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RESEARCH ARTICLE

Science and Technology Finance, Technology Transfer, and Upgrading of the Manufacturing Value Chain*

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Abstract

In the current "dual circulation" development paradigm, science and technology finance provides strong support for breaking the low-end lock-in of China's manufacturing sector within the global value chain. Utilizing provincial panel data from China covering the period from 2011 to 2021, this study empirically examines the impact of science and technology finance on the upgrading of the manufacturing value chain from the perspective of technology transfer. The findings indicate that science and technology finance can promote the upgrading of the manufacturing value chain, with this promoting effect exhibiting regional and source heterogeneity. For one thing, the impact of science and technology finance on value chain upgrading is notably significant in Chinese eastern regions. For another, science and technology finance inputs from venture capital institutions, capital markets, and enterprises significantly drive the upgrading of the manufacturing value chain. In terms of the impact mechanism, technology transfer plays a partial mediating role in the process by which science and technology finance promotes the upgrading of the manufacturing value chain; however, the mediating effect of technology transfer varies based on the source of science and technology finance input. Furthermore, the promoting effect of science and technology finance on the upgrading of the manufacturing value chain also displays nonlinear characteristics, becoming more pronounced when the level of technology transfer surpasses a certain threshold.

Keywords science and technology finance; technological sophistication; technology transfer; manufacturing value chain

1 Introduction

In recent years, the international economic situation has been highly volatile, prompting China to establish a new "dual circulation" (the domestic economic cycle plays a leading role while the international economic cycle remains its extension and supplement) development paradigm, while exports continue to play a significant role in China's economic development. In 2021, exports contributed 1.7 percentage points to GDP growth, accounting for 20.9% of the total GDP growth. Simultaneously, the structure of export products has undergone significant changes. By 2021, the share of processing trade in total exports fell to 21.7%, while the share of general trade rose to 61.6%. Upgrading of the manufacturing value

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chain is characterized by notable effects in technological progress (Wang et al., 2021; Yang et al., 2022), energy conservation, emission reduction (He & Xie, 2022; Zhou et al., 2021), and economic growth (Zhou et al., 2022). Achieving the upgrading requires continuous enhancement of the technological sophistication of manufacturing exports, with the primary focus being on strengthening industrial innovation capabilities (Li et al., 2019). A lot of scholars have explored the theoretical logic and operational mechanisms affecting export technological sophistication from perspectives such as human capital, the openness of producer service sectors, and the application of industrial robots (Lu & Jin, 2020). From a financing perspective, both the transformation and upgrading of traditional manufacturing sectors and the research and development (R&D) of new technologies in advanced manufacturing sectors require substantial inputs of human and material capital, which entail high costs. To mitigate risks, enterprises may reduce or even halt investments in high-risk R&D projects with uncertain or unstable future returns. This can severely hinder the enhancement of China's innovative capabilities, adversely impacting the quality and technological content of manufacturing export products and making it difficult to achieve global value chain (GVC) upgrading. As a new business model, science and technology finance can overcome the limitations of traditional finance, which often fails to meet the diverse funding needs of enterprises at different stages. It provides diversified financial services (Li et al., 2023; Zhou et al., 2022) and can also offer non-financial resources and supervision during and after the process of new product R&D, effectively enhancing the technology innovation capabilities of manufacturing enterprises (Tian et al., 2020). Therefore, it is essential to conduct an in-depth study on how science and technology finance, through the provision of supportive products, services, and policy assistance, can help enterprises strengthen their technology innovation capabilities, thereby aiding China's manufacturing sector in breaking the "low-end lock-in" situation and achieving product technological upgrades and GVC upgrading.

Research has shown that technology markets in various regions enhance China's export technological sophistication through multiple pathways, thereby supporting the manufacturing sector's climb in the GVC (Dai, 2018). In 2021, the transaction volume of China's technology market reached 3,729.43 billion yuan, marking a growth rate of 32%. Furthermore, the Ministry of Science and Technology of China explicitly proposed a plan to build a market scale of 5 trillion yuan in 2022. This raises the question: Does technology transfer play a significant role in alleviating financing constraints and strengthening oversight in the context of science and technology finance, thereby improving the technological sophistication of China's manufacturing exports? Addressing this question is crucial for enhancing the export technological sophistication of China's manufacturing sector and positioning it favorably within the "smile curve" of global industrial chain division.

Many scholars measure the technological sophistication of manufacturing exports to assess the level of upgrading in the manufacturing value chain. However, research on the relationship between science and technology finance and upgrading in the manufacturing value chain is relatively scarce. Literature discussing their indirect connections can provide valuable insights. For instance, Rossi et al. (2020) analyze sources of venture capital and find that it fosters technology innovation, creating new markets and enabling enterprises to reconfigure their value chains. Sun (2022) studies the relationship between digital finance, the development of small and medium enterprises (SMEs), and the GVC upgrading of manufacturing sectors, concluding that digital finance promotes this upgrading by enhancing the development levels of regional SMEs. Xu (2022) argues that the factor characteristics and market advantages of digital technology empower the manufacturing industry to achieve value chain upgrading, and provides an in-depth analysis of the practical influencing factors and targeted pathways through which the digital economy promotes the upgrading of the manufacturing value chain. These studies provide valuable experience for analyzing the relationship between science and technology finance and upgrading in the manufacturing value chain. They reveal that science and technology finance can assist the manufacturing sector in achieving innovative breakthroughs through new technologies or processes, prompting continuous innovation and value chain upgrading.

Research on the relationship between science and technology finance and technology transfer is relatively limited. For instance, Wang et al. (2022) find that science and technology finance policies can effectively regulate technology transfer networks, which serve as important spaces for promoting the application of intellectual property in China. Dong (2022) discovers that science and technology finance facilitates technology transfer between different regions, with R&D investment playing a partial mediating role in this process. Cui et al. (2019) measure the support efficiency of finance for technology transfer in the Yangtze River Basin and conduct a comparative analysis with other basins to explore factors affecting technology transfer efficiency. Xu et al. (2022) find that enterprises receiving venture capital, when forming alliances with enterprises that have strong technology transfer capabilities, can significantly enhance their levels of technology transfer. Civera et al. (2020), focusing on universities as the research subject, find that universities endowed with abundant knowledge resources positively impact technology transfer. From the above analysis, it is evident that science and technology finance, as a crucial supporting factor, can stimulate technology innovation in manufacturing sectors by promoting technology transfer among different entities or regions, thereby having a significant impact on the upgrading of the manufacturing value chain.

Regarding the relationship between technology transfer and upgrading in the manufacturing value chain, many scholars have conducted effective research. For example, Dai (2018) finds that the development of technology markets can enhance the technological sophistication of product exports through multiple pathways, promoting the upgrading of high-tech industry value chains, although this promoting effect can be influenced by major events or shifts in dominant policies. Durand and Milberg (2020) find that achieving GVC integration requires dense information flow and the mobilization and circulation of intangible assets. Swinnen and Kuijpers (2019) discover that value chain innovation is closely related to technology transfer in developing and emerging countries. The promoting effect of technology transfer on the upgrading in the manufacturing value chain is also reflected in technology innovation; for instance, Du and Wang (2021) find that skill-biased technological progress directly drives the upgrading in the manufacturing value chain, with intellectual property protection playing a role in this process. Han and Yan (2018) apply the GMM model and find that the impact of green technology innovation capabilities on the upgrading of China's manufacturing value chain is overall nonlinear. From the aforementioned literature, it is evident that technology transfer can impact the upgrading of China's manufacturing value chain in both linear and nonlinear ways through mechanisms like technological spillovers. Placing science and technology finance, technology transfer, and upgrading in the manufacturing value chain within the same research framework and analyzing their interrelationships is significant for the advancement of China's manufacturing sector in the context of a challenging economic environment. Therefore, this paper conducts a systematic exploration from both theoretical and empirical perspectives based on the existing literature.

2 Theoretical Foundation and Research Hypotheses

2.1 Science and Technology Finance and Upgrading of the Manufacturing Value Chain

Export technological sophistication is a comprehensive reflection of the technological content and production efficiency of export products (Hausmann et al., 2007), and its level primarily depends on the degree of technology innovation and progress (Wang et al., 2010). Within the global system of international vertical specialization, persistent advancements in the technological sophistication of a sector's exports signal its ongoing ascent toward higher segments of the value chain (Chen & Liu, 2013). Therefore, a region with a high level of technological sophistication in manufacturing exports signifies that its manufacturing sector is positioned at the high end of the value chain, characterized by products with high added value and technological content, resulting in strong market competitiveness and high bargaining power. Science and technology finance represents an emerging integration of technology and finance. It encompasses a multi-layered financial system that includes technology funding from the government, technology loans from financial institutions, venture capital, internal R&D funding from enterprises, and capital market channels. This system can provide comprehensive support for technology innovation in enterprises and promote their upgrading in the GVC. Firstly, science and technology finance offers funding support for new product R&D and production, technology innovation, and equipment upgrades. This helps to facilitate innovation output and commercialization and enhances the technological content and differentiation of China's manufacturing export products, thereby expanding the international competitive advantage of its manufacturing sector and achieving upgrading in the manufacturing value chain. Secondly, the accumulation of innovative resources generated through science and technology finance inputs also aids enterprises in strengthening their independent innovation capabilities and improving innovation efficiency, allowing them to upgrade to the high end of the GVC while catching up with the forefront of science and technology in the world. Finally, enterprises face various risks during the processes of technology innovation and production application. Science and technology finance effectively mitigates and transfers these risks by providing a range of tailored financial systems, tools, policies, and services, thereby reducing liquidity issues and minimizing market risks encountered during the upgrading of the manufacturing value chain. In summary, science and technology finance promotes the upgrading of the manufacturing value chain through pathways such as facilitating innovation output and new product production, achieving equipment upgrades, improving innovation efficiency, and diversifying innovation risks.

Therefore, this paper proposes the following hypothesis:

H1: Science and technology finance effectively promotes the upgrading of the manufacturing value chain.

2.2 Mediating Effects of Technology Transfer

Science and technology finance influences enterprise development at various stages of technology innovation. It rationally allocates financial resources through fiscal funds, venture capital, or credit capital, and facilitates the subsequent transformation and value compensation of technological achievements through means such as technology licensing, transfer of usage rights, and commercialization (Cui et al., 2019). As a result, the technological sophistication of manufacturing enterprises' product exports is enhanced, continuously upgrading the overall industry value chain. This effect manifests in three main aspects: Firstly, science and technology finance promotes the transfer of innovation outcomes from the supply side to the demand side, enhancing innovation capabilities through the productization and commercialization of these outcomes (Cai, 2015). This further incentivizes both parties involved in technology transfer to continue engaging in technology innovation and new product R&D, ultimately facilitating the upgrading of the manufacturing GVC. Secondly, science and technology finance inputs assist enterprises in achieving equipment upgrades or developing new products, thereby helping them continuously enhance their competitiveness and, in turn, realize the GVC upgrading (Zhang et al., 2016). Lastly, the technology-oriented nature of science and technology finance inputs stimulates invested enterprises to acquire cutting-edge technologies through technology transfer, thus reducing R&D risks, shortening innovation cycles, and rapidly generating technology spillover effects that propel the upgrading of the manufacturing value chain. Therefore, this paper proposes the following hypothesis:

H2: Technology transfer plays a mediating role in the process by which science and technology finance promotes the upgrading of the manufacturing value chain.

In the process where science and technology finance promotes industrial value chain upgrading through technology transfer, the differing aspirations of enterprises at different life cycle stages lead to variations in the types of science and technology finance inputs and methods of technology transfer. As shown in Table 1, for seed-stage enterprises, science and technology finance inputs primarily consist of venture capital and internal R&D funding. At this stage, the aspirations for technology transfer are primarily manifested in two ways: For one thing, stimulating independent R&D to identify technological advantages and product features; for another, diversifying R&D risks to enhance the success rate of innovation and entrepreneurship. For growth-stage enterprises, science and technology finance inputs mainly come from capital markets and internal R&D funding. Here, the aspirations for technology transfer focus on: Firstly, introducing, absorbing, and applying new technologies to fully exploit market potential and continuously strengthen the enterprise's technological advantages and product features; secondly, continually upgrading technical equipment to reduce production costs and improve efficiency, thereby enhancing market competitiveness. For maturity-stage enterprises, venture capital gradually withdraws, and market capital cautiously decides on entry and exit strategies based on the enterprise's trajectory. At this stage, pure technology transfer is often insufficient for gaining a competitive advantage; enterprises increasingly rely on their own R&D investments for exploratory technology innovation to address market challenges, respond to competitive risks, and expand their competitive edge. Clearly, the operational mechanisms through which science and technology finance influences the upgrading in the manufacturing value chain via technology transfer are potentially linked to the life cycle stage of the enterprise and the types of science and technology finance inputs. Notably, the path effects are more significant in the seed and growth stages, while they are relatively less significant in the maturity stage (and even the exit stage), particularly concerning venture capital that opts to exit strategically. Therefore, this paper proposes the following hypothesis:

H3: The mediating effect of technology transfer in the process by which science and technology finance inputs promote the upgrading of the manufacturing value chain will vary depending on the type of science and technology finance input.

Table 1 Sources of Science and Technology Finance Input and Technology Transfer Aspirations at Different Life Cycle Stages

Life cycle stage	Type of science and technology finance input	Entry and exit decisions	Technology transfer aspirations
Seed stage	Venture investment	Input	Technology upgrading, risk (R&D) diversification
	Corporate R&D funding	Input	Technology upgrading
	Technology capital markets	–	–
Growth stage	Venture investment	–	–
	Corporate R&D funding	Input	Technology upgrading, equipment upgrading
	Technology capital markets	Input	Technology upgrading, equipment upgrading

(*To be continued*)

(*Continued*)

Life cycle stage	Type of science and technology finance input	Entry and exit decisions	Technology transfer aspirations
Maturity stage	Venture investment	Exit	–
	Corporate R&D funding	Input	Technology upgrading, risk (market) diversification
	Technology capital markets	Input/exit	Technology upgrading, equipment upgrading

2.3 Threshold Effect of Technology Transfer

The impact of science and technology finance on the upgrading in the manufacturing value chain varies across different levels of technology transfer.

In regions with low levels of technology transfer, the technology market is underdeveloped, making it difficult to assess patent values. The forms of technology transactions are limited, and a comprehensive technology transaction service system has yet to be established. As a result, local enterprises struggle to learn advanced technologies from other regions through technology transfer. Additionally, these regions lack a solid technological foundation and a favorable innovation environment, leading to a shortage of scientific and technological talent and weak technology innovation capabilities, which creates a vicious cycle. Large enterprises often prefer to partner with firms that have a strong innovation base and abundant technical talent when selecting R&D collaborators. Consequently, in regions with low levels of technology transfer, science and technology finance fails to fully realize its innovative effects, making it challenging to acquire advanced technologies through technology transfer and achieve corporate technology and equipment upgrades. This hinders improvements in product quality, enhancements in corporate competitiveness, and the upgrading of the manufacturing value chain.

In contrast, regions with high levels of technology transfer feature a well-developed and mature technology transaction market. Supporting services such as intellectual property protection, value assessment, and business consulting are comprehensive, providing local enterprises with abundant resources and a conducive innovation environment. Seed-stage enterprises, even without access to high technology, can utilize the technology transaction market to obtain advanced technologies or patents and then engage in secondary R&D and other innovative activities based on these assets. Furthermore, favorable regional conditions help attract scientific and technological talent, creating agglomeration effects that further enhance local technology innovation capacity, efficiency, and quality. Enterprises also have more opportunities to collaborate with other high-tech firms, improving their technology innovation efficiency and quality. Therefore, in regions with high levels of technology transfer, the advantages of science and technology finance inputs, such as funding, technology, and talent, assist enterprises in increasing the technological content and differentiation of their products, expanding into overseas markets, and subsequently promoting the upgrading of the manufacturing value chain. Therefore, this paper proposes the following hypothesis.

H4: Technology transfer has a threshold effect in the process through which science and technology finance inputs influence the upgrading of the manufacturing value chain.

3 Research Design

3.1 Variable Definition

3.1.1 Explained Variable

Upgrading of the manufacturing value chain. Drawing on the methods of Hausmann et al. (2007) and Qiu et al. (2012), the GVC position of the manufacturing sector is measured using the technological sophistication of regional manufacturing exports. The technological sophistication of exports reflects the quality of export products (Qiu et al., 2012); the higher the sophistication, the higher the position in the GVC. Hausmann et al. (2007) construct the measure of technological sophistication of export products (*PRODY*) based on this logic and then calculate the overall technological sophistication (*EXPY*), which includes all types of products. However, the per capita GDP used in this indicator can be affected by information from non-manufacturing sectors, making it ineffective in reflecting the actual state of manufacturing development. Improvements to this method are necessary (Li et al., 2022). Therefore, drawing from the measurement method of Li et al. (2022), Manufacturing Labor Productivity (*ML*), which effectively reflects the human, financial, and technological conditions of the manufacturing sector (Li & Yan, 2018), is used instead of per capita GDP to optimize the *PRODY* and *EXPY* indicators. The calculation formula is as follows:

$$PRODML_m = \sum_i \frac{x_m / X_i}{\sum_i x_{im} / X_i} ML_i, \tag{1}$$

$$EXPML_i = \sum_m \frac{x_{im}}{X_i} PRODML_m. \tag{2}$$

In this context, $PRODML_m$ and $EXPML_i$ represent the optimized product technological sophistication and the technological sophistication of manufacturing exports, respectively. This paper uses $EXPML_i$ to measure the upgrading of the manufacturing value chain in various provinces of China. Here, ML_i denotes the manufacturing labor productivity in province i, x_{im} represents the export value of category m products from the manufacturing sector in province i, and x_i indicates the total export value of the manufacturing sector in province i.

3.1.2 Explanatory Variable

Science and technology finance. Science and technology finance embodies a rich conceptual connotation. Xu et al. (2011) and Zhang et al. (2015) establish different indicator systems for science and technology finance by applying various methods. This paper draws on relevant research methods to select the following indicators to measure the financial contributions to technology innovation from various sources: technology funding from government (*TF*), technology loans from financial institutions (*TL*), total market value of technology-based listed companies (*TMV*), venture capital amount (*VC*), and corporate funds (*CF*). These indicators represent the financial investments from government departments, financial institutions, capital markets, venture capital firms, and enterprises. Additionally, the entropy method is employed to calculate the science and technology finance composite indicator (*STF*). Table 2 presents the indicator system for science and technology finance along with the weights assigned to each indicator.

Table 2 Construction of Composite Indicators for Science and Technology Finance

Variable	Indicator	Indicator description	Weight
Science and technology finance (*STF*)	Technology funding from government (*TF*)	*TF* / regional GDP	0.0896035
	Technology loans from financial institutions (*TL*)	*TL* / regional GDP	0.1529796
	Venture capital amount (*VC*)	*VC* / regional GDP	0.451961
	Capital market (*TMV*)	*TMV* / regional GDP	0.2310129
	Corporate R&D funding (*CF*)	*CF* / regional GDP	0.074443

3.1.3 Mediating/Threshold Variable

Level of technology transfer. Gibson and Smilor (1991) redefine technology transfer based on previous studies, asserting that all technology transfers occurring in spatial domains—such as interactions and activities between different individuals, groups, and institutions—fall under the category of technology transfer. Many scholars measure regional technology transfer levels from various perspectives. Since the transaction volume of the technology market can reflect the exchange of technological goods among provinces (Dai, 2018; Zhang et al., 2016), this paper uses the ratio of the technology market contract transaction volume to regional GDP to represent technology transfer levels, thereby avoiding the influence of regional economic development levels.

3.1.4 Control Variables

Drawing on relevant literature, this paper selects the following control variables: technology innovation (*LAPPLY*), measured by the logarithm of the number of patents granted in each province; fiscal expenditure (*FISCAL*), assessed by the ratio of fiscal expenditure to regional GDP for each province; human capital (*LRDP*), represented by the logarithm of the equivalent number of R&D personnel in each province; and industrial structure (*SH*), evaluated by the ratio of the added value of the tertiary industry to that of the secondary industry. All variable selections are summarized in Table 3.

Table 3 Selection of Variables

Variable category	Variable meaning	Selected indicator	Variable symbol
Explained variable	Manufacturing value chain upgrading	Technological sophistication of manufacturing exports	*EXPML*
Core explanatory variable	Science and technology finance	Total science and technology finance input	*STF*
Mediating/threshold variable	Technology transfer	Technology market turnover / regional GDP	*TT*
Control variable	Industrial structure	Added value of tertiary industry / added value of secondary industry	*SH*
	Fiscal expenditure	Fiscal expenditure amount / regional GDP	*FISCAL*
	Human capital	Logarithm of the equivalent number of R&D personnel	*LRDP*
	Technology innovation	Logarithm of patent granted number	*LAPPLY*

3.2 Model Construction

3.2.1 Basic Model Construction

$$EXPML_{it} = \gamma_0 + \gamma_1 STF_{it} + \gamma_i \sum X_{it} + u_i + \lambda_i + \varepsilon_{it}. \tag{3}$$

In the equation, i represents the region, and t denotes the year. $EXPML_{it}$ is the explained variable indicating the level of value chain upgrading in the manufacturing sector. STF_{it} is the core explanatory variable representing the level of science and technology finance inputs. X_{it} represents the control variables, λ_i denotes the cross-section effect, u_i is the time-fixed effect, and ε represents the random disturbance term that varies with individuals and time.

3.2.2 Mediating Effect Model Construction

Referring to the mediating effect test method by Wen et al. (2014), the mediating effect model is established as shown in equations (4) and (5).

$$TT_{it} = \alpha_0 + \alpha_1 STF + \alpha_i \sum X_{it} + u_i + \lambda_i + \varepsilon_{it}, \tag{4}$$

$$EXPML_{it} = \gamma_0 + \gamma_1 STF_{it} + \gamma_2 TT_{it} + \gamma_i \sum X_{it} + u_i + \lambda_i + \varepsilon_{it}. \tag{5}$$

In this context, TT_{it} represents the mediating variable of technology transfer. The mediating effect test process is as follows:

First, the regression method is applied to equation (3) to assess the significance of the science and technology finance coefficient, determining whether the overall effect of science and technology finance on the upgrading of the manufacturing value chain is significant. If the coefficient is significant, the overall effect is deemed significant and vice versa.

Next, the ordinary least squares (OLS) regression method is employed for equations (4) and (5). If the science and technology finance coefficient in equation (4) is significant and the technology transfer coefficient in equation (5) is also significant, then the indirect effect is considered significant and vice versa.

Then, the science and technology finance coefficient in equation (5) is tested. If it is significant, the direct effect is deemed significant; if not, the mediating effect is established.

Finally, by comparing the symbols of the indirect and direct effects, if both symbols are the same, a mediating effect exists; if they differ, it indicates a suppression effect.

3.2.3 Threshold Effect Model Construction

Referring to Hansen (1999), the technology market turnover is considered as the threshold variable for the model. The following model is established:

$$EXPML_{it} = \eta_0 + \eta_1 STF_{it} \cdot I(TT_{it} \leqslant \delta_1) + \eta_2 STF_{it} \cdot I(TT_{it} > \delta_1) + \eta_i \sum X_{it} + \varepsilon_{it}. \qquad (6)$$

In this model, δ_1 represents the threshold value corresponding to the technology market turnover. The indicator function $I(\cdot)$ is defined such that if the equation inside the parentheses holds true, I takes the value of 1; otherwise, I takes the value of 0.

3.3 Sample Selection and Data Sources

This paper selects 30 provinces and municipalities in the Chinese mainland (excluding Xizang Autonomous Region due to significant data deficiencies) as the research subjects, covering the period from 2011 to 2021. For the science and technology finance variables, *TF* data are sourced from the *China Statistical Yearbook on Science and Technology*, while *TL* data come from the *China Financial Statistical Yearbook*. Other data are obtained from the Wind database. Additionally, export data related to the technological sophistication of manufacturing exports are sourced from the DRCNet, and the technology market turnover data are also derived from the *China Statistical Yearbook on Science and Technology*. Control variable data are sourced from various editions of the *China Statistical Yearbook on Science and Technology* and *China Statistical Yearbook*. Some missing data are supplemented using interpolation methods. The empirical analysis, including data and model computations, is conducted using EViews and Stata software.

To ensure the accuracy of the data, descriptive statistics for each variable are conducted, with results presented in Table 4. The findings indicate that the data are normal with no outliers.

Table 4 Results of Descriptive Statistics

Variable	*M*	*SD*	*Max.*	*Min.*	*Skewness*	*Kurtosis*
EXPML	8.1893	0.0828	7.9784	8.4730	0.0523	3.0916
STF	0.1077	0.1264	0.0167	0.8448	3.5131	17.0563
TT	0.0164	0.0287	0.0002	0.1757	3.7359	17.9844
FISCAL	0.2492	0.1030	0.1050	0.6422	1.4551	5.5316
LRDP	11.2216	1.1959	8.2960	13.6936	–0.3672	2.7377
SH	1.3612	0.7515	0.5270	5.5800	3.2701	15.3981
LAPPLY	10.7764	1.3955	6.5958	13.7960	–0.3963	3.0149

4 Empirical Results and Analysis

4.1 Benchmark Regression Results

First, F-tests and Hausman tests were performed to determine whether to choose the fixed effects model, random effects model, or mixed OLS model. The results indicate that a double fixed effects model should be selected. To accurately examine the impact of science and technology finance on the upgrading of the manufacturing value chain, we follow a general-to-specific approach, with detailed regression results presented in Table 5.

Table 5 Basic Regression Results

Variable	*EXPML*				
	(1)	(2)	(3)	(4)	(5)
STF	0.1065*** (2.7955)	0.1103*** (2.9293)	0.1166*** (3.1106)	0.1184*** (3.0896)	0.1313*** (3.4152)
FISCAL		–0.1643*** (–2.9063)	–0.1627*** (–2.8973)	–0.1595*** (–2.7522)	–0.2561*** (–3.6038)
LRDP			0.0135** (2.2115)	0.0131** (2.0991)	–0.0259** (2.3146)
SH				–0.0024 (–0.2336)	–0.0045 (–0.4313)
LAPPLY					0.0153** (2.4315)
C	8.1779*** (1,897.4220)	8.2184*** (563.4491)	8.0723*** (119.3712)	8.0782*** (111.8969)	8.37010*** (57.5735)
Province	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
R^2	0.9262	0.9283	0.9295	0.925505	0.9309
F-statistic	90.7308	91.0047	90.1545	76.02143	87.2029
N	330	330	330	330	330

Note. The values in parentheses represent *t*-statistics. *** $p < 0.01$ and ** $p < 0.05$.

In column (1), the relationship between science and technology finance and upgrading in the manufacturing value chain is analyzed separately. The result shows that the coefficient for science and technology finance is 0.1065, which is significantly positive. This indicates that science and technology finance can promote the upgrading of the manufacturing value chain, enhancing the international competitiveness of China's manufacturing products and facilitating high-quality exports. As control variables are added sequentially, columns (2) to (5) demonstrate that the science and technology finance coefficient remains significantly positive at the 1% level. This indicates that the parameter estimates for the core explanatory variable are robust, further validating the positive impact of science and technology finance on the upgrading of the manufacturing value chain, thereby confirming *H1*. Notably, column (5) shows that after controlling for all other variables, the science and technology finance coefficient is 0.1313 and remains significant. This suggests that with the assistance of current information technologies, such as big data and cloud computing, supported by science and technology finance, substantial social capital is injected into the field of technology innovation. This revitalizes the R&D of new products, technology innovation, and high-quality development in manufacturing, helping China's manufacturing sector adapt to changes in external economic conditions, break the "low-end lock-in" of the division of labor, and achieve a rise in the GVC.

4.2 Heterogeneity Analysis

4.2.1 Regional Heterogeneity Analysis

Table 6 presents the regression results for regional heterogeneity in columns (1) to (3), indicating that the coefficient for science and technology finance is significantly positive only in the eastern region, while it is not significant in the central and western regions. This demonstrates that science and technology finance has a clear incentivizing effect on the upgrading of the manufacturing value chain solely in the eastern region. The reasons for this include the following: First, enterprises in the eastern region have a solid technological foundation and outstanding resource advantages, attracting top innovative talent from across the country. This makes them more likely to receive venture capital and other forms of science and technology finance, leading to a concentration of science and technology finance in the eastern region and creating a polarization effect. Second, the manufacturing sector in the eastern region predominantly consists of technology- or capital-intensive industries with higher sophistication, while lower-sophistication labor-intensive and resource-intensive industries are gradually shifting to the central and western regions. Based on industrial development prospects, science and technology finance tends to favor technology-intensive industries in the eastern region. Additionally, to help address China's "bottleneck" technology challenges, science and technology finance is also more inclined to focus on the eastern region under the guidance of national policies. In contrast, the central and western regions are primarily dominated by labor-intensive and resource-intensive industries, which have relatively backward technology. As a result, the influence of science and technology finance in these regions is limited and insufficient to promote the upgrading of their manufacturing value chain.

Table 6 Regression results of regional heterogeneity

Variable	*EXPML*		
	(1) Eastern region	(2) Central region	(3) Western region
STF	0.0510** (2.3014)	–0.002571 (–0.0104)	0.087156 (0.8507)
CONTROLS	Yes	Yes	Yes
C	8.7486*** (36.5582)	8.962587*** (35.2523)	7.222237*** (18.6675)
Province	Yes	Yes	Yes
Year	Yes	Yes	Yes
R^2	0.9612	0.9414	0.9289
F-statistic	94.1327	52.3572	46.2896
N	121	99	110

Note. Due to space limitations, the regression results for the control variables are omitted here and in similar contexts. The values in parentheses represent *t*-statistics. *** $p < 0.01$ and ** $p < 0.05$.

4.2.2 Heterogeneity Analysis of Science and Technology Finance Input Types

Table 7 presents the regression results for the heterogeneity of science and technology finance input types in columns (1) to (5). The results indicate that the coefficients for *VC*, *CF*, and *TMV* are significantly positive in their impact on the upgrading of the manufacturing value chain. In contrast, the coefficients for *TF* and *TL* are not significant, suggesting that currently only *VC*, *CF*, and *TMV* have a clear incentivizing effect on the upgrading of the manufacturing value chain. Among the three, *CF* has the most significant incentivizing effect, as it directly supports the R&D of new technologies or products, thereby enhancing the technological sophistication of product exports and directly driving the upgrading of the manufacturing value chain. Although *VC* and *TMV* can be freely allocated by enterprises after injection, they may be used for operational or management activities, resulting in a weaker incentivizing effect compared to *CF*. *TF* shows a positive but insignificant effect on the upgrading of the manufacturing value chain. This is due to limited *TF*, which is provided to enterprises without charge. Additionally, the lack of constraints leads to issues such as inequitable distribution and difficulties in regulation, rendering these funds ineffective in promoting technology innovation and unable to significantly drive the upgrading of the manufacturing value chain. *TL* has a negative but insignificant impact on the upgrading of the manufacturing value chain. This is primarily due to the limited availability of *TL* and issues such as supply-demand imbalance and resource misallocation. Specifically, most banks prefer stable lending channels to mitigate risks, making it challenging for smaller private enterprises, which are crucial for technology innovation, to secure *TL*. Consequently, insufficient R&D investment hinders the technological R&D activities of these private enterprises, adversely affecting the upgrading of China's manufacturing value chain.

Table 7 Regression Results of Source Heterogeneity

Variable	*EXPML*				
	(1)	(2)	(3)	(4)	(5)
VC	0.35929*** (3.0325)				
CF		2.4248** (1.9875)			
TMV			0.0511** (2.0988)		
TF				1.8167 (1.0827)	
TL					–3.1026 (–0.4131)
CONTROLS	Yes	Yes	Yes	Controls	Yes
C	8.3192*** (57.4267)	8.4374*** (53.4068)	8.3189*** (85.3598)	8.3961*** (51.4756)	8.3254*** (56.2295)
Province	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
R^2	0.9306	0.9290	0.9287	0.9283	0.9281
F-statistic	86.9012	84.7673	84.3386	83.8901	83.5738
N	330	330	330	330	330

Note. The values in parentheses represent *t*-statistics. *** $p < 0.01$ and ** $p < 0.05$.

4.3 Mediating Effect Test

The impact of science and technology finance on the upgrading of the manufacturing value chain is realized through technology transfer pathways, with the mediating effect regression results shown in Table 8. The results indicate that in column (1), the regression coefficient for science and technology finance is positive and significant at the 1% level, suggesting that science and technology finance aids in improving regional technology transfer levels. In column (2), the regression coefficient for technology transfer is positive and significant at the 10% level, indicating a significant indirect effect. The regression coefficient for science and technology finance in column (2) is also significantly positive at the 1% level, confirming a significant direct effect. The regression coefficient γ_1 is 0.1172, which is less than the 0.1313 in column (5), demonstrating that technology transfer serves as a mediating variable whereby science and technology finance promotes the upgrading of the manufacturing value chain. This means that science and technology finance, through resource investments, facilitates equipment upgrades or process improvements, leading to continuous innovation output. These innovations are then transferred and commercialized among innovation entities, enhancing the innovation levels of enterprises and promoting the upgrading of China's manufacturing value chain. New products resulting from this transformation possess differentiated advantages, helping to strengthen international competitiveness and promote high-quality manufacturing exports. Additionally, technology transfer shortens product R&D cycles and improves technology innovation efficiency, further driving the upgrading of China's manufacturing value chain. This validates *H2*.

Table 8 Regression Results of the Mediating Effect of Technology Transfer

Variable	(1) *TT*	(2) *EXPML*
STF	0.0379*** (3.5309)	0.1172*** (2.9940)
TT		0.3727* (1.7644)
CONTROLS	Yes	Yes
C	0.0529 (1.3013)	8.3513*** (57.4800)
Province	Yes	Yes
Year	Yes	Yes
R^2	0.9550	0.9316
F-statistic	137.6000	85.9664
N	330	330

Note. The values in parentheses represent *t*-statistics. *** $p < 0.01$ and * $p < 0.1$.

In the process of science and technology finance driving the upgrading of the manufacturing value chain, the varying types of science and technology finance inputs may lead to different mediating effects of technology transfer, as shown in the regression results in Table 9. It is found that the regression coefficients for *TF* and *TL* are not significant, indicating that neither has a notable promoting effect. Column (2) shows that *CF* and *TMV* regression coefficients are significantly positive, and in column (3), the regression coefficient for technology transfer is also significantly positive, suggesting a significant indirect effect of technology transfer. However, the coefficients for *CF* and *TMV* in column (3) are positive but not significant, indicating that the direct effects are not significant. This means that in the process of *CF* and *TMV* promoting the upgrading of the manufacturing value chain, technology transfer plays a complete mediating role. This indicates that *CF* and *TMV* investments must obtain technical and resource support through technology transfer methods such as transactions or collaborations in order to effectively enhance the technology innovation capabilities of enterprises, increase the technological sophistication of product exports, and thereby promote the upgrading of the GVC. In both columns (1) and (3), the coefficients for *VC* are significantly positive, and the coefficient for technology transfer in column (3) is also significantly positive, indicating that both *VC* and technology transfer significantly advance the upgrading of the manufacturing value chain. However, the coefficient for *VC* in column (2) is not significant, suggesting that *VC* does not yet enhance technology transfer levels. In the process of *VC* driving the upgrading of the manufacturing value chain, technology transfer plays a significant mediating role. This aligns with the theoretical reasoning presented earlier, as *VC* typically enters during the seed stage to support innovation and entrepreneurship, then exits during the maturity stage, leading to gaps in the complete action cycle of technology transfer between *VC* and enterprise value chain upgrading. This impacts the effectiveness of the mediating effect and validates *H3*.

Table 9 Regression Results of the Mediating Effect of Technology Transfer in Different Sources of Science and Technology Finance Inputs

Science and technology finance	Variable	(1) *EXPML*	(2) *TT*	(3) *EXPML*
Corporate R&D funding	*CF*	2.4248** (1.9875)	1.5909*** (4.8137)	1.7581 (1.3924)
	TT			0.4191* (1.9257)
	CONTROLS	Yes	Yes	Yes
	R^2	0.9290	0.9566	0.9299
	F-statistic	84.7673	142.7847	83.7536
Technology capital markets	*TMV*	0.0511** (2.0988)	0.0516*** (6.1636)	0.0285 (0.9914)
	TT			0.4372** (2.2948)
	CONTROLS	Yes	Yes	Yes
	R^2	0.9287	0.9586	0.9296
	F-statistic	84.3386	149.9622	83.3697
Venture capital	*VC*	0.3724*** (3.2723)	0.0151 (0.4652)	0.3651*** (3.2322)
	TT			0.4838** (2.3449)
	CONTROLS	Yes	Yes	Yes
	R^2	0.9306	0.9531	0.9320
	F-statistic	86.9012	131.6665	86.4335

Note. The values in parentheses represent *t*-statistics. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

4.4 Threshold Effect Test

The impact of science and technology finance on the upgrading of the manufacturing value chain is complex, presenting different effects at varying levels of technology transfer. Therefore, this paper further establishes a panel threshold model, using technology transfer as the threshold variable for empirical testing and analysis. When applying the panel threshold model, the bootstrap method is employed for repeated sampling, with the number of bootstrap samplings limited to 400. Additionally, regressions are conducted sequentially under different threshold numbers to select the appropriate threshold number, as shown in Table 10. The results indicate that only the single-threshold effect is significant, leading to further examination of the single-threshold regression model to estimate the threshold value for technology transfer. The results reveal that in the single-threshold model, the threshold value is approximately 0.0019, with technology transfer levels primarily distributed between low ($TT \leqslant 0.0019$) and high ($TT > 0.0019$) intervals. Based on this, a statistical chart is created to illustrate the impact of science and technology finance on the upgrading of the manufacturing value chain, as shown in Figure 1, utilizing likelihood ratios to demonstrate the data formation process.

Table 10 Test Results of Threshold Effects

Threshold variable	Number of thresholds	*F* value	*P* value	Number of bootstrap samplings	Critical value			Threshold value
					10%	5%	1%	
Technology transfer	Single threshold	28.24*	0.0825	400	27.6199	30.6982	37.4411	0.0019
	Double threshold	21.96	0.225	400	27.9392	31.4285	41.853	/
	Triple threshold	9.04	0.94	400	36.802	39.9099	47.0988	/

Note. The values in parentheses represent t-statistics. * $p < 0.1$.

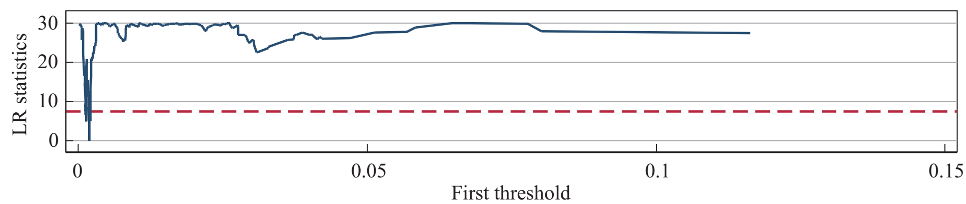

Figure 1 Statistics of Likelihood Ratio Test

The regression results of the single-threshold model are presented in Table 11. It can be observed that the impact of science and technology finance on the upgrading of the manufacturing value chain varies at different levels of technology transfer. At lower technology transfer levels, the coefficient for science and technology finance is negative (−1.0433), while at higher levels, the coefficient is positive (0.0579). This indicates that technology transfer plays different roles in the process of science and technology finance, promoting the upgrading of the manufacturing value chain. At lower levels of technology transfer, science and technology finance hinders the rise. In contrast, as the level increases, science and technology finance gradually exerts an incentivizing effect, promoting local upgrading in the manufacturing value chain. This is because, at lower levels of technology transfer, the regional technology transaction market is not well-developed, and enterprises have weaker technology innovation capabilities with fewer opportunities for R&D collaboration, making it difficult to attract *VC* and other science and technology finance resources. As technology transfer levels continue to rise, opportunities for R&D collaboration among innovative entities increase, and technology transactions or exchanges become more frequent, providing a superior innovation foundation and environment for the manufacturing sectors. This also encourages science and technology finance to fully exert its influence, helping enterprises improve their technology innovation efficiency and quality, continually achieve technological upgrades, and promote the upgrading of the manufacturing value chain. Thus, this validates *H4* of this paper.

Table 11 Regression Results of Threshold Effects

Variable	*EXPML*	*t* value
Interval 1 ($TT \leqslant 0.0019$)	−1.043335***	−4.80
Interval 2 ($TT > 0.0019$)	0.0579	0.71
LAPPLY	−0.0168737*	−1.76
FISCAL	−0.7696903***	−5.73
SH	0.0095	0.58
LRDP	−0.0369461*	−1.73
C	8.967547***	43.18
F value	15.32	/

Note. The values in parentheses represent *t*-statistics. *** $p < 0.01$ and * $p < 0.1$.

4.5 Robustness Test

4.5.1 Replacement of Core Explanatory Variable

In the previous analysis, the input data for science and technology finance is calculated using the entropy method. To conduct a robustness test, we replace the core explanatory variable and remeasure using principal component analysis. The resulting science and technology finance indicator, *STF1*, is then subjected to regression estimation, with the results shown in Table 12. The results indicate that the coefficient for science and technology finance's impact on the technological sophistication of manufacturing exports remains significantly positive. Furthermore, technology transfer plays a partial mediating role in this process, consistent with earlier findings. This suggests that the conclusions of this paper are robust and that the use of the entropy method to measure science and technology finance levels is accurate.

Table 12 Regression Results of Robustness Test

Variable	(1) *EXPML*	(2) *TT*	(3) *EXPML*
STF1	0.0683** (2.2242)	0.0467*** (5.6961)	0.0499* (1.7263)
TT			0.3931** (2.1997)
CONTROLS	Yes	Yes	Yes
C	8.3232*** (56.8896)	0.0403 (1.0294)	8.3074*** (82.5445)
Province	Yes	Yes	Yes
Year	Yes	Yes	Yes
R^2	0.9293	0.9579	0.9300
F-statistic	85.0821	147.2764	83.8959
N	330	330	330

Note. The values in parentheses represent *t*-statistics. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

4.5.2 Endogeneity Test

There may be an endogeneity issue due to potential bidirectional causality between science and technology finance and the upgrading of the manufacturing value chain. Therefore, we use the lagged value of science and technology finance inputs as a variable and employ an instrumental variable approach for the endogeneity test. The results show that the Anderson canon. corr. LM statistic is 69.54 ($p = 0.0000$); the minimum eigenvalue statistic, the Cragg-Donald Wald *F* statistic, is 89.16, which exceeds the critical value (16.38) at the 10% error level, indicating that there is no issue of under-identification or weak identification, confirming that the instrumental variable is valid and exogenous. The endogeneity test results are presented in Table 13. It can be observed that whether replacing the explained variable or considering the endogeneity issue, science and technology finance continues to significantly promote the upgrading of the manufacturing value chain, with regression results being fundamentally consistent with previous findings, thus validating the robustness of the research conclusions.

Table 13 Results for Endogeneity Test

Variable	(1)*STF*	(2)*EXPML*
STF		0.1319* (1.66)
L.STF	0.4919*** (9.44)	
CONTROLS	Yes	Yes
Province	Yes	Yes
Year	Yes	Yes
F value	89.1600	83.5400
N	300	300

Note. The values in parentheses represent *t*-statistics. *** $p < 0.01$ and * $p < 0.1$.

5 Conclusions and Policy Recommendations

5.1 Conclusions

This paper utilizes provincial panel data from China between 2011 and 2021 to measure the technological sophistication of manufacturing exports, assessing the position of manufacturing sectors within the GVC. It empirically examines the impact of science and technology finance on the upgrading of the manufacturing value chain from the perspective of technology transfer, reaching several conclusions. Firstly, science and technology finance promotes the upgrading of the GVC in manufacturing. Secondly, the promoting effect of science and technology finance inputs demonstrates significant regional and type-based heterogeneity, being more pronounced in eastern regions, while *VC*, *TMV*, and *CF* also exhibit notable effects. Thirdly, technology transfer plays a partial mediating role in this process, as *TMV* and *CF* leverage its effects throughout the enterprise life cycle. Lastly, when using technology transfer as a threshold variable, the promoting effect of science and technology finance shows nonlinear characteristics, facilitating the upgrading of the manufacturing value chain only when technology transfer levels surpass a specific threshold.

5.2 Policy Recommendations

(1) To foster the advancement of science and technology finance, it is imperative to enhance the investment and financing mechanisms for scientific and technological endeavors. First, establish *VC* guidance funds for various sub-sectors within manufacturing to attract angel investments and *VC* to the manufacturing innovation sector, while improving exit channels. Second, improve the intellectual property pledge financing system to provide new financing avenues for technology innovation enterprises, increasing the utilization rate of intellectual property and alleviating financing constraints. Finally, diversify the sources of science and technology finance, accelerate the development of *VC*, and guide private capital, insurance

funds, and foreign capital into the *VC* field to strengthen support for startups. This will promote independent innovation in advanced manufacturing sectors and the transformation of traditional manufacturing sectors, addressing critical technology constraints and facilitating the rise to high-end segments of the GVC.

(2) To facilitate the upgrading of China's manufacturing value chain, it is essential to enhance the nation's technology transfer capacity and strengthen the promotion mechanisms of science and technology finance. Accelerate the construction of technology transaction markets to form a diverse, distinctive, well-structured, and well-governed technology element transaction network that offers services such as intellectual property assessment, equity custody transfer, and technology property transactions. Increase opportunities for domestic and international technology exchange and cooperation among manufacturing enterprises, fostering technology spillover and raising technology transfer levels to enhance the role of domestic science and technology finance in supporting technology innovation and product exports, thereby boosting manufacturing competitiveness and value-added capabilities to upgrade to the high end of the GVC.

(3) To facilitate the efficient flow of technology and innovation resources, it is crucial to establish robust technology transfer platforms and networks. First, accelerate the digital transformation of China's manufacturing sector, improve technology information platform construction, and promote the flow of funds, talent, industry-academia-research collaboration, and technology transfer. This will enhance the role of technology transfer in increasing the technological sophistication of manufacturing exports through science and technology finance. Second, create an open information exchange platform to facilitate the flow and sharing of information, data, and resources between manufacturing and other industries, accelerating the process of industrial integration. Lastly, the technology innovation environment should be optimized by providing funding and talent for technology transfer, improving China's manufacturing innovation network, and fostering knowledge accumulation. This will strengthen the international competitiveness of Chinese manufacturing.

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