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DATA-DRIVEN EVALUATION OF REGIONAL SCI-TECH FINANCE EFFICIENCY

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Abstract: Sci-tech finance is the catalyst for the transformation of technological progress into real productivity. Hence, to improve sci-tech finance efficiency and promote high-quality regional economy development, a data-driven evaluation model of sci-tech finance efficiency is constructed. The collected data are processed using the DEA-Malmquist index. The efficiency level of sci-tech finance is determined according to the Total Factor Productivity index, and the main influencing factors of sci-tech finance efficiency are determined through the decomposition analysis of this index. This study calculates the efficiency level and dynamic change of sci-tech finance in the Yangtze River Delta. The results show that technological progress is an important factor affecting sci-tech finance efficiency. Surprisingly, the growth of R&D personnel has a negligible effect on sci-tech financial efficiency instead, and Shanghai ranked third in terms of sci-tech financial efficiency, which is no match for Zhejiang and Jiangsu provinces. Hence, we propose targeted suggestions to improve sci-tech finance efficiency in the Yangtze River Delta. This study not only provides theoretical and methodological support for the evaluation of regional sci-tech financial efficiency but also provides a reference for sci-tech finance policymakers and researchers.
Keywords: DEA-Malmquist index; Sci-tech finance; High-quality development

1 INTRODUCTION

1.1 Background

Sci-tech is a primary productive force, and the activation of innovation processes in the sci-tech field has become essential for economic and efficient development [1]. Scientific and technological innovation in innovative countries has a greater than 70% average contribution rate worldwide, and sci-tech innovation has increasingly become decisive in enhancing international competitiveness. The development of sci-tech innovation requires sufficient scientific and technological investment as a fundamental guarantee. Strengthening the integration of sci-tech and finance can greatly promote economic and social development. Sci-tech finance has the important function of optimizing the allocation of innovation resources and resolving risks. It is a new tool to effectively address the capital and risks faced by sci-tech innovation. Therefore, it is very necessary to study the allocation efficiency of sci-tech financial resources in sci-tech innovation.

The relationship between sci-tech innovation and finance was first established by Austrian economist Schumpeter as part of his "innovation theory" in 1912. He believed that banks and other financial institutions promote the flow of funds through credit creation, guide the industrial sector, and stimulate technological innovation activities [2]. Thereafter, the relationship between sci-tech innovation and finance has been widely studied by many scholars. Financial capital has a positive impact on sci-tech innovation [3–5]. Moreover, a long-term equilibrium relationship exists between finance and technological innovation [6]. Through an empirical study of Italian companies, Benfratello proved that local bank support has significantly improved the success rate of technological innovation activities [7]. Khan et al. used data from a survey of enterprises in 21 countries of the World Bank to prove that bank-based financing is key in promoting various innovative methods in developing countries [8]. Lee proved that innovative financing can improve the technological innovation ability and business performance of innovative small and medium-sized enterprises (SMEs) using a structural equation model [9]. Financial support for sci-tech innovation can improve enthusiasm for R&D activities according to several theoretical and empirical analyses [10,11].

Scholars have extensively examined the impact of different sources of financial capital on sci-tech innovation. Davidenko et al. determined the close relationship between various financing channels and innovation [12]. While researching selected African countries' enterprise data, Fombang found that the form of overdraft promoted innovation more significantly than trade credit and asset financing [4]. Based on cross-border samples from 52 countries or regions, Zhang Ling concluded that equity financing is more conducive to supporting technological innovation than debt financing [13]. Adikari also found that foreign direct investment does not yield higher innovation [14]. Compared with the dominant position of national R&D funds, market capital presents more significant achievements in sci-tech innovation [15]. Scholars have also demonstrated the importance of bank financing and bank structure in enterprise innovation activities [16,17].

Continuous science & technology and finance integration has resulted in the coining of "sci-tech finance" [18]. Moreover, the evaluation and optimization of sci-tech finance efficiency have received increasing attention. Sci-tech

finance efficiency is considered a measure of the integration of science & technology and finance. This helps accelerate sci-tech innovation and promote rapid and efficient economic development [19]. Experts and scholars evaluated and optimized sci-tech finance efficiency.

Many scholars use stochastic frontier analysis (SFA) [20], data envelopment analysis (DEA) [21,22], and the analytic hierarchy process (AHP) [23] to evaluate sci-tech finance efficiency. As a parameter estimation method, although SFA considers the impact of random factors on output, it produces only an efficiency measurement of multiple inputs and a single output. As a nonparametric estimation method, not only does DEA make up for this deficiency, but it also has significant advantages. DEA can be used for multi-input and multi-output efficiency evaluation [24]. It can evaluate the efficiency of Decision-Making Units (DMUs) with complex production relations. The weight is generated by mathematical programming and, therefore, is not affected by human subjective factors. The evaluation of DMUs is relatively fair. By analyzing relaxation variables, we can further understand the resource utilization of inefficient DMUs and move toward improving inefficient DMUs. Using DEA, Adamovsky selected several EU countries to analyze the innovation efficiency of each country [25]. However, neither SFA nor DEA can decompose the total factor productivity (TFP) index to study the change in efficiency. Thus, this is often combined with the Malmquist index to measure sci-tech financial efficiency. Liu Lanjian used DEA and the Malmquist index to analyze the static and dynamic aspects of the sci-tech input-output of China and the OECD innovative countries from 2003 to 2016 [26]. To identify the preferred solution, scholars introduce secondary objectives in DEA cross efficiency evaluations [27] or establish a model of CCR and multi-objective linear programming [28]. The AHP is also used to study the input-output efficiency of sci-tech finance. However, the standard AHP model requires accurate judgment and, hence, is rarely used.

To measure sci-tech finance efficiency, Li Junxia constructed an evaluation index system based on the relative values of direct financing ratio, venture capital intensity, and incubation capacity of sci-tech business incubators from the perspective of financial resources and innovation achievement quality [22]. Overall, sci-tech finance investment indicators are mostly considered from the state, enterprise, financial institution, and financial market perspectives. Therefore, R&D activity investment, state R&D investment, loans from financial institutions, and venture capital often become investment indicators for efficiency evaluation of sci-tech finance [29,30]. Output indicators of sci-tech finance are mostly considered in terms of both knowledge and value outputs. Therefore, implementing new processes and developing new products [12], scientific papers, patent authorization, new product sales revenue, technology market turnover [31], and so on will more likely become output indicators for evaluating sci-tech financial efficiency [32,33]. Different scholars choose evaluation indicators according to their research needs.

1.2 Study Limitations

Based on the analysis of the above results, many scholars have made great progress in sci-tech finance research, but several limitations remain. (1) Currently, many achievements have been made in researching sci-tech financial efficiency. However, the measuring of sci-tech financial efficiency needs to consider the policy environment, capital environment, human environment, and other factors of the sci-tech innovation ecosystem. Therefore, selecting a reasonable evaluation index of sci-tech finance efficiency to objectively evaluate sci-tech finance efficiency is necessary. (2) Data-driven methods [34] can establish a more objective and accurate evaluation system based on actual sci-tech finance development data. (3) Correctly evaluating the efficiency level of regional sci-tech finance, revealing the relationship between influencing factors and sci-tech financial efficiency, and proposing targeted opinions are practically significant for improving the efficiency of using sci-tech finance resources. This promotes industrial upgrading and high-quality economic development.

1.3 Theoretical Contribution and Practical Value

To address the aforementioned research limitations, this study establishes a new evaluation model of regional sci-tech finance efficiency and analyzes the regional sci-tech finance efficiency of the Yangtze River Delta (YRD). This study has both theoretical contribution and practical value. This study subdivides the types of sci-tech financial resources and measures sci-tech finance efficiency from the two main sources of sci-tech financial capital investment—state and enterprises—which is more realistic. We study the evaluation of sci-tech financial efficiency from a data-driven perspective and further broaden the types of research on sci-tech finance. Taking YRD as an example, we focused on the effect of regional financial resource support and enriched the theoretical knowledge of sci-tech innovation and sci-tech financial development. Moreover, the results of this study are practically significant as they can help national decision makers identify the factors that affect the efficiency of sci-tech finance and provide decision support for formulating sci-tech innovation policies, improving the ecological environment of sci-tech finance, and promoting the transformation of sci-tech achievements, which has important practical value. The research results on sci-tech finance efficiency have clear practical guiding significance for the practice subjects of sci-tech finance. Finally, we propose research methods and conclusions, providing research reference for academic researchers.

1.4 Overview

The remainder of this paper is organized as follows. The second section presents the method, which mainly includes data-driven data collection, data modeling, and data analysis and application. The third section contains a case study comparing and analyzing the TFP of sci-tech finance and the decomposition factors of TFP in three provinces and Shanghai in YRD. Finally, the fourth section concludes the paper.

2 MATERIALS AND METHODS

This section introduces the data-driven evaluation method of regional sci-tech finance efficiency, including the method, data collection, data model, and data analysis.

2.1 Method and Process

To determine the efficiency level of regional sci-tech finance and propose ways to improve it, based on determining both research scope and purpose, this study constructs a data-driven evaluation method of sci-tech financial efficiency to measure regional sci-tech finance efficiency. Essentially, we gather the original input and output data of sci-tech finance in YRD, process the original data using the DEA-Malmquist index method, and obtain the index results. These results comprise the technical efficiency, technological progress, pure technical efficiency, scale efficiency, and TFP of sci-tech finance in YRD. Finally, according to the evaluation results of regional sci-tech finance efficiency in YRD, this study proposes methods and suggestions to improve regional sci-tech finance efficiency. The flowchart of the method is shown in Figure 1.

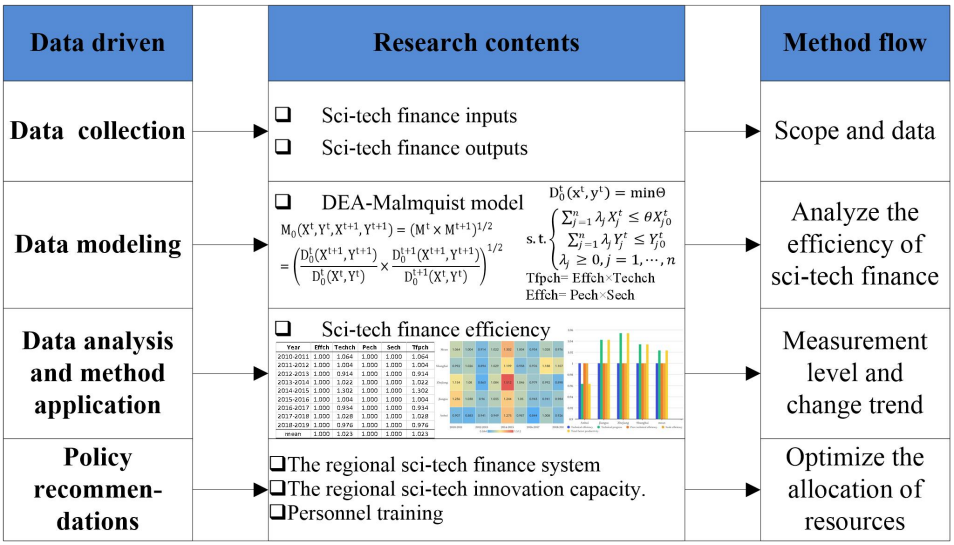

Figure 1 Method Flow

2.2 Evaluation Index

Sci-tech finance comprises states, enterprises, markets, and social intermediaries providing financing resources and their activities in the sci-tech innovation financing process. Therefore, sci-tech finance is a multi-input, multi-output system. In Figure 2, we distinguish the operation system of sci-tech finance from the perspective of input-output.

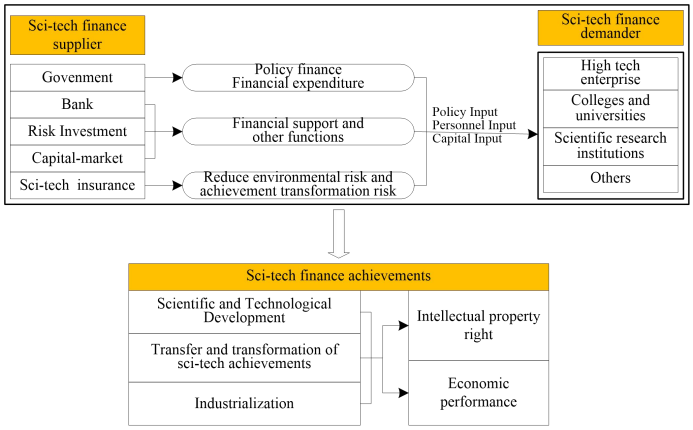

Figure 2 Sci-Tech Finance System Based on Input-Output Perspective

Sci-tech finance investment comprises the state, financial markets, and the financial environment. The state not only directly allocates capital for financial sci-tech expenditures but also guides and optimizes the sci-tech finance environment through systems and policies. The financial market supports sci-tech enterprises through scientific and technological loans, venture capital, and other financial instruments. Moreover, it is the main source of sci-tech finance funds. Although the financial environment does not directly fund sci-tech enterprises, it supports sci-tech activities, such as intermediary service institutions. However, financial environment support will not be transformed into direct and specific investment forms. Therefore, both the state and financial market provide sci-tech finance suppliers with policy, manpower, and capital investments. Considering that quantifying policy resources is difficult, this study selects personnel and capital investment as the investment index of sci-tech finance. The personnel investment index comprises R&D personnel converted into full-time equivalent and R&D personnel investment. Conversely, the capital investment index adopts R&D internal expenditure and financial sci-tech expenditure. Sci-tech finance output can be divided into two categories: economic and knowledge outputs. The economic output indicators are technology market turnover and sales revenue of new high-tech products. These can better reflect the effect of sci-tech investment on economic development. Patents and scientific papers were selected as indicators of knowledge output. The specific index system is shown in Table 1.

Table 1 Input-Output Indicators of Regional Sci-Tech Financial Efficiency

	Primary index	Secondary index
Input in sci-tech finance	Personnel input	Full-time equivalent of R&D personnel (x_1) R&D personnel input (x_2)
	Capital input	Internal expenditure of R&D funds (x_3) Financial sci-tech expenditure（X_4）
Output in sci-tech finance	Economic output	Technology market turnover（Y_1） Sales revenue of high-tech new products（Y_2）
	Knowledge output	Patent（Y_3）
		Scientific papers（Y_4）

Based on data accuracy and availability, this study collected and sorted panel data of sci-tech finance input and output in Anhui Province, Zhejiang Province, Jiangsu Province, and Shanghai City from 2010 to 2019. All data are from the China Statistical Yearbook [35] and the Statistics Bureaus of three provinces and Shanghai in YRD [36–39]. Because the number of sci-tech papers in Anhui Province in 2019 cannot be queried, it was calculated using SPSS software according to data on scientific and technological papers in Anhui Province from 2010 to 2018.

2.3 Data Modeling

Sci-tech innovation is a complex activity with multi-factor input and output. Thus, the specific form of its production function is difficult to estimate. Therefore, we chose to conduct DEA.

American operations research scientists Charnes, Cooper, and Rhodes (1978) proposed DEA based on Farrell's method and the concept of deterministic nonparametric frontier and relative efficiency. Its advantage is that it does not need to standardize the data and set the weight. Moreover, its operation is simple and convenient, and there are many models to choose from. Hence, the most representative DEA models are the CCR, BCC, FG, and ST models.

The Malmquist index was first proposed in 1953 and applied to measuring production efficiency changes by Caves, Christensen, and Diewert in 1982. In 1994, Fare et al. combined a nonparametric linear programming method of this theory with the DEA theory to form the DEA-Malmquist model, which is widely used for analyzing the efficiency changes of DMUs in different periods. Thereafter, to improve the applicability and effectiveness of calculating the DMU productivity change in a fuzzy environment, an extended Malmquist model was proposed [40].

This study analyzes regional sci-tech finance efficiency using the DEA-Malmquist model and panel data. First, regional sci-tech finance involves multi-financial resources and different types of output. Therefore, the evaluation should consider multiple inputs and outputs simultaneously. Second, regional sci-tech finance is complex; thus, more objective evaluation is needed. Therefore, the data-driven DEA model is an effective method to overcome these difficulties. DEA is a mathematical programming method to evaluate the relative efficiency of a group of decision-making units with multiple inputs and outputs. From the result, the combination of data-driven and DEA-Malmquist models ensures the clarity of data and the objectivity of the evaluation results. DEA can clarify which regions should further improve sci-tech finance efficiency. Based on the DEA, the Malmquist index and its decomposition are used to reveal the law of sci-tech finance efficiency changing with time and the reasons for those change. Therefore, this study constructs a data-driven DEA-Malmquist evaluation model to evaluate the regional sci-tech finance efficiency to promote the high-quality development of the regional economy.

The basic principle is as follows: assuming n DMUs (J = 1, 2,..., n) and that each DMU has m inputs (I = 1, 2,..., m) and s outputs (r = 1, 2,..., s), X_{ij} is the DMU, and $X_j^t$and Y_j^t represent the input and output index values of sci-tech finance in the j DMU of period t.

$$X_j^t = \left(X_{1j}^t, X_{2j}^t, \cdots X_{mj}^t\right)^T \tag{1}$$

$$Y_j^t = \left(Y_{1j}^t, Y_{2j}^t, \cdots Y_{sj}^t\right)^T \tag{2}$$

D_0^t (X^t,Y^t) represents the technical efficiency of the input-output configuration of the DMU in period t; thus,

$$D_0^t(x^t, y^t) = \min\Theta$$
$$\text{s.t.}\begin{cases} \sum_{j=1}^{n} \lambda_j X_j^t \le \theta X_{j0}^t \\ \sum_{j=1}^{n} \lambda_j Y_j^t \le Y_{j0}^t \\ \lambda_j \ge 0, j = 1, \cdots, n \end{cases} \quad (3)$$

Similarly, $D_0^{t+1}(x^{t+1}, y^{t+1})$ represents the technical efficiency of the input-output configuration of the DMU in period t+1.

The construction of the Malmquist index was based on the distance function. By comparing distance functions, the change in technical efficiency was analyzed from a dynamic perspective.

Hence, under the technical conditions of period t, the change in technical efficiency from period t to period t + 1 is as follows:

$$M^t = \frac{D_0^t(X^{t+1},Y^{t+1})}{D_0^t(X^t,Y^t)} \quad (4)$$

Under the technical conditions of period t+1, the change in technical efficiency from period t to period t + 1 is as follows:

$$M^{t+1} = \frac{D_0^{t+1}(X^{t+1},Y^{t+1})}{D_0^{t+1}(X^t,Y^t)} \quad (5)$$

Thus, the change in productivity from period t to period t+1 is as follows:

$$M_0(X^t, Y^t, X^{t+1}, Y^{t+1}) = (M^t \times M^{t+1})^{1/2}$$
$$= \left(\frac{D_0^t(X^{t+1},Y^{t+1})}{D_0^t(X^t,Y^t)} \times \frac{D_0^{t+1}(X^{t+1},Y^{t+1})}{D_0^{t+1}(X^t,Y^t)}\right)^{1/2} \quad (6)$$

The calculated M index is used for analyzing regional sci-tech finance efficiency from a dynamic perspective. If the M index is above 1, the TFP is in a state of growth from period t to period t+1, and sci-tech financial efficiency improves. If the M index is equal to 1, both the TFP from period t to period t+1 and sci-tech financial efficiency remain unchanged. If the M index is less than 1, the TFP shows a downward trend from period t to period t+1, and sci-tech financial efficiency decreases.

Using the Malmquist index to analyze regional sci-tech finance efficiency, TFP can also be decomposed into a technical efficiency change index and a technical progress index. Moreover, the technical efficiency change index can be further decomposed into the product of the pure technical efficiency and scale efficiency indices as follows:

$$\text{Tfpch} = \text{Effch} \times \text{Techch} \quad (7)$$
$$\text{Effch} = \text{Pech} \times \text{Sech} \quad (8)$$

By decomposing TFP, we can further observe whether the investment decision of sci-tech finance is correct and measure the degree of technological progress. If the technical efficiency change index is greater than 1, then technical efficiency has improved. This indicates that the investment decision of sci-tech finance was correct. If the change index of technical efficiency is less than 1, then the technical efficiency has deteriorated. This means that the investment decision of sci-tech finance was unproductive. A technological progress index greater than 1 indicates the overall scientific and technological progress. Finally, if the technological progress index is less than 1, overall sci-tech is experiencing a declining trend.

2.4 Data Analysis and Application

This research is a data-driven evaluation method for regional sci-tech finance efficiency. The specific data analysis and application are as follows. First, we construct the input-output index of regional sci-tech finance, evaluate the dynamic change of TFP of regional sci-tech finance using the DEA-Malmquist index, determine the level of regional sci-tech financial efficiency, and evaluate the change trend of regional sci-tech financial efficiency.

Second, we evaluate the dynamic changes in the TFP of sci-tech finance in different provinces and cities according to the DEA-Malmquist index of regional sci-tech finance and analyze the level and change trend of sci-tech financial efficiency in different provinces and cities within the region.

Third, we identify the main factors affecting the improvement of the TFP of regional sci-tech finance according to its decomposition.

Fourth, we propose policy suggestions to improve regional sci-tech finance efficiency according to the actual input-output environment of regional sci-tech finance (Figure 3).

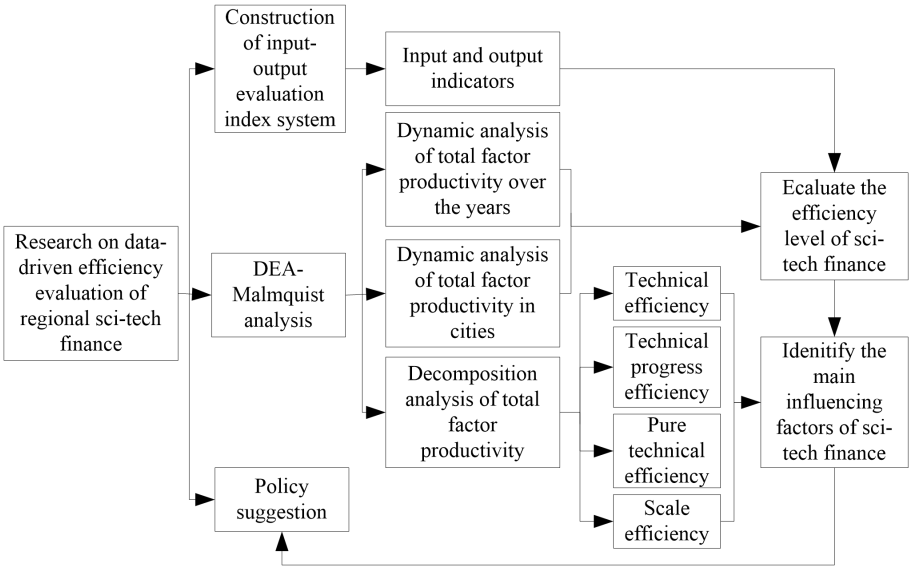

Figure 3 Analysis and Application of Regional Technology Financial Efficiency Data

3 CASE STUDY

Because of the differences in regional sci-tech finance resource endowment and environmental policies, this study selects YRD as the research object and proposes targeted policy suggestions.

3.1 Case Study Background

YRD region, including Shanghai, Jiangsu Province, Zhejiang Province, and Anhui Province, is significant for China's economic development. The region has a strong economic foundation, an excellent system, and strong overall competitiveness. The integrated development strategy of YRD requires that it strengthen its innovation drive, build a modern economic system, improve the industrial chain level to play to regional drivers and demonstration, and form a regional cluster with high-quality development. Increasing financial investment is more conducive to promoting scientific and technological innovation and development. For the past decade, the input and output of sci-tech finance in three provinces and Shanghai in YRD have increased significantly.

3.2 Results

Based on the input-oriented DEA-Malmquist index method, without considering output lag, this study uses DEAP 2.1 software to calculate the sci-tech finance efficiency of YRD from 2010 to 2019.
(1) Full-sample technology financial efficiency.
According to the software calculation results, the TFP, technical efficiency, technological progress, pure technical efficiency, and scale efficiency of regional sci-tech finance are obtained. See Table 2 for details.

Table 2 Malmquist Index and Breakdown of Sci-Tech Finance in YRD from 2010 to 2019

Year	Effch	Techch	Pech	Sech	Tfpch
2010-2011	1.000	1.064	1.000	1.000	1.064
2011-2012	1.000	1.004	1.000	1.000	1.004
2012-2013	1.000	0.914	1.000	1.000	0.914
2013-2014	1.000	1.022	1.000	1.000	1.022
2014-2015	1.000	1.302	1.000	1.000	1.302
2015-2016	1.000	1.004	1.000	1.000	1.004
2016-2017	1.000	0.934	1.000	1.000	0.934
2017-2018	1.000	1.028	1.000	1.000	1.028
2018-2019	1.000	0.976	1.000	1.000	0.976
mean	1.000	1.023	1.000	1.000	1.023

TFP can comprehensively reflect the comprehensive level of technology and management in provinces and cities. The average TFP of the three provinces and Shanghai is 1.023, which is greater than 1. This indicates that the overall sci-tech financial efficiency in YRD is good. On the one hand, YRD has high scientific research strength, a good foundation for modern industrial development, and competitive high-tech industries and is thus in a leading position in the country. It gives full play to its own scientific and technological endowment resources to conduct cutting-edge innovation. On the other hand, the state's policy support for YRD not only increased scientific and technological

investment but also distributed some key scientific research institutes and major scientific and technological research projects in YRD. These actions promoted the scientific and technological progress of YRD.

(2) Sci-tech finance efficiency in the time dimension.

According to the calculation results, Figure 4 provides the line chart of sci-tech finance TFP in three provinces and Shanghai in YRD split to describe the change trend of sci-tech financial efficiency of the three provinces and Shanghai from 2010 to 2019.

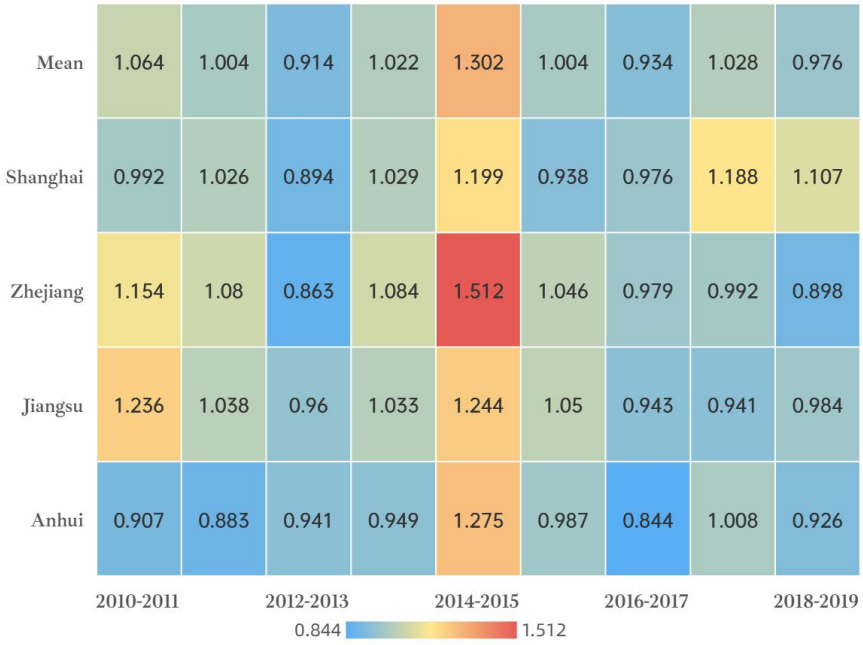

Figure 4 Change Trend of Sci-Tech Financial Efficiency in YRD

Overall, sci-tech finance efficiency in three provinces and Shanghai in YRD is unstable. Sci-tech finance efficiency in YRD presented the first concave point from 2012 to 2013, increased rapidly, and reached its highest point from 2014 to 2015. However, it soon fell back, showing the second concave point from 2016 to 2017. It then increased slightly, resulting in the second convex point from 2017 to 2018. Given the increasing investment in sci-tech finance, the efficiency of sci-tech finance is unstable, mainly due to the uncertainty of technology research and development.

(3) Comparison of scientific and technological financial efficiency between provinces and cities

The efficiency values of sci-tech finance in YRD are presented in Figure 5.

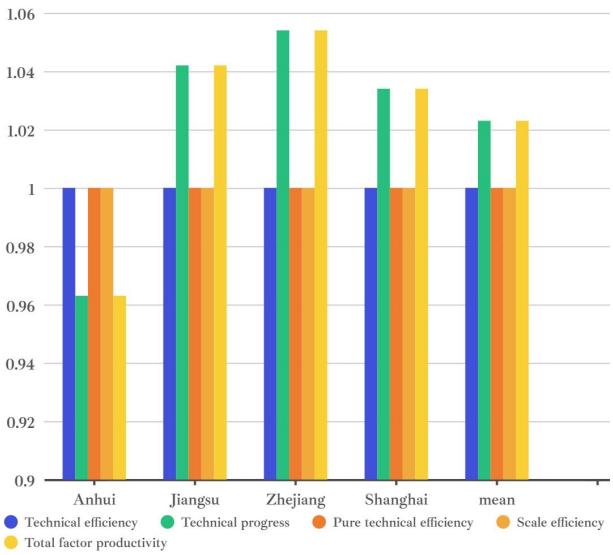

Figure 5 Malmquist Index and Decomposition of Sci-tech Finance in YRD

According to the results in Figure 5, sci-tech financial efficiency in Zhejiang Province was the highest (1.054), followed by Jiangsu (1.042) and Shanghai (1.034). In contrast, TFP in Anhui is slightly lower than 1 (0.963). In combination with Figure 3, sci-tech financial efficiency in Zhejiang Province has remained above average in the recent decade; however, the fluctuation range is the largest. Anhui Province was below the average level. Sci-tech financial efficiency in Jiangsu

Province and Shanghai fluctuates slightly above and below average, and sci-tech finance efficiency in Jiangsu Province is slightly higher than that in Shanghai.

Based on the decomposition results, the technical efficiency, pure technical efficiency, and scale efficiency of YRD reach 1, indicating good performance. This also means that TFP is directly affected by technological progress. Zhejiang Province has a technological progress value of 1.054, ranking first among the three provinces and Shanghai. This shows that Zhejiang Province is at the production frontier composed of the optimal DMU. Moreover, it demonstrates that resource allocation of financial input and output in Zhejiang Province is reasonable, and the contribution of technological progress to TFP has reached 5.4%. The technological progress index of Jiangsu Province and Shanghai is higher than 1, and only the technological progress value of Anhui Province is lower than 1. The reason is that among the three provinces and one city, the sci-tech development of Anhui Province is relatively late, and its sci-tech level is relatively low.

(4) Low personnel input efficiency

When DEA-Malmquist is used for processing index data, the impact of R&D personnel investment on the measurement results of scientific and technological financial efficiency can be ignored. This demonstrates that although R&D personnel investment is increasing yearly, the quality of scientific and technological personnel is low, and an internal roll phenomenon is found. In fact, the quality of research talents is a key factor in the application of technological innovation and technology marketization [41].

3.3 Policy Recommendations

This study is based on a data-driven evaluation of regional sci-tech finance efficiency and provides a clear evaluation of sci-tech finance efficiency in YRD. According to the analysis, since 2010, YRD has vigorously promoted sci-tech innovation and strengthened the financing support of sci-tech innovation and sci-tech innovation enterprises, which have not only continuously improved the sci-tech innovation ability but also developed the financial industry. Based on the purpose of optimizing the efficiency of resource allocation, to further improve sci-tech financial efficiency in YRD, we propose the following policy suggestions.

(1) Improve the regional sci-tech finance system

To improve the innovation capability of key core technologies, we should improve the innovation investment mechanism and sci-tech finance policies. To improve sci-tech finance resource allocation efficiency, we must establish a regional sci-tech finance resource allocation system covering the entire life cycle of high-tech enterprises to ensure sci-tech finance resource investment in different stages of technological innovation and development. Simultaneously, we accelerate innovation of financial instruments, achieve sci-tech finance risk management, and provide diversified investment channels for sci-tech enterprises.

(2) Accelerate the improvement in regional scientific and technological innovation capacity.

Sci-tech innovation is essential for cultivating and developing strategic emerging industries, which is highly significant for high-quality economic development. According to the above analysis, sci-tech finance efficiency is directly affected by technological progress. Therefore, to improve regional sci-tech finance efficiency, we must improve the ability of regional sci-tech innovation. From the perspective of enterprises, improving sci-tech innovation depends on introducing and retaining medium and high-end sci-tech talents. From a regional perspective, an efficient sci-tech park should be built and promote the agglomeration of innovative industries. The state should develop and improve business incubators in the region to facilitate the formation and rapid growth of new high-tech enterprises in the region.

(3) Strengthen the training of scientific, technological, and financial talent

The development of sci-tech finance is inseparable from the introduction and training of sci-tech finance talents, especially medium- and high-end sci-tech finance talents who understand both finance and sci-tech. The talent introduction policy and service system after the introduction of sci-tech finance talents must be improved. Simultaneously, the policy must strengthen the evaluation system for sci-tech finance talents, encourage sci-tech personnel to maximize their scientific research abilities, and reduce the continuous internal turnover of human resources.

(4) Strengthening the synergy of regional sci-tech finance

This region is the center of national economic development. Provinces and cities in the region are not only geographically adjacent but also have a greater spillover effect. Shanghai's financial innovation leads the country, and its universities and scientific research institutes lead the region. Jiangsu Province has built a relatively complete sci-tech finance system, the speed of sci-tech innovation in Zhejiang Province is accelerated, and the market in Anhui Province is larger. Establishing cooperative relationships, which are expected to improve sustainability performance, is crucial for regional development [42]. Therefore, enterprises, universities, and scientific research institutes in the region should be actively encouraged to cooperate in tackling key sci-tech problems and transforming sci-tech achievements to create a new regional win-win collaborative development system.

3.4 Discussion and Management Enlightenment

Compared with the existing literature [30,31], this study has three advantages. First, the efficiency evaluation indicators of regional sci-tech finance are more representative. The input indicators comprehensively consider the personnel input and capital input. The capital input indicators select the internal expenditure of R&D funds and the financial sci-tech

expenditure, which represent the enterprise sci-tech innovation investment and the state sci-tech innovation investment, respectively, and are the main source of financial resources for sci-tech innovation. The output index comprehensively considers knowledge and economic output, which is in line with sci-tech's goal of industrialization and economy. The turnover of the technology market and the sales revenue of high-tech products can better represent the economic achievements of the sci-tech industry. Second, based on the data-driven method for measuring sci-tech financial efficiency, the combined data-driven and DEA-Malmquist model ensures not only clear results, but also the objectivity of the results. Finally, it analyzes the efficiency of sci-tech finance from static and dynamic aspects and determines the main factors affecting sci-tech financial efficiency. Based on the improvement of the allocation efficiency of regional sci-tech finance resources, this study proposes countermeasures and suggestions for improving the sci-tech finance system and enhancing the more targeted regional innovation ability and talent training. These allow for more targeted decisions.

Combined with the above research and conclusions, we get the following management enlightenment.

(1) In the long run, all provinces and cities in China need to accelerate the transition from extensive to intensive economic growth, and sci-tech finance is of great significance to the quality of economic development [43]. Different regions have different sci-tech finance resources, state policies, and financial environments. Hence, designing a scientific and reasonable evaluation index system for regional sci-tech finance efficiency is necessary. This is not only conducive to grasping and understanding the current situation of regional sci-tech finance but also helps clarify the main influencing factors and change trend of regional sci-tech financial efficiency.

(2) Developing regional sci-tech finance is crucial to improving regional sci-tech innovation. Many subjects related to regional sci-tech finance and the internal and external environment cooperate through currency circulation and credit flow to form a dynamic balance system. The regional sci-tech finance system directly affects regional sci-tech finance efficiency. Therefore, clarifying the operation mechanism of regional sci-tech finance systems and scientifically decomposing input-output elements of regional sci-tech finance improve the comprehensiveness and accuracy of the efficiency analysis of regional sci-tech finance.

(3) In the digital economy era, through standardized and modeled processing and big data use, data are organized to form an information flow, which is conducive to scientific decision-making with the support of data [44]. Therefore, research on regional sci-tech finance should make full use of big data and explain the development status and change trends of sci-tech finance more accurately and scientifically through data driving.

4 CONCLUSIONS

The degree of sci-tech innovation and financial integration represents a country's social productivity and comprehensive competitiveness. Improving the efficiency of sci-tech finance is an important factor in giving full play to the advantages of financial resources, promoting the deep integration of sci-tech, finance and industry, and promoting the transformation of sci-tech achievements and high-quality economic development. This study proposes a data-driven evaluation method for regional sci-tech finance efficiency. Taking YRD as an example, the DEA-Malmquist index is used to calculate the efficiency of sci-tech finance in YRD, analyze the factors affecting the input-output efficiency of sci-tech finance in YRD, and propose suggestions to improve regional sci-tech finance efficiency.

The main innovations of this study are as follows. (1) This study constructs an evaluation index of regional sci-tech finance efficiency. The index system includes four input indices: R&D personnel equivalent, R&D personnel investment, internal expenditure of R&D funds, and financial scientific and technological expenditure. Moreover, four output indices are included: technology market turnover, sales revenue of high-tech new products, patents, and sci-tech studies. The evaluation indices are more representative, and evaluating sci-tech financial efficiency is more reliable. (2) This study constructs a data-driven evaluation of regional sci-tech finance efficiency, which allows for a more objective and accurate evaluation process and more credible evaluation results. (3) The data-driven efficiency evaluation of regional sci-tech finance can accurately identify factors influencing the improvement of regional sci-tech financial efficiency to provide an accurate decision-making basis for the effective use of sci-tech finance.

This study also has several limitations. First, the sci-tech finance system is a complex system, the factors affecting sci-tech finance efficiency are diverse, and it is difficult to obtain more data. Therefore, the evaluation indices of sci-tech finance efficiency in this study cannot be comprehensively selected. The DEA method also has limitations. As DEA assumes a linear model, it cannot measure efficiency with negative output, such as energy consumption and pollution emission, which restricts the application scope of the model. Additionally, this method is usually used to evaluate past performance [45], so it cannot be used to plan future performance objectives.

Evaluating regional sci-tech finance efficiency is complex. We only evaluate the efficiency of sci-tech finance based on a time series, and there is a lack of spatial dynamic analysis of regional sci-tech finance efficiency. This will be our next research direction. On this basis, we will further improve the input-output index system of sci-tech finance in terms of the aspects of ecological environment and investment risk, explore ways to promote the deep integration of finance and sci-tech innovation, and promote the high-quality integrated development of the regional economy.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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AUTHOR CONTRIBUTIONS

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