and (6) present the corresponding regression results. The results indicate that the estimated coefficients of digital inclusive finance are all significantly positive at the 1% level. It suggests that digital inclusive finance can effectively alleviate firms' financing constraints, reduce their risk levels, and enhance their degree of digitalization.

Table 2. Mechanism Test for the Impact of Digital Inclusive Finance on Innovation Efficiency

	(1) Baseline Regression	(2) The Effect of Alleviating Financing Constraints	(3) The Effect of Controlling Risk Levels	(4) The Effect of Driving Digital Transformation	(5)	(6)	(7)
digfin	0.1084*** (5.0123)	-0.0243*** (-3.3243)	0.1063*** (4.9142)	-0.0141** (-2.3312)	0.1054*** (4.8628)	2.5511*** (10.1368)	0.0658*** (3.0326)
fincon			-0.0877** (-2.3664)				
risk					-0.2180*** (-3.8989)		
dcg							0.0167*** (12.4115)
cons	-0.6423*** (-5.3261)	0.0822* (1.8349)	-0.6351*** (-5.2696)	0.1034*** (3.0857)	-0.6198*** (-5.1214)	-12.8907*** (-9.2103)	-0.4270*** (-3.5415)
controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	7128	7128	7128	7128	7128	7128	7128
Adj-R ²	0.3432	0.3399	0.3453	0.0355	0.3449	0.3295	0.3593

Columns (3), (5), and (7) present the regression results of Equation (6) with the inclusion of intermediary variables. The results show that digital inclusive finance injects financial vitality into firms' innovation by alleviating financing constraints. It enhances firms' risk resilience and innovation enthusiasm through risk control effects. It also improves firms' resource allocation and operational efficiency through the technological spillover effects of digital transformation, thereby enhancing their innovation capabilities. Compared to the baseline regression in column (1), the coefficients of digital inclusive finance decrease after incorporating the three intermediary variables. However, they remain significantly positive, confirming the presence of the three intermediary channels and aligning with Hypothesis.

6. Conclusions and Recommendations

6.1. Conclusions

Digital inclusive finance can aggregate financial resources and innovation elements, thereby expanding innovation channels and enhancing innovation efficiency within high-tech enterprises. Based on this, this paper theoretically explains the impact of digital inclusive finance on enterprise innovation efficiency from the perspective of supply and demand. High-tech manufacturing enterprises listed on the Shanghai and Shenzhen stock exchanges from 2015 to 2022 were selected as research objects. Enterprise innovation efficiency was calculated based on the three-stage DEA model. Combining data from Peking University on digital inclusive finance, the empirical study examined the impact mechanism of digital finance on enterprise innovation efficiency. The main conclusions are as follows:

(1) Digital inclusive finance significantly promotes the improvement of innovation efficiency in high-tech manufacturing enterprises. This conclusion remains reliable after considering endogeneity and robustness issues. The promotion effect of digital finance is more significant in economically backward regions, state-owned enterprises, and small-scale enterprises.

(2) The promotion of digital inclusive finance on the improvement of innovation efficiency in high-tech manufacturing enterprises is mainly achieved through alleviating enterprise financing constraints, reducing enterprise risk levels, and enhancing the degree of digital transformation.

6.2. Conclusions

Based on the research conclusions, the following recommendations are proposed:

(1) Relevant departments should focus on regional strategic positioning and increase investment in digital financial resources and infrastructure construction. They are supposed to solidify the foundation for the development of digital finance and provide a better external environment for enterprise technological innovation. At the same time, regulatory authorities should strengthen supervision of digital inclusive finance. Financial regulatory authorities need to actively formulate systematic risk prevention and control systems to reduce the possibility of systemic risk contagion.

(2) High-tech manufacturing enterprises should leverage digitalization to restructure the industrial chain, achieving collaborative sharing across all stages of production and manufacturing. Moreover, enterprises should enhance risk

awareness, improve employees' risk identification capabilities and constructs comprehensive risk management systems. They should strengthen information disclosure and enhance transparency. Efforts should be directed towards strengthening fund supervision and cost control to ensure the rational utilization and efficient operation of innovation funds.

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