Climate Finance and Export Technological Sophistication of Manufacturing Firms: Evidence from China

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Abstract. Climate finance has become an important institutional arrangement linking climate governance, financial resource allocation, and low-carbon industrial transformation. Under the dual pressures of green transition and changing international trade requirements, manufacturing export upgrading should be evaluated not only by export scale but also by technological sophistication. This study examines whether city-level climate finance is associated with the export technological sophistication of Chinese manufacturing firms. Using a multi-source firm-city-year panel dataset covering Chinese manufacturing listed firms from 2008 to 2024, this paper matches firm-level product export information and financial characteristics with city-level climate finance indicators and regional economic variables. The empirical analysis applies a two-way fixed-effects model with firm and year fixed effects, and standard errors are clustered at the city level. The results show that city-level climate finance is positively associated with firms' export technological sophistication. Mechanism analysis suggests that R&D input, export resilience, and financing constraints are plausible channels linking climate finance to export upgrading. Heterogeneity analysis further indicates that the association is more pronounced among non-state-owned firms, smaller firms, firms located in non-eastern regions. Overall, this study provides firm-level evidence on how local climate-finance conditions are related to manufacturing export upgrading and offers a computer-assisted multi-source data integration and product-level index computation framework for economic management, sustainable finance, and international trade research.

Keywords: Climate finance; Export technological sophistication; Multi-source panel data

1 Introduction

Climate finance has become an important field linking climate governance and financial decision-making [1]. Global climate-finance flows support mitigation and adaptation activities across public and private sectors [2]. Recent evidence shows that carbon-transition risk is priced in financial markets [3], while climate regulation and firm-level climate exposure affect bond pricing, valuation, and corporate responses [4,5]. Information on carbon risk can also redirect investor demand and capital flows

L. W. Koon et al. (eds.), *Proceedings of the 2026 7th International Conference on Management Science and Engineering Management (ICMSEM 2026)*, Advances in Economics, Business and Management Research 399,
https://doi.org/10.2991/978-94-6239-758-3_75

toward lower-carbon assets [6]. Climate finance therefore represents not only an environmental policy arrangement but also a local financial condition that may shape firms' investment and transformation decisions.

In China, the dual-carbon strategy and the development of city-level climate finance have strengthened the connection between local financial conditions and firms' low-carbon transition [7]. This connection is particularly relevant to manufacturing exporters, which increasingly face carbon disclosure, environmental certification, low-carbon product standards, and sustainable supply-chain requirements. Export upgrading should therefore be evaluated not only by export scale but also by the productivity and technological characteristics associated with export structures. The PRODY–EXPY framework provides a widely used basis for measuring export technological sophistication [8].

Manufacturing firms are embedded in local financial and institutional environments. Financial development can promote green growth by reallocating capital toward cleaner activities [9], while green bond issuance can ease financing constraints and improve corporate environmental performance [10]. City-level climate finance may thus influence firms through the availability, maturity, and allocation of transition-oriented capital, together with policy signals, information services, and technical support. These conditions matter because exporting and technological upgrading require substantial fixed and long-term investment, and financing constraints or financial shocks can affect firms' entry into and continued participation in foreign markets [11,12].

Existing studies associate green finance with export green sophistication [13] and export sophistication under green-tax conditions [14]. Environmental regulation and financing constraints may also jointly shape firms' export green sophistication [15], while evidence on green returns indicates that climate-related preferences affect asset returns and investor demand [16]. However, comparatively limited attention has been paid to climate finance as a broader city-level condition combining the local policy environment, climate-oriented investment and financing, and climate-related outcomes.

This study examines whether city-level climate finance is associated with the export technological sophistication of Chinese manufacturing firms. We construct a firm-city-year panel covering 2008–2024 by matching listed manufacturing firms with city-level climate finance indicators and regional economic variables. The explanatory variable is a city climate finance index covering the development environment, climate investment and financing, and climate-finance performance [7]. The dependent variable is a productivity-adjusted firm-level proxy based on the PRODY–EXPY framework [8]. The empirical analysis uses firm and year fixed effects with city-clustered standard errors.

The results show a positive association between city-level climate finance and firms' export technological sophistication. The relationship remains generally stable across alternative variable treatments, sample adjustments, a lagged specification, and a Bartik-type instrumental-variable exercise. The mechanism evidence is consistent with R&D-based capability building, export resilience, and lower financing constraints, while the association is more evident among non-state-owned firms, firms in non-eastern regions, and small firms.

This paper contributes by extending climate-finance research to manufacturing export upgrading, focusing on export technological sophistication rather than export scale alone, and integrating multi-source firm, city, industry, and regional data within a high-dimensional fixed-effects framework. The remainder of the paper presents the hypotheses, data and methods, empirical results, and conclusions.

2 Theoretical Analysis and Hypotheses

2.1 Climate Finance and Export Technological Sophistication

City-level climate finance forms part of the local financial and institutional environment in which firms obtain transition-oriented capital, policy signals, climate-related information, and professional services [7]. Financial development can promote green growth by reallocating capital toward cleaner activities [9], while green bond issuance may ease financing constraints and improve firms' environmental performance [10]. Climate finance may therefore affect not only the amount of capital available to manufacturing firms but also its allocation, maturity, and intended use.

Export upgrading requires substantial fixed and long-term investment in product development, production technology, quality control, certification, and foreign-market entry. Under low-carbon transition, firms may also need to invest in cleaner equipment, energy-saving processes, carbon-data management, and supply-chain adjustment. Financing constraints and financial shocks can restrict firms' ability to undertake these investments and maintain participation in international markets [11,12].

Climate finance may also alter the relative costs and expected returns of different production activities. As carbon-transition risk, climate regulation, and firm-level climate exposure become increasingly reflected in financial decisions [3–5], carbon-intensive and technologically backward activities may face higher financing and compliance costs. Cleaner technologies and higher-quality production may, by contrast, receive stronger financial and institutional support. This reallocation effect is consistent with evidence that green finance and environmental policy conditions are associated with export sophistication [13–15].

Technological capability provides a further connection between climate finance and export upgrading. R&D investment supports product development, process improvement, productivity growth, and exporting [17]. Climate-related financing and policy incentives may also redirect technological change toward cleaner production, consistent with the induced-innovation argument [19]. By improving firms' capital access, technological capability, and adaptation to foreign-market environmental requirements, city-level climate finance is expected to support more sophisticated export activities.

H1: City-level climate finance is positively associated with the export technological sophistication of manufacturing firms.

2.2 Mechanism Channels

The relationship between climate finance and export technological sophistication may operate through three complementary channels: R&D-based capability building, export resilience, and financing-constraint relief.

First, climate finance may increase firms' R&D input. Export upgrading depends on product development, process improvement, quality enhancement, and knowledge accumulation. R&D investment is closely related to exporting and productivity dynamics [17], while climate-related incentives may direct technological effort toward cleaner and more advanced production [19]. A stronger local climate-finance environment may therefore increase firms' capacity and incentives to undertake R&D investment.

H2: City-level climate finance is positively associated with firms' R&D input, which in turn is positively associated with export technological sophistication.

Second, climate finance may strengthen export resilience. Export upgrading requires continuous participation in foreign markets, stable buyer relationships, market learning, and repeated adjustment to external standards. Firm trade theory emphasizes that productivity and the ability to bear fixed costs shape firms' entry into and continued participation in export markets [18]. Financing conditions also influence firms' responses to external shocks [11,12]. By helping firms absorb the costs of certification, carbon standards, and supply-chain adjustment, climate finance may support the continuity required for export upgrading.

H3: City-level climate finance is positively associated with firms' export resilience, which in turn supports export technological sophistication.

Third, climate finance may ease financing constraints. Technological renovation, cleaner production, certification, and market expansion require long-term external financing. When financing constraints are strong, firms may postpone or reduce these investments even when upgrading opportunities exist [11,12]. Existing evidence further suggests that green finance and environmental regulation may affect export upgrading through firms' access to financial resources [13,15]. By expanding the supply of transition-oriented capital, city-level climate finance may improve firms' ability to undertake long-term technological and export-upgrading investment.

H4: City-level climate finance is associated with lower financing constraints, which in turn support higher export technological sophistication.

3 Data and Methodology

3.1 Data

This study constructs a multi-source firm-city-year panel data set to examine the relationship between city-level climate finance and the export technological sophistication of Chinese manufacturing firms. The sample covers the period from 2008 to 2024. Firm-level data are obtained from the Wind database and listed firms' annual reports, including export information, financial characteristics, operating performance, R&D expenditure, and other firm-level indicators. City-level climate finance data are obtained from the city climate finance index developed by Shanghai Finance and Development Laboratory and Tianfu New Area Liyan Institute for Finance and Development Research Group, Chen and Zeng (2026)[7]. Regional economic variables are collected from city-level statistical sources.

The firm-level and city-level datasets are matched by firm location, city code, and year. The sample is restricted to listed manufacturing firms. ST firms, financial firms, observations with missing values in core variables, and abnormal observations are excluded. Continuous variables are winsorized at the 1st and 99th percentiles to reduce the influence of outliers. After data matching and sample screening, the final baseline sample contains 26,435 firm-year observations covering 219 cities. The panel is an unbalanced firm-city-year panel.

The empirical design relies on multi-source data integration rather than a stand-alone prediction exercise. By linking firm-level export and financial information with city-level climate finance conditions and regional economic characteristics, the dataset provides a structured basis for examining manufacturing export upgrading under low-carbon transition.

3.2 Variables

Export technological sophistication (*ESI*) is constructed following the *PRODY–EXPY* framework proposed by Hausmann, Hwang, and Rodrik (2007). Product-level *PRODY* is first calculated using international trade data and country-level per capita GDP, reflecting the income and productivity characteristics associated with each exported product. HS products are subsequently matched to manufacturing industries through a standardized HS–industry concordance. For each industry and year, *EXPY* is calculated as the Chinese export-share-weighted average of product-level PRODY. To incorporate firm heterogeneity, the industry-year *EXPY* measure is further adjusted by each firm's total factor productivity relative to the corresponding industry-year average. For product *k*, product-level sophistication is calculated as:

$$PRODY_k = \Sigma_j [\frac{(x_{jk}/X_j)}{\Sigma_j (x_{jk}/X_j)}] Y_j$$

where x_{jk} is country *j*'s export value of product *k*, X_j is country j's total exports, and Y_j is country *j*'s per capita GDP. The weight reflects the revealed importance of product k in each country's export basket and helps reduce the influence of country size.

Based on product-level *PRODY*, this study constructs firm-level ESI through a computer-assisted product-level index computation procedure. For each firm-year observation, product export records are grouped by firm, year, and product code. The export share of product k in firm i's export basket in year t is calculated as:

$$\boldsymbol{s}_{ikt} = \frac{x_{ikt}}{\Sigma_k x_{ikt}}$$

where x_{ikt} is firm *i*'s export value of product k in year *t*. The firm's export basket can then be represented as a sparse product-share vector $\boldsymbol{s}_{it}$ = (s_{i1t}, s_{i2t}, ..., s_{iKt}). Firm-level export technological sophistication is computed as the dot product between the firm's product-share vector and the product-level **P** $=(PRODY_1, PRODY_2, \ldots, PRODY_K)$ vector:

$$ESI_{it} = \boldsymbol{s}_{it}{}' \, \mathbf{P} \; = \Sigma_k (\frac{x_{ikt}}{\Sigma_k x_{ikt}}) PRODY_k$$

where x_{ikt} is firm *i*'s export value of product *k* in year *t.* A higher *ESI* indicates that the firm's export basket contains products with higher associated productivity and technological content. Compared with export value or export participation, *ESI* provides a quality-oriented measure of export upgrading because it captures the technological sophistication embodied in the firm's own export product basket.

The resulting *ESI* combines the sophistication of the export structure of the firm's industry with the firm's productivity position relative to its industry peers. Changes in product composition enter the measure through the annual recalculation of industry-level *EXPY*, which reflects product entry, product exit, and changes in the export shares of continuing HS products within each industry. The construction relies on industry-level export structure rather than firm-product customs transaction records. Accordingly, firm-specific changes in multi-product export baskets are not separately identified. The standardized HS–industry concordance improves the consistency of product-industry matching, although aggregation from products to industries may obscure some within-industry and within-firm heterogeneity. In addition, a listed firm's assigned industry may not fully represent all of its export activities. *ESI* is therefore interpreted as a productivity-adjusted firm-level proxy for export technological sophistication.

The core explanatory variable is the city-level climate finance development index, denoted by CTCF. The index is obtained from Chen and Zeng (2026) [7], which constructs a city climate finance measurement system for Chinese prefecture-level and above cities over 2008-2024. It is a composite city-year indicator rather than a direct observation of a single financial instrument. The underlying information is collected from official statistical sources, city-level policy and public-information records, financial and enterprise financing information, green patent data, and environmental outcome indicators. A higher value of *CTCF* indicates a higher level of city-level climate finance development.

The measurement system contains three first-level dimensions. The development environment dimension captures the policy, media, and technological conditions that support climate-finance innovation. The climate investment and financing dimension measures climate-related investment and financing activities by governments, firms, commercial banks, and social investors, including government environmental fiscal expenditure, commercial-bank green credit, and equity, loan, and bond financing of climate-friendly firms. The climate finance performance dimension reflects outcomes related to climate mitigation and adaptation, including pollution reduction, air quality improvement, green space, climate-friendly firms, and climate-friendly patents. In this sense, CTCF is not only a financial-scale indicator, but also a comprehensive measure of the local climate-finance system. Following Chen and Zeng (2026)[7], the city climate finance index can be expressed as:

$$CTCF_{ct} = w_1 ENV_{ct} + w_2 IVFN_{ct} + w_3 PERF_{ct}$$

where *c* and *t* denote city and year, respectively. ENV_{ct} denotes the development environment dimension, $IVFN_{ct}$ denotes climate investment and financing, and $PERF_{ct}$ denotes climate finance performance. The weights are determined objectively using the CRITIC method after standardizing the underlying indicators:

$$w_j = \frac{C_j}{\Sigma_{j=1}^{m} C_j}$$

$$C_j = \sigma_j \Sigma_{k=1}^{m} (1 - r_{jk})$$

where σ_j is the standard deviation of indicator j, and r_{jk} is the correlation coefficient between indicators *j* and *k.* The CRITIC method assigns higher weights to indicators with larger variation and lower information overlap, thereby reducing subjectivity in index construction.

The index therefore reflects the overall development of city-level climate finance through a composite measurement system. It should not be interpreted as a direct measure of firms' access to any specific climate-finance instrument. Accordingly, the coefficient of *CTCF* captures the association between the overall local climate-finance system and firms' export technological sophistication, rather than the isolated effect of any single instrument.

The mechanism variables include R&D input, export resilience, and financing constraints. R&D input is measured by the logarithm of R&D expenditure plus one, or by R&D intensity in alternative specifications. Export resilience captures the firm's ability to sustain and adjust export activities under external shocks and changing market conditions. Financing constraints are measured by the *WW index*, where a higher value indicates stronger financing constraints.

The control variables include firm-level and regional-level characteristics. Firm-level controls include leverage, profitability, operating cash flow, tangible asset ratio, liquidity, inventory intensity, and intangible asset ratio. Inventory intensity is measured as inventories divided by total assets. Regional economic development is controlled by the logarithm of real GDP per capita. To address the concern that environmental regulation intensity may be an omitted city-level factor, we further control for *EREG*. *EREG* is constructed as the number of environmental administrative penalties imposed on firms by local environmental protection authorities, divided by the total population of the city.

Table 1 presents the descriptive statistics of the main variables. Both export technological sophistication and city-level climate finance show sufficient variation across firms, cities, and years. The control variables also display reasonable dispersion in firms' financial conditions and asset structure. These patterns indicate that the matched firm-city-year panel is suitable for the subsequent fixed-effects analysis.

Table 1. Descriptive statistics.

Variables	(1) N	(2) mean	(3) sd	(4) min	(5) max
ESI	31,077	10.16	1.117	5.146	14.56
CTCF	36,620	1.345	0.332	0.811	2.763
LEV	44,751	0.398	0.196	0.0535	0.929
ROA	44,749	7.784	9.140	-21.56	38.94
CFO	44,752	0.0613	0.0795	-0.166	0.303
TANG	44,700	0.223	0.135	0.0107	0.617
PGDP	37,000	2.009	0.534	-0.0629	3.128
LIQ	44,749	0.167	0.131	0.00913	0.642
INV	44,666	0.144	0.0884	0.0144	0.466
INTANG	44,427	0.0442	0.0349	0.00108	0.198

3.3 Computer-Assisted Data Processing and Empirical Modeling Framework

This study uses a computer-assisted data processing framework to construct the analytical firm-city-year panel. The framework integrates product-level export records, firm financial statements, city-level climate finance indicators, and regional economic variables through standardized firm identifiers, product codes, city codes, and year variables. This structure allows heterogeneous data sources to be transformed into a unified panel for empirical estimation.

The first component is computer-assisted index construction. The original *CTCF* index relies on manual data collection and web scraping to collect climate-related policy, media, financial, and environmental indicators. Its CRITIC weighting method is implemented through a matrix-based procedure that uses indicator standard deviations and the correlation matrix to assign objective weights. Therefore, *CTCF* is not a subjective score, but a computer-assisted composite index that summarizes multidimensional city-level climate-finance information.

The second component is product-level vector computation. Firm export records are grouped by firm, year, and product code. Product export shares are then represented as a sparse product-share vector, and firm-level *ESI* is computed as the dot product between this vector and the product-level PRODY vector. This procedure converts high-dimensional product export records into a firm-year measure of export technological sophistication.

3.4 Empirical Model

To examine the relationship between city-level climate finance and export technological sophistication, this study estimates the following two-way fixed-effects model:

$$ESI_{ict} = \alpha + \beta\, CTCF_{ct} + \gamma X_{ict} + \mu_i + \lambda t + \varepsilon ict \quad (1)$$

where i, c, and t denote firm, city, and year, respectively. ESI_{ict} is the export technological sophistication of firm i in city c and year t. $CTCF_{ct}$ is the city climate finance index. X_{ict} denotes the vector of firm-level and regional-level control variables. μ_i denotes firm fixed effects, and λ_t denotes year fixed effects. The coefficient of interest is β. A positive β indicates that firms located in cities with higher levels of climate finance tend to have higher export technological sophistication.

Standard errors are clustered at the city level because the core explanatory variable varies at the city-year level and firms located in the same city may be affected by common local shocks. The baseline specification includes firm and year fixed effects.

To examine potential mechanism channels, this study further estimates the following models:

$$M_{ict} = \alpha + \beta\, CTCF_{ct} + \gamma X_{ict} + \mu_i + \lambda_t + \varepsilon_{ict} \tag{2}$$

$$ESI_{ict} = \alpha + \beta\, CTCF_{ct} + \theta M_{ict} + \gamma X_{ict} + \mu_i + \lambda_t + \varepsilon_{ict} \tag{3}$$

where M_{ict} denotes the mechanism variable, including R&D input, export resilience, and financing constraints. The first equation examines whether city-level climate finance is associated with the mechanism variable. The second equation examines whether the mechanism variable is associated with export technological sophistication after controlling for city-level climate finance and other covariates. These mechanism tests are interpreted as supportive channel evidence rather than definitive causal mediation.

4 Empirical Results

This section reports the empirical evidence on the relationship between city-level climate finance and firm-level export technological sophistication. The empirical analysis uses firm and year fixed effects, controls for firm financial characteristics and local economic conditions, and clusters standard errors at the city level.

4.1 Baseline Results

Table 2 reports the baseline regression results. All columns include firm fixed effects and year fixed effects, while control variables are added step by step. The coefficient of *CTCF* remains positive across all specifications. This pattern indicates that the positive association between city-level climate finance and export technological sophistication is not sensitive to the gradual inclusion of firm-level and regional controls.

In the preferred specification in column (5), the coefficient of CTCF is 0.0802 and is significant at the 5 percent level. The preferred model includes 26,213 firm-year observations. These results suggest that firms located in cities with higher levels of climate finance tend to have higher export technological sophistication. The evidence supports H1. Since the empirical design is based on panel fixed-effects regressions, the result is interpreted as a positive association rather than definitive causal evidence.

Table 2. Baseline results with two-way fixed effects.

	(1)	(2)	(3)	(4)	(5)
Variables	ESI	ESI	ESI	ESI	ESI
CTCF	0.0746*	0.0840**	0.0942***	0.0883**	0.0802**
	(0.0414)	(0.0328)	(0.0333)	(0.0342)	(0.0340)
LEV		0.9469***	1.0223***	0.9594***	0.9232***
		(0.0704)	(0.0759)	(0.0817)	(0.0791)
ROA		0.0254***	0.0213***	0.0215***	0.0207***
		(0.0012)	(0.0013)	(0.0013)	(0.0013)
CFO			0.6539***	0.7081***	0.7699***
			(0.0806)	(0.0802)	(0.0839)
TANG			-1.0194***	-1.1162***	-1.0719***
			(0.1324)	(0.1386)	(0.1369)
PGDP				0.0959	0.1156
				(0.0891)	(0.0900)
LIQ				-0.2490***	-0.2106***
				(0.0680)	(0.0700)
INV					0.6414***
					(0.1757)
INTANG					-0.9295***
					(0.3197)
EREG					0.0804**
					(0.0389)
Constant	10.0877***	9.5478***	9.7191***	9.6220***	9.5575***
	(0.0558)	(0.0461)	(0.0513)	(0.1831)	(0.1871)
Observations	26,213	26,213	26,213	26,213	26,213
R-squared	0.8505	0.8685	0.8725	0.8729	0.8748
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses*** $p<0.01$, ** $p<0.05$, * $p<0.10$

4.2 Robustness Checks

Table 3 reports the robustness checks. The positive association between *CTCF* and *ESI* remains stable under alternative sample and variable treatments. The winsorized specification in column (2) continues to show a positive and statistically significant coefficient, suggesting that the baseline result is not driven by extreme values. After excluding the year 2020 (column (3)) , the coefficient also remains positive and significant, indicating that the result is not mainly driven by the special economic shock during that year. The nonlinear specification in column (4) further suggests that the relationship between climate finance and export technological sophistication may exhibit diminishing marginal effects. The positive first-order term and the negative squared term indicate that climate finance is more strongly associated with export technological sophistication at relatively lower levels of climate-finance development, while the marginal association becomes weaker at higher levels.

Column (5) further examines the persistence of the climate-finance effect by replacing current *CTCF* with the one-period lagged *CTCF*. This result suggests that the baseline relationship is not limited to a purely contemporaneous association. Rather, city-level climate finance may operate as a continuing local financial and institutional environment that supports firms' export upgrading over time. Given the persistence of city-level climate-finance development, this specification provides a complementary robustness check.

Table 3 column (6) also reports a Bartik-type instrumental-variable specification. The first-stage result indicates a strong relationship between the instrument and city-level climate finance, and the second-stage result remains positive and significant. This provides supportive IV evidence for the positive association between climate finance and export technological sophistication. However, because the exclusion restriction of the Bartik-type instrument cannot be fully verified, this result should be interpreted as supportive evidence rather than conclusive causal identification.

Overall, the robustness checks support the main finding that city-level climate finance is positively associated with firms' export technological sophistication.

Table 3. Robustness checks.

	(1)Baseline	(2)Winsorized	(3)Excluding 2020	(4)Nonlinear	(5)Lagged climate finance	(6)Bartik IV
Variables	ESI	ESI	ESI	ESI	ESI	ESI
CTCF	0.0843**		0.0845**	0.2182***	0.0720*	0.1083**
	(0.0343)		(0.0347)	(0.0838)	(0.0368)	(0.0480)
CTCF_w99		0.0749**				
		(0.0366)				
CTCF2				-0.0368**		
				(0.0172)		
Constant	9.5575***	9.5792***	9.5471***	9.4398***		
	(0.1871)	(0.1900)	(0.1804)	(0.2082)		
First-stage F						256.59
Second-stage CTCF						0.1083**
						(0.0480)
IV type	No	No	No	No	No	Bartik national
Observations	26,213	26,213	23,964	26,213	25,688	26,265
R-squared	0.8737	0.8768	0.8718	0.8738	0.8816	
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses*** $p<0.01$, ** $p<0.05$, * $p<0.10$

4.3 Mechanism Tests

Table 4 reports the mechanism tests for three channels: R&D input, export resilience, and financing constraints. These channels respectively reflect capability building, market adaptation, and financial resource allocation. The results provide supportive evidence for the R&D input channel. City-level climate finance is positively associated with firms' R&D input, and R&D input is positively related to export technological sophistication. This suggests that climate finance may support export upgrading by strengthening firms' innovation input and technological capability. This interpretation is consistent with evidence that R&D investment supports productivity improvement, technological capability, and export performance[17], as well as the induced-innovation argument that policy and market incentives can redirect technological change [19]. The export resilience channel is also supported. *CTCF* is positively associated with *EPRS*, and *EPRS* is positively related to *ESI*. This indicates that climate finance may help firms maintain export adjustment capacity and continue upgrading under external shocks and low-carbon transition pressures. This finding is consistent with studies showing that financial conditions affect firms' continued participation in export markets and their ability to respond to external shocks[11,12]. The financing-constraint channel operates in the expected direction. *CTCF* is negatively associated with *FCWW*, while *FCWW* is negatively related to *ESI*. Since a higher *FCWW* indicates stronger financing constraints, this pattern suggests that climate finance may improve the allocation of financial resources by easing the financing pressure associated with long-term technological and export-upgrading investment [13,14].

Table 4. Mechanism tests.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	R&D input	ESI	Export resilience	ESI	Financing constraints	ESI
CTCF	0.0289*	0.0756**	1.4039***	0.0623*	-0.0199*	0.0770**
	(0.0627)	(0.0319)	(0.3323)	(0.0593)	(0.0101)	(0.0340)
LRD		0.2563***				
		(0.0406)				
EPRS				0.048***		
				(0.0007)		
FCWW						-0.1421**
						(0.0630)
Constant	17.3774***	5.5861***	2.5192*	9.5908***	-1.0149***	9.3775***
	(0.3582)	(0.7367)	(1.2873)	(0.2795)	(0.0407)	(0.1843)
Observations	13,810	13,810	9,340	9,340	25,820	25,820
R-squared	0.9234	0.9533	0.6009	0.8776	0.2120	0.8757
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.10

Overall, the mechanism results are consistent with three complementary channels: capability building through higher R&D input, market adaptation through stronger export resilience, and improved resource allocation through lower financing constraints.

4.4 Heterogeneity Analysis

Table 5 reports the heterogeneity results by ownership, region, and firm size. The analysis focuses on three channels: R&D input, export resilience, and financing constraints. The estimated coefficients are positive in all subsamples, but their statistical strength is not the same. In the ownership grouping, the coefficient is positive for both non-state-owned and state-owned firms, while the estimate for non-state-owned firms is supported by stronger statistical significance. In the regional grouping, the coefficient for eastern cities is positive but not statistically significant, whereas the coefficient for non-eastern cities is larger and significant. The firm-size results show a similar pattern. The coefficient is positive and significant for small firms, but positive and insignificant for large firms.

These insignificant estimates should be interpreted with caution. They do not necessarily imply that climate finance is unrelated to export technological sophistication in these sub samples. Rather, they suggest that the evidence is weaker under these sample splits.

Overall, the heterogeneity results indicate that the positive association between climate finance and export technological sophistication is more evident among firms and regions facing stronger resource constraints. This pattern is consistent with a constraint-relief and catch-up interpretation. However, these subgroup estimates should not be read as definitive evidence that the coefficients differ across groups. Formal interaction tests would be needed to confirm whether the differences between subsamples are statistically significant.

Table 5. Heterogeneity analysis.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Non-SOE	SOE	Eastern	Non-eastern	Small firms	Large firms
CTCF	0.0889**	0.1016*	0.0467	0.1598**	0.0860**	0.0740
	(0.0420)	(0.0595)	(0.0407)	(0.0773)	(0.0414)	(0.0478)
Constant	9.2889***	9.8152***	9.7573***	9.5065***	8.8775***	10.0881***
	(0.2508)	(0.2659)	(0.2454)	(0.2557)	(0.2311)	(0.2435)
Observations	18,205	7,697	17,941	8,272	12,895	12,998
R-squared	0.8773	0.8720	0.8805	0.8621	0.8176	0.8812
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses*** $p<0.01$, ** $p<0.05$, * $p<0.10$

4.5 Summary of Empirical Findings

The empirical results provide support for the paper's main argument. The baseline results show that city-level climate finance is positively associated with firm-level export technological sophistication. The robustness checks based on winsorization, exclusion of 2020, nonlinear specification, and a Bartik-type IV exercise generally preserve the positive relationship. The mechanism tests are consistent with capability building through higher R&D input, market adaptation through stronger export resilience, and improved financial resource allocation through the easing of financing constraints. The heterogeneity results further suggest that the association is more evident among non-state-owned firms, firms in non-eastern regions, and small firms.

5 Conclusion

This study examines the relationship between city-level climate finance and the export technological sophistication of Chinese manufacturing firms. Using a multi-source firm-city-year panel dataset from 2008 to 2024, the paper matches firm-level export and financial information with city-level climate finance indicators and regional economic variables. The empirical analysis applies a two-way fixed-effects model with firm and year fixed effects, and standard errors are clustered at the city level.

The main findings are as follows. First, city-level climate finance is positively associated with firms' export technological sophistication. After progressively adding firm-level financial controls and regional controls, the coefficient of *CTCF* remains positive and statistically significant. Robustness checks based on winsorization, exclusion of 2020, nonlinear specification, and a Bartik-type instrumental-variable exercise generally support this positive relationship.

Second, the mechanism evidence is consistent with three complementary channels: capability building, market adaptation, and financial resource allocation. Climate finance is positively associated with firms' R&D input and export resilience, suggesting stronger technological capability and greater capacity to maintain and adjust export activities. In addition, climate finance is negatively associated with financing constraints, while stronger financing constraints are negatively associated with export technological sophistication.

Third, the heterogeneity results show that the positive association is more evident among non-state-owned firms, firms in non-eastern regions, and small firms. This pattern is consistent with a constraint-relief interpretation, although subgroup differences still require further formal interaction tests.

Overall, the findings suggest that climate finance can serve as an important local financial and institutional condition for manufacturing export upgrading under low-carbon transition. The paper also provides a computer-assisted data processing framework that integrates multi-source firm, product, city, and regional data, uses matrix-based objective weighting for the climate finance index, and applies product-level vector computation to measure firm-level export technological sophistication. Future research can further use firm-bank matched data, more detailed product-level trade data, or quasi-natural experiment designs to identify the micro-level mechanisms more directly.

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