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Sci-Tech finance, digital economy and high-quality development of regional economy: empirical evidence from 273 cities in China

Jingshi He[1,2], Yongjun Chen[3], Haoyang Chen[4], Jingting Zhao[3], Chunsheng Wang[5]✉ & Lan Xu[1]

This study uses panel data from 273 prefecture-level cities in China between 2011 and 2022 to demonstrate that science and technology (Sci-Tech) finance significantly contributes to high-quality development in regional economies. This conclusion remains robust after accounting for endogeneity and robustness tests, including the application of instrumental variable methods. By analyzing the underlying mechanisms, this study indicates that Sci-Tech finance cultivates high-quality economic development by enhancing innovation vigor and driving financial agglomeration. Heterogeneity analyses indicate that the positive effects of Sci-Tech finance on economic quality are amplified in regions with high human capital, robust innovation ecosystems, and advanced digital infrastructure. In addition, this study highlights the positive moderating influence of the digital economy on the relationship between Sci-Tech finance and high-quality economic development. The promoting effect of Sci-Tech finance on the high-quality development of the economy has a threshold effect on the level of development of the digital economy. With the continuous development of the digital economy, the impact of Sci-Tech finance on the high-quality development of the economy may experience a process of first weakening and then strengthening, and its impact is nonlinear.

[1] Dongguan Polytechnic, Dongguan, China. [2] City University of Macau, Macao, China. [3] Guangdong University of Technology, Guangzhou, China. [4] Guangdong Polytechnic Normal University, Guangzhou, China. [5] Tongling University, Tongling, China. ✉email: paperspring@163.com

Introduction

In the transformation of China's economic structure, there has been a crucial shift from an emphasis on growth indicators to an approach that values economic vitality, innovation, and environmental sustainability. This transition highlights the not only augmenting the quality of economic output but also the rational development of quantity. How to promote high-quality economic development has gradually become the focus of attention of academics and professionals. Sci-Tech finance is an innovative investment and financing system composed of governments, financial institutions, and technology enterprises, including financial instruments, financial systems, financial policies, and financial services (Lu et al., 2023). The impact of Sci-Tech finance on high-quality economic development has far-reaching significance. It not only promotes innovation and industrial upgrading (Shen et al., 2022; Shi, 2023), optimizes resource allocation and economic efficiency but also facilitates regional coordination and balanced development (Wen et al., 2021), improves the quality and efficiency of financial services, and drives the sustainable development of the economy (Liu et al., 2024). Sci-Tech finance has become a crucial force driving high-quality economic development. Research on the relationship between Sci-Tech finance and the economy has shifted from focusing on economic growth, the quality of economic growth, and high-quality economic growth in the past to high-quality economic development. The first three terms focus more on growth, while high-quality economic development emphasizes input-output efficiency and sustainable development (Wen et al. 2021), transformation of the development mode, optimization of the economic structure, and conversion of growth drivers. Therefore, with the deepening of the conceptual connotations of Sci-Tech finance in promoting economic development, its impact mechanism remains to be studied in depth. This study constructs a comprehensive index of high-quality economic development using the entropy method. The key focus is on high-quality development rather than merely concentrating on economic growth.

However, with the development of the digital economy, the levels of financial digitalization and fintech have been enhanced. The regional and urban-rural differences brought about by the digital divide may lead to a more prominent imbalance and unevenness in the development of Sci-Tech finance and regional economies. The development of Sci-Tech finance shows regional differences. There are significant variations not only among different provinces but also among different prefecture-level cities within the same province. This regional difference poses many challenges to the role of Sci-Tech finance in promoting high-quality economic development. Therefore, it is of great significance to correctly understand the mechanisms and impact effects of Sci-Tech in promoting high-quality regional economic development. This is conducive to the government formulating more scientific and reasonable policies to promote the deep integration of Sci-Tech finance and high-quality economic development, as well as regional coordinated development, and to drive the sustainable and balanced development of China's economy.

Compared with other studies, the marginal contributions of this study are as follows. First, previous studies primarily emphasized the impact relationship between Sci-Tech finance and economic growth. However, high-quality development is currently the primary theme. This study constructs an index of high-quality economic development that consists of four sub-indices, which reflect high-quality development, rather than focusing solely on economic growth. Second, previous research on the influence of Sci-Tech finance on high-quality economic development primarily conducted analyses at the provincial level across the 31 provinces in China, with a lack of studies carried out at the municipal level. This study is based on panel data from 273 municipalities, enabling in-depth analysis to reveal the uniqueness and disparities among different cities, which is conducive to a more profound understanding of the underlying impact mechanisms. Third, research on the impact of Sci-Tech on high-quality economic development from the perspective of the digital economy has been scarcely explored before. Incorporating the three themes of the digital economy, Sci-Tech finance, and high-quality economic development into the research simultaneously can further enrich the relevant theoretical research. Exploring the moderating and threshold effects of the digital economy on the relationship between Sci-Tech finance and high-quality economic development provides a novel analytical dimension for uncovering new driving forces for high-quality economic development. Fourth, in the analysis of the conduction mechanism test, unlike the mediation effect model adopted by other studies based on the OLS model using the stepwise test method, this study uses the two-stage least squares (2SLS) method to avoid the potential reverse effect of the mediating variable and the endogeneity problem that may exist in the traditional mediation effect method. By gradually adding the variables of the mediating influence mechanism using the 2SLS method, this study analyzes whether the mediating mechanism variables have a positive or negative conduction mechanism.

As the world's second-largest economy, China's high-quality economic development model has a broad demonstration effect. The effective application of Sci-Tech finance has promoted regional high-quality economic development in China. By re-examining the mechanisms and impacts of Sci-Tech finance on high-quality development through panel data of 273 cities at the municipal level, this study revealed the mechanism by which Sci-Tech finance promotes high-quality economic development through technological innovation and financial agglomeration. This provides China with experience and wisdom for the theory of sustainable economic development and prompts the financial and economic academic community to reexamine the dynamic mechanism of high-quality economic development. The research ideas of this study are as follows: First, based on the literature review, we clarify the mechanism by which Sci-Tech finance promotes regional high-quality economic development through a literature summary and deduction, and propose hypotheses. Then, we construct models and define various variables, conduct an empirical analysis based on panel data, and verify the reliability of the regression results using instrumental variables and other methods. To avoid the potential reverse effect and endogeneity problems that may exist in the mediating variables in traditional methods, we gradually add the variables of the mediating influence mechanism using the 2SLS method to analyze whether the mediating mechanism variables have a positive or negative conduction mechanism. Next, we explore the moderating and threshold effects of the digital economy on Sci-Tech finance's promotion of regional high-quality economic development. Finally, we propose the policy suggestions.

Literature review

Sci-Tech finance and high-quality economic development. The advancement of financial markets plays a crucial role in the economic growth of a region by enhancing its efficiency and economy. This, in turn, boosts the willingness to invest, ultimately leading to economic growth (Gao et al., 2022; Yang et al., 2023). However, some studies present a counterargument, asserting that the relationship between finance and economic development is not significant (Khan and Senhadji, 2023; Hsueh et al., 2013). Nonetheless, some studies propose that Sci-Tech finance holds profound significance for high-quality economic development. It not only spurs innovation-driven development and industrial upgrading (Shen et al., 2022; Shi, 2023), optimizes resource allocation and economic efficiency but also promotes regional coordination and balanced development (Wen et al., 2021), enhances total factor productivity (Li et al., 2024), and fuels sustainable economic development (Liu et al., 2024).

The term "Sci-Tech finance" initially emerged in the announcement released by the Shenzhen Science and Technology Bureau of China in 1993 (Shen, 2022). In 2011, China introduced the "Several Opinions on Promoting the Integration of Science and Technology and Finance and Accelerating the Implementation of the Independent Innovation Strategy" to advance the pilot initiatives for the integration of Sci-Tech and finance. Driven by the Chinese government's industrial policies, Sci-Tech finance constitutes an essential part of the national Sci-Tech innovation and financial systems. It encompasses the systems formed by entities such as the government, enterprises, markets, and social intermediaries, along with their behavioral activities during the financing process for science and technology innovation. Sci-Tech finance represents a series of financial tools that facilitate the development of science and technology, the transformation of achievements, and the growth of high-tech industries (Zhang et al., 2018). These tools comprise financial systems, policies, and services that foster industrial growth as well as governments, enterprises, markets, and social institutions that provide funding for Sci-Tech innovation activities. Sci-Tech finance is also an innovation in the scientific and technological domains and a series of financial service ecosystems.

A comprehensive literature review indicates that research on the influence of finance on scientific and technological innovation is a popular topic among scholars worldwide. However, among the literature searched under the themes of "Sci-Tech finance," "Tech-Finance," "science and technology finance" or "technology finance," there are relatively more studies conducted by Chinese scholars, while scholars from other countries have relatively fewer discussions on Sci-Tech finance.

The research domain of economic development has traversed a series of distinct phases, namely economic growth, the quality of economic growth, high-quality economic growth, and high-quality economic development. The former three terminologies predominantly center around growth, which is customarily gauged by a solitary indicator, such as per capita GDP, GDP growth rate, or total factor productivity (Ding et al., 2022; Shen, 2022). Conversely, high-quality economic development accentuates the input-output dimension, with an emphasis on the transformation of the developmental paradigm, optimization of the economic structure, and conversion of growth impetus, rather than being confined to a single index (Yu et al., 2022 and Qi et al., 2023). Finance can effectively apport resources to technologically sophisticated and highly productive sectors, and the augmentation of enterprise productivity catalyzes high-quality economic growth (Ilyina and Samaniego, 2012). Existing research indicates that Sci-Tech finance exerts a remarkably positive influence on high-quality economic growth. Specifically, for every 1% increment in the Sci-Tech metric, high-quality economic growth increases by 0.664% (Shen et al., 2022). Zhang and Tian (2024) posit that enhancing the efficiency of Sci-Tech finance engenders a salutary effect on the growth of the real economy across diverse regions of China. By galvanizing and safeguarding entrepreneurial activities, digital inclusive finance propels high-quality development of the real economy (Gao et al., 2025). Technological finance effectively fosters the high-quality development of the real economy through enlarging the scale of the real economy, augmenting technological content, optimizing the industrial structure, and enhancing the ecological environment (Zou and Zhou, 2024).

A comprehensive literature review reveals that research on how Sci-Tech finance fosters high-quality regional economic development remains scarce. Exploration of the underlying impact mechanism is also inadequately lucid, particularly the dearth of data research at the prefecture-level city tier. We advocate that the construction of a high-quality economic development index, which is composed of four sub-indices, namely, the innovation-driven index, industrial upgrading index, economic efficiency index, and green economic efficiency index, effectively epitomizes high-quality development as opposed to a myopic focus on growth. Through an empirical analysis of panel data from 273 cities regarding the mechanism by which Sci-Tech finance impacts high-quality economic development, the outcomes of this study will further augment and fortify the theoretical foundation within this field.

Digital economy, Sci-Tech finance and high-quality economic development. In the context of the digital economy, digital transformation has emerged as a crucial avenue for the sustainable development and innovation of enterprises (Li et al. 2023; He et al. 2024). The digital economy provides substantial and far-reaching benefits across the economic and social spectrum. Digital infrastructure can be harnessed to address the performance-related challenges of financial instruments within financial institutions, thereby guaranteeing their capacity to buttress economic investment (Kräussl et al., 2022). Propelled by digital technologies, the realms of financial digitalization and fintech have witnessed further elevation. The modern financial sector is characterized by prominent traits such as inclusiveness, universality, and innovativeness, which enhance financial efficiency and widen financial access (Panagariya, 2022). Consequently, it is better to facilitate the development of the real economy and foster high-quality economic growth.

The digital transformation perspective describes how a digital economy can cultivate firm innovation. This facilitation occurs through avenues such as open innovation, shifts in human capital levels, and organizational management models (Mikalef and Pateli, 2017). Innovation, which is reflected by high risk, long-term returns, and significant upfront investments, often yields uncertain returns. Therefore, innovators frequently struggle to meet standard principal and interest repayments on bank loans (Cornaggia et al., 2015). R&D implementation requires significant, consistent, and long-term capital infusions. However, internal financing, typically earmarked for daily production and operations, is insufficient for meeting innovation-focused capital requirements. This internal shortfall, compounded by uncertainty in innovation activities, often leads to external financing limitations. Therefore, a robust Sci-Tech finance investment system that includes both governmental and societal support is crucial. The rise of the digital economy has expanded communication pathways between businesses and investors, leading to faster and more accurate information dissemination (Mueller and Grindal, 2019) and is the driving force for a new round of high-quality economic development in the future (Chen and Wang, 2023). By reducing the information asymmetry between lenders and borrowers, the digital economy helps alleviate firms' financing constraints, thereby stimulating their innovation capacity and contributing to high-quality regional economic advancement.

In summary, the existing studies have not incorporated the digital economy into the regression analyses analyzing the effect of Sci-Tech finance on high-quality economic development. Several questions remain unanswered: How does the digital economy affect the relationship between Sci-Tech finance and high-quality economic development? Is this relationship linear or non-linear? Does the threshold effect exist? By considering Sci-Tech finance and the digital economy together, we gain a fresh perspective for thoroughly exploring the evolving drivers of high-quality economic development.

Research hypothesis

Sci-Tech finance promotes high-quality economic development. From the perspective of in-depth macroeconomic analysis, Sci-Tech finance, as an innovative financial support strategy, enables the capital allocation function of finance to drive economic transformation toward higher quality and a more rational structure (Sun and Tang, 2022; Wang et al., 2022). It also promotes the effective enhancement of production technology (Irfan et al., 2022) and lays a solid foundation for stable economic growth (Alquist et al., 2022). Specifically, Sci-Tech finance comprises a series of financial tools, policy systems, and service mechanisms. They are designed to accelerate scientific and technological developments, facilitate the transformation of achievements, and boost the growth of high-technology industries. These include financial mechanisms for industrial growth support, government and enterprise policies for funding technological innovation, and the active participation of market and social institutions in innovation activities. Together, they form a comprehensive and multi-level financial support network that provides a continuous driving force for technological innovation. The role of Sci-Tech finance in promoting innovation and optimizing industrial structure is particularly significant (Lu et al., 2023). It advances sustainable economic development by enhancing green innovation capabilities, upgrading and rationalizing industrial structures, and increasing green total factor productivity (Zou et al., 2024). By analyzing the data of A-share listed companies in China, Liu and Wang (2024) discovered that the development of Sci-Tech finance promotes the development of new qualitative productive forces of Chinese enterprises. Zhong and Jin (2024) empirically examine the impact of Sci-Tech finance on the high-quality development of enterprises based on Chinese provincial data and data on A-share listed companies. Using provincial panel data, Li et al. (2022) find that Sci-Tech finance has a positive effect on regional collaborative innovation. The deep integration and proper matching of Sci-Tech and finance have led to the rapid growth of technology companies and the vigorous development of regional economies (Li and Yusoff, 2024). In conclusion, the following hypothesis is proposed:

Hypothesis H1: The development of Sci-Tech finance promotes high-quality economic growth.

Sci-Tech finance promotes high-quality economic development through innovation dynamism and financial agglomeration. The development of Sci-Tech finance offers more financing alternatives for scientific and technological innovation activities and mitigates innovation risks. This plays a significant role in promoting the total factor productivity of industries, particularly in regions with relatively high levels of financial development. Sci-Tech finance primarily drives the enhancement of industrial total factor productivity by augmenting the technological innovation capabilities of industries (Li et al., 2024). However, the laggard development of Sci-Tech finance may, to a certain extent, constrain the progress of scientific and technological innovation (Dongfan and Huayang, 2015). The development of technological innovation serves as the core impetus for finance to propel and remarkably accelerate high-quality economic development (Shen et al., 2022). Han and Shen (2015) highlight that financial development significantly contributes to the growth of total factor productivity through technological progress. The more rapidly Sci-Tech finance develops, the more effectively it can rectify mismatches in resource allocation, thereby facilitating the growth of total factor productivity. In the digital economy era, information-based Sci-Tech finance is conducive to project supervision and risk management, improves the efficiency of optimal capital allocation, enhances innovation efficiency, and promotes high-quality economic development. Sci-Tech finance encourages a collaborative advancement in science and technology alongside technological innovation, invigorating a passion for innovation. This collaborative progression between Sci-Tech finance and technological innovation spearheads premium development of the economy by impacting both the total factor productivity and the efficiency of market operations. The fundamental role of Sci-Tech finance in cultivating high-quality economic growth lies in its ability to invigorate innovation and encourage financial agglomeration. In this context, we propose the following hypothesis H2.

Hypothesis H2: The development of Sci-Tech finance promotes the entry of financial capital into industries, stimulates innovative vitality, and facilitates high-quality regional economic development.

In the modern economic system, moderate financial agglomeration can boost technological innovation in the surrounding regions, allocate resources rationally, narrow regional gaps, and drive high-quality economic development (Wen et al., 2021). With the significant elevation in the informatization level of Sci-Tech finance, the big data platform, via its data mining and information matching functions, enables capital to more precisely evaluate the development prospects, profit potential, and business behaviors of all parties in the financing industry, thereby enhancing the efficiency of capital allocation. The intensification of market competition induces financial institutions to collaborate to optimize production and trading activities, thereby gathering relevant resources and gradually spawning the formation of financial agglomeration areas, which improves trading efficiency, reduces financing costs and investment risks, optimizes the financial market environment, increases total factor productivity (Li et al., 2024), and ultimately promotes economic growth (Chen and Zhang, 2023; Liu et al., 2024). Financial regulatory institutions are increasingly emphasizing the coordinated agglomeration development of financial technologies within the region to address the challenges between high operating costs and the demand for enhanced financial expertise. This coordinated agglomeration development promotes the agglomeration of financial technologies in specific spatial regions, evolving into a high-end financial agglomeration phenomenon (He et al., 2024). These processes may strengthen the flow of financial resource elements, optimize resource allocation, and promote the spillover of production efficiency (Xie et al., 2021). Financial agglomeration can enhance regional productivity growth through direct financial agglomeration effects (Zhang et al., 2023), spatial spillover effects, and technological innovation (Li and Ma, 2021). Sci-Tech finance can direct capital to highly efficient high-tech industries. The effective allocation of technology and financing resources can relieve distortions in the financial market, improve the efficiency of resource allocation, further promote the agglomeration of financial resources, and strengthen the capacity to serve high-tech industries. China has always emphasized and adhered to deepening the reform of its financial system, vigorously promoting the construction of financial agglomeration areas, creating conditions and an environment for the agglomeration and development of financial resources, utilizing financial service capabilities to support the real economy, and contributing to economic development (Hu et al., 2023). Overall, Sci-Tech finance services effectively promote financial agglomeration and play a positive role in promoting high-quality economic development. Based on the above analysis, the research hypothesis H3 is proposed:

Hypothesis H3: The development of Sci-Tech finance promotes the entry of financial capital into industries, facilitates financial agglomeration, and thus promotes high-quality regional economic development.

The effect of the digital economy on Sci-Tech finance for high-quality economic development has a non-linear effect. The integration of technology and finance into the digital economy cultivates sustainable practices and drives the creation of innovative financial solutions by changing economic forces and transforming industries (Trivedi et al., 2024). The expanding digital economy empowers Sci-Tech finance to offer financial frameworks and government bodies with insightful analyses. By leveraging the power of big data analytics and artificial intelligence algorithms applied to enterprise and industry data, these analyzes offer a deeper understanding of enterprise operations and business conditions. This approach facilitates the identification of enterprises suffering from financial limitations despite their growth potential, encouraging governments, societal stakeholders, and financial institutions to collaborate on solutions that alleviate these constraints, thus strengthening the collaboration between science and technology and finance. Digital technologies afford businesses access to the network resources crucial for nurturing innovation (Rodon Modol and Eaton, 2021). In addition, these technologies can be leveraged to optimize the performance of financial instruments employed by financial institutions, enabling a comprehensive assessment of their activities and ensuring their capacity to effectively support economic investments (Kräussl et al., 2022). The significance of the digital economy in driving production and overall economic prosperity has been widely recognized (Schade and Schuhmacher, 2022). The expansion of the digital economy helps deepen access to financial credit, and mobile technology deepens the inclusive development of finance (Olaoye et al., 2024).

However, the promotion of the development of total factor productivity in industries by Sci-Tech finance is not linear, and there is a certain threshold effect (Li et al., 2024). The growth of the digital economy allows Sci-Tech innovation activities to fully capitalize on big data resources, leading to a reduction in the capital required for enterprise financing. Accordingly, this cultivates a more favorable financing environment and optimizes the allocation of financial resources, ultimately cultivating a climate with enhanced innovation potential. As the sophistication of the digital economy's Sci-Tech advances, so does its capacity to amplify the effect of Sci-Tech finance on elevating economic quality. This correlation highlights the significant effect of a robust digital economy on the ability of Sci-Tech finance to drive high-quality economic development. Based on these observations, we propose hypothesis H4.

Hypothesis H4: The effect of the digital economy on promoting high-quality economic development through Sci-Tech finance has a positive regulatory strengthening effect and a nonlinear effect.

The research hypothesis framework of this study is illustrated in Fig. 1.

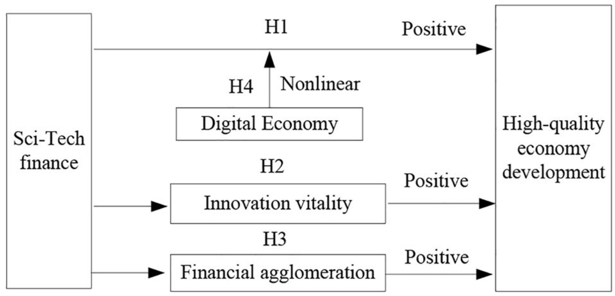

Fig. 1 Research hypothesis framework model.

Model and variable

Model

Baseline regression model. We construct the benchmark regression model of Sci-Tech finance on the high-quality economic development, as presented in Eq. (1).

$$Quali_{it} = \alpha_0 + \alpha_1 Scifi_{it} + \alpha_2 X_{it} + \mu_i + \varphi_t + \varepsilon_{it} \tag{1}$$

where *Quali* denotes high-quality economic development, *Scifi* represents the level of Sci-Tech finance, X_{it} indicates a control variable. i refers to the prefecture-level city, t stands for the year, μ_i and φ_t are fixed effects of individual and time in the city, ε_{it} describes the error term. α_1 connote the effect coefficients of the independent variables on the dependent variables, and α_2 implies the coefficient of the impact effect of the control variables.

Moderating effect model and threshold model. To incorporate the moderating effect of the digital economy into the analysis, the interaction between the digital economy and Sci-Tech finance is integrated into the regression analysis, as shown in Eq. (2), to construct the moderating effect model.

$$Quali_{it} = \beta_0 + \beta_1 Scifi_{it} + \beta_2 Dieco + \beta_2 Scifi_{it} \times Dieco_{it} + \beta_4 X_{it} + \varepsilon_{it} \tag{2}$$

where, β represents the effect coefficient of the independent variable on the dependent variable; *Dieco* represents the digital economy; and $Scifi \times Dieco$ denotes the interaction term between Sci-Tech and the digital economy.

To further examine the non-linear impact of the digital economy on Sci-Tech finance in the regional economy, we establish a threshold model, as illustrated in Eq. (3), with digital economy serving as the threshold variable.

$$Quali_{it} = \alpha_0 + \alpha_1 Scifi_{it} \times I(Dieco \le \gamma) + \alpha_2 Scifi_{it} \times I(Dieco > \gamma) + \alpha_3 X_{it} + \varepsilon_{it} \tag{3}$$

where, γ reflects the threshold, $I(\cdot)$ is a dummy variable, and the expression in parentheses is 1 if true and 0 otherwise.

Variables

Dependent variable. In this study, high-quality economic development (*Quali*) is the dependent variable. Drawing on previous research, a multi-indicator system is constructed to measure the index of high-quality economic development (Yu et al., 2022; Qi et al., 2023; Zou and Zhou, 2024). In this study, high-quality economic development is measured using four dimensions: innovation-driven index, industrial upgrading index, economic efficiency index, and green economic efficiency index. The entropy method is used to obtain the regional high-quality economic development index.

(I) Innovation-driven index: Measured by the number of comprehensive patent authorizations obtained from each region. Specifically, a comprehensive score is calculated based on the number of invention patents, utility model patents, and design patents, with weights of 0.5, 0.3, and 0.2, respectively assigned to obtain the number of comprehensive patent authorizations, thereby measuring the level of scientific and technological innovation in each region.

(II) Industrial upgrading index: It is measured by the industrial structure optimization and upgrading index. Specifically, the industrial structure sophistication and industrial structure rationalization indices are calculated using the entropy method. The industrial structure sophistication index is the ratio of the tertiary industry to the secondary industry, and the industrial structure rationalization index is obtained after positive processing of the Theil index.

(III) Economic efficiency index: High-quality economic development emphasizes enhancing the efficiency of economic input-output. This dimension is measured by the input-output efficiency index, where the inputs consist of human, capital, land, and energy resources, and GDP is the output. The human capital indicator is derived from annual employment figures in municipal jurisdictions and expressed in tens of thousands. Capital inputs are calculated based on the capital stock estimated using the perpetual inventory method (Han and Shen, 2015). The land input is measured by the built-up area of each city (square kilometers), and the energy input is measured by the total energy consumption (tons of standard coal). Output indicators are measured by real GDP (ten thousand yuan). Finally, the input-output efficiency index is derived using the Super-SBM model.

(IV) Green economic efficiency index: High-quality economic development emphasizes sustainable development. Drawing on existing research (Lu et al., 2023), we adopt the SBM-GML index with unexpected output to measure the green economic efficiency index. This approach utilizes human, capital, land, and energy as inputs along with GDP as the desired output, and incorporates industrial wastewater, exhaust emissions, and soot and dust emissions as non-desired outputs. The resulting of SBM-GML index, including these non-desired outputs, addresses the traditional DEA limitations. The SBM-GML index compensates for the shortcomings of the traditional DEA and avoids the problem of no feasible solution for the decision unit that may occur in the traditional method.

Explanatory variables. Sci-Tech finance (*Scifi*) is the core explanatory variable in this study. It comprises a myriad of financial backings and innovative financial practices aimed at cultivating advancements in science and technology sectors. Fundamentally, Sci-Tech finance represents not only innovation itself but also a comprehensive financial services ecosystem dedicated to the Sci-Tech domain. Currently, the field lacks a universally accepted evaluation index system for measuring Sci-Tech finance. Zou (2022) measures the level of Sci-Tech finance using four indicators: government Sci-Tech expenditure, the balance of loans in financial institutions, the amount of venture capital (VC), and enterprise R&D investment. Li et al. (2022) measure Sci-Tech finance in two major dimensions: public Sci-Tech finance and market Sci-Tech finance. Drawing on the results of previous literature, such as Li et al. (2022), Shen et al. (2022), and Zou and Zhou (2024), this study measures Sci-Tech finance from four aspects and obtains the Sci-Tech finance index using the entropy method. The details are as follows:

(I) Intensity of government financial support for Sci-Tech: Measured by the proportion of government financial expenditure on science and technology to GDP.
(II) Intensity of R&D investment: Measured by the proportion of R&D funds of each prefecture-level city to GDP.
(III) Intensity of market financial support: Measured by the proportion of the balance of loans of regional financial institutions to GDP.
(IV) Venture capital intensity: Measured by the total investment in social VC institutions in each prefecture-level city. Referring to the literature such as (Zhang et al., 2023), VC capital amounts are collected from VC fundraising data disclosed in the annual reports of listed companies and various equity investment data published on the official websites of VC and other online sources. A total of 295,465 VC data of prefecture-level cities are gathered and corresponded to 273 cities to summarize the venture capital amounts of each city over the years, thereby measuring the intensity of market venture capital.

Moderating variables. In this study, the digital economy (*Dieco*) is employed as a moderator and threshold variable to analyze the promotion of high-quality regional economic development by Sci-Tech finance. Drawing on the findings of existing research (Zhang et al., 2024; Lin et al., 2025), this study constructs a digital economy index through the entropy method. The index is composed of four sub-indices: total volume of telecommunications services, number of mobile phone users, quantity of digital talents, and heat of the digital economy. The quantity of digital talents is measured by the number of employees in the information transmission, computer services, and software industries. The heat of the digital economy is gauged by capturing the frequency of digital economy-related words in local government work reports via big data to analyze the degree of government attention to the digital economy.

Mediating mechanism variable. (I) Innovation vigor (*Innovi*). Sci-Tech finance plays a critical role in boosting Sci-Tech innovation activities and motivating scientists and technologists to actively engage in innovative efforts, which, in turn, supports economic progress (Li et al., 2022). While granted patents indicate innovation output, the volume of patent applications captures the innovative spirit of a region more accurately. In this study, the vitality of Sci-Tech innovation is measured by the number of comprehensive patent applications. The specific method assigns weights of 0.5, 0.3, and 0.2 to the number of invention patent applications, utility model patents, and design patents, respectively, and then obtains the number of comprehensive patent applications through weighted calculation.

(II) Financial agglomeration (*Finagg*). At the heart of Sci-Tech finance lies the enhancement of regional financial systems through financing activities orchestrated by governments, enterprises, markets, intermediaries, and other agents of science and technology innovation. Central to Sci-Tech finance, the integration of social capital, government finance, and financial expertise, along with other innovations, cultivates financial agglomeration. This process not only draws financial intermediaries and instruments closer but also elevates the efficiency of credit fund allocation. Sci-tech finance plays a critical role in facilitating the execution of science and technology innovation projects through a capital aggregation mechanism (Lu et al., 2023). A high degree of financial agglomeration can swiftly pool idle capital, thereby boosting financial productivity (Li and Ma, 2021), and propelling high-quality economic development. Existing research often uses the financial output percentage or volume of deposits and loans as a measure of financial agglomeration (Tian et al., 2021; Xie et al., 2021). However, a single indicator is insufficient to measure the degree of *Finagg*. Therefore, this study intends to weight two indicators: financial capital agglomeration and financial talent agglomeration. Financial capital agglomeration is measured by the proportion of the deposit and loan amounts in each region to the total number of sample regions, and financial talent agglomeration is measured by the proportion of financial

Table 1 Variable Definition.

Variable Type	Variable Name	Variable Labels	Specific Explanation of Variables
Explanatory Variable	high-quality economic development	*Quali*	Innovation-driven index Industrial upgrading index Economic efficiency index Green economic efficiency index
Core Explanatory Variables	Sci-Tech finance	*Scifi*	Intensity of government financial support for Sci-Tech Intensity of R&D investment Intensity of market financial support Venture capital intensity
Moderating Variables	digital economy	*Dieco*	Total volume of telecommunication services Number of mobile phone subscribers Quantity of digital talents Heat of the digital economy
Mechanism Variables	Innovation vigor	*Innovi*	Weighted comprehensive number of patent applications.
	Financial agglomeration	*Finagg*	Comprehensive Financial Agglomeration Index
Control Variables	Government intervention	*Gov*	Ratio of government fiscal expenditure to GDP
	Degree of opening-up	*Open*	Ratio of the total import and export volume to GDP
	Human capital level	*Hum*	Ratio of the number of college students to the permanent population
	Population density	*Pop*	Ratio of the permanent population to the administrative area
	Informatization level	*Inter*	Mobile phone coverage

Table 2 VIF for each explanatory variable.

Variable	*Scifi*	*Dieco*	*Gov*	*Open*	*Pop*	*Hum*	*Inter*	Mean VIF
VIF	2.165	1.739	1.639	1.686	1.626	1.621	1.279	1.681
1/VIF	0.462	0.575	0.610	0.593	0.615	0.617	0.782	0.595

employees in each region to the total number of sample regions. A comprehensive *Finagg* index is obtained using the entropy method.

Control variables. We controlled for the following factors to reduce the effect of omitted variables:

(I) Government intervention (*Gov*). Government fiscal expenditure can stimulate and guide regional economic growth. Therefore, the allocation of government fiscal expenditures has a significant effect on the direction of industrial restructuring. This study employs the ratio of government fiscal expenditure to GDP to measure the degree of *Gov* (Li et al., 2022).

(II) Degree of opening-up (*Open*). Imports and exports are important indicators of a region's participation in the international division of labor. These activities can lead to optimal resource allocation and improvements in economic efficiency. We measure the level *Open* by the ratio of the total import and export volume to GDP in the current year (Gao et al., 2022).

(III) Human capital level (*Hum*). Generally, a large student body indicates a well-developed higher education system. High-quality talent cultivated by higher education institutions significantly enhances human capital and plays a critical role in local economic development. The level of *Hum* is measured by the ratio of the number of college students to the permanent population (Li et al., 2024; Han and Shen, 2015).

(IV) Population density (*Pop*). Regions with high population density are more prone to forming economic agglomerations and scale effects, which promote regional economic development. However, the development of regional economies attracts more people to aggregate in these regions. This is measured by the ratio of the permanent population to the administrative area.

(V)Informatization level (*Inter*). The level of informatization and digitization in a region is an important influencing factor for economic and financial development. In the era of 5 G, it is measured by mobile phone coverage (Kräussl et al., 2022).

Table 1 summarizes the definitions of each variable.

Data sources. In this study, the variables Quali, Scifi, and Dieco are all composite indices derived from multiple sub-indicators through the entropy method. The data processing and calculation methods for each sub-indicator are elaborated in detail in the description of each variable previously presented.The foundational data for this research primarily derives from the annual statistical yearbooks of each prefecture-level city, the China Science and Technology Statistical Yearbook(CSTSY), the China Financial Yearbook (CFY), and the EPS data platform, etc, with supplemental figures collected from industry reports. The study focuses on prefecture-level cities as the research object. The dataset comprises 273 prefecture-level cities, selected in light of data unavailability for certain indicators in some localities. The period of analysis extends from 2011 to 2022, aligning with the starting point of China's strategy of integration of Sci-Tech and finance in 2011.

Empirical analysis

Sample descriptive statistics. To test for the presence of multicollinearity in the variables, the Variance Inflation Factor (VIF) test is performed; the results are presented in Table 2. The maximum VIF value of each variable is 2.165, the minimum value is 1.279, and the average VIF value is 1.680, which is much smaller than the test requirement of 10. Thus, the effect of multicollinearity can be ignored to some extent. The descriptive statistics for each variable are provided in Table 3. The maximum and minimum values of the sample data vary considerably from one variable to another, indicating a great deal of variability across regions. Notably, some values in Table 3 are negative because the control variable is logarithmic and is included in the regression.

Benchmark regression. Benchmark regression models were used to rigorously appraise the relationship between Sci-Tech finance and the advancement of high-quality economic development. Table 4 details the findings, the robustness of which was evaluated using a city-based clustering approach. The analysis is segmented in this table: columns (1) and (2) center on national sample data regressions, controlling for both time and individual city effects. Column (1) presents the findings without control variables, whereas column (2) includes control variables. When both time and city influences are controlled, the regression result for the national sample data is 0.295, which is statistically significant at the 1% significance level. This finding suggests a significant correlation, in which a one-unit increase in Sci-Tech finance corresponds to a 0.295 unit increase in the index of high-quality economic development. Columns (3) to (5) present the regression results based on the subsamples of the eastern, central, and western region respectively. The regression coefficient in the eastern region is 0.199, and that in the central region is 0.2789, both of which have passed the significance test. The results showed that the impact of regional Sci-Tech finance on high-quality economic development is the greatest in the central region, followed by the eastern region, while it is not significant in the western region. The overall economic and Sci-Tech finance levels in the western region are comparatively low. Analysis based on the Gini coefficient indicates that the Gini coefficient for the Sci-Tech finance index in the western region is higher than that in the eastern region, implying significant internal disparities and pronounced polarization within the Sci-Tech finance landscape of the western region. Specifically, provincial capital cities such as Guiyang, Chengdu, Xi'an, and Lanzhou have exhibited robust development, whereas other prefecture-level cities in the western region have lagged behind in Sci-Tech finance development, resulting in substantial regional variations in the Sci-Tech finance development index. This disparity constitutes one of the key factors contributing to the insignificant regression results observed in samples from the western region. The regression results of the samples indicate that Hypothesis H1 has been verified.

Table 3 Descriptive statistics of variables.

Variable	N	Mean	p50	SD	Min	Max
Quali	3276	0.166	0.148	0.076	0.054	0.812
Scifi	3276	0.070	0.056	0.045	0.008	0.354
Dieco	3276	0.101	0.088	0.068	0.008	0.676
Gov	3276	2.887	2.857	0.407	1.479	4.255
Open	3276	2.031	2.085	1.404	−3.829	5.518
Hum	3276	0.111	0.071	1.107	−6.317	2.868
Pop	3276	1.188	1.334	0.902	−2.996	3.300
Inter	3276	3.394	3.511	0.403	1.805	4.370

Endogeneity issues

IV method test. The endogeneity problem should be fully taken into account in regression analysis. In this study, the sources of the endogeneity problem are as follows: First, there is the bias of omitted variables. Despite the thorough inclusion of various factors such as government influence, open to the outside world, and human capital, and employing both city-fixed and time-fixed effects in the analysis, there remains the possibility that certain unseen variables could affect the relationship between Sci-Tech finance and the high-quality economic development, yet are not accounted for. Another concern raised is the selection bias in the sample. Focusing on 273 prefecture-level cities, the research strives to exclude cities with missing data to mitigate this issue. However, despite efforts to compensate for minor data gaps through interpolation, the potential for sample bias occurs.

The study utilizes 1984 postal history data as an instrumental variable to test the endogeneity problem. The rationale behind this choice lies in two key observations. Historically, the postal service played a critical role in laying down telephone networks and served as a crucial channel for remittances, significantly influencing financial operations. The intertwining of financial industry development with the advent of telecommunications, due to the extensive adoption of telephones, highlights the relevance of this historical context. Additionally, the historical data on fixed-line telephone density and the scale of postal and telecommunication activities in cities have a negligible effect on the contemporary indices measuring economic quality development across these cities. Therefore, it can be considered that choosing the per capita postal and telecommunications business volume in 1984 (PTBV) as an instrumental variable meets the two requirements of instrumental variable correlation and exogeneity. Some literature also uses the lagged one period of the core explanatory variable as an instrumental variable. Since this study is panel data and PTBV is cross-sectional data, therefore, the product of PTBV and the lagged one period of the core explanatory variable is taken as the IV instrumental variable.

Table 4 Empirical results of benchmark regression.

	(1)	(2)	(3)	(4)	(5)
VARIABLES	Nationwide	Nationwide	Eastern Region	Central region	Western Region
Scifi	0.312*** (2.924)	0.295*** (3.528)	0.199* (1.796)	0.289*** (2.746)	0.169 (0.675)
Gov		−0.079*** (−8.771)	−0.111*** (−4.960)	−0.084*** (−7.130)	−0.081*** (−3.711)
Open		−0.004 (−1.638)	−0.016 (−1.545)	0.002 (0.572)	−0.002 (−0.830)
Hum		−0.015*** (−3.974)	−0.042*** (−4.216)	−0.001 (−0.170)	−0.006**
Pop		0.160* (1.831)	0.251** (2.154)	0.037 (0.576)	0.048 (0.793)
Inter		−0.011 (−1.239)	0.021 (0.720)	−0.024* (−1.769)	−0.006 (-0.716)
Constant	0.144*** (19.399)	0.228** (2.049)	0.019 (0.084)	0.421*** (4.065)	0.380*** (4.648)
Time FE	NO	YES	YES	YES	YES
City FE	NO	YES	YES	YES	YES
Observations	3276	3276	1032	1368	876
R-squared	0.781	0.810	0.836	0.798	0.806

Clustering robustness *t*-statistics are in parentheses.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 5 demonstrates the results from applying the instrumental variable method, where column (1) presents the regression results of the first stage and column (2) displays the regression results of the second stage. The first stage shows an *F*-value of 23.030, exceedinging the threshold of 10. This is in line with the benchmarks set by Cragg and Donald (1993) as well as Stock and Yogo (2002). The result of the Cragg-Donald Wald F statistic is 452.70. This figure exceeds the critical value for the 10% significance level, set at 16.38, thus refuting the original hypothesis of "instrumental variables are weakly identified" (Stock and Yogo, 2002). This finding confirms the test's requirements are satisfied. Moreover, the *p* value of Kleibergen-Paap rk LM statistic is 0.000, demonstrating the non-identifiable test's results are valid. The regression coefficient in column (2) is 1.102 and passes the 1% significance test, the analysis indicates a significant and positive correlation between Sci-Tech finance and high-quality economic development, echoing the benchmark regression findings. This indicates the robustness of the results of this study.

Considering lagged effects. Considering the sustained and lagged effect of Sci-Tech finance on the high-quality economic development, this study aims to mitigate potential endogeneity concerns by regressing the explanatory variables with a one-period lag, as illustrated in Table 6. Column (1) and columns (3) accounts for time-fixed effects and individual fixed effects without incorporating control variables, while columns (2) through (4) both include control variables. It can be seen that regardless of whether the control variables are added or not, the regression results are significantly positive after lagging one period and lagging two periods of the explanatory variables. These findings emphasize the impact of Sci-Tech finance on the high-quality development of the economy has a certain sustained effect and lagged effect.

Table 5 Instrumental variable regression results.

Variable	(1)	(2)
IV	0.050*** (4.800)	
Scifi		1.102*** (2.982)
Control	YES	YES
Time FE	YES	YES
City FE	YES	YES
F-test of excluded instruments:	23.030	
statistic of Cragg-Donald Wald F statistic	452.70	
Kleibergen-Paap Wald rk F statistic	23.030	
P value of Kleibergen-Paap rk LM statistic	0.000	

Clustering robustness *t*-statistics are in parentheses.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Robustness tests

Winsorization. To minimize the potential effect of data outliers, the sample data is subjected to winsorization. In the 1% winsorization, values less than the 1st percentile are replaced with the value at the 1st percentile, and values greater than the 99th percentile are replaced with the value at the 99th percentile. The results of the 1% and 5% winsorization are presented in Table 7. After controlling for time-fixed effects, city-fixed effects, and control variables, the regression coefficient with a 1% reduction was 0.355; while the regression coefficient with a 5% reduction was 0.369, displaying no significant difference from the coefficients of the original benchmark regression. The results confirm the robustness of the sample data.

Indicators of replacement variables. To further verify the reliability of the model, we propose substituting the indicators of the dependent and independent variables for regression validation. The results are summarized in Table 8. Column (1) presents the results of the recalculation by replacing one variable with the constituent indicators of the Sci-Tech finance index. Columns (2) and (3) present the results obtained after replacing the calculation methods of the sub-indices with the measurement indicators of the high-quality economic development index. By changing the explanatory variables and the explained variables, the regression coefficients remain significant, indicating that Sci-Tech finance has a significant promoting effect on high-quality economic development and is robust and reliable.

Heterogeneity analysis. To delve deeper into the effect of Sci-Tech finance on the advancement of high-quality economic development, this analysis explores the role of Sci-Tech finance through three perspectives: the level of human capital, the degree of innovation, and digital infrastructure. We utilizing Fisher's Permutation test by self-sampling (Bootstrap) 1000 times to calculate the *P* value, indicating the differences in coefficient impacts across various groups, as detailed in Table 9.

First, grouping by human capital level, the regression results for different groups in Sci-Tech finance on economic development are illustrated in Table 9. The data with higher human capital levels, as presented in column (1), has a regression coefficient of 0.407, and passes the 1% significance test. In contrast, the data for groups with lower human capital, indicated in column (2), does not exhibit a significant regression coefficient. The *P* value for the test comparing coefficient differences across these groups stands at 0.004, meeting the criteria for the 1% significance level. This highlights a significant difference in the effect of Sci-Tech finance on high-quality economic development,

Table 6 Results of lag test.

Lagging one-period behind			Lagging two-period behind		
Variable	**(1)**	**(2)**	**Variable**	**(3)**	**(4)**
L.Scifi	0.324*** (2.664)	0.303*** (3.105)	*L2.Scifi*	0.303** (2.280)	0.285*** (2.628)
Control	NO	YES	Control	NO	YES
Time FE	YES	YES	Time FE	YES	YES
City FE	YES	YES	City FE	YES	YES
Observations	3003	3003	Observations	2730	2730
R-squared	0.786	0.813	R-squared	0.796	0.821

Clustering robustness *t*-statistics are in parentheses.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

dependent on the regional levels of human capital. Specifically, regions endowed with a richer human capital base exhibit a greater benefit from digital infrastructure, such as networks, in cultivating digital financial inclusion (Niu et al., 2022). The analysis confirms that areas with higher human capital levels exhibit a more significant regression coefficient than the aggregate sample, highlighting a more significant effect of Sci-Tech finance on enhancing economic quality in these regions. Conversely, in areas with low levels of human capital, the effect of Sci-Tech finance on cultivating high-quality economic growth appears negligible. This underlines the critical role human capital plays in economic excellence, necessitating increased investment in education to uplift regional human capital standards.

Secondly, in exploring the effect of Sci-Tech finance on the advancement towards high-quality economic development, a distinction is made between regions based on their innovation levels. This distinction is measured through the perspective of authorized invention patents per capita, which serve as a proxy for measuring innovation. Analysis is categorized into two cohorts, with findings detailed in Table 9. For regions classified under the high innovation tier, as presented in column (3), the regression coefficient is observed at 0.331, and statistically significant at the 5% level. Conversely, the coefficient associated with regions of lower innovation, as demonstrated in column (4), the regression coefficient for regions with low levels of innovation 0.020 but not significant. A comparison of coefficient variances between these groups yields a p value of 0.024 at a 5% significance level. This result highlights a significant difference in how Sci-Tech finance catalyzes high-quality economic progression across regions characterized by varying innovation intensities. Specifically, the significant regression coefficient in regions of high levels of innovation suggests that Sci-Tech finance plays a more critical role in cultivating high-quality economic results in these regions. This is in contrast to regions with low levels of innovation footprint, where the effect of Sci-Tech finance on economic quality is negative. This difference may be attributed to the weak Sci-Tech foundation and innovation capabilities.

Third, in analyzing the relationship between digital infrastructure and economic development, analyzes were segmented into two categories as presented in columns (5) and (6) of Table 9. The digital infrastructure index is a comprehensive index calculated by the entropy method based on the number of local data centers, the coverage rate of Internet users, the coverage rate of mobile phones and so on. Analysis of regression results indicates that the effect of Sci-Tech finance on the advancement towards a high-quality economic state is markedly more significant in zones with extensive digital infrastructure, with a coefficient of 0.355 and passes the 1% significance test. In contrast, such effect appears negligible in areas with lower digital infrastructure. The statistical test for coefficient difference between these groups underlines a significant difference, highlighted by a p value of 0.013 at the 5% significance level, thereby confirming a moderating effect of digital infrastructure on the efficacy of Sci-Tech finance in cultivating economic excellence. The observed difference in regression coefficients, favoring regions with digital infrastructure, highlights the enhanced effect of Sci-Tech finance in such locales. This phenomenon accentuates the urgency for accelerated enhancements in digital infrastructure and mobile information network accessibility. Such strategic developments are essential for catalyzing the confluence of Sci-Tech and financial sectors, thereby amplifying the role of Sci-Tech finance in elevating the standard of economic development to a higher quality.

In summary, the study of the data indicates that the effect of Sci-Tech finance on enhancing economic quality is notably more significant in regions characterized by high human capital, a high degree of innovation, and high level digital infrastructure. This

Table 7 Winsorization results.

Variable	1% winsorization		5% winsorization	
	(1)	(2)	(3)	(4)
Scifi	0.312*** (2.924)	0.355*** (3.256)	0.312*** (2.924)	0.369*** (3.207)
Control	NO	YES	NO	YES
Time FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES
Observations	3276	3276	3276	3276
R-squared	0.781	0.802	0.781	0.800

Clustering robustness t-statistics are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table 8 Results of replacing the regression of explanatory and interpreted variables.

Variable	(1) *Quali*	(2) *Quali2*	(3) *Quali3*
Scifi2	0.203*** (2.689)		
Scifi		0.283*** (3.523)	0.155** (2.292)
Control	YES	YES	YES
Time FE	YES	YES	YES
City FE	YES	YES	YES
Observations	3,276	3,276	3,276
R-squared	0.807	0.826	0.808

Clustering robustness t-statistics are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table 9 Results of heterogeneity analysis.

Variable	Classification of human capital		Classification of innovation levels		Classification of digital infrastructure	
	Hig(1)	Low(2)	High(3)	Low(4)	High(5)	Low(6)
Scifi	0.407*** (3.137)	0.033 (0.507)	0.311** (2.366)	0.020 (0.331)	0.355*** (2.650)	0.041 (0.912)
Control	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES
R-squared	1634	1633	1626	1620	1618	1627
Observations	0.818	0.817	0.818	0.840	0.797	0.852
P value	0.004		0.024		0.013	

Clustering robustness t-statistics are in parentheses. P value refers to the test for differences in coefficients between groups using the Fischer test.
***p < 0.01, **p < 0.05, *p < 0.1.

Table 10 2SLS results of *Innovit* and *Finagg*.

Variable	*Innovit*		*Finagg*	
	First stage	Second stage	First stage	Second stage
	Scifi	*Quali*	*Scifi*	*Quali*
IV	0.041*** (8.550)		0.089*** (4.980)	
Innovit		0.564*** (20.087)		
Finagg				17.219*** (5.868)
Control	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES
F test of excluded instruments:	73.160		186.890	
statistic of Cragg-Donald Wald F statistic	1626.950		2305.140	
Kleibergen-Paap Wald rk F statistic	73.160		186.890	
P value of Kleibergen-Paap rk LM statistic	0.039		0.093	

Clustering robustness *t*-statistics are in parentheses.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

highlights the necessity for a customized approach to the application of Sci-Tech finance, tailored to the specific conditions of each region. In areas where Sci-Tech finance plays a critical role in cultivating high-quality economic development, it is crucial not only to leverage its potential to guide this development effectively but also to address and bridge the gaps in regions where its effect is less significant. Accordingly, it is possible to further realize the potential of Sci-Tech finance as a where for advancing the cause of high-quality economic growth.

Analysis of the impact mechanisms

Testing strategy for mediating transmission mechanism. To further explore the mediating transmission mechanism of Sci-Tech finance on high-quality economic development, numerous studies generally adopt the three-step mediating effect model proposed by Wen and Ye (2014) to test whether the mediating effect exists and analyze the influence transmission role of the mediating variables. Specifically, the first step is to examine the impact of *Scifi* on *Quali*, as shown in formula (1); the second step is to analyze the impact of *Scifi* on the mediating variable M_{it}, as shown in Eq. (4); and the third step is to incorporate the mediating variables and the Scifi into the regression model simultaneously to test their impacts on Quali, as shown in Eq. (5).

$$M_{it} = \alpha_0 + \alpha_1 Scifi_{it} + \alpha_2 X_{it} + \mu_i + \varphi_t + \varepsilon_{it} \quad (4)$$

$$Y_{it} = \beta_0 + \beta_1 Scifi_{it} + \beta_2 M_{it} + \beta_3 X_{it} + \mu_i + \varphi_t + \varepsilon_{it} \quad (5)$$

However, when this method is applied in economics, endogeneity issues may occur, and the mediating variables may have reverse causality (Jiang, 2022). This study adopts the following methods to overcome the shortcomings of the traditional three-step test.

First, referring to the method for addressing the endogeneity issue of Sci-Tech finance in IV method test, the mediating mechanism variables, namely, Innovit and Finagg are taken as the core explanatory variables for the analysis, and the IV method is employed to verify whether Innovit and Finagg are exogenous variables in the regression of Quali. Second, to overcome the potential endogeneity influence of the mediating variables, in contrast to the traditional analysis method that adopts the OLS benchmark regression analysis model, the 2SLS model is utilized for the regression analysis in steps (4) and (5). The specific idea is that in the 2SLS regression model of Scifi on the Quali, the influence mechanism variables are gradually incorporated to observe whether the regression coefficient of Scifi becomes larger or smaller after the addition of these mediating influence mechanism variables. If the regression coefficient of Scifi decreases after adding a mediating influence mechanism variable, it indicates that this influence mechanism variable is a positive transmission mechanism through which Scifi affects Quali. Conversely, an increase in the regression coefficient implies that the mediating influence mechanism variable is a negative transmission mechanism.

Results of mechanism testing. First, the IV method is employed to verify whether the mediating mechanism variables, namely *Innovit* and *Finagg*, are exogenous variables in the regression of *Quali*. Table 10 presents the results of the 2SLS regression analysis.

Analyzing *Innovit* as an influential mechanism variable, the *F*-statistic value in the first stage is 73.160, exceeding the required threshold of 10 and thus passing the test requirement. The Cragg-Donald Wald F statistic yields a value of 1626.950, surpassing the critical value of 16.38 at a 10% significance level. In addition, the *p* value of the Kleibergen-Paap rk LM statistic is 0.039, verifying the non-identifiable test results. The second-stage regression coefficient of *Innovit* is 0.564 and is significant at the 1% level, demonstrating that *Innovit* meets the criteria for an exogenous variable.

Analyzing *Finagg* as an influential mechanism variable, the first-stage *F*-statistic is 186.89, which also exceeds the threshold of 10 and satisfies the test requirements. The Cragg-Donald Wald *F* statistic results in a value of 2305.14, exceeding the critical value of 16.38 at a 10% significance level. In addition, the *p* value of the Kleibergen-Paap rk LM statistic is 0.093, confirming that the non-identifiable test results are valid. The second-stage regression coefficient is 17.219, which is significant at the 1% level, confirming that *Finagg* meets the requirements of an exogenous variable.

In summary, *Innovit* and *Finagg* qualify as eligible exogenous variables.

In the second step, *Innovit* and *Finagg* are individually incorporated into the regression model. The resulting 2SLS regression results are presented in Table 11. Column (1) illustrates the regression of *Scifi* on *Quali* by 2SLS model, deriving a regression coefficient of 1.102. Columns (2) and (3) demonstrate the regression results of *Scifi* on *Innovit* and *Finagg*, respectively. The respective regression coefficients are 2.651, 0.045 and all of them pass the 1% significance test. This significance indicates that Sci-Tech finance affects the mediating mechanism, *Innovit* and *Finagg*. Column (4) presents the 2SLS results obtained after including both *Scifi* and *Innovit* in the regression

Table 11 2SLS regression results.

Variable	(1) *Quali*	(2) *Innovit*	(3) *Finagg*	(4) *Quali*	(5) *Quali*
Scifi	1.102*** (2.982)	2.651*** (3.293)	0.045** (2.564)	0.608* (1.723)	0.788*** (3.467)
Innovit				0.186*** (3.027)	
Finagg					7.006** (2.276)
Control	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES
Observations	3003	3003	3003	3003	3003
R-squared	0.034	−0.693	−0.846	0.160	0.120

While the R-squared values in columns (2)(3) are negative, it does not mean that the 2SLS parameters are no good. As demonstrated by Sribney et al. (2005), R-squared lacks statistical significance in 2SLS or instrumental variable (IV) estimation. In the first stage of 2SLS, certain regress ors represent instrumental variables. However, since our objective is to estimate the structural model, the regression sum of squares (ESS) is determined utilizing the actual values of the independent variables, not their instruments. Therefore, the model residuals are calculated based on a set of independent variables that differs from the regress ors employed in the model fitting. This implies that, while the 2SLS model estimates an intercept, a simple constant model of the dependent variable is not nested in it. Accordingly, the residual sum of squares (RSS) is not constrained to be less than the total sum of squares (TSS), leading to negative ESS and R^2 values when RSS surpasses TSS.

Table 12 Empirical results of regressions adding digital economy as a moderating variable.

Variable	(1) Nationwide	(2) East area	(3) Central area	(4) Western area
Scifi	0.089 (1.328)	−0.126 (−0.932)	0.228*** (2.846)	−0.066 (−0.529)
Dieco	0.023 (0.542)	−0.054 (−0.830)	−0.022 (−0.373)	0.107 (1.307)
Scifi Dieco*	2.922*** (8.941)	2.934*** (6.392)	2.406 (1.558)	3.005* (1.705)
Control	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
City FE	NO	YES	YES	YES
Observations	3276	1032	1368	876
R-squared	0.829	0.853	0.803	0.824

Clustering robustness *t*-statistics are in parentheses.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

equation. The inclusion of *Innovit* as a variable reduces the coefficient of *Scifi* impact on *Quali* to 0.608, representing a 44.83% decrease from the initial value of 1.102. Similarly, column (5) displays the 2SLS results after incorporating both *Scifi* and *Finagg* into the regression equation. The addition of *Finagg* as a variable results in a coefficient of 0.788 for the effect of *Scifi* on *Quali*, marking a 28.49% reduction from 1.102.

In summary, these findings suggest that the two mediating mechanism variables, *Innovit* and *Finagg*, play a positive transmission role in the mechanism of the effect of Sci-Tech finance on the high-quality economy development. This means that hypothesis H2 and H3 is verified.

Analysis of moderating effects considering digital economy

Regression results of moderating effects. Considering the digital economy as the moderating variable, we explore its interaction with Sci-Tech finance (*Scifi**Dieco*) in the regression model, as illustrated in Table 12. Column (1) shows the regression results of the national sample data. The regression coefficient of the interaction term (*Scifi**Dieco*) is 2.922 and is significantly positive. These findings emphasize that the digital economy has a significant positive moderating effect on Sci-Tech finance in promoting high-quality economic development. From a regional perspective, the interaction terms in the eastern and western regions are significantly positive, with regression coefficients of 2.934 and 2.406, respectively, whereas the interaction term in the central region is not significant. The significant positive interaction term in the eastern region may be attributed to the relatively high level of digital economy development and strong Sci-Tech innovation capabilities in this area, where a favorable interactive effect between the digital economy and Sci-Tech finance has been formed. The significant positive interaction term in the western region can be explained by the fact that, in recent years, the western region has increased its investment and development efforts in the digital economy, driving the rapid development of Sci-Tech finance. To a certain extent, the catch-up effect also accounts for the significant positive interaction term in the western region. Based on this, we hypothesize that there may be a certain threshold for the digital economy, meaning that the degree of influence of the digital economy may vary under different levels of the digital economy.

Table 13 Regression results of lagged effects of adding digital economy as a moderator variable.

Lagging one-period behind		Lagging two-period behind	
Variable	**(1) *Quali***	**Variable**	**(2) *Quali***
L.Scifi	0.045 (0.591)	*L2.Scifi*	0.007 (0.101)
L.Dieco	0.100** (2.560)	*L2.Dieco*	0.135*** (3.339)
L.(Scifi Dieco)*	2.041*** (5.900)	*L2. (Scifi* Dieco)*	2.449*** (5.489)
Control	YES	Control	YES
Time FE	YES	Time FE	YES
City FE	YES	City FE	YES
Observations	2730	Observations	2457
R-squared	0.839	R-squared	0.837

Clustering robustness *t*-statistics are in parentheses.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Lagged effects of moderating effects. Considering the sustainability and lagged nature of Sci-Tech finance, and digital economy and high-quality economic development, this study analyzes the variables of *Scifi* and *Dieco*, along with their interactive effects, with a one-period lagged and two-period lagged, as illustrated in Table 13. It can be seen that the regression coefficients of the interaction terms (*Scifi** Dieco*) are all significantly positive after controlling for time and individual city effects. In essence, this indicates that the moderating effect of digital economic on Sci-Tech finance to the high-quality economy development is lagged and sustained.

Analysis of threshold effects. To further investigate the role of the digital economy in the process of Sci-Tech finance promoting high-quality economic development, this study uses the digital economy as a threshold variable. This approach aims to reveal the nonlinear relationship between Sci-Tech finance and high-quality economic development. The findings illustrated in Table 14 and depicted in Fig. 2 present the results of the threshold effect analysis. The analysis in Table 14 shows that the single- and double-threshold models are statistically significant at the 1% level. However, when the threshold value is 0.178, the third threshold of the triple-threshold model has a p value of 0.233, which failed to meet the requisite significance criteria. This

Table 14 Threshold effect test results.

Threshold model	Threshold	Estimated threshold	Fstat	Prob	Crit10	Crit5	Crit1
Single Threshold model	Single threshold	0.275	264.330	0.000	20.333	27.733	39.628
Double-Threshold model	First threshold	0.275	249.540	0.000	21.376	26.511	41.688
	Second threshold	0.058	30.840	0.017	18.145	22.741	32.873
Triple-threshold model	First threshold	0.275	249.540	0.000	19.306	24.278	37.523
	Second threshold	0.058	30.840	0.013	16.489	19.758	32.934
	Third threshold	0.178	31.670	0.233	40.927	46.070	64.357

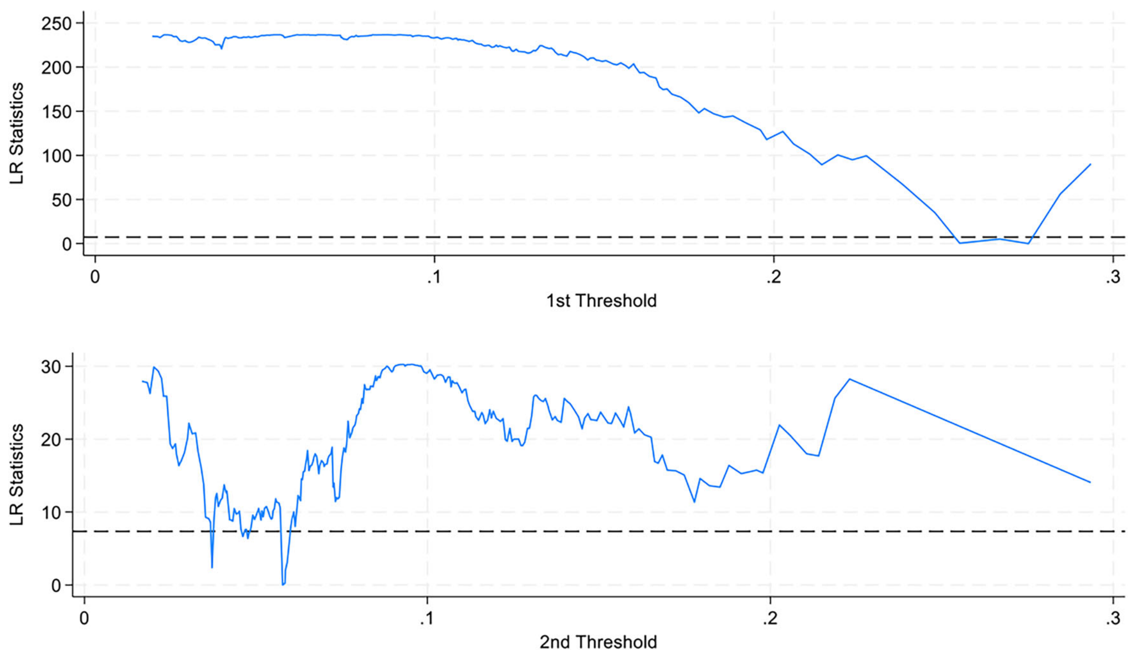

Fig. 2 Threshold effect regression results.

Table 15 Threshold effect regression results.

VARIABLES	*Quali*
Scifi (*Dieco* < 0.058)	0.305*** (3.970)
Scifi (0.058 < *Dieco* < 0.275)	0.135** (2.186)
Scifi (*Dieco* > 0.275)	0.619*** (5.633)
Control	YES
Time FE	YES
City FE	YES
Observations	3276
Number of code	273
R-squared	0.686

indicates that there are two threshold values in the threshold model: 0.058 and 0.275.

According to the regression coefficient in Table 15, when the digital economy level is lower than 0.058, the regression coefficient of *Scifi* on *Quality* is 0.305, which passes the significance test. This indicates that in a very underdeveloped digital economy, Sci-Tech finance still has a positive impact on high-quality economic development. When the digital economy level is between 0.057 and 0.275, the regression coefficient drops to 0.135 but still passes the significance test. This means that with the gradual development of the digital economy, the impact of Sci-Tech finance on high-quality economic development is relatively weak but remains significant. When the digital economy level is higher than 0.275, the regression coefficient increases significantly to 0.619 and passes the significance test. This shows that in the case of a highly developed digital economy, the impact of Sci-Tech finance on high-quality economic development becomes very significant, even exceeding the impact when the digital economy is at a very low level.

In summary, we conclude that the impact of Sci-Tech finance on high-quality economic development is most prominent when the digital economy is at an extremely low or extremely high level, whereas such an impact is relatively weak when the digital economy is at a medium level. Moreover, with the continuous advancement of the digital economy, the impact of Sci-Tech finance on high-quality economic development may undergo a process of first weakening and then strengthening, exhibiting a non-linear pattern. Thus, the previous hypothesis H4 is tested.

Conclusions and implications

Conclusion. Previous studies primarily emphasized the impact relationship between Sci-Tech finance and economic growth. However, high-quality development is currently the primary theme. This study constructs an index of high-quality economic development that consists of four sub-indices: innovation-driven index, industrial upgrading index, economic efficiency index, and green economic efficiency index. This reflects high-quality development, rather than focusing solely on economic growth, thus broadening the research field of the impact of Sci-Tech finance on high-quality economic growth. Based on panel data from 273 cities, this study enables the analysis to delve deeper into revealing the uniqueness and differences among different cities, which is conducive to a more in-depth understanding of the impact mechanism. Specifically, this research is the first to incorporate digital economy variables into the regression analysis of Sci-Tech finance and high-quality economic development. By analyzing this relationship at the prefecture-level city level, the study seeks to explain the influence and mechanisms of Sci-Tech finance, specifically its impact on high-quality economic development. In addition, it aims to explain the moderating and non-linear effects of the digital economy on the ability of Sci-Tech finance to drive high-quality economic development, there by offering novel insights into this critical area of economic inquiry.

Analyzing national sample data, this study indicates that Sci-Tech finance plays a crucial role in cultivating high-quality economic development. With each incremental unit in Sci-Tech finance, the index for high-quality economic development increases by 0.295 units. Geographically, the effect of Sci-Tech finance on economic quality is more significant in the eastern region compared to the overall national sample, while no significant in the central region and western region. To ensure the validity of the study, a robustness test was carried out. It used the product of the per capita postal and telecommunications business volume in 1984 and the lagged one-period of the core explanatory variable as the IV instrumental variable, meeting the dual criteria of correlation and exogeneity. Through various regression analyses, including the instrumental variable method, accounting for lagged effects, applying reduced-tail treatment, and switching variable indicators, the benchmark regression's reliability was confirmed. The findings indicate that both financial agglomeration and innovation vigor act significant intermediary influence factors enhancing the contribution of Sci-Tech finance to high-quality economic development. Central to cultivating new quality productive forces is Sci-Tech innovation, which demands significant capital investment. The advancement of Sci-Tech finance aids in directing financial resources towards superior industries, thereby boosting financial concentration levels. With the infusion of additional funding, the momentum of innovation is augmented, leading to an uplift in both the caliber and efficiency of innovation activities. This, in turn, is a catalyst for high-quality economic development. The analysis into group heterogeneity and the study of coefficient variances across groups have indicated that the positive effect of Sci-Tech finance on economic quality is particularly significant in regions characterized by a wealth of human capital, a robust innovation landscape, and extensive digital economic. It is observed that Sci-Tech finance gravitates towards areas endowed with substantial human capital, cutting-edge innovation capabilities, and advanced levels of information technology. This concentration of financial resources cultivates a rich ecosystem of scientific and innovative activities, bolstering the vigor of innovation and leading to an increase in innovative outputs. Such dynamics further propel the high-quality development of the economy. Further analyzes found that digital economic has a significant positive moderating effect in the process of Sci-Tech finance for high-quality economic development, which can enhance the impact of Sci-Tech finance on high-quality economic development. From a regional perspective, digital infrastructure in the eastern and western regions has a significantly positive moderating effect on Sci-Tech finance in promoting high-quality economic development, while the moderating effect in the central region is not significant. With the continuous development of the digital economy, the impact of Sci-Tech finance on high-quality economic development may undergo a process of first weakening and then strengthening, and its impact exhibits a non-linear pattern.

Recommendations. Sci-Tech finance plays a crucial role in allocating financial resources to the science and technology sector, aiming to boost Sci-Tech innovation. In the digital economy, enhancing both Sci-Tech finance and digital infrastructure is crucial for cultivating China's innovative productivity and driving high-quality economic growth. Drawing on research findings, several recommendations are proposed:

(I) Boost government financial backing for Sci-Tech, utilize financial funds to attract social capital into Sci-Tech, and amplify the contribution of Sci-Tech finance to the science and technology sector. With financial support as a catalyst, encourage private investment in science and technology innovation, optimize the financing service framework of Sci-Tech finance, introduce innovative financial solutions, and ensure Sci-Tech finance accurately supports the industry. Implement specialized financial services for enterprises with the "specialized, special and new" characteristics, directing financial resources towards small and medium-sized enterprises in the science and technology field.

(II) Strengthen synergistic cooperation between Sci-Tech financial regions and guiding financial resources to flow across regions. By leveraging the eastern region's strengths in finance and science and technology, along with its information technology capabilities, there is an initiative to establish a financial service docking platform between the east and west. This strategy aims to motivate investment from the East in the West's technology sector, facilitating the exchange and collaboration of technological and financial assets. Such an approach is designed to spur balanced regional growth.

(III) Give full play to the facilitating role of information infrastructure and enhance the level of financial technology. It is necessary to continuously push and enhance the construction of digital infrastructure, with an emphasis on expanding big data centers and mobile information networks, including the rollout of 5G base stations. This infrastructure serves as the backbone for digital economy growth. There is an accelerated push towards adopting blockchain and other cutting-edge fintech innovations. The eastern region is encouraged to leverage digitization to amplify financial innovation and cultivate the innovative use of blockchain, internet of things, and other digital technologies in finance. Meanwhile, the western region is intensifying efforts to upgrade its digital infrastructure, enhance mobile information networks, and extend 5G connectivity. This is aimed at cultivating a merger between information technology and finance, thereby advancing the sector's digitization and intelligent capabilities.

(IV) Establishing a shared Sci-Tech financial platform is essential to enhance the accurate allocation of Sci-Tech financial resources. To achieve this, the government should assume a guiding and regulatory role by ensuring the real-time dissemination of relevant financial policies, product information, service details, and financing channels, with a strong emphasis on accuracy. This will facilitate the development of a robust Sci-Tech financial system led by the government, marked by the proactive involvement of both financial institutions and Sci-Tech enterprises. This system should encourage adaptable and diverse investment and financing models across a wide array of channels, enabling the exchange of financial information among these three key stakeholders. Therefore, this will effectively direct social capital toward high-potential scientific and technological enterprises, offering a consistent influx of capital to propel technological innovation and industrial upgrading. In addition, the system should facilitate the efficient flow of social capital to Sci-Tech enterprises, injecting a steady stream of financial resources into their technological innovation and industrial upgrading. Simultaneously, financial institutions must prioritize ongoing innovation, readily adopting digital finance trends and utilizing cutting-edge technologies to drive the transformation of financial service platforms towards enhanced intelligence and digitalization. By integrating and optimizing financial resources, financial institutions should focus on establishing closer, more accurate collaborative mechanisms with technology enterprises. This will result in greater accuracy in investment decisions and effective management of investment risks. Moreover, financial institutions should leverage the full potential of internet technology to continuously enhance the Sci-Tech financial information sharing platform. This ensures the timeliness, comprehensiveness, and accuracy of investment and financing information, thereby expediting the efficient connection of capital with promising projects and finally injecting renewed vigor into Sci-Tech innovation and broader economic development.

Data availability
Data will be made available through the corresponding author.

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Author contributions
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Competing interests
The authors declare no competing interests.

Ethical approval
This study used publicly available data and, therefore, needed no ethical approval.

Informed consent
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Additional information
Correspondence and requests for materials should be addressed to Chunsheng Wang.