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The Role Mechanism of Digital Finance Development on the Improvement of Financing Efficiency of Small and Medium-sized Enterprises in China

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Abstract With the rise of digital finance, improving financial services through advanced technologies such as the Internet and big data has gradually become a key factor in optimizing the financing efficiency of small and medium-sized enterprises (SMEs). This paper analyzes the impact of digital finance development on the financing efficiency of Chinese SMEs through a two-stage network DEA model. The study selected the financial data of 200 SMEs during the period of 2020-2024, and used input indicators such as labor costs, fixed assets, and financial expenses, intermediate indicators such as equity financing amount and debt financing amount, and output indicators such as operating income and investment income. The results show that the financing efficiency of SMEs is generally low during the period of 2020-2024, among which the financing efficiency is the highest in 2022, and the pure technical efficiency reaches 0.823, which indicates that the management and technical level of the enterprise has improved in that year. Further regression analysis shows that the digital finance index (DFI) is significantly positively correlated with enterprise financing efficiency, indicating that the development of digital finance can significantly improve the financing efficiency of SMEs. Specifically, the breadth of coverage, depth of use and degree of digitization of digital finance all have a positive effect on the improvement of financing efficiency, especially the depth of use has the greatest impact. It is concluded that digital finance significantly contributes to the improvement of SMEs' financing efficiency by reducing financing costs and improving the efficiency of capital utilization.

Index Terms Digital finance, financing efficiency, DEA model, enterprise management, capital utilization, information asymmetry

I. Introduction

With the development of digital technology, digital finance, as an emerging financial industry, is triggering profound changes globally [1]. Digital finance is committed to serving a wider group of users, reflecting the diversity of its user base. Although the essence of finance has not been changed by digital technology, digital finance has indeed changed the operation and risk characteristics of traditional finance, and the phenomenon of “disintermediation” of financial transactions is increasingly visible [2], [3]. Digital finance is not limited to new technology enterprises to provide solutions, traditional financial institutions are also through technical means to continuously improve the quality of service, the depth of integration of finance and technology is promoting the continuous innovation and optimization of financial services [4]-[6].

Nowadays, digital finance is indispensable and contributes to the development of the real economy [7]. However, there is still a serious financial supply and demand gap between China's financial system and the real economy; large enterprises can obtain external financing at a lower unit cost because of their large scale. Small and medium-sized enterprises (SMEs), with small scale, poor transparency of business results, insufficient collateral guarantees, and high business risks, therefore face a more severe financing environment, which hinders the benign development of SMEs [8]-[10]. Compared with traditional finance, digital finance can get rid of the geographical limitations of the network, the banking industry, with the help of big data, cloud computing and artificial intelligence and other technologies, launched a series of online credit products, these products not only simplify the financing process, but also improve the availability of funds, for the SMEs to open up a diversified financing channels [11]-[14]. The introduction of digital finance helps SMEs to optimize the credit approval process and speed up the approval of financing through technical means, reduce the cost of financing and improve the financing environment [15], [16]. It can be seen that the development of digital finance has brought new opportunities to the financing efficiency of SMEs.

This study analyzes in depth the specific impact of digital finance on the financing efficiency of Chinese small and medium-sized enterprises (SMEs) through a two-stage network DEA approach. First, the DEA model is used to

calculate the efficiency of enterprises in the stages of fund raising and fund allocation, so as to comprehensively assess their financing efficiency. Second, combined with the regression analysis of the level of digital finance development and the financing efficiency of enterprises, the study further verifies the role of digital finance on the improvement of financing efficiency and explores its possible mechanism of action. The study not only provides theoretical support for enterprises to optimize their financing structure, but also provides policymakers with practical guidance for digital finance to support SME financing.

II. Analysis of the efficiency of SME financing

II. A.Research Methodology and Selection of Indicators

In the traditional single-stage DEA analysis, the whole production process is usually regarded as a "black box", only considering the initial inputs and final outputs, ignoring the role of intermediate outputs [17]. Network DEA helps intermediate outputs to open the "black box", revealing the efficiency of each sub-stage in the production process of the decision-making unit and the overall efficiency. In this paper, the financing link of small and medium-sized enterprises (SMEs) is divided into two sub-stages: fund-raising stage and fund-allocation stage, which is analyzed by two-stage network DEA methodology, in which the financing link of SMEs is shown in Figure 1.

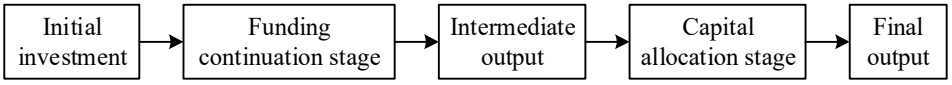

Figure 1: Financing of smes

Suppose there are K SMEs, each of which produces L intermediate outputs and M final outputs using N initial inputs, where $X=(x_1,x_2,\cdots,x_N)$ denotes inputs in the capital mobilization stage for each firm. $Y=(y_1,y_2,\cdots,y_M)$ denotes the output of each firm in the capital allocation stage. $Z=(z_1,z_2,\cdots,z_L)$ then denotes the intermediate outputs of each firm connecting the fund-raising stage and the fund-allocation stage, which can be interpreted as playing the role of both outputs in the fund-raising stage and inputs in the fund-allocation stage. $\lambda=(\lambda_1,\cdots,\lambda_k),\mu=(\mu_1,\cdots,\mu_k)$ and $\gamma=(\gamma_1,\cdots,\gamma_k)$ denote the weights of initial inputs, intermediate outputs and final outputs, respectively. Equation (1) can calculate the financing efficiency E_0 of the output-oriented two-stage network-based DEA based on linear programming, where the objective function requires the maximization of final output. In the constraints, the first line indicates the assumption of constant inputs, the second and third lines introduce the fund-raising and fund-allocation phases, respectively, and the last line is the weight restriction on each variable.

$$\begin{aligned} E_0 &= \max \sum_{k=1}^{K} \mu_k y_{km} \\ s.t. &\sum_{k=1}^{K} \lambda_k x_{kn} = 1 \\ &\sum_{k=1}^{K} \gamma_k z_{kl} - \sum_{k=1}^{K} \lambda_k x_{kn} \le 0 \\ &\sum_{k=1}^{K} \mu_k y_{km} - \sum_{k=1}^{K} \gamma_k z_{kl} \le 0 \\ &\lambda_k \ge \varepsilon, \mu_k \ge \varepsilon, \gamma_k \ge \varepsilon \end{aligned} \tag{1}$$

In Equation (1), . ε . is a non-Archimedean infinitesimal. Assuming that λ_k^*,μ_k^* and γ_k^* are the optimal solutions for the evaluation weights of the initial inputs, intermediate outputs, and final outputs financing efficiency, respectively, in accordance with the constraints provided by Eqn. (1), SMEs' financing chain can be decomposed into two sub-stages, i.e., capital mobilization efficiency E_1 and capital allocation efficiency E_2 as shown in Equation (2) and Equation (3).

$$E_1 = \frac{\sum_{k=1}^{K} \gamma_k z_{kl}}{\sum_{k=1}^{K} \lambda_k x_{kn}} \tag{2}$$

$$E_2 = \frac{\sum_{k=1}^{K} \mu_k y_{km}}{\sum_{k=1}^{K} \gamma_k z_{kl}} \tag{3}$$

Combining equations (1)-(3), since $E_0 = E_1 \times E_2$, if the financing efficiency $E_0 = 1$, it means that the firm's financing efficiency is technologically efficient and that both its fund-raising efficiency E_1 and its capital allocation efficiency E_2 are effective . Considering that SMEs have growth, assuming that SMEs have variable returns to scale, a two-stage network DEA based on variable returns to scale is chosen to measure and analyze the financing efficiency of Chinese SMEs and their sub-stage efficiency [18].

In this paper, 200 SMEs from 20220-2024 are selected as research samples. The data in this paper mainly comes from CSMAR economic and financial database, Wind database and the financial data disclosed in the annual reports of each enterprise. The evaluation dimensions of SMEs' financing efficiency are mainly considered from the inputs of all aspects of financing and the outputs after financing. In this paper, three input indicators of labor cost, fixed assets and financial cost, two intermediate indicators of equity financing amount and debt financing amount, and two output indicators of operating income and investment income are selected, and the description of the indicators is shown in Table 1.

Table 1: Indicator explanation

Index	Name	Meaning
Input index	Manpower cost	Labor investment
	Fixed assets	Investment in fixed assets
	Financial cost	Capital investment
Intermediate index	Equity financing	Amount raised
	Amount of debt	Amount raised
Output indicator	Operating income	Main business income
	Investment income	Other investment income

At least the following two requirements need to be met to realize the two-stage network DEA. First, the sample size selected is not less than two times the sum of the number of indicators in each stage. Second, the values of input, intermediate and output indicators are non-negative, and corresponding data processing should be carried out if negative values exist. This paper takes 200 SMEs as the research sample, which meets the first requirement. For the second requirement, due to the existence of negative value samples in the selected indicators of SMEs' financing efficiency, the data need to be processed. The SME financial indicators are dimensionless, and the initial data of SME financing efficiency evaluation indicators are transformed into [0, 1], as shown in Equation (4). Where m_j is the minimum value of x_{ij}, M_j is the maximum value of x_{ij}, and the final obtained x_{ij} is between 0 and 1 $(i = 1, 2, \cdots, n)$.

$$x_{ij}^{*} = 0.1 + \frac{x_{ij} - m_j}{M_j - m_j} \times 0.9 \tag{4}$$

The values with distributions between 0 and 1 obtained after dimensionless quantization of the indicators satisfy the second basic requirement of network DEA, while the values obtained after the transformation have no substantial impact on the calculation results.

II. B.Descriptive statistics

In this paper, descriptive statistics are provided for each efficiency evaluation indicator of 200 SMEs selected in 2020-2024. The descriptive statistics of the SME financing efficiency evaluation indicators are shown in Table 2. Among the input indicators, there is a large heterogeneity among the sample enterprises in terms of fixed assets, with a standard deviation of 30.5361, which is much higher than the other two input indicators. In terms of enterprise financing structure, the total amount of equity-integrated funds is higher than the total amount of debt-integrated funds in terms of the mean value, indicating that enterprises prefer to use equity financing as a method of integrating funds. The standard deviation of the amount of debt financing is larger, which is mainly due to the fact that some sample firms still face certain debt financing constraints, and there are impediments to integrating funds in debt

financing. In terms of revenue generation, the standard deviation of operating income is large, indicating that there are significant differences in the revenue generation ability of the sample firms.

Table 2: Descriptive statistics of the evaluation index for small and medium-sized enterprises

Index	Name	Observed quantity	Maximum value	Minimum value	Mean	Standard deviation
Input index	Manpower cost	4165	67.713	0	0.3232	1.8872
	Fixed assets	4165	454.2199	0.0155	14.8539	30.5361
	Financial cost	4165	49.9574	-4.0322	0.4516	0.852
Intermediate index	Equity financing	4165	464.6949	0.5226	19.2022	24.9193
	Amount of debt	4165	624.7229	0.0031	17.1962	41.6102
Output indicator	Operating income	4165	2433.5346	0.8331	46.3526	111.5785
	Investment income	4165	145.7604	-7.2599	0.4503	3.3436

III. Evaluation and analysis of the efficiency of SME financing

In this section, in order to analyze the financing efficiency of Chinese SMEs in depth, the magnitude of the financing efficiency values of all sample companies from 2020 to 2024 is obtained sequentially by establishing a DEA model. The financing efficiency of SMEs is specifically categorized into four grades: the financing efficiency grades are shown in Table 3.

Table 3: Financing efficiency division

Financing efficiency	0<e<0.5	0.5<e<0.8	0.8<e<1	e=1
Financing efficiency grade	Ineffectiveness	Relatively ineffective	Relatively effective	In effect

III. A. DEA efficiency mean analysis

According to the table for the division of financing efficiency of SMEs, the input-output indicators of 200 SMEs in 2020-2024 are processed by using DEAP software to calculate the size of the financing efficiency value of each SME in each sample year. This financing efficiency value mainly includes technical efficiency value (crste), pure technical efficiency value (vrste) and scale efficiency value (scale). Technical efficiency is a comprehensive reflection of an enterprise's management ability, resource allocation and scale level, and the larger the value, the greater the value indicates that an enterprise's management ability, resource allocation and scale level can make the company's financing efficiency reach the best state. Pure technical efficiency is the refinement of the enterprise management ability and technical level, the larger the value, the more indicates that the enterprise financing efficiency to reach the effective level, the enterprise in the use of funds to maximize the efficiency. Scale efficiency is an evaluation index that reflects the scale of output obtained by the enterprise in the use of input funds, through the size of the efficiency value can be seen whether there is a surplus of inputs and insufficient outputs, the larger the value, indicating that the enterprise is in the optimal state, and is able to maximize the efficiency of the use of inputs to obtain outputs.

The results of the average DEA efficiency values for 2020-2024 are shown in Table 4. Overall, the individual efficiency values are low, and most of the values are below 0.8, in a relatively ineffective state, which shows that all 200 SMEs in the sample have low financing efficiency.

(1) For technical efficiency, the efficiency value is the lowest in 2020, and then the efficiency value increases in the following four years, which can be seen that the SMEs are steadily improving the management ability, resource allocation and scale level of the enterprise between 2020 and 2024. However, in 2024, there is a decline in the efficiency value, which is only greater than in 2020.

(2) For pure technical efficiency, as a refined decomposition of enterprise management ability and technology level, the average value of pure technical efficiency in each year is around 0.8, with a small range of variation. Among them, the value of pure technical efficiency in 2022 is the largest at 0.823, reaching a relatively effective state. It indicates that at this time the pure technical efficiency of the firm in utilizing the incorporated capital to obtain the output is maximum. After 2023, the pure technical efficiency of the enterprise is back to below 0.8, and the whole again shows a relatively ineffective state.

(3) For scale efficiency, except for the scale efficiency value of 0.783 in 2020, the efficiency values of the other four years are higher than 0.9, indicating that the overall scale efficiency of SMEs in recent years has been relatively effective, and the efficiency of enterprises in utilizing funds to obtain the output scale is high, and 2023 is the optimal input-output scale state.

Table 4: Average results of DEA efficiency from 2020 to 2024

Year	Technical efficiency(TE)	Pure technical efficiency(PTE)	Scale efficiency(SE)
2020	0.616	0.795	0.783
2021	0.716	0.779	0.918
2022	0.775	0.823	0.953
2023	0.793	0.793	0.959
2024	0.681	0.784	0.896

III. B. Integrated efficiency analysis

Combined efficiency, i.e. combined technical efficiency, can be further expressed as the product of both technical efficiency and scale efficiency, which collectively reflects the efficiency of firms in integrating and utilizing finance to obtain outputs.The results of the evaluation of combined efficiency for the period 2020-2024 are shown in Table 5. As can be seen from the table, the comprehensive efficiency of SMEs is low, with the 200 SMEs having the highest number of effective enterprises reaching 16 in 2021 only, but then the number of comprehensively effective enterprises drops to 4 in 2024, with the number of enterprises dropping by more than half.

Table 5: Comprehensive efficiency evaluation results from 2020 to 2024

Year	Efficiency type	In effect		Relatively effective		Relatively ineffective		Ineffectiveness	
		Number	Proportion	Number	Proportion	Number	Proportion	Number	Proportion
2020	Comprehensive efficiency (TE)	15	7.50%	23	11.50%	113	56.50%	49	24.50%
2021		16	8.00%	51	25.50%	109	54.50%	24	12.00%
2022		13	6.50%	91	45.50%	85	42.50%	11	5.50%
2023		11	5.50%	82	41.00%	79	39.50%	28	14.00%
2024		4	2.00%	52	26.00%	121	60.50%	23	11.50%

III. C. Pure technical efficiency analysis

Pure technical efficiency is the ratio of inputs to outputs when the scale efficiency of an enterprise is optimized, reflecting the management level and technical level of the enterprise. When the value of pure technical efficiency is larger, it indicates that the management level and technical level of the enterprise is higher.The evaluation results of pure technical efficiency in 2020-2024 are shown in Table 6. As can be seen from the table, the number of effective SMEs is 23, 17, 33, 30 and 21 respectively. For the number of effective enterprises of pure technical efficiency, its proportion is higher than that of comprehensive technical efficiency, but the number of effective enterprises in the sample interval is small, the proportion is only about 10%, and reaches a maximum of 16.50% in 2022.

Table 6: Evaluation results of pure technical efficiency from 2020 to 2024

Year	Efficiency type	In effect		Relatively effective		Relatively ineffective		Ineffectiveness	
		Number	Proportion	Number	Proportion	Number	Proportion	Number	Proportion
2020	Pure technical efficiency (PTE)	23	11.50%	92	46.00%	62	31.00%	23	11.50%
2021		17	8.50%	89	44.50%	71	35.50%	23	11.50%
2022		33	16.50%	91	45.50%	62	31.00%	14	7.00%
2023		30	15.00%	81	40.50%	74	37.00%	15	7.50%
2024		21	10.50%	84	42.00%	79	39.50%	16	8.00%

III. D. Scale efficiency analysis

The scale efficiency of SMEs, i.e., the situation of the scale efficiency of enterprises in the current scale of input capital to obtain output, can analyze the problem of excess inputs or insufficient outputs of enterprises through the size of the value of this efficiency.The results of the evaluation of the scale efficiency in 2020-2024 are shown in Table 7. From the table, it can be seen that the number of effective homes reached by scale efficiency in the past five years is 15, 21, 20, 45 and 12 respectively. It can also be seen from the data that, except for the number of relatively ineffective enterprises in 2020, which is 103, the number of relatively ineffective and ineffective enterprises in other years is very small, especially the number of ineffective SMEs in 2021 and 2022 is 0, which indicates that the overall business environment and business conditions of SMEs in these two years are better, and the enterprises

can improve the scale efficiency of the enterprises by innovating the enterprise technology or the management level and so on.

Table 7: Evaluation results of scale efficiency from 2020 to 2024

Year	Efficiency type	In effect		Relatively effective		Relatively ineffective		Ineffectiveness	
		Number	Proportion	Number	Proportion	Number	Proportion	Number	Proportion
2020	Scale efficiency (SE)	15	7.50%	74	37.00%	103	51.50%	8	4.00%
2021		21	10.50%	174	87.00%	5	2.50%	0	0.00%
2022		20	10.00%	171	85.50%	9	4.50%	0	0.00%
2023		45	22.50%	144	72.00%	6	3.00%	5	2.50%
2024		12	6.00%	165	82.50%	22	11.00%	1	0.50%

III. E. Analysis of financing efficiency in different regions

In this section, the efficiency evaluation will be conducted mainly based on the economic differences of different regions (region A, region B and region C).The results of the efficiency evaluation of different regions in 2020-2024 are shown in Table 8. Through the table, it can be seen that in the sample interval of region A, the comprehensive efficiency value is low, always in the state of relative inefficiency, which indicates that the overall business conditions of small and medium-sized enterprises in region A are poor, and the cost of obtaining funds is high, resulting in low comprehensive efficiency. And the pure technical efficiency are also below 0.8, the same in the state of relative ineffectiveness, indicating that SMEs to strengthen the technical capacity to improve the technical efficiency of the space. Scale efficiency, on the other hand, is around 0.8, with a maximum value of 0.924, indicating that enterprises are less likely to underutilize funds to obtain output.

Table 8: Efficiency evaluation results of different regions in 2020-2024

Year	Efficiency type	Zone A	Zone B	Zone C
2020	(TE)	0.658	0.69	0.596
	(PTE)	0.745	0.844	0.698
	(SE)	0.895	0.834	0.833
2021	(TE)	0.659	0.762	0.664
	(PTE)	0.743	0.795	0.753
	(SE)	0.862	0.935	0.876
2022	(TE)	0.671	0.839	0.703
	(PTE)	0.747	0.839	0.773
	(SE)	0.921	0.945	0.918
2023	(TE)	0.663	0.792	0.719
	(PTE)	0.721	0.818	0.752
	(SE)	0.919	0.935	0.954
2024	(TE)	0.654	0.805	0.703
	(PTE)	0.698	0.837	0.797
	(SE)	0.924	0.953	0.896

IV. Study on the impact of digital finance on the financing efficiency of SMEs

IV. A. Theoretical assumptions

Digital finance is an important milestone in the development of finance, relying on the Internet, big data and other advanced technologies to expand the coverage of financial services, reduce transaction costs, efficiently facilitate financing transactions and improve the efficiency of enterprise financing. At the same time, the development of digital finance effectively improves the transparency of enterprise information, thus providing more solid basis for financial institutions to make financing decisions and contributing to the improvement of enterprise financing efficiency. The development of digital finance enables enterprises to obtain information more efficiently and comprehensively, the information asymmetry problem obtains a more effective solution, and the enterprise financing efficiency can be continuously transformed in a favorable direction.

In summary, this paper puts forward hypothesis H1: compared with traditional finance, the development of digital finance can improve the efficiency of enterprise financing. Whether the cutting-edge information technology

embedded in digital finance can more accurately analyze the financial situation and development prospects of enterprises, or the development of digital finance itself has optimized the credit-granting process of traditional financial institutions to a certain extent, it has provided more convenience and concessions for enterprise financing - improving the financing constraints of enterprises and reducing their financing costs, thus playing a positive role in the improvement of enterprise financing efficiency.

IV. B. Study design

IV. B. 1) Data sources

The data used in the empirical analysis in this section are all annual data. The data involved in the enterprise subject mainly includes the information related to financing efficiency and control variables of Chinese A-share listed enterprises in 2020-2024, which is obtained from the Cathay Pacific database. Data processing includes excluding financial enterprises and ST enterprises, performing downsizing and logarithmic processing.

IV. B. 2) Selection of variables

In this paper, corporate financing efficiency is defined as the input-output ratio of capital, which is measured by the return on net assets (ROE), i.e., net profit/net assets.

(1) Core explanatory variables

In this paper, the 2020-2024 financial index is selected as the main explanatory variable in the empirical model. The index is compiled based on various characteristics of finance. In order to further study which dimension of digital finance has an impact on the efficiency of corporate finance, this paper also uses three subdimensions of breadth of coverage, depth of use and degree of digital support services for analysis.

(2) Control variables

In order to minimize the impact of omitted variables, this paper chooses equity concentration, current ratio, operating income growth rate, net profit growth rate, inventory turnover, accounts receivable turnover, operating cycle, gearing ratio, total assets and GDP as model control variables.

The description of the main variables is shown in Table 9.

Table 9: Key variables explanation

Variable class	Variable name	Variable symbol
Explained variable	Enterprise financing efficiency	ROE
Core interpretation variable	Digital finance	DFI
	Coverage span	Cov
	Usage depth	Use
	digitization	Dig
Control variable	Equity concentration	Own
	Mobility ratio	Liq
	Revenue growth	Bus
	Net profit growth rate	Net
	Inventory turnover	Inv
	Receivable turnover	Rec
	Business cycle	Ope
	Asset ratio	Deb
	Total assets	Ass
	Gross domestic product	GDP

IV. B. 3) Model construction

In order to explore the impact of digital finance and its secondary indicators on the efficiency of corporate finance, this paper sets the following benchmark model:

$$ROE_t = \alpha_0 + \alpha_1 DFI_t + \sum(\alpha_n \times Control_t) + \varepsilon_t \quad (5)$$

where ROE is corporate financing efficiency and DFI is digital finance. $Control$ is the control variable. ε denotes the random error term and t represents time.

V. Results and analysis

V. A. Basic statistical analysis and regression analysis

V. A. 1) Descriptive statistics and correlation analysis

The descriptive statistics of the variables are shown in Table 10. From the perspective of explanatory variables, the mean value of financing efficiency (ROE) is 54.958, the minimum value is 10.237, and the maximum value is 240.727, indicating that the financing efficiency of listed SMEs as a whole is low, and there are significant differences in financing efficiency among different individuals. In terms of explanatory variables, the minimum value of Digital Finance Index (DFI) is 0.251, and the maximum value is 3.676, indicating that the level of digital finance development varies greatly among regions in China, but it has been growing faster in recent years, and the descriptive statistics of its three sub-indices are consistent with the total index as a whole.

Table 10: Descriptive statistical results of variables

Variable	Observed quantity	Mean value	Median	Standard deviation	Minimum value	Maximum value
ROE	4165	54.958	53.873	9.022	10.237	240.727
DFI	4165	2.315	2.484	0.377	0.251	3.676
Cov	4165	1.884	2.284	0.476	0.234	4.03
Use	4165	2.099	1.953	0.873	0.046	3.477
Dig	4165	2.42	2.81	0.948	0.262	4.215
Own	4165	21.915	21.836	1.131	17.787	26.861
Liq	4165	2.794	3.799	18.474	-478.019	744.378
Bus	4165	38.844	36.986	23.357	1.193	499.346
Net	4165	30.41	28.255	14.549	2.409	86.665
Inv	4165	10.69	8.33	11.365	0.108	466.422
Rec	4165	4.334	3.73	4.241	0.108	48.846
Ope	4165	1.577	2.899	2.493	1.203	3.764
Deb	4165	1.251	0.298	0.544	0.369	2.75
Ass	4165	2.499	1.921	2.978	0.829	4.213
GDP	4165	1.687	4.622	2.459	2.027	4.333

The Pearson correlation test is conducted for the main variables, and the correlation analysis of the main variables is shown in Table 11 (***, **, * indicate significant at the 1%, 5%, and 10% statistical levels, respectively). It can be seen that the correlation coefficient between corporate financing efficiency and digital finance is significantly positive at the 1% level, indicating that corporate financing efficiency increases with the development of digital finance.

Table 11: The main variable correlation analysis

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ROE	1														
DFI	0.087***	1													
Cov	0.087***	0.078***	1												
Use	0.072***	0.077***	0.985***	1											
Dig	0.107***	0.082***	0.987***	0.942***	1										
Own	0.086***	0.12**	0.948***	0.896***	0.918***	1									
Liq	0.09***	0.073***	0.393***	0.384***	0.388***	0.984***	1								
Bus	0.035***	0.088***	0.071***	0.079***	0.081***	0.977***	0.94***	1							

Net	-0.096***	0.043***	0.208***	0.197***	0.182***	0.944***	0.898***	0.916***	1						
Inv	0.262***	-0.105***	-0.218***	-0.206***	-0.207***	0.396***	0.391***	0.39***	0.395***	1					
Rec	0.084***	0.263***	-0.059***	-0.047***	-0.065***	0.074***	0.075***	0.075***	0.089***	0.041***	1				
Ope	0.087***	0.071***	-0.006***	-0.008***	-0.007***	0.204***	0.198***	0.183***	0.197***	0.35***	-0.373***	1			
Deb	-0.007***	0.078***	0.985***	0.942***	0.918***	-0.221***	-0.205***	-0.213***	-0.226***	0.056***	0.079***	-0.001***	1		
Ass	-0.085***	0.077***	0.987***	0.896***	0.388***	-0.054***	-0.046***	-0.057***	-0.052***	-0.282***	-0.08***	-0.084***	-0.119***	1	
GDP	-0.05***	0.082***	0.948***	0.384***	0.081***	-0.007***	-0.019***	-0.004***	0.027***	-0.029***	0	-0.056***	-0.011***	0.099***	1

V. A. 2) Analysis of baseline regression results

In order to test whether H1 is true, this paper conducts regression analysis on the financing efficiency of the sample enterprises and the digital finance index at the prefecture-level city level, and the regression results of digital finance on financing efficiency are shown in Table 12 (*, **, and *** stand for being significant at the 10%, 5%, and 1% levels, respectively, with standard errors in parentheses). Regarding the key explanatory variables, the first one is the Digital Finance Index DFI, whose regression coefficient on corporate financing efficiency is 6.752, which is significant and positive at the 1% level. The regression result confirms the theoretical hypothesis 1, indicating that digital finance has an enhancing effect on SMEs' financing efficiency, and that digital finance can effectively alleviate the degree of information asymmetry between the financial market and SMEs, reduce the cost of services, and improve the efficiency of services by utilizing its technological advantages and inclusive characteristics, which leads to the improvement of SMEs' capital availability, the reduction of financing costs, and thus the improvement of financing efficiency. Secondly, the regression results of the three dimensions of the digital finance index, the regression coefficients of the breadth of coverage (Cov), the depth of use (Use) and the degree of digitization (Dig) and the efficiency of enterprise financing are all positive, of which the coefficient of the breadth of coverage is significant at 5% level as 2.891, and the coefficients of the depth of use and the degree of digitization are significant at 1% level as 3.339 and 1.721, further verifying the basic hypotheses of this paper. , further verifying the basic hypothesis of this paper, indicating that all three ways of digital finance, namely, breadth of coverage, depth of use and degree of digitization, can increase the availability of funds to enterprises, reduce the cost of financing and improve the efficiency of the use of funds. The higher the breadth of coverage, the deeper the application and the more advanced the digitization of digital finance, the more pronounced the positive impact on the financing efficiency of SMEs in the region. In addition, comparing the regression results in Tables (2) to (4), it can be found that among the different dimensions of digital finance, the depth of the use of digital finance has the greatest effect on the enhancement of SMEs' financing efficiency, the breadth of coverage has the second greatest effect, and the degree of digitization has the least effect. This is due to the fact that the technological and innovative nature of digital finance enriches the variety of financial products, expands the audience of financial services, broadens the path for SMEs to obtain effective financial services, reduces the financing cost of SMEs, and thus promotes the improvement of SME financing efficiency.

Table 12: The return of digital finance to financing efficiency

Variable	(1) ROE	(2) ROE	(3) ROE	(4) ROE
DFI	6.752***(1.562)			
Cov		2.891**(1.403)		

Use			3.339***(0.982)	
Dig				1.721***(0.571)
Own	3.205***(0.189)	3.22***(0.189)	3.222***(0.189)	3.238***(0.189)
Liq	0.017***(0.006)	0.008***(0.006)	0.022***(0.006)	0.022***(0.006)
Bus	-0.068***(0.008)	-0.064***(0.008)	-0.062***(0.008)	-0.06***(0.008)
Net	0.102***(0.019)	0.095***(0.019)	0.106***(0.019)	0.098***(0.019)
Inv	3.207***(0.012)	3.229***(0.012)	3.228***(0.012)	3.245***(0.012)
Rec	0.02***(0.036)	0.017***(0.036)	0.015***(0.036)	0.007***(0.036)
Ope	-0.025***(0.206)	-0.03***(0.206)	-0.029***(0.206)	-0.048***(0.206)
Deb	-0.066***(0.211)	-0.068***(0.211)	-0.059***(0.211)	-0.062***(0.211)
Ass	0.093***(0.129)	0.103***(0.129)	0.104***(0.129)	0.093***(0.129)
GDP	0.085***(0.13)	0.084***(0.13)	0.069***(0.13)	0.081***(0.13)
_cons	17.686***(4.303)	-15.695***(4.303)	-15.967***(4.087)	-14.544***(4.162)
Year	Control	Control	Control	Control
Individuals	Control	Control	Control	Control
Sample size	4165	4165	4165	4165
R2	0.095	0.092	0.094	0.096

V. B. Further testing and analysis

V. B. 1) Robustness Tests

In order to ensure the accuracy of the empirical results, this paper adopts three ways of replacing Tobit model, lag one period and dynamic panel model for the robustness test. The efficiency values measured by SBM-DEA are concentrated in a certain range, and the range of values of the explanatory variables is restricted, so in order to avoid certain bias of ordinary regression methods, this paper adopts the Tobit model for the robustness test. The standard Tobit regression model is as follows:

$$\begin{aligned} y^* &= \beta' x_i + \mu_i \\ y_i^* &= y_i, \quad Iif \quad y_i^* > 0 \\ y_i^* &= 0, \quad Iif \quad y_i^* < 0 \end{aligned} \tag{6}$$

where y_i^* is the dependent variable, x_i is the independent variable, the coefficient variable, and the error term.

The robustness test is shown in Table 13. The coefficient of the impact of digital finance on the financing efficiency of SMEs is positive and significant at the 1% level, and the regression results are consistent with the benchmark analysis and pass the robustness test. The benchmark regression shows that the two secondary indicators of digital finance have a significant effect on the financing efficiency of SMEs. Therefore, in this study, the breadth of coverage of digital finance and the depth of use of digital finance are lagged by one period for the robustness test. As can be seen from (2) (3) of the table, the coefficient of the coverage breadth of digital finance on the financing efficiency of SMEs is almost unchanged after one period of lagging, but the coefficient of the depth of the use of digital finance on the financing efficiency of SMEs increases, which indicates that the depth of the use of digital finance has a lagged effect on the financing efficiency of SMEs. This paper adopts the dynamic panel model for robustness test, as can be seen from Table's (4), the coefficient of lagged one period of the explanatory variables is 0.662, and it is significant at the 1% level, indicating that digital finance can still improve the financing efficiency of SMEs under the dynamic panel model.

Table 13: Robustness test

Variable	(1) ROE	(2) ROE	(3) ROE	(4) ROE
DFI	0.051***(22.65)			
Cov		0.041***(7.36)		
Use			0.043***(7.33)	
Dig				0.662***(6.29)
Own	0.123***(-6.84)	0.096***(-3.93)	0.097***(-4.01)	0.131***(-3.76)
Liq	0.254***(7.61)	0.209***(10.27)	0.11***(10.41)	0.196***(10.37)
Bus	-0.206***(16.21)	-0.412***(16.08)	-0.419***(15.87)	-0.43***(16.17)
Net	-0.022***(-10.73)	-0.041***(-28.9)	-0.026***(-28.7)	-0.051***(-28.61)
Inv	-0.019***(-0.31)	-0.025***(-2.89)	-0.017***(-2.95)	-0.011***(-3.24)
Rec	0.135***(-5.89)	0.115***(-4.56)	0.115***(-3.76)	0.126***(-6.05)

Ope	0.247***(6.32)	0.188***(14.56)	0.184***(11.46)	0.184***(8.44)
Deb	-0.242***(14.5)	-0.442***(17.91)	-0.452***(17.19)	-0.442***(5.69)
Ass	-0.015***(-12.25)	-0.04***(-26.86)	-0.031**(-28.26)	-0.034***(-16.31)
GDP	0.133***(5.55)	0.011**(-0.03)	0(-0.1)	0.001*(-0.2)
_cons	0.651***(8.55)	0.633***(11.86)	0.644***(12.28)	0.672***(13.03)
Industry effect	YES	YES	YES	YES
Time effect	YES	YES	YES	YES
Observations	6401	5821	5810	5812
R-squared		0.555	0.555	0.751

V. B. 2) Mechanism testing

Based on the perspective of enterprise input and output, this part mainly examines the transmission mechanism of "digital finance development→ reducing the financing cost of SMEs →improving the financing efficiency of SMEs" and "improving the capital utilization rate of SMEs → improving the financing efficiency of SMEs → improving the financing efficiency of SMEs". Using the operation suggestion of mediation effect analysis, firstly, the proxy variables are constructed according to the economic theory, and the influence of the proxy variables on the explanatory variables is proved through the economic theory. Secondly, the influence of explanatory variables on proxy variables is proved through empirical research, and finally, the complete transmission mechanism of "explanatory variables → proxy variables→ explanatory variables" is obtained. The results of the mechanism test are shown in Table 14. According to the table, digital finance can significantly reduce the financial expenses of small and medium-sized enterprises, and the reduction of financial expenses represents the reduction of the operating cost ratio of small and medium-sized enterprises. It means that from the perspective of capital investment, small and medium-sized enterprises have reduced capital investment, which in turn has increased the financing efficiency of small and medium-sized enterprises.

Table 14: Mechanism test results

Variable	(1) ROE	(2) Net profit	(3) ROE	(4) Financial cost
DFI	0.183***(-3.84)	-0.009***(7.29)	0.184***(-3.86)	-0.23***(25.49)
Own	-0.457***(11.24)	-0.044***(1.12)	-0.443***(10.08)	0.032***(-5)
Liq	-0.026***(17.18)	0.034***(0.35)	-0.016***(16.23)	-0.022***(-13.27)
Bus	-0.001***(-29.94)	0.034***(-3.07)	-0.018***(-30.92)	0.137***(0.72)
Net	0.047***(7.51)	0.015***(2.07)	0.044***(7.26)	-0.049***(-5.81)
Inv	-0.013***(-3.8)	0.019***(6.44)	-0.011**(-3.92)	0.07*(25.87)
Rec	0.116***(10.21)	0.032***(1.48)	0.123***(10.48)	-0.074***(-4.47)
Ope	0.171***(16.89)	0.019***(1.5)	0.185***(16.7)	-0.217***(-13.11)
Deb	-0.452***(-30.29)	-0.045***(-2.11)	-0.447***(-30.42)	0.018***(0.82)
Ass	-0.031***(-3.26)	0.028***(3.1)	-0.028***(-3.28)	-0.044***(-3.39)
GDP	0.009***(-0.37)	0.036***(1.11)	-0.002***(-0.23)	0.138***(4.39)
_cons	0.629***(12.07)	23.103***(302.72)	0.627***(11.9)	18.836***(238.05)
Industry effect	YES	YES	YES	YES
Time effect	YES	YES	YES	YES
Observations	4165	4165	4165	4165
R-squared	0.556	0.023	0.556	0.229

V. B. 3) Heterogeneity analysis

The above empirical analysis shows that digital finance can have a positive effect on the financing efficiency of SMEs. In this part, SMEs are grouped according to three attributes according to the database, namely: SMEs of state-owned nature and SMEs of non-state-owned nature, SMEs in regions with high economic development level and SMEs in regions with low economic development level, and high-tech SMEs and non-high-tech SMEs. The results of heterogeneity analysis are shown in Table 15. The regression results (3) (4) show that the coefficients of the impact of digital finance on the financing efficiency of SMEs in regions with high economic development level and SMEs in regions with low economic development level are positive and significant at the 1% level, indicating that digital finance can improve the financing efficiency of SMEs in regions with different economic development levels. The impact coefficient of digital finance on the financing efficiency of SMEs in regions with low economic development level is larger than the impact coefficient of digital finance on the financing efficiency of SMEs in regions with high economic development level, which indicates that digital finance can improve the financing efficiency of SMEs in regions with low economic development level more effectively. The reason is that the development of digital finance can broaden the financing channels of SMEs, which has a greater impact on regions

with a lower level of economic development, and local SMEs are more likely to obtain financing, which in turn improves their financing efficiency.

Table 15: Heterogeneity analysis results

Variable	(1) Nonstate	(2) State	(3) Low economy	(4) High economy	(5) Nonhigh	(6) High and new
DFI	-0.033***	-0.027***	-0.112***	-0.013*	-0.077***	-0.024***
	(8.77)	(2.46)	(7.97)	(7.51)	(3.4)	(8.99)
Own	0.134***	0.118***	0.187***	0.091*	0.08*	0.12***
	(14.82)	(11.32)	(6.82)	(16.23)	(12.86)	(13.17)
Liq	0.169***	0.25***	0.118***	0.183***	0.23***	0.158***
	(-1.68)	(0.16)	(-2.06)	(-2.54)	(-0.14)	(-3.89)
Bus	-0.467***	-0.241***	-0.474***	-0.453***	-0.384***	-0.484***
	(1.06)	(-2.27)	(-0.97)	(-1.3)	(0.11)	(0.1)
Net	0.035***	0.072***	0.111***	0.019***	0.08***	0.021***
	(5.88)	(4.51)	(3.56)	(1.55)	(6.94)	(3.66)
Inv	-0.006***	-0.024***	-0.012***	0.001*	-0.011***	-0.005*
	(-2.24)	(-6.46)	(-2.32)	(-2.5)	(-1.8)	(-2.74)
Rec	0.129***	0.112***	0.19***	0.091***	0.086***	0.121***
	(10.15)	(3.38)	(8.2)	(6.98)	(4.41)	(9.17)
Ope	0.17***	0.253***	0.118***	0.195***	0.217***	0.162***
	(13.9)	(9.62)	(5.63)	(15.34)	(11.63)	(11.8)
Deb	-0.466***	-0.253***	-0.478***	-0.449***	-0.386***	-0.479***
	(-28.81)	(-7.76)	(-16.33)	(-25.63)	(-14.77)	(-26.67)
Ass	-0.019***	0.021***	-0.034***	-0.022***	-0.013***	-0.04***
	(-2.83)	(0.9)	(-1.62)	(-2.47)	(-0.7)	(-3.9)
GDP	0.024***	-0.234***	0.011***	0.004***	0.013***	-0.001
	(1.13)	(-3.76)	(0.35)	(-0.01)	(0.24)	(-0.07)
_cons	0.557***	1.041***	0.494***	0.652***	0.46***	0.682***
	(10.11)	(7.69)	(4.17)	(10.59)	(4.88)	(11.01)
Industry effect	YES	YES	YES	YES	YES	YES
Time effect	YES	YES	YES	YES	YES	YES
Observations	4165	4165	4165	4165	4165	4165
R-squared	0.553	0.707	0.56	0.564	0.539	0.576

VI. Conclusion

From the analysis of the data from 2020 to 2024, the overall financing efficiency of SMEs is low, and most of the enterprises are in a relatively ineffective state.In 2020, the technical efficiency is 0.616, which is at a low level, but with the passage of time, the efficiency of enterprise management and resource allocation gradually improves, and the technical efficiency of 2022 and 2023 is 0.775 and 0.793, respectively, which indicates that management and resource allocation gradually improves. However, scale efficiency is always higher, especially reaching 0.959 in 2023, indicating that SMEs are close to optimal in capital utilization.

The development of digital finance significantly improves the financing efficiency of SMEs. Regression analysis shows that there is a significant positive correlation between the digital finance index (DFI) and financing efficiency, and the depth of use of digital finance has the greatest effect on the improvement of financing efficiency. During the period of 2020-2024, the breadth of coverage, the depth of use, and the degree of digitization of digital finance have all had a positive impact on the financing efficiency, especially in the case of SMEs facing financing constraints, digital finance effectively reduces financing costs and improves the utilization rate of funds.

From the perspective of mechanism testing, digital finance significantly promotes the improvement of SMEs' financing efficiency by reducing financing costs and improving the efficiency of capital utilization. For policymakers, continuing to promote the development of digital finance, especially enhancing the depth and popularity of its application, will further optimize the financing environment for SMEs and promote high-quality economic development.

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