Proceedings of ICFTBA 2026 Symposium: Strategic Management & Business Analytics: Data-Driven Performance Models
DOI: 10.54254/2754-1169/2026.LD39231

The Impact of Digital Inclusive Finance on Enterprise Innovation Output

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Abstract. This paper matches data on Chinese A-share listed companies from 2011 to 2022 with city-level digital inclusive finance indices to obtain a panel sample covering 36,599 firm-year observations, 4,699 firms, and 282 cities, and tests the relationship between digital inclusive finance and enterprise innovation output. The baseline model includes city and year fixed effects, with standard errors clustered at the city level. The results show that the development of city-level digital inclusive finance is significantly positively correlated with both invention patent applications and total patent applications. Further analysis finds that digital inclusive finance is significantly correlated with lower financing constraints, and that stronger financing constraints are associated with lower invention patent output by firms, a result consistent with the theoretical expectation of the financing constraints channel. Grouped regressions show that the positive relationship mainly appears in non-state-owned and private enterprises, and is more prominent in the central and western regions. After replacing the innovation measures, winsorizing, using the one-period lagged digital inclusive finance index, and excluding the financial industry, the core conclusions do not change substantially. Overall, the development of digital inclusive finance is significantly associated with improved enterprise innovation output, and the alleviation of financing constraints may be an important channel.

Keywords: Digital Inclusive Finance, Enterprise Innovation, Invention Patents, Financing Constraints, Listed Companies

1. Introduction

Enterprise innovation requires sustained investment, but R&D activities usually have the characteristics of long cycles, uncertain returns, and knowledge assets that are difficult to mortgage, so they are particularly sensitive to external financing conditions. Existing studies have found that R&D and innovation activities are easily constrained by funding gaps, especially for young firms and firms that rely heavily on external financing, whose innovation decisions are more likely to adjust with changes in financing conditions [1-3]. The development of the financial system can change the way innovation projects obtain funds and the risk-sharing mechanism, and further affect technological output [4]. Therefore, whether the information identification cost of innovative firms can be reduced and funds can be allocated more effectively to high-potential projects is an important perspective for understanding how finance affects enterprise innovation.

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DOI: 10.54254/2754-1169/2026.LD39231

Digital inclusive finance provides a new research scenario for this issue. Relying on big data, mobile internet, digital payment, and platform-based services, financial institutions can break through some offline service constraints and improve the efficiency of information acquisition, processing, and risk identification [5, 6]. The Peking University Digital Inclusive Finance Index measures the development of regional digital finance from the dimensions of coverage breadth, depth of use, and degree of digitalization, providing a city-level continuous indicator for examining its microeconomic consequences [7]. The data formed by firms in the processes of payment, transaction, and online operation can supplement traditional financial and mortgage information, and digitalized credit processes also help reduce search, review, and transaction costs. For R&D projects, these changes may improve the supply of external funds and reduce the probability that innovation activities are blocked by financing disruptions.

Regarding digital finance and enterprise innovation, existing literature based on data of Chinese listed companies has found a positive relationship between the development of digital finance and patent output and R&D activities, and financing constraints and credit availability are considered important explanatory channels [8, 9]. On this basis, this paper extends the research period to 2011–2022 and simultaneously uses invention patent applications, total patent applications, and granted invention patents to characterize enterprise innovation output. This paper focuses on three questions: first, whether the development of city-level digital inclusive finance is related to the improvement of enterprise innovation output; second, whether the alleviation of financing constraints constitutes a possible channel; third, whether this relationship varies with firm ownership, regional location, and the city's initial digital financial infrastructure.

The empirical results show that for every 1-unit increase in DIF_index_100, ln(1+invention patent applications) and ln(1+total patent applications) increase by 0.5039 and 0.4478, respectively. The financing constraints test further shows that digital inclusive finance is significantly negatively correlated with AbsSA, while AbsSA is significantly negatively correlated with invention patent output. In the ownership groups, the positive coefficient of digital inclusive finance mainly appears in non-state-owned enterprises and private enterprises; in the regional groups, the point estimates of the central and western samples are larger and reach statistical significance. After changing the innovation measures, winsorizing, using the one-period lagged digital inclusive finance index, and adjusting the sample scope, the direction of the core results remains consistent. The above findings provide supplementary evidence from the perspective of enterprise innovation output that digital finance improves financing conditions.

The empirical analysis of this paper is mainly reflected in three aspects. First, it constructs a firm-year panel from 2011 to 2022 and matches the digital inclusive finance index at the city level, thereby covering the period of rapid expansion of digital finance in China and the continuous growth of the listed company sample. Second, it compares invention patent applications, total patent applications, and granted invention patents within the same framework, so that the application and granting sides of innovation can be mutually verified. Third, it conducts mechanism analysis around financing constraints, and further examines heterogeneity from the three dimensions of ownership, region, and the city's initial digital financial infrastructure, thereby characterizing the conditional differences in the effect of digital inclusive finance on enterprise innovation in more detail.

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2. Theoretical analysis and research hypotheses

2.1. Digital inclusive finance and enterprise innovation output

Digital inclusive finance may first affect innovation financing by changing the way information is obtained between banks and enterprises. Traditional credit decisions rely more on financial statements, mortgage assets, and historical credit records, but the technical value, growth potential, and future cash flows of innovation projects are often difficult to be fully reflected by this static information. Digital payment, transaction flows, supply chain relationships, and online operation records provide financial institutions with higher-frequency and more continuous business information, so that credit identification no longer relies entirely on traditional financial and mortgage information. At the same time, online services can compress the costs brought by geographical distance and business processes, and improve the efficiency of credit application, review, and risk management [5, 6].

Innovation activities are highly sensitive to changes in financing supply. R&D projects often have long investment cycles and high failure probabilities, and the knowledge capital formed is also difficult to serve as traditional collateral, so the information friction between firms and external fund providers is more prominent [1]. When financing conditions tighten, firms may delay, reduce, or even terminate R&D projects; when external funds are more stable, firms are better able to continuously bear expenditures on R&D personnel, equipment, and experiments, and push technological achievements into the patent application and granting stages [2, 10]. Existing cross-country evidence also shows that financial development can significantly affect firms' technological innovation activities [4]. Based on the above logic, this paper proposes:

H1: There is a significant positive relationship between the development of city-level digital inclusive finance and enterprise innovation output.

2.2. The financing constraints channel

Financing constraints are a possible channel through which digital inclusive finance affects enterprise innovation. When firms cannot obtain sufficient external funds due to information asymmetry, insufficient collateral, or high risk pricing, R&D investment is often more subject to internal cash flow constraints. Smaller firms or firms with weaker credit foundations usually face stronger financing constraints [3]. By introducing non-traditional information such as transactions, payments, and business behaviors, and using digitalized risk control to reduce pre-loan investigation and risk assessment costs, digital finance helps financial institutions identify firm risks more precisely. If external financing constraints are thereby alleviated, firms' dependence on internal funds will decline, and the possibility of R&D projects continuing across periods will also increase.

This paper uses the absolute value of the SA index, AbsSA, to measure financing constraints. The SA index is mainly constructed from relatively exogenous characteristics such as firm size and age, and is a commonly used financing constraints indicator in corporate finance research [11]. According to the variable processing method of this paper, a larger AbsSA indicates stronger financing constraints faced by the firm. Accordingly, this paper proposes:

H2: Digital inclusive finance can promote enterprise innovation output by alleviating financing constraints.

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2.3. Ownership and regional heterogeneity

The marginal effect of digital inclusive finance may vary with the existing financing conditions of firms. State-owned enterprises usually have relatively stable bank-enterprise relationships, stronger credit foundations, and richer traditional financing channels, so the marginal improvement space of new digital information for their credit granting and risk pricing is relatively limited. In contrast, non-state-owned enterprises and private enterprises rely more on market-based credit identification, and their traditional collateral and credit support are also relatively insufficient, so digitalized business information may have higher value in improving financing availability and risk pricing. It is therefore expected that the positive relationship between digital inclusive finance and enterprise innovation is more obvious in non-state-owned and private enterprises.

The regional financial environment also affects the functioning of digital finance. On the one hand, digital finance can be complementary to the relatively well-developed financial infrastructure and data ecosystem; on the other hand, in regions where traditional financial outlets and offline services are relatively insufficient, online finance may also play a gap-filling role. Cities with higher initial digital financial foundations usually have more mature digital service ecosystems, while the central and western regions are relatively insufficient in traditional financial resources and offline service density, so digitalized services may more obviously reduce geographical distance and information search costs. Based on the two types of mechanisms, the relationship between digital inclusive finance and innovation output may vary with regional location and the initial digital financial foundation. Accordingly, this paper proposes:

H3a: The positive relationship between digital inclusive finance and innovation output is stronger in non-state-owned enterprises and private enterprises.

H3b: The relationship between digital inclusive finance and enterprise innovation output varies with region and the city's initial digital financial foundation.

3. Research design

3.1. Data and sample

This paper uses firm-year data of Chinese A-share listed companies from 2011 to 2022. Enterprise innovation indicators include invention patent applications, total patent applications, and granted invention patents; firm-level variables cover size, asset-liability ratio, return on total assets, proportion of independent directors, board size, and the SA financing constraints index. The development level of regional digital inclusive finance adopts the Peking University Digital Inclusive Finance Index, and is matched with company data according to the city and year where the firm is located [7]. After organizing the sample according to the principle that all variables required for the baseline regression are non-missing, 36,599 firm-year observations are obtained, involving 4,699 firms and 282 cities.

The baseline sample temporarily retains financial industry firms, and further excludes financial industry observations in the robustness checks. To facilitate coefficient interpretation, this paper divides the original digital inclusive finance index by 100 to obtain DIF_index_100, so its regression coefficient corresponds to a change of 100 points in the original index. HighDFI2011 is divided according to whether the city's 2011 digital inclusive finance index is higher than the median of cities in that year. The regional heterogeneity analysis examines the eastern and central and western (central, western) samples separately; the ownership heterogeneity further distinguishes state-owned, non-state-owned, private, and non-private enterprises.

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The sample composition shows that non-state-owned enterprises have 24,042 observations, accounting for 65.7% of the baseline sample; among them, private enterprises have 21,262 observations, accounting for 58.1%. The eastern region contains 25,355 observations, accounting for 69.3%, and the central and western regions have 9,729 observations, accounting for 26.6%, with the rest mainly from the northeastern region. Divided by the city's 2011 digital financial foundation, the high initial DFI group accounts for 89.5% of all firm-year observations. In addition, the financial industry sample has a total of 1,070 observations, accounting for 2.9%; after excluding this industry, 35,529 observations are still retained for the robustness checks.

3.2. Variable definitions

Enterprise innovation output is constructed using patent counts. The baseline indicator ln_InventPatent is defined as ln(1+invention patent applications), and the alternative indicators ln_PatentTotal and ln_GrantInvent are defined as ln(1+total patent applications) and ln(1+granted invention patents), respectively. The core explanatory variable DIF_index_100 is the total digital inclusive finance index of the city where the firm is located in that year divided by 100. The mechanism variable AbsSA takes the absolute value of the SA index, and a larger value indicates stronger financing constraints. Control variables include firm size Size (natural logarithm of total assets), asset-liability ratio Lev, return on total assets ROA, proportion of independent directors IndDirRatio, and the logarithm of board size LnBoardSize.

Table 1. Descriptive statistics of main variables

Variable	N	Mean	Std. Dev.	P25	Median	P75
ln_Invent	36,599	1.3152	1.4596	0.0000	1.0986	2.3026
ln_Patent	36,599	1.8348	1.7257	0.0000	1.7918	3.0910
DIF/100	36,599	2.4259	0.7831	1.8926	2.6034	3.0375
AbsSA	36,599	3.8148	0.3216	3.6497	3.8299	3.9971
Size	36,599	22.2754	1.5201	21.2642	22.0266	23.0035
Lev	36,599	0.4394	0.4627	0.2537	0.4145	0.5853
ROA	36,599	0.0338	0.6550	0.0127	0.0367	0.0677
IndDirRatio	36,599	0.3970	0.1014	0.3333	0.3846	0.4545
LnBoardSize	36,599	2.2273	0.2845	2.0794	2.1972	2.3979

Note: Descriptive statistics are based on the baseline regression sample. ln_Invent, ln_Patent, and DIF/100 correspond to ln_InventPatent, ln_PatentTotal, and DIF_index_100, respectively; P25 and P75 denote the 25th and 75th percentiles, respectively.

As can be seen from Table 1, the sample mean of ln_Invent is 1.3152 and the mean of ln_Patent is 1.8348, and both have a large degree of dispersion, indicating that sample firms differ significantly in innovation output. The mean and standard deviation of DIF_index_100 are 2.4259 and 0.7831, respectively, reflecting that the digital inclusive finance level of the sample cities has sufficient cross-sectional and temporal variation. The mean of AbsSA is 3.8148, which also provides the necessary sample variation for the subsequent test of the relationship between digital finance and firm financing constraints.

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3.3. Model specification

To test the relationship between digital inclusive finance and enterprise innovation output, the baseline regression adopts a city fixed effects and year fixed effects model:

$$Innovation_{irt} = \alpha + \beta\, DIF_{rt} + \gamma\, X_{it} + | \mu_r + \lambda_t + \varepsilon_{irt} \quad (1)$$

where $Innovation_{irt}$ denotes the innovation output of firm i in city r in year t, DIF_{rt} denotes the development level of digital inclusive finance in city r in year t, X_{it} are firm-level control variables, and μ_r and λ_t denote city fixed effects and year fixed effects, respectively. City fixed effects are used to absorb city-level characteristics that do not change over time, and year fixed effects are used to control for common national annual shocks. Standard errors are clustered at the city level to allow for correlation in the error terms of firms within the same city. The core coefficient β characterizes the conditional correlation between changes in digital inclusive finance over time within the same city and enterprise innovation output.

The financing constraints channel is tested using stepwise regression: first, AbsSA is used as the dependent variable to examine the relationship between digital inclusive finance and financing constraints; then AbsSA is included in the innovation output regression, observing the estimated coefficients of financing constraints and DIF at the same time. The heterogeneity analysis groups the samples by the 2011 initial digital financial foundation, the eastern and central and western regions, state-owned and non-state-owned enterprises, and private and non-private enterprises, respectively. The robustness checks then successively switch to granted invention patents, winsorize the invention patent indicator at 1% and 99%, use the one-period lagged digital inclusive finance index, exclude the financial industry, and replace it with total patent applications.

4. Empirical results and analysis

4.1. Baseline regression

Table 2. Digital inclusive finance and enterprise innovation output: baseline regression

Variable	(1) ln_InventPatent	(2) ln_PatentTotal
DIF_index_100	0.5039***(0.1316)	0.4478**(0.1821)
Size	0.1575***(0.0230)	0.1345***(0.0306)
Lev	-0.2097**(0.1032)	-0.2700**(0.1259)
ROA	-0.0198(0.0212)	-0.0261(0.0246)
IndDirRatio	0.2409**(0.1183)	0.4447***(0.1287)
LnBoardSize	-0.1693***(0.0594)	-0.2684***(0.0748)
City fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Observations	36,599	36,599
R-squared	0.1200	0.1283

Note: Standard errors clustered at the city level are in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The same applies to subsequent tables.

DOI: 10.54254/2754-1169/2026.LD39231

Table 2 presents the baseline regression results. Column (1) uses ln(1+invention patent applications) as the dependent variable, and the estimated coefficient of DIF_index_100 is 0.5039, significant at the 1% level; column (2) replaces innovation output with ln(1+total patent applications), and the core coefficient is 0.4478, significant at the 5% level. Both indicators yield significantly positive results, consistent with the expectation of H1. Since DIF_index_100 equals the original index divided by 100, the above coefficients correspond to the conditional change in the logarithmic indicator of innovation output when the city's original digital inclusive finance index increases by 100 points.

Looking further at the economic magnitude, the standard deviation of DIF_index_100 in the baseline sample is 0.7831. Based on the point estimate of column (1), a one-standard-deviation difference in digital inclusive finance corresponds to a change of about 0.395 log points in ln(1+invention patent applications). This result shows that the statistical relationship between digital finance and enterprise innovation holds not only in significance but also has certain economic significance in magnitude. The consistent direction of columns (1) and (2) also indicates that this relationship is not driven by only one patent measure.

The estimation results of the control variables show that Size is significantly positive in both columns and Lev is significantly negative, meaning that larger firms usually have higher patent output, while higher leverage is associated with lower innovation output. The coefficient of IndDirRatio is significantly positive, LnBoardSize is significantly negative, and ROA does not reach the conventional significance level. Overall, after controlling for firm characteristics as well as city and year fixed effects, the core coefficient of digital inclusive finance remains significantly positive.

4.2. Financing constraints channel

Table 3. Test of the financing constraints mechanism

Variable	(1) AbsSA	(2) ln_InventPatent	(3) ln_InventPatent
DIF_index_100	-0.1940***(0.0396)	—	0.3806***(0.1350)
AbsSA	—	-0.6376***(0.0657)	-0.6355***(0.0658)
Size	-0.0474*(0.0254)	0.1271***(0.0185)	0.1274***(0.0186)
Lev	-0.0088(0.0109)	-0.2151**(0.0973)	-0.2153**(0.0974)
ROA	-0.0074*(0.0044)	-0.0244(0.0188)	-0.0244(0.0189)
IndDirRatio	-0.0640(0.0491)	0.2018*(0.1184)	0.2002*(0.1181)
LnBoardSize	0.0058(0.0112)	-0.1662***(0.0580)	-0.1656***(0.0580)
City fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	36,599	36,599	36,599
R-squared	0.2125	0.1353	0.1354

Table 3 examines the financing constraints channel. In column (1), with AbsSA as the dependent variable, the coefficient of DIF_index_100 is −0.1940, significant at the 1% level; given that a larger AbsSA represents stronger financing constraints, this result means that the development of digital inclusive finance is significantly correlated with a decline in financing constraints. In column (2), the coefficient of AbsSA on ln_InventPatent is −0.6376, significant at the 1% level, indicating that firms with stronger financing constraints usually have lower invention patent output. In column (3),

DOI: 10.54254/2754-1169/2026.LD39231

after including both DIF_index_100 and AbsSA, the two maintain significantly positive and negative coefficients, respectively, with DIF_index_100 at 0.3806. The overall results are consistent with the theoretical chain of "development of digital inclusive finance - alleviation of financing constraints - improvement of innovation output", providing supportive evidence for H2; however, this set of regressions is mainly used as a clue for mechanism identification and is not equivalent to a strict causal mediation effect test.

4.3. Heterogeneity in region and initial digital financial infrastructure

Table 4. Heterogeneity in region and initial digital financial infrastructure

Variable	(1) High Initial DFI	(2) Low Initial DFI	(3) Eastern	(4) Central and Western
DIF_index_100	0.4655***(0.1568)	0.4773(0.3346)	0.2506(0.1815)	0.5017**(0.2017)
Control variables	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	32,755	3,844	25,355	9,729
R-squared	0.0986	0.3514	0.0925	0.1792

The first two columns of Table 4 divide the samples according to whether the city's 2011 digital inclusive finance index is higher than the median. The DIF_index_100 coefficient of the high initial digital financial foundation group is 0.4655, significant at the 1% level; the coefficient of the low foundation group is 0.4773, with a point estimate close to that of the high foundation group, but it does not reach the conventional significance level due to the larger standard error. Therefore, judging only from the existing grouping results, the two groups do not show obvious differences in coefficient direction and magnitude, and the positive relationship between digital finance and innovation output is not limited to cities with higher initial digital financial foundations. It should be noted that the high initial DFI group accounts for a relatively high proportion at the firm-year level, and the imbalance in sample sizes between groups may also affect estimation precision.

Columns (3) and (4) further compare the eastern and central and western regions. The core coefficient of the eastern sample is 0.2506, which does not reach the conventional significance level; the coefficient of the central and western samples is 0.5017, significant at the 5% level. From the point estimates and within-group significance, the positive relationship between digital inclusive finance and enterprise innovation output is more prominent in the central and western regions, consistent with the theoretical explanation that digital finance plays a gap-filling role in regions where traditional financial resources and offline services are relatively insufficient. However, the fact that one group is significant while the other is not does not directly prove that there is a statistical difference between the two groups' coefficients, and strict heterogeneity judgments still need to be combined with between-group coefficient tests.

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4.4. Ownership heterogeneity

Table 5. Ownership heterogeneity

Variable	(1) State-Owned Enterprises	(2) Non-State-Owned Enterprises	(3) Private Enterprises	(4) Non-Private Enterprises
DIF_index_100	-0.2108(0.2641)	0.7212***(0.1772)	0.7044***(0.1971)	0.1857(0.2200)
Control variables	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	12,557	24,042	21,262	15,337
R-squared	0.2108	0.1411	0.1566	0.1817

Table 5 presents the ownership grouping results. In the state-owned enterprise sample, the coefficient of DIF_index_100 is −0.2108 and not significant; in the non-state-owned enterprise sample, the coefficient is 0.7212, significant at the 1% level. Further divided by private attribute, the coefficient of private enterprises is 0.7044 and significant at the 1% level, while the coefficient of non-private enterprises is 0.1857 and not significant. In terms of point estimates and within-group significance, the positive relationship between digital inclusive finance and innovation output is mainly concentrated in non-state-owned and private enterprises, consistent with the directional expectation of H3a, and also consistent with the explanation that digitalized credit identification has greater marginal value for firms with relatively limited traditional financing conditions. As with the regional grouping, whether there is a strict between-group coefficient difference still needs to be further confirmed through formal coefficient comparison tests.

4.5. Robustness checks

Table 6. Robustness checks

Variable	(1) Granted Invention	(2) Winsorized	(3) Lagged DIF	(4) Excluding Finance	(5) Total Patents
DIF_index_100	0.3320*** (0.1277)	0.4925*** (0.1306)	—	0.4971***(0.1365)	0.4478** (0.1821)
L.DIF_index_100	—	—	0.3984*** (0.1247)	—	—
Control variables	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	36,599	36,599	32,221	35,529	36,599
R-squared	0.1067	0.1182	0.1236	0.1297	0.1283

Note: In column (1), the dependent variable is ln(1+granted invention patents); column (2) winsorizes ln_InventPatent at the 1% and 99% levels; column (3) uses the one-period lagged digital inclusive finance index; column (4) excludes the financial industry; in column (5), the dependent variable is ln(1+total patent applications).

Table 6 tests the baseline results from the three aspects of innovation measures, sample processing, and time setting. In column (1), with granted invention patents as the dependent

DOI: 10.54254/2754-1169/2026.LD39231

variable, the coefficient of DIF_index_100 is 0.3320, significant at the 1% level, indicating that the positive relationship also appears in the granting stage. In column (2), after winsorizing ln_InventPatent at 1% and 99%, the coefficient is 0.4925, close to the baseline estimate. In column (3), when the digital inclusive finance index is lagged by one period, the coefficient is 0.3984 and significant at the 1% level, indicating that digital finance and subsequent innovation output maintain a significantly positive relationship. In column (4), after excluding the financial industry, the core coefficient is 0.4971; in column (5), after switching to total patent applications, the coefficient is 0.4478. Under different settings, the direction and significance of the core coefficients are generally stable, indicating that the baseline conclusion is not driven by a single indicator or sample processing method.

5. Conclusions and policy implications

5.1. Main conclusions

Based on 36,599 firm-year observations of Chinese A-share listed companies from 2011 to 2022, this paper matches firm data with city digital inclusive finance indices to examine the relationship between digital inclusive finance and enterprise innovation output. The baseline regression shows that digital inclusive finance is significantly positively correlated with both invention patent applications and total patent applications. After further using granted invention patents, winsorized innovation indicators, the one-period lagged digital finance index, and excluding financial industry samples, the core conclusions still hold.

The financing constraints analysis provides supportive evidence for the channel of the above relationship: the development of digital inclusive finance is significantly correlated with lower AbsSA, and the stronger the financing constraints, the lower the firm's invention patent output; after including both digital inclusive finance and financing constraints, the two still maintain significantly positive and negative coefficients, respectively. The heterogeneity results show that the positive coefficient of digital inclusive finance mainly appears in non-state-owned enterprises and private enterprises; the point estimates of the central and western samples are larger and reach statistical significance, while the coefficient magnitudes of groups with different initial digital financial foundations are relatively close. Overall, these results indicate that the relationship between digital inclusive finance and enterprise innovation has obvious financing condition and regional environment characteristics.

5.2. Policy implications

First, further improve the availability of digital financial infrastructure and firm credit data. The financing constraints test shows that digital inclusive finance is significantly correlated with the decline in firm financing constraints, so the important foundation for digital finance to support innovation lies in improving the efficiency of information acquisition and risk identification. Under the premise of compliant authorization and data security, the standardization and verifiability of firms' business, transaction, and credit information should be improved, and multi-dimensional business data should be more effectively incorporated into the credit evaluation and risk pricing process, thereby enhancing financial institutions' ability to identify innovative firms and assess their innovation financing needs.

Second, enhance the adaptability of digital finance to the innovation activities of private and non-state-owned enterprises. The grouping results show that the positive relationship between digital

DOI: 10.54254/2754-1169/2026.LD39231

inclusive finance and innovation output is mainly reflected in non-state-owned and private enterprises. In view of the problems of such firms, such as long R&D cycles, prominent asset-light characteristics, and relatively insufficient traditional collateral, financial institutions can make more use of digital information such as transaction flows, supply chain relationships, and business behaviors on the basis of prudent risk control, improve firm credit profiles, and design digital credit products whose maturity and repayment arrangements better match R&D investment cycles, so as to improve the ability of innovation projects to obtain continuous financial support.

Third, improve the coverage and conversion efficiency of digital financial services in the central and western regions. The regional grouping results show that the coefficient of digital inclusive finance in the central and western samples is positive and reaches statistical significance, indicating that digitalized finance has greater application space in regions where traditional financial resources and offline services are relatively insufficient. Policies can be advanced in coordination from the three aspects of digital infrastructure, online financial service coverage, and firms' digital operation capabilities, so that digital information can be more smoothly converted into credit identification and financing support. At the same time, the point estimates of the initial digital financial foundation groups are relatively close, meaning that the positive relationship between digital finance and innovation output does not exist only in cities with higher starting points.

5.3. Research extensions

This paper mainly uses invention patent applications, total patent applications, and granted invention patents to measure enterprise innovation output, which can observe the quantity of innovation outcomes from the two stages of application and granting, but does not yet fully distinguish innovation quantity from innovation quality. Subsequent research can further introduce indicators such as patent citation counts, the proportion of invention patents, and patent value, and combine variables such as R&D investment and new product revenue to identify the differences in the role of digital finance in the different links of innovation input, output, and quality improvement.

In addition, this paper conducts analysis based on matched data of A-share listed companies and city digital inclusive finance indices, and the sample still consists mainly of larger firms with more standardized information disclosure. Future research can be extended to non-listed enterprises and small, medium, and micro enterprises to more directly test the inclusive attribute of digital inclusive finance; at the same time, digital finance policy pilots, platform access adjustments, or other institutional changes with exogeneity can be used to further strengthen the identification of the causal relationship between digital inclusive finance, financing constraints, and enterprise innovation.

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