

Breaking the Wall of Information Asymmetry: Can Digital Financial Inclusion Quench the Thirst of SME Financing?

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Abstract. This paper mainly discusses the path and mechanism of digital financial inclusion on the financing constraints of small and medium-sized enterprises (SMEs). Based on the panel data of Chinese enterprises from 2010 to 2024, this paper adopts a two-way fixed effects model. The research results show that digital financial inclusion significantly alleviates the financing constraints of SMEs mainly through the core mechanism of mitigating information asymmetry, by improving information transparency, reducing risk premiums and lowering financing thresholds. The study also reveals significant regional and ownership heterogeneity — enterprises in eastern regions and state-owned enterprises benefit more obviously. This finding reveals the boundary conditions of the effect of digital financial inclusion: simply promoting digital technology without improving the "data ecosystem" in central and western regions and the information quality of private enterprises can hardly achieve the balanced effect of inclusive finance. The research of this paper also provides decision-making enlightenment for improving the digital credit reporting system, optimizing the allocation of inclusive financial resources, and promoting the coordinated development of regional finance.

Keywords: Digital Financial Inclusion, Financing Constraints, Information Asymmetry, Small and Medium-sized Enterprises

1. Introduction

1.1. Research background and literature review

As an important pillar of the national economy, SMEs contribute a considerable proportion of jobs and GDP. However, high financing thresholds and persistently high costs have long been a major dilemma that SMEs cannot avoid. The root cause lies in information asymmetry between the supply and demand sides of funds [1], which is manifested as adverse selection and moral hazard. Zhang Jie's study finds that compared with large enterprises, SMEs are unable to provide audited "hard information" due to problems such as imperfect financial systems and low operational transparency [2]. This forces financial institutions to bear higher costs of information acquisition and supervision, leading to a significantly prudent lending tendency toward SMEs. Nevertheless, with the development of digital financial inclusion, SMEs have ushered in a new opportunity to break the dilemma. First, in terms of measurement, Guo Feng, Wang Jingyi et al. designed a set of digital

financial inclusion evaluation systems covering multiple dimensions [3], which provides key support for follow-up research. On this basis, existing studies show that digital financial inclusion can effectively break the financing bottleneck of SMEs [4] and effectively improve credit availability [5, 6]. Meanwhile, digital financial inclusion also helps reduce enterprises' debt financing expenditures [7], and improves financing matching efficiency by curbing resource misallocation [8]. Furthermore, scholars such as Wan Jiayu and Zhou Qin find that digital financial inclusion can promote enterprise technological upgrading and investment efficiency by alleviating financing difficulties [9, 10]. In terms of heterogeneity, existing studies have noted the moderating effects of property right nature and regional environment, and find that digital financial inclusion has a more significant financing improvement effect on state-owned enterprises [11] and enterprises in regions with prosperous economy, wide network penetration and abundant human capital [12]. Overall, existing literature has analyzed how digital financial inclusion affects SME financing from multiple dimensions, and has gradually incorporated information asymmetry, corporate governance, institutional environment and other factors into the analytical framework as action mechanisms or heterogeneity conditions, presenting a relatively clear research system.

However, most existing literature takes information asymmetry as a theoretical background and lacks direct tests of its action mechanism. For this reason, the follow-up research of this paper will focus on information asymmetry theory to supplement the deficiencies of existing studies.

1.2. Research framework

Based on the foreshadowing of the previous research background, this paper focuses on the effect of digital financial inclusion on the financing constraints of SMEs, and aims to answer three questions: whether digital financial inclusion can reverse the passive financing situation of SMEs; whether this effect is realized through the theoretical channel of alleviating information asymmetry; and whether there are significant differences in its impact effect at the regional level and enterprise ownership level. To this end, this paper adopts a two-way fixed effects model that takes into account both enterprise individual and year dimensions for analysis. The research modules include benchmark regression, mechanism test, effect heterogeneity analysis and model robustness test. The research aims to reveal the micro transmission mechanism of digital financial inclusion in solving the financing dilemma of SMEs from the perspective of information asymmetry, expand information asymmetry from background explanation to a testable channel, and provide policy enlightenment for improving the digital credit reporting system, optimizing the allocation of inclusive financial resources, and promoting the coordinated development of regional finance.

2. Theoretical analysis and research hypotheses

2.1. Definition of core concepts

2.1.1. Digital financial inclusion (DIF)

The deep integration of digital technology and the concept of inclusive finance has given birth to digital financial inclusion. Its core is to enable all groups in society to access effective and equal financial services through digital means at an affordable cost. Compared with traditional inclusive finance, digital financial inclusion has significantly expanded the breadth and depth of financial services through platform-based services, realizing convenient service access and intensive cost structure. More importantly, the foundation built by digital technology for digital financial inclusion

allows it to reshape the information transmission mechanism and credit evaluation logic: it integrates fragmented "soft information" from SMEs' daily operations into quantifiable and verifiable credit basis, thereby partially eliminating the information gap between financing parties [13]. The core explanatory variable adopted in this paper is the Peking University Digital Financial Inclusion Index constructed by Guo Feng, Wang Jingyi et al. in 2020 [3]. Its design covers depth of use, breadth of coverage and degree of digitalization, and is widely representative and scientific.

2.1.2. Financing constraints

Financing constraints encountered by enterprises in external financing refer to the situation where enterprises cannot obtain sufficient external financial support due to factors such as information asymmetry, insufficient collateral or imperfect credit records, or have to bear relatively high costs even if they can obtain financing. This problem is particularly prominent for SMEs. Their opaque information disclosure and limited mortgageable assets make it difficult for financial institutions to accurately assess risks, and they tend to implement credit rationing or require higher risk premiums [14]. In terms of measuring financing constraints, this paper adopts the SA index proposed by Hadlock and Pierce in 2010 [15]. The SA index is usually negative, and a smaller value indicates a higher degree of financing restrictions faced by the enterprise. The construction of this index relies on the scale and operating years of the enterprise, which has strong exogeneity and can effectively overcome endogeneity bias.

2.2. How digital financial inclusion alleviates the financing dilemma of SMEs

In the traditional credit system, financial institutions' credit granting decisions highly rely on standardized financial information and sufficient mortgage assets, while SMEs are at a disadvantage due to insufficient financial standardization and few mortgageable assets. Digital financial inclusion provides new possibilities for alleviating this contradiction through technology-driven and service model innovation. On the one hand, the Internet and smart terminals expand the coverage of financial services and break through the limitations of physical outlets. On the other hand, digital financial integration integrates multi-level information from enterprises' daily operations to form a more comprehensive and dynamic credit portrait, enabling enterprises with stable operations but lacking traditional collateral to obtain financing opportunities.

Overall, digital financial inclusion improves the external environment for SME financing from the dimensions of coverage, evaluation basis and decision-making efficiency. Accordingly, the following hypothesis is proposed:

H1: The improvement of regional digital financial inclusion level will reduce the degree of financing constraints faced by SMEs.

2.3 The Path of Digital Financial Inclusion in Alleviating Financing Constraints from the Perspective of Information Asymmetry

Digital financial inclusion can change the financing constraints of SMEs through multiple paths. This study holds that its rise has reshaped the information environment of SMEs, thus creating new opportunities for breaking financing constraints.

2.3.1. Approaches of digital financial inclusion in reducing information asymmetry

Based on existing research, this paper argues that digital financial inclusion breaks the situation of information asymmetry mainly through two channels: "digital credit enhancement" and "risk control

efficiency improvement", thereby reducing financing restrictions. Specifically, in terms of data credit enhancement, first, platform-based data integration gathers multi-dimensional information by connecting with taxation, industry and commerce, credit reporting and other departments. Second, fragmented information is constructed into digital credit portraits, which facilitates lenders to obtain a more comprehensive evaluation basis. Third, data credit replaces the credit granting logic that over-relies on collateral, enabling enterprises with active operations but lacking collateral to obtain financing opportunities [9]. Ren Xiaoyi's study points out that the lack of standardized "hard information" for SMEs will raise the credit granting threshold, while digital financial inclusion can integrate operating data into "data assets" recognized by financial institutions, which objectively reflects the credit level [13]. In terms of risk control efficiency improvement, the intelligent risk control model reduces the cost of manual due diligence and dynamically optimizes risk identification, enabling banks to serve more SMEs at lower costs [4]. Meanwhile, digital technology facilitates dynamic monitoring of enterprise operating flows, transactions, tax payments and other information, alleviating post-loan moral hazard. In summary, "digital credit enhancement" and "risk control efficiency improvement" jointly reshape the information structure and credit logic of the credit market.

2.3.2. Can breaking information barriers resolve the financing dilemma

In the transmission mechanism of digital financial inclusion affecting financing constraints, eliminating information gaps is only an intermediate link. Whether it can eventually be transformed into a substantive improvement in enterprise financing constraints still needs further theoretical exploration.

In the traditional credit market, information asymmetry is the main reason why financial institutions charge high risk premiums: since they cannot accurately identify the real risk of borrowers, institutions can only price based on average risk or raise interest rates to compensate for potential losses. The emergence of digital financial inclusion has fundamentally changed this situation. After obtaining multi-dimensional operating data of enterprises through online platforms, institutions can shift from relying on "prior average risk" to differentiated pricing based on "individual real risk", thereby reducing the "ambiguity premium". As Petersen and Rajan point out, the improvement of bank-enterprise information sharing can significantly reduce loan interest rates, which essentially lies in that information advantages reduce lenders' preventive pricing for unknown risks [16]. Meanwhile, through information integration and intelligent risk control, digital financial inclusion enables institutions to identify a large number of SMEs with stable operations but lacking traditional collateral at a lower cost, thus expanding the boundary of credit services.

The reduction of financing thresholds guided by the alleviation of information asymmetry further clears the obstacles to SME financing from the "access side". The intervention of digital financial inclusion has fundamentally changed the difficulty of information acquisition and verification under the traditional credit model. Financial institutions can quickly assess the operating conditions of SMEs without significantly increasing marginal costs, making it possible for enterprises that were originally excluded from formal credit services due to excessive due diligence costs to obtain credit. Based on data from China's Accounts Receivable Financing Registration and Publicity System, scholars such as He Haonan and Peng Lingling find that the circulation cost of collateral information has been significantly reduced due to digital upgrading, enabling more micro, small and medium-sized enterprises to obtain financing by virtue of accounts receivable rather than real estate mortgage [17].

Therefore, this paper holds that on the premise of breaking information barriers, digital financial inclusion systematically improves the financing environment of SMEs through two paths: "decline in risk premiums and improvement in credit supply" and "decline in financing thresholds". Accordingly, the following hypothesis is proposed:

H2: Digital financial inclusion alleviates the financing constraints of SMEs by improving their information asymmetry.

2.4. Theoretical analysis of heterogeneity: region and ownership

2.4.1. Regional heterogeneity: eastern regions vs. central and western regions

China has a vast territory, and there are significant differences in economic development, financial resources, digital infrastructure and institutional environment among regions, which may lead to different effects of digital financial inclusion. Based on the mechanism and initial endowment, this paper proposes a "strengthening effect" framework: eastern regions have perfect digital infrastructure and more complete data chains, and financial institutions have stronger technology adoption and competition, which makes it easier to transform digital dividends into credit supply. In central and western regions, there are problems such as imperfect financial systems and uneven data quality. Risk control models may identify high-risk characteristics more accurately, and even a "siphon" effect where credit resources concentrate to the east may occur. Wang Xiaoshu finds that this promotion effect is more obvious in regions with leading economy and high Internet penetration [12]; Chi Lihua and Shi Wanju also point out that enterprise performance in eastern regions is more significantly driven [18]. Accordingly, it is predicted that the financing constraints of SMEs in eastern regions are more significantly improved by digital financial inclusion, while the effect in central and western regions may be weak or insignificant.

2.4.2. Ownership heterogeneity: state-owned enterprises vs. private enterprises

Starting from the particularity of China's institutional environment, ownership attribute is a key structural factor affecting enterprise financing behavior and financing environment, which may differentiate the role of digital financial inclusion. This paper expects that compared with private enterprises, digital financial inclusion has a stronger effect on alleviating the financing constraints of state-owned enterprises. The reason is that although digital financial inclusion can improve information transparency, big data risk control can more accurately identify the operational risks of private enterprises, while state-owned enterprises gain greater advantages in credit resource allocation due to their stable operations [19]. In addition, scholars such as Chen Qi'an and Wang Wen find that state-owned enterprises have higher financial standardization and more continuous operating data, and when banks grant credit based on big data risk control, they are more likely to pass risk assessment and obtain preferential conditions. In contrast, even if private enterprises operate well, they are often at a disadvantage due to lack of guarantees [20]. Accordingly, the following hypothesis is proposed:

H3: The alleviation effect of digital financial inclusion on the financing constraints of SMEs shows significant differences at both the regional level and the enterprise ownership level.

3. Research design

3.1. Variable setting

3.1.1. Explained variable: financing constraints (SA)

This paper takes the degree of financing constraints faced by SMEs as the explained variable, and follows the construction method of Hadlock and Pierce [15], taking the SA index as the benchmark proxy variable for measuring financing constraints. The SA index is constructed as follows:

$$SA = -0.737 \times Size + 0.043 \times Size^2 - 0.040 \times Age$$

In the formula, Size is obtained by logarithmizing the total assets of the enterprise, and Age represents the operating years of the enterprise. The SA index is usually negative, and a smaller value indicates a more serious financing dilemma faced by the enterprise. Its construction only relies on two variables with strong exogeneity: enterprise scale and operating years, which can effectively avoid the endogeneity problem of traditional indicators. Therefore, it has become a commonly used variable in empirical research on financing constraints.

3.1.2. Explanatory variable: digital financial inclusion (DIF)

The development level of digital financial inclusion in each region constitutes the core explanatory variable of this paper, and the index used is the Peking University Digital Financial Inclusion Index [3]. Meanwhile, to more accurately capture the digital financial environment faced by the actual operating place of the enterprise, this paper applies the city-level digital financial inclusion index and matches it according to the city where the enterprise is registered.

3.1.3. Mechanism variable: information asymmetry

To test the mediating role of information asymmetry, this paper uses the annual audit fee (AuditFee) of enterprises as the proxy variable of information transparency. The study by Ke Ming and Zhu Xiaoping shows that audit fees are positively correlated with the quality of information disclosure. Higher audit fees enable enterprises to invest more sufficient audit resources and implement more rigorous procedures, thereby improving the authenticity and reliability of financial information, and also convey the signal that enterprises actively accept external supervision [21]. Therefore, higher audit fees correspond to higher information transparency, and the improvement of information transparency means the alleviation of information asymmetry. Based on this, this paper takes audit fees as a positive proxy variable for information transparency, and examines whether digital financial inclusion can solve the financing dilemma faced by SMEs by increasing audit fees (i.e., improving the information environment) in the follow-up mechanism test.

3.1.4. Selection of control variables

(1) Regional economic development level (LnGDP), measured by the logarithm of the gross domestic product of the city where the enterprise is located. Its inclusion in the model can control the systematic impact of macro-environmental differences on enterprise financing capacity.

(2) Financial leverage (Lev), measured by the asset-liability ratio. Its inclusion in the model can control the impact of enterprise capital structure and debt repayment risk on financing constraints.

(3) Green information disclosure (GreenDisc), expressed by an indicator of whether the enterprise discloses environment-related information within the year. It is assigned 1 if yes, and 0 if no. Its inclusion in the model helps to isolate the impact of environmental information disclosure on enterprise financing behavior in the regression.

(4) Customer concentration (LnTop5Ratio), measured by the concentration of sales of the top five customers (i.e., the logarithm of their proportion of total sales). This value mainly reflects the enterprise's dependence on major customers. The study by Shi Jinyan and Qin Jichao shows that higher customer relationship concentration will increase the company's external financing cost, thereby affecting financial decisions such as corporate cash holdings [22].

(5) Profitability (ROE), measured by return on equity. Its inclusion in the model can effectively control the impact of enterprise internal accumulation on financing demand.

(6) Enterprise growth (Growth), calculated by the growth rate of total enterprise assets. Its inclusion in the model helps to control the differentiated financing needs of enterprises at different development stages and avoid estimation bias caused by differences in growth.

(7) Investment opportunity (TobinQ), expressed by Tobin's Q value, which is regarded as a key measure of enterprise investment opportunities. Reasonably controlling the measurement bias of Tobin's Q is a prerequisite for accurately testing the financing constraint hypothesis, which can avoid estimation bias caused by differences in enterprise investment opportunities.

3.1.5. Grouping variables

(1) Regional grouping

According to the standards of the National Bureau of Statistics, this paper divides the cities where enterprises are located into eastern regions and central and western regions. Specifically, 10 provinces (municipalities) including Beijing, Tianjin, Shanghai, Jiangsu, Hebei and Zhejiang are classified as eastern regions; 18 provinces (autonomous regions and municipalities directly under the Central Government) including Shanxi, Hubei, Henan, Jiangxi and Anhui are classified as central and western regions. Based on this, this paper sets the regional variable *Region*. If the enterprise is located in the eastern region, *Region* is assigned 1; if it is located in the central and western regions, it is assigned 0; if it is located in other regions, it is assigned 2.

(2) Ownership grouping

According to the ownership nature of enterprises, this paper divides the samples into state-owned enterprises and non-state-owned enterprises, and sets the ownership dummy variable *SOE*. If the enterprise is a state-owned enterprise, *SOE* is assigned 1; if it is a non-state-owned enterprise, it is assigned 0.

3.2. Data sources and sample construction

3.2.1. Data sources

The data involved in this paper are mainly taken from two levels: enterprise dimension and regional dimension. Enterprise-level data are taken from the CSMAR Database, covering financial data, corporate governance information and supply chain-related indicators of all listed companies on China's Shanghai, Shenzhen and Beijing Stock Exchanges from 2010 to 2024. The explained variables, mechanism variables and control variables involved in this paper can be directly obtained from this database. It should be added that although the research theme of this paper focuses on the financing of SMEs, the sample is not limited to SMEs. This can not only accurately identify the

general law of the role of digital financial inclusion, but also effectively control factors such as enterprise scale, avoid exaggerating or underestimating the effect of digital financial inclusion due to sample selection bias, and provide direct and robust reference for understanding the solution to the financing dilemma of SMEs. Regional-level data are mainly indicators of regional economic development level. The original data used in this paper come from *China City Statistical Yearbook* and provincial and municipal statistical yearbooks. In the follow-up processing, this indicator is matched to the enterprise-year panel data according to the city where the enterprise is registered.

3.2.2. Sample screening and processing

To ensure the reliability and reproducibility of the panel data, this paper cleans and processes the samples according to the following steps. First, test sample uniqueness with "stock code-year-city" as the composite key, and remove duplicate values. Second, delete enterprises marked as ST or *ST during the sample period and observations with abnormal data. On this basis, all continuous financial variables and economic variables are subjected to bilateral 1% winsorization by year. In addition, natural logarithms are taken for strictly positive scale variables, $\ln(1+x)$ transformation is adopted for variables that may take zero values, and logarithmic transformation is not performed for indicators that may take negative values and index variables that have been winsorized, so as to ensure the interpretability of economic meaning.

After the above cleaning process, 42,870 valid samples are finally obtained from the original 67,400 observations, forming a three-dimensional panel data of "enterprise-year-city", which can be used for a series of follow-up studies.

3.3. Econometric model specification

3.3.1. Benchmark model: two-way fixed effects

To test hypothesis H1, this paper sets the following two-way fixed effects model as the benchmark regression:

$$SA_{i,t} = \alpha + \beta DIF_{r,t} + \gamma X_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}$$

In the formula, subscript i represents the enterprise, t represents the year, and r represents the city where the enterprise is located. The explained variable $SA_{i,t}$ represents the degree of financing constraint of enterprise i in year t ; the explanatory variable $DIF_{r,t}$ represents the digital financial inclusion level of city r where the enterprise is located in year t ; $X_{i,t}$ is a vector of control variables at the enterprise and regional dimensions; μ_i represents the fixed effect at the enterprise level; λ_t represents the fixed effect at the time level, which aims to control macro time trends and common shocks; $\varepsilon_{i,t}$ is the random error term. In this paper, the standard errors are adjusted by clustering at the enterprise level in the regression to alleviate the serial correlation problem of the same enterprise in different years.

The reason for adopting this model is mainly that the index adopted in this paper is city-year level data, and its changes include both inter-city differences and inter-year changes. The two-way fixed effects model can use these two sources of variation to achieve consistent estimation of β .

3.3.2. Mechanism test: information asymmetry channel

To test hypothesis H2, this paper refers to the common practice of existing research and constructs the following two-step model to verify the mechanism of this paper:

The first step examines the effect of digital financial inclusion on the information environment

$$AuditFee_{i,t} = \alpha + \theta DIF_{r,t} + \delta X_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}$$

Among them, the explained variable $AuditFee_{i,t}$ is the annual audit fee of the enterprise, and the coefficient θ of $DIF_{r,t}$ is expected to be significant and positive.

The second step, combined with the theoretical relationship of existing literature, fully identifies the transmission mechanism of "digital financial inclusion development → information asymmetry alleviation → financing constraint decline".

3.3.3. Heterogeneity analysis: grouped regression

To test hypothesis H3, that is, the alleviation effect of digital financial inclusion on the financing constraints of SMEs has significant differences at the regional level and enterprise ownership level, this paper will divide the full sample into different sub-samples according to the regional grouping variable and ownership grouping variable, and estimate the benchmark model in each sub-sample. By examining the estimated coefficient value and significance test result of the explanatory variable $DIF_{r,t}$, the existence and direction of the heterogeneity effect are identified. If the difference direction and magnitude of the coefficient in the two groups of sub-samples are consistent with the theoretical expectations above, it can be considered that the heterogeneity effect is established, thus providing empirical support for hypothesis H3.

3.4. Robustness checks

To ensure the credibility of the conclusions obtained from the benchmark regression, the empirical part of this study will conduct robustness tests from the following four dimensions: Replace digital financial inclusion with the sub-dimensions of the Peking University Digital Financial Inclusion Index: breadth of coverage, depth of use and degree of digitalization as explanatory variables, and substitute them into the benchmark model again to obtain new coefficient estimation results; Consider the lag effect of the explanatory variable, and replace the core explained variable with the SA index of the next period; Replace the explained variable. To avoid estimation bias caused by the specific construction method of the SA index, the WW index will be used as the explained variable later; Change the winsorization range. To test whether the benchmark conclusion is sensitive to the winsorization range, this paper will adopt bilateral 2.5% winsorization and bilateral 5% winsorization for continuous variables respectively.

4. Empirical results and analysis

4.1. Descriptive statistics

Table 1. Descriptive statistics of main variables

Variable	Symbol	Observations	Mean	Std. Dev.	Min	Max
Digital Financial Inclusion	DIF	36895	262.790	83.855	21.260	403.079
Breadth of Coverage	cov	36895	271.185	92.765	-10.490	440.922
Depth of Use	depth	36895	246.459	75.054	12.490	357.269
Degree of Digitalization	digi	36895	264.763	85.013	3.390	581.230
Total Audit Fee	AuditFee	42244	1384423.543	1559655.046	200000.000	12608000.000
Regional Economic Development Level	LnGDP	37972	9.108	1.113	5.490	10.895
Financial Leverage	Lev	42870	1.314	0.967	-0.390	11.670
Green Information Disclosure	GreenDisc	33734	0.359	0.480	0	1
Customer Concentration	LnTop5Ratio	40870	20.109	1.483	16.170	24.761
Return on Equity	roe	42694	0.086	0.061	-0.001	0.389
Growth	growth	37950	0.145	0.245	-0.232	3.081
Tobin's Q	TobinQ	42870	2.017	1.798	0.611	102.430

4.2. Benchmark regression results: whether DIF alleviates financing constraints

Table 2. Benchmark regression results

variable	(1)	(2)	(3)	(4)	(5)
	SA	SA	SA	SA	SA
DIF	5.13e-05 (0.000156)	0.000232 (0.000158)	0.000267* (0.000160)	0.000431** (0.000178)	0.000402** (0.000175)
lev		-0.00236*** (0.000689)	-0.00243*** (0.000672)	0.000326 (0.000730)	-0.000296 (0.000714)
lnGDP			0.00470 (0.00873)	0.0148 (0.00937)	0.0124 (0.00911)
GreenDisc				0.00878*** (0.00138)	0.00854*** (0.00137)
LnTop5Ratio					0.00865*** (0.00184)
roe		-0.0630*** (0.0131)	-0.0628*** (0.0134)	-0.0372*** (0.0129)	-0.0604*** (0.0139)
growth		-0.0224*** (0.00194)	-0.0222*** (0.00195)	-0.00957*** (0.00193)	-0.0104*** (0.00188)
tobinq		0.00596*** (0.000793)	0.00593*** (0.000802)	0.00449*** (0.000875)	0.00488*** (0.000832)
Constant	-3.868*** (0.0408)	-3.932*** (0.0413)	-3.982*** (0.0791)	-4.173*** (0.0870)	-4.318*** (0.0984)
Observations	36,661	32,294	31,835	25,509	24,742
R-squared	0.965	0.965	0.966	0.976	0.976

Note: *, **, *** indicate significance at the 10%, 5% and 1% levels respectively, and robust standard errors clustered at the enterprise level are in parentheses.

This study uses a two-way fixed effects model to test hypothesis H1. The model incorporates both enterprise and year fixed effects to isolate individual heterogeneity and time trend effects. The regression results show that the financing constraints of SMEs are significantly negatively correlated with the level of regional digital financial inclusion. Specifically, after controlling for other variables and two-way fixed effects, each 1-unit increase in DIF increases the SA index by an average of 0.000402 units. Combined with the standard deviation of DIF in the sample (83.855), when the regional DIF development level increases by 1 standard deviation, the enterprise SA index increases by an average of about 0.0337 units, which is economically significant.

This result verifies theoretical hypothesis H1 and lays a solid foundation for further research.

4.3. Mechanism test: information asymmetry channel

4.3.1. Whether DIF improves the information environment

To test whether digital financial inclusion effectively optimizes the information situation of enterprises, this paper takes audit fee (AuditFee) as the proxy variable of information transparency to examine how digital financial inclusion plays a role in the enterprise information environment.

Table 3. Mechanism test results

variable	(1)
	AuditFee□
DIF	3,822** (1,587)
lnGDP	143,283* (86,845)
lev	29,804*** (7,943)
GreenDisc	61,904*** (13,984)
LnTop5Ratio	187,283*** (20,336)
roe	-267,190** (117,932)
growth	-100,804*** (20,592)
tobinq	-12,173** (5,384)
Constant	-4.638e+06*** (999,691)
Observations	24,687
R-squared	0.936

Note: *, **, *** indicate significance at the 10%, 5% and 1% levels respectively, and robust standard errors clustered at the enterprise level are in parentheses.

The empirical results in Table 3 show that after controlling for multi-dimensional factors and two-way fixed effects, the coefficient of DIF is 3822 ($p < 0.05$), reflecting that the annual audit fee of enterprises has an obvious positive correlation with the development of local digital financial inclusion. According to the theoretical logic of Ke Ming and Zhu Xiaoping (2011), high audit fees reflect that enterprises improve the authenticity and reliability of financial information by increasing audit resource input and implementing more rigorous audit procedures, and at the same time convey the signal of low information asymmetry [21].

4.3.2. Discussion on the effect of information environment improvement on enterprise financing constraints

The key inducement of financing constraints is information asymmetry, and improving the quality of information disclosure and information transparency is widely regarded as an effective means to alleviate this problem. Zeng Ying and Lu Zhengfei have revealed that enterprises with more sufficient information disclosure have relatively lower equity financing costs, and the logic is that sufficient information disclosure reduces the uncertainty of risk assessment [23]. Follow-up studies have further extended this logic to the field of credit financing. Based on the data of China's listed companies, Li Zhijun and Wang Shanping observe that the quality of information disclosure is significantly negatively correlated with bank loan interest rates, and this phenomenon is more prominent in enterprises with poor information transparency [24]. This means that when enterprises take the initiative to improve information transparency, banks can reduce the risk compensation they require by virtue of more efficient identification of credit risks.

In addition to reducing financing costs, the optimization of enterprise information environment can also significantly improve the availability of external financing, which is highly consistent with the "credit supply improvement" described in Section 2.3.2 of this paper. From the perspective of accounting information quality, scholars such as Xu Zhiwei and Li Shaoyu find that high-quality accounting information can promote enterprises to obtain commercial credit [25].

From a more microscopic mechanism, the improvement of information transparency can break the hidden barriers in the financing process. Botosan's pioneering research shows that when business owners improve their own information environment, external capital providers no longer over-rely on collateral for risk assessment, and enterprises with stable operations but lacking traditional mortgage assets gain the opportunity to access the formal credit market [26].

Based on the above literature, the improvement of information transparency can systematically improve the financing dilemma faced by enterprises through multiple channels such as reducing risk premiums, expanding credit supply and lowering financing thresholds. Combined with the previous empirical results, it can be concluded that digital financial inclusion follows the transmission path of "improving information environment → reducing information asymmetry", and finally achieves the effect of alleviating the financing constraints of SMEs through the above mechanisms.

4.4. Heterogeneity analysis

4.4.1. Regional heterogeneity analysis

According to the regional grouping variable *Region*, a two-way fixed effects regression is conducted.

Table 4. Regional grouped regression results

variable	Eastern Region Sample (1) SA	Central and Western Region Sample (2) SA
DIF	0.000652** (0.000258)	-0.000307 (0.000318)
lnGDP	0.0153 (0.0133)	0.0161 (0.0126)

Table 4. (continued)

lev	-0.000209 (0.000976)	-0.000330 (0.00104)
GreenDisc	0.00845*** (0.00164)	0.00968*** (0.00250)
LnTop5Ratio	0.00702*** (0.00219)	0.0122*** (0.00324)
roe	-0.0662*** (0.0167)	-0.0223 (0.0222)
growth	-0.0103*** (0.00222)	-0.0122*** (0.00356)
tobinq	0.00465*** (0.00106)	0.00558*** (0.00116)
Constant	-4.386*** (0.142)	-4.237*** (0.117)
Observations	18,154	6,429
R-squared	0.977	0.975

Note: *, **, *** indicate significance at the 10%, 5% and 1% levels respectively, and robust standard errors clustered at the enterprise level are in parentheses.

The results in Table 4 show that the DIF regression coefficient of the eastern region sample is 0.000652 (with 5% statistical significance), while in the central and western region sample, the estimated DIF coefficient is -0.000307 (insignificant). This reflects that the financing constraints of enterprises in eastern regions are more significantly improved with the development of digital financial inclusion. This result is also highly consistent with the theoretical expectations in Section 2.4.1 of this paper.

4.4.2. Ownership heterogeneity analysis

According to the enterprise ownership grouping variable *SOE*, grouped two-way fixed effects regression is conducted.

Table 5. Enterprise ownership grouped regression results

variable	State-Owned Enterprise Sample (1) SA	Private Enterprise Sample (2) SA
DIF	0.000957*** (0.000267)	0.000103 (0.000225)
lnGDP	0.0187 (0.0141)	0.00812 (0.0114)
lev	0.000749 (0.000955)	-0.000828 (0.000988)

Table 5. (continued)

GreenDisc	0.000696 (0.00219)	0.0130*** (0.00184)
LnTop5Ratio	0.0166*** (0.00292)	0.00175 (0.00211)
roe	-0.119*** (0.0263)	-0.0303* (0.0166)
growth	-0.00201 (0.00370)	-0.0168*** (0.00208)
tobinq	0.00738*** (0.00144)	0.00393*** (0.00113)
Constant	-4.707*** (0.156)	-4.025*** (0.115)
Observations	8,221	13,801
R-squared	0.978	0.978

Note: *, **, *** indicate significance at the 10%, 5% and 1% levels respectively, and robust standard errors clustered at the enterprise level are in parentheses.

The results in Table 5 show that the estimated DIF coefficient of the state-owned enterprise sample is 0.000957 (with 1% statistical significance), while the DIF regression coefficient of the non-state-owned enterprise sub-sample is 0.000103 (insignificant). This reflects that digital financial inclusion has significantly improved the financing situation of state-owned enterprises, but has a limited effect on private enterprises. This is highly consistent with the theoretical expectation in Section 2.4.2 of this paper, that is, state-owned enterprises benefit more obviously from this effect.

Based on the above analysis, it can be seen that the financing constraints of state-owned enterprises are more strongly alleviated by digital financial inclusion. The implication behind this finding is that simply improving information transparency does not necessarily automatically benefit all types of enterprises. The financing dilemma of private enterprises, especially SMEs, still needs to be solved collaboratively by improving financial systems, improving information quality and building diversified credit enhancement mechanisms.

4.5. Robustness checks

4.5.1. Robustness check with sub-dimensional indicators as explanatory variables

This paper replaces the DIF index in the benchmark model with depth of use (depth), breadth of coverage (cov) and degree of digitalization (digi) as explanatory variables respectively, and uses the same two-way fixed effects model for regression.

The final results show that the coefficient of depth of use is 0.000282, with 5% statistical significance; the coefficient of degree of digitalization is 0.000102, with 10% statistical significance; while the coefficient of breadth of coverage is 6.18e-05, which fails the significance test. It is worth noting that the estimated coefficients of the three sub-dimensional indicators are all positive, which is consistent with the direction of the total index in the benchmark regression, and both depth of use and degree of digitalization reach a certain level of statistical significance. This fully shows that the

effect of digital financial inclusion in curbing financing restrictions found in the benchmark regression is not accidentally caused by the index aggregation method, but has internal dimensional support.

4.5.2. Robustness check considering the lag effect of explanatory variables

Although the benchmark regression has controlled some endogeneity bias with the help of two-way fixed effects, the possibility of reverse causality still exists. To eliminate this endogeneity problem as much as possible, and to examine the persistence and time lag of digital financial inclusion on enterprise financing conditions, this study replaces the core explained variable with the SA index of the next period, and still uses the current DIF as the core explanatory variable to re-conduct the two-way fixed effects regression. After testing, the regression coefficient of current DIF is 0.000478, with 5% statistical significance. The magnitude of this coefficient is basically equivalent to that of the benchmark regression, and the significance level is consistent. This reflects that digital financial inclusion can not only curb the current financing restrictions of enterprises, but also have a sustained alleviation effect on the financing constraints of the next period.

4.5.3. Robustness check with different explained variables

In the empirical research on financing constraints, existing literature has developed a variety of financing constraint proxy variables. Different indexes have significant differences in construction logic, data dependence and endogeneity treatment. The SA index selected in the empirical part of this paper is based on two indicators with high exogeneity: enterprise scale and operating years, but its simplified setting may also lose some dynamic information of enterprise-level financing constraints. To exclude the possible estimation bias caused by different construction methods of the SA index, this paper will further adopt the WW index constructed by Whited Toni M and Wu Guojun [27] as the explained variable to re-conduct the two-way fixed effects regression. The construction logic of this index is significantly different from that of the SA index. If the results are still significant and the direction is consistent with expectations, the reliability of the benchmark conclusion will be more strongly supported.

After controlling all enterprise-level and regional-level variables as well as two-way fixed effects, the coefficient of the explanatory variable DIF is -0.000126, passing the 10% significance test. The construction logic of the WW index determines that as the index increases, the financing constraints of the enterprise become stronger. Therefore, the negative coefficient of DIF means that the further development of digital financial inclusion can significantly reduce the financing constraints faced by enterprises. This conclusion is completely consistent with the positive estimation result of the SA index in the benchmark regression in terms of economic meaning, which further verifies the robustness of research hypothesis H1 in this paper.

4.5.4. Robustness check with different winsorization ranges

In the benchmark regression part, this paper performs bilateral 1% winsorization on continuous financial variables and economic variables, aiming to control the potential impact of extreme values. To test whether the benchmark conclusion is sensitive to the choice of winsorization range, this paper will adopt stricter bilateral 2.5% winsorization and bilateral 5% winsorization, and substitute them into the benchmark two-way fixed effects model for regression respectively.

It is found that after 2.5% winsorization, the DIF coefficient is 0.000503, with 1% statistical significance; after 5% winsorization, the DIF coefficient is 0.000349, also with 1% statistical significance. Compared with the results in the benchmark regression, the sign and direction of the coefficients under the two winsorization treatments have not changed substantially, and the significance level has even improved. This result fully shows that the inhibitory effect of digital financial inclusion on the financing constraints of SMEs is not affected by the winsorization range, and the core estimation results remain robust. Therefore, the robustness test by changing the winsorization range also verifies the credibility of the benchmark regression conclusion of this paper.

5. Conclusions and policy implications

5.1. Main conclusions

Based on enterprise panel data from 2010 to 2024, this paper deeply discusses the channels and logic of digital financial inclusion affecting enterprise financing constraints, and further analyzes the heterogeneity effects at the regional and ownership levels, drawing the following conclusions: First, the financing constraints of SMEs are significantly alleviated under the effect of digital financial inclusion, and this conclusion still holds when replacing explanatory variables, explained variables, setting lags and changing winsorization ranges. Second, the mechanism test shows that digital financial inclusion improves information transparency and acts on financing constraints through the channel of information asymmetry alleviation. Third, there are regional and ownership heterogeneity in the effect: the improvement of financing dilemmas is more significant for enterprises in eastern developed regions and state-owned enterprises, while it is weaker for enterprises in central and western regions and private enterprises. These findings reveal that simply promoting digital technology without improving the "data ecosystem" in central and western regions and the information quality of private enterprises can hardly achieve the balanced effect of inclusive finance.

5.2. Policy implications

5.2.1. Strengthen the core transmission channel of "information asymmetry alleviation" and promote the construction of a data-driven credit system

Digital financial inclusion significantly improves the information environment of enterprises through the dual paths of "digital credit enhancement" and "risk control efficiency improvement", thereby reducing financing constraints. Therefore, policy formulation should pay more attention to giving play to the core advantages of digital financial inclusion in information integration and credit evaluation.

In this regard, we should actively promote the compliant connection between government affairs data and financial institutions. Financial regulatory departments at or above the provincial level should take the lead in promoting the standardization and sharing compliance of data interfaces such as taxation, industry and commerce, customs, electricity and water affairs, and build a digital credit reporting system covering the whole life cycle of SMEs (for example, piloting a "government-bank-enterprise data security house" in the east first). Meanwhile, financial institutions should be guided to tap the "soft information" of enterprises and reduce their dependence on collateral. Regulatory authorities can set up an "intelligent risk control innovation reward fund" or relax financing restrictions to incentivize institutions with remarkable risk control effects. In addition, local

governments should support central and western regions and private enterprises to adopt standardized financial software and access taxation and transaction data platforms through financial subsidies or procurement, so as to gradually accumulate verifiable operating data and release the financing dividend brought by the alleviation of information asymmetry.

5.2.2. Tailor measures to local conditions to fill the "data ecosystem" shortboard in central and western regions and avoid "technical idling"

The analysis of regional heterogeneity in this paper finds that the financing constraints of SMEs in eastern regions are significantly improved by digital financial inclusion, while no similar effect is seen in central and western regions. To solve this dilemma, this paper holds that the construction of digital financial inclusion needs to shift from "expanding coverage" to "improving quality", and the policy focus in central and western regions should prioritize supporting the construction of financial standardization and digital infrastructure improvement of local SMEs. For example, the provincial local financial supervision bureau can take the lead and cooperate with the finance department to set up a special fund to give certain subsidies to SMEs in central and western regions for purchasing compliant financial software and accessing taxation and transaction data platforms.

5.2.3. Precisely address "ownership discrimination" against private SMEs and build a diversified credit enhancement mechanism

Digital financial inclusion has an obvious improvement effect on the financing restrictions of state-owned enterprises, but the weakening effect on private enterprises is not obvious. This shows that simply relying on digital technology cannot automatically eliminate the "ownership prejudice" encountered by private enterprises. Therefore, in view of this situation, we should work on both improving information quality and improving external credit enhancement mechanisms. On the one hand, the Federation of Industry and Commerce and industry and information technology departments should organize a "special action on financial standardization", systematically train financial personnel of private enterprises, promote the establishment of standardized financial systems, and open a "data credit green channel" on the digital financial inclusion platform for private enterprises that meet corresponding requirements. On the other hand, a "special fund for risk compensation of digital financial inclusion for private enterprises" shared by the central and provincial finances should be set up to compensate for the bad losses formed by banks' loans to small and medium-sized private enterprises in proportion. Meanwhile, local governments can set up a "tax credit enhancement fund for private enterprises" to share risks for first-time borrowers. In addition, financial regulatory authorities should optimize the differentiated assessment mechanism, add a sub-indicator of "proportion of digital credit for private enterprises" in the inclusive finance indicators, and link its completion with the performance of the person in charge of local bank branches.

5.3. Research limitations and future prospects

Although this paper has made some progress in theoretical analysis and empirical testing, there are still several limitations that need to be further explored and improved in the future.

First, in terms of index measurement and causal identification, this paper draws on existing literature and uses audit fees as the proxy variable of information transparency. Although this index is widely used, it may still be interfered by factors such as enterprise scale and business complexity.

Meanwhile, this paper mainly deals with endogeneity problems through two-way fixed effects and lagged variables, but unobservable time-varying confounding factors are still difficult to completely exclude. Future research can try to use richer measures of information asymmetry, such as instrumental variable estimation or difference-in-differences analysis, to enhance the robustness of conclusions.

Second, in terms of action mechanism, this paper focuses on the core transmission channel of information asymmetry, but digital financial inclusion may also alleviate financing constraints through paths such as reducing the operating costs of financial institutions and improving entrepreneurs' financial literacy. Future research can further expand the perspective of mechanism analysis and explore multi-path and multi-level mediating effects, so as to more comprehensively reveal the deep mechanism of digital financial inclusion helping SME financing. Follow-up research can continue to deepen in aspects such as proxy variable optimization, causal identification strengthening and mechanism path diversification, so as to provide a more solid empirical basis for policy formulation.

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