Green Finance and China's Industrial Transformation: Pathways and Pitfalls

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ABSTRACT

The intensifying challenges posed by climate instability and ecological deterioration have highlighted the urgent need for environmentally-conscious economic advancement, propelling green finance to the forefront as a strategic mechanism for harmonizing industrial progress with ecological preservation objectives.This study investigates the impact of green finance on industrial structure transformation in China, leveraging provincial-level panel data from 2003 to 2022. Employing fixed-effects models, instrumental variable approaches, and Doubly Debiased LASSO (DDL) regression to address endogeneity, we systematically analyze the mechanisms and regional heterogeneity of green finance's effects. Results reveal that green finance significantly promotes industrial structure upgrading, primarily through enhancing green technology innovation and constraining carbon emissions. Mediating effect tests confirm these dual pathways, with green patents and emission reductions serving as critical channels. Heterogeneity analysis highlights pronounced effects in western and northeastern regions, high climate-risk areas, and provinces with stringent environmental regulations, while the eastern region exhibits a negative correlation, suggesting potential "green mismatch" issues. Robustness checks, including alternative variable specifications and lagged effects, corroborate these findings. The study underscores the necessity of region-specific green finance policies, enhanced coordination with environmental regulations, and targeted support for green innovation. These insights provide empirical support for optimizing green finance frameworks to advance China's "dual carbon" goals and sustainable industrial transformation.

Keyword: Green finance, industrial structure transformation, mediating effect, DDL regression.

1 Introduction

The intensifying perils of planetary warming and ecosystem collapse have precipitated a structural transformation in global economic paradigms, compelling nations to transition toward low-carbon development models that balance ecological integrity with industrial modernization. China has institutionalized its climate commitments through binding policy mechanisms, establishing an operational framework targeting greenhouse gas peaking within this decade and net-zero transitions under a mid-century timeline—a systematic decarbonization approach now academically termed the "emission-curb paradigm" (Wen and Diao, 2022). These commitments are not solely environmental in nature; they signal a profound restructuring of China's economy—one that demands systemic changes in resource allocation, industrial configuration, and innovation pathways(Zhang and Sun, 2025).

At the heart of this transformation lies the imperative to upgrade the industrial structure—namely, to shift from high-emission, energy-intensive industries toward cleaner, low-carbon, and innovation-driven sectors. This structural evolution is vital not only for achieving long-term sustainability but also for enhancing economic resilience and productivity. However, the transition process is complex and capital-intensive, often marked by long investment horizons, uncertain returns, and heightened financial risks—particularly in the early phases of green technology diffusion. These barriers are exacerbated in regions with underdeveloped financial systems, where market failures and risk aversion inhibit the reallocation of capital to greener sectors.

Against this backdrop, green finance has gained prominence as a key policy and market-based tool to reconcile economic growth with environmental sustainability. By directing financial resources toward environmentally friendly industries and projects, green finance mechanisms help reduce the cost of capital, mitigate investment risks, and mobilize private sector participation in the low-carbon transition. More importantly, green finance can serve as an effective lever to guide the broader restructuring of industrial systems in line with climate objectives.

While the conceptual importance of green finance is widely acknowledged, its actual impact on industrial transformation remains insufficiently explored at the empirical level. To address this gap,this study empirically investigates the extent to which green finance contributes to industrial structure upgrading in China. It focuses on analyzing whether green finance can effectively promote the transition toward more sustainable and innovation-driven industries, explores the potential mechanisms through which green finance influences industrial restructuring—such as green technology innovation channels or carbon emissions forced mechanism.—and examines whether these effects vary across different regions due to disparities in financial development and industrial foundations. By constructing a provincial-level panel dataset and employing rigorous econometric methods, this paper aims to provide robust evidence and policy-relevant insights on how green finance can serve as a strategic lever in advancing China's dual carbon goals and long-term sustainable development.

2 Literature reviews

2.1 The Connotation and Advancement of Green Finance

Green finance channels monetary resources toward ecologically sound, low-carbon, and enduring development via financial instruments, fostering synchronized economic expansion and environmental preservation (Cojoianu et al., 2025). UNEP characterizes green finance as "financial activities backing sustainable development," while China stresses its role in "bolstering eco-friendly industries and curbing highly polluting, energy-intensive sectors"(Jiang et al., 2025). Key mechanisms encompass ecological credit, sustainable bonds, environmental insurance, carbon funding, and ESG investing (Zheng et al., 2025).

At the international level, the development of green finance began in the late 2000s and entered a stage of rapid advancement especially after the signing of the Paris Agreement. Developed countries represented by Europe and the United States have formed a series of standards and practice systems in terms of green bonds, ESG rating systems and sustainable information disclosure (Khanche et al., 2025; Nguyen et al.,

2025). Since China issued the "Guiding Opinions on Establishing a Green Financial System" in 2016, it has gradually established a green credit statistics system, a green bond directory, a green fund support mechanism, and a carbon trading market, providing institutional guarantees for the development of green finance (Zhao et al., 2025; Wang et al., 2025).

2.2 Relevant Research on Industrial Structure Transformation

Industrial restructuring primarily involves two trajectories: first, industrial escalation, entailing a shift from rudimentary and manufacturing sectors to the service industry; and second, industrial refinement, entailing ameliorating resource deployment efficacy and inter-sectoral harmonization (Hu et al., 2025; Gao et al., 2025; Zhang et al., 2025). Typical metrics for gauging industrial escalation encompass alterations in tri-sectoral ratios, the Theil index, industrial configuration disparity, and total factor productivity enhancement (Liu et al., 2024; Li et al., 2024).

Prior studies indicate that the principal determinants influencing industrial restructuring encompass technological advancement, accretion of human capital, influx of overseas capital, the extent of market liberalization, and the sophistication of financial deepening. Notably, technological advancement has augmented industrial productive capacity and constitutes the pivotal impetus propelling the expansion of high value-added industries (Xia et al., 2024); Human capital furnishes personnel endowment for industrial escalation (Zhao et al., 2025); The introduction of foreign capital not only infuses monetary resources but also technical know-how and administrative acumen, thereby fostering enhancements in the caliber and effectiveness of domestic industries (Zhao et al., 2025); Market-oriented deregulation facilitates industrial optimization by elevating the efficacy of resource deployment (Zhao and Yan, 2024); Financial deepening governs the flux and allocation of capital. A more robust financial architecture is better equipped to underpin the burgeoning of nascent industries, thus expediting industrial escalation (Li and Luo, 2025).

2.3 Research on the Relationship between Green Finance and Industrial Structure Transformation

The scholarly consensus positions green finance within theoretical frameworks as a structural mechanism for industrial system optimization. Contemporary research demonstrates that specialized financial instruments—including climate-aligned lending mechanisms, environmental debt securities, and sustainability-focused investment vehicles—strategically reallocate capital flows toward eco-innovation sectors encompassing renewable energy systems, circular production models, and emission-reduction technologies (Li et al., 2025; Tchuiendem et al., 2025; Konstantakis et al., 2025). This capital reallocation dynamics fundamentally restructures economic input-output matrices by diverting fiscal allocations from carbon-intensive industrial complexes to climate-resilient productive systems, establishing resource redistribution mechanisms that inherently disincentivize polluting sectors while systematically reinforcing green industrial ecosystems (Yuan et al., 2025).

On the other hand, green finance plays a key role in alleviating the financing constraints of green projects. Due to the fact that green technological innovation usually faces problems such as large initial investment, high risk and long payback period, traditional financial institutions often lack investment and financing incentives(Yang et al., 2025; Wu and Lin, 2025).Green finance enhances the financing feasibility of green

technology research and promotion through means such as policy support, risk compensation and incentive mechanisms, thereby encouraging enterprises to increase investment in green transformation and promoting technological progress and product upgrading (Liu et al., 2025; Wang et al., 2025).

Furthermore, green finance also has the governance function of "soft constraints" (Hu et al., 2025). Through means such as green ratings, environmental information disclosure systems, and carbon trading mechanisms, green finance can enhance the transparency of corporate environmental performance and guide the market to price corporate environmental behaviors (Habib et al., 2025; Kwilinski et al., 2025). When the business environment performs poorly, its financing costs will increase significantly and it may even face the risk of restricted financing (Zhang et al., 2024). This transmission mechanism of "environmental information - market response - financing punishment" can effectively exert reverse pressure on highly polluting enterprises, prompting them to accelerate the exit from backward production capacity or shift to a green development path, thereby promoting the green transformation of the entire industrial system on a larger scale (Roy, 2023).

2.4 Research Review and Commentary

Contemporary academic inquiries have substantiated three pivotal advancements in green finance scholarship: Primarily, scholarly investigations have systematically validated the structural transformation dynamics that eco-financial mechanisms exert on industrial upgrading trajectories. Secondary analyses have successfully deciphered the operational mechanics through which specialized instruments—including climate-aligned lending instruments and environmental, social, and governance (ESG)-compliant securities—mediate sustainable capital deployment and ecological stewardship. Complementing these insights, emergent studies have empirically demonstrated how regional heterogeneity in financial architectures and regulatory enforcement capacities fundamentally modulates green finance's policy efficacy across jurisdictional boundaries.

However, there are still several deficiencies: First, most studies focus on the micro level, such as enterprise pollution control or changes in financing costs, and rarely systematically examine the impact of green finance on the industrial structure from the macro level; Second, the influence mechanism of green finance has not yet reached a unified consensus, and the empirical tests on the "green technology innovation path" and the "carbon emission reverse pressure mechanism" are still relatively weak. Thirdly, there is insufficient research on regional heterogeneity, and there is a lack of grouped comparative analysis of regions with differences in climate risks in the eastern, central and western regions.

This study intends to start from provincial panel data, systematically assess the actual impact of green finance on the upgrading of industrial structure, deeply explore its mechanism of action, and identify its heterogeneous effects through regional and structural analysis, with the aim of enriching the existing literature and providing empirical support for the optimization of green finance policies.

3 Research Methods

3.1 Model Settings

This paper constructs the following benchmark regression model to test the effect of green finance in promoting the transformation of industrial structure and the corresponding mechanism:

$$IND_{it} = \beta_0 + \beta_1 gfi_{it} + \sum_{j=1}^{6} \beta_j control + \varepsilon_{it} \quad (1)$$

According to theoretical analysis, it can be known that green technological innovation and carbon emissions may play a mediating role in the process of green finance promoting industrial structure transformation. To test whether the mediating effect exists, this paper draws on the "two-step method" for mediating effect testing proposed by Jiang (2022), and sets the relevant model as follows:

$$IND_{it} = \beta_0 + \beta_1 gfi_{it} + \sum_{j=1}^{6} \beta_j control + \varepsilon_{it} \quad (2)$$

$$\mathrm{lngi_{it}} = \alpha_0 + \alpha_1 \mathrm{gfi_{it}} + \sum_{j=1}^{6} \beta_j control + \varepsilon_{it} \quad (3)$$

$$IND_{it} = \beta_0 + \beta_1 gfi_{it} + \sum_{j=1}^{6} \beta_j control + \varepsilon_{it} \quad (4)$$

$$\mathrm{lncei_{it}} = \gamma_0 + \gamma_1 \mathrm{gfi_{it}} + \sum_{j=1}^{6} \beta_j control + \varepsilon_{it} \quad (5)$$

Among them, IND stands for Industrial Structure Transformation Index; gfi stands for Green Finance Development Index; lngi is the logarithm of the number of green patent authorizations; lncei is the logarithm of carbon emissions; control represents a control variable.

Due to the numerous controversies regarding the mediating effect in the academic circle at present, this paper simultaneously refers to the three-step method proposed by Wen and Ye (2014) to supplement and verify the existence of the mediating effect. However, due to the endogeneity problem of the three-step method, in order to alleviate the possible estimation bias caused by omitted variables, this paper revises the double biased LASSO (Doubly Debiased LASSO, DDL) regression method proposed by Guo et al (2022). DDL regression is an advanced statistical inference tool applicable to high-dimensional data scenarios, mainly used to address the bias problem caused by hidden confounding variables on causal estimation(Chen et al.,2024). The core principle lies in constructing two mutually independent correction equations to respectively correct the biases caused by the selection of high-dimensional parameters and potential confounding factors, thereby achieving a more robust and consistent estimation of the target parameters. This method has good theoretical properties under high-dimensional settings and can effectively improve the explanatory power and estimation accuracy of the model. The specific model of DDL is as follows.

Firstly, construct the high-dimensional linear model of the benchmark regression (Equation 6). Among them, y_i is the industrial structure transformation index, d_i is the green finance index, β_0 is the high-dimensional covariate, and θ_0 is the parameter of concern.

$$y_i = d_i\theta_0 + X_i^\top \beta_0 + \varepsilon_i \tag{6}$$

Secondly, to eliminate the bias caused by potential confounding variables and high-dimensional covariates, we introduce a pretest model for d_i (as in Equation 7) :

$$d_i = X_i^\top \gamma_0 + v_i \tag{7}$$

Furthermore, LASSO was used to estimate the above two regression models and calculate the residuals of the processing variables (Equation 8).

$$\hat{v}_i = d_i - X_i^\top \hat{\gamma} \tag{8}$$

Finally, the Doubly Debiased LASSO estimator is constructed as follows (Equation 9) :

$$\hat{\theta}^{DDL} = \left(\frac{1}{n}\sum_{i=1}^{n} \hat{v}_i d_i\right)^{-1} \left(\frac{1}{n}\sum_{i=1}^{n} \hat{v}_i \left(y_i - X_i^\top \hat{\beta}\right)\right) \tag{9}$$

3.2 Indicator selection

3.2.1 Explained variable (IND)

This paper refers to the existing literature on the measurement index of industrial structure transformation and upgrading, and selects the advanced data of industrial structure as the measurement index(Xu et al., 2021 ; zhou and Chen, 2021). The calculation formula of industrial structure upgrading index is as follows :

$$Industrial\ Structure\ Upgrading\ Index(IND) = second\ industry\ output\ value\ /\ third\ industry\ output\ value \tag{10}$$

3.2.2 Core explanatory variables (gfi)

Currently, many scholars have explored methods to measure green finance development. Based on existing studies (Sun and Chen, 2019; Shi et al., 2022; Zhou et al., 2022), a green financial development index system is constructed, comprising seven parts and calculated via the entropy weight TOPSIS method. The green financial development index system is detailed in the appendix.

3.2.3 Mediating variables

Green technology innovation(gi): Climate-aligned financial instruments lower green tech financing barriers through mechanisms like eco-credit systems, alleviating corporate liquidity constraints during eco-transition to stimulate eco-innovation investments. These advancements drive dual optimization in resource circularity and emission mitigation efficiency while fostering eco-industrial clusters that structurally reorient economies toward knowledge-intensive, low-carbon models, quantified through provincial green patent grants aligned with international classification standards.

Total carbon emissions(cei) : Green finance enforces capital discipline on carbon-intensive sectors through market-based environmental regulations , generating coercive pressures that accelerate industrial phase-outs. This market-driven resource reallocation mechanism—empirically quantified through EDGAR-derived carbon emission metrics—systematically propels structural transitions toward climate-resilient industries.

3.2.4 Control variables

In the selection of control variables, this study also refers to the previous literature to select policy support(sup), urbanization rate(urban), financial development level(fi), degree of opening up(open), labor level(labor), information level(infor), energy structure(energy) and economic development level as control variables (Yu and Xu, 2019; Liu and He, 2021).

3.3 Data Sources and Descriptive Statistics

This study employs a longitudinal provincial panel dataset spanning 2003-2022, encompassing 30 mainland provincial-level administrative units. Data were systematically compiled from cross-agency governmental databases and multi-dimensional official statistical compilations. The core variable metrics are detailed in Table 1.

Table 1: Variables descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
IND	600	1.214489	0.6698483	0.527051	5.282933
gfi	600	0.2892781	0.1198815	0.0557923	0.6317453
sup	600	0.2293343	0.1058536	0.0841992	0.7583024
urban	600	0.5458572	0.1507111	0.1488628	0.8958333
fi	600	1.347824	0.4551813	0.5886187	2.77409
open	600	0.3089906	0.3581878	0.0076268	1.711288
labor	600	7.561355	0.7995614	5.545177	8.863899
infor	600	0.0686019	0.1095692	0.0151436	2.52042
energy	600	0.033312	0.0234229	0.0030809	0.1080011
lnpgdp	600	10.41669	0.7613102	8.218248	12.15472
lngi	600	4.970834	1.833019	0	9.165866
lncei	600	19.07931	1.034931	14.98107	20.88716

4 Results and discussion

4.1 Baseline regression

The results of the benchmark regression are shown in table 2 below. Column (1) is the benchmark regression without control variables, column (2) is the benchmark regression with control variables, and column (3) is the benchmark regression after clustering at the provincial level. It can be seen from Table 4 that green finance can significantly promote the transformation of industrial structure regardless of whether to add control variables or change the clustering level.

Table 2: Baseline regression[a]

Variable	（1） IND	（2） IND	（3） IND
gfi	4.3589	3.5432	3.5431
	{0.4589}	{0.3895}	{0.9915}
	[9.50]	[9.10]	[3.57]
	(0.000)	(0.000)	(0.001)
Control variables	NO	YES	YES
Year fixed effect	YES	YES	YES
Province fixed effect	YES	YES	YES
Provincial level Clustering	NO	NO	YES
N	600	600	600
R^2	0.9116	0.9418	0.9418

4.2 Robustness test

4.2.1 Change the explained variable

There are many indicators to measure industrial structure transformation. This paper chooses industrial structure upgrading to replace industrial structure upgrading in the benchmark regression, and carries out the robustness test. Table 3 indicates that with a different measure of the explained variable, the green finance coefficient is still significant, which further confirms that green finance can promote the transformation of industrial structure.

Table 3: Replace the explained variables

Variable	IND’
gfi	0.3490
	{0.0829}

[a] In the table, { } is the standard error of the text in brackets, [ ] is the T value in brackets, ( ) is the P value in brackets, and the other tables in this paper are the same (except table 7, column (3) and table 9).

	[4.21]
	(0.000)
Control variables	YES
Year fixed effect	YES
Province fixed effect	YES
N	600
R^2	0.9520

4.2.2 Adjusting the clustering form

Since this paper uses the provincial panel data of 30 provinces in China on multiple year dimensions, the number of sample clusters is small (the number of clusters is only 30), which is prone to bias in the traditional clustering robust standard error estimation (Cameron & Miller, 2015). Especially in the case where the number of clusters is less than 50, the standard error is often underestimated, resulting in false significant problems. In order to alleviate the impact of small sample clustering errors on regression inference, this paper uses Wild Cluster Bootstrap to adjust the standard error. This method has higher robustness and accuracy when dealing with a small number of panel data clustering, and can provide a more reasonable significance level test. It can be seen from Table 4 that after adjusting the clustering form, the regression results are still consistent with the main conclusions of the benchmark regression.

Table 4: Adjusting the clustering form

Variable	IND
gfi	3.5431
	[3.57]
	(0.004)
Control variables	YES
Year fixed effect	YES
Province fixed effect	YES
N	600

4.2.3 The time lag effect of green finance

Given the potential time lag in green finance's impact on industrial structure transformation, the core explanation Variable is replaced by the moving average including the current and previous two periods. The corresponding empirical results are shown in table 5, which shows that the coefficient of variable is still significant and still supports the main conclusions of the benchmark regression in this paper.

Table 5: Consider the effect of time delay

Variable	IND
gfi_3	3.2191
	{0.3869}
	[8.32]
	(0.000)
Control variables	YES
Year fixed effect	YES
Province fixed effect	YES
N	600
R^2	0.9586

4.2.4 Supplementary robustness test

To ensure the benchmark regression's robustness, this study employs three additional strategies: First, it incorporates information level and energy structure as control variables (Column 1). Second, it excludes the four centrally administered municipalities—Beijing, Shanghai, Chongqing, and Tianjin—due to their disproportionately high green finance development stemming from abundant political and economic resources (Column 2). Third, to mitigate the influence of outliers, the study applies tail reduction to the data before re-running the regression (Column 3). These robustness checks are presented in Table 6.

Table 6: Other robustness analysis

Variable	（1） IND	（2） IND	（3） IND
gfi	3.5103	3.2881	3.2938
	{0.3963}	{0.4944}	{0.4079}
	[8.86]	[6.65]	[8.07]
	(0.000)	(0.000)	(0.000)
Control variables	YES	YES	YES
Year fixed effect	YES	YES	YES
Province fixed effect	YES	YES	YES
N	600	520	600
R^2	0.9416	0.8678	0.9440

4.3 Endogenous test

One of the endogenous problems that needs urgent attention is that regions with better industrial structure and better foundation for green transformation are more likely to promote the development of green

finance. At the same time, green financial resources may also tend to flow to these areas with high industrial upgrading potential, resulting in a two-way causal relationship between green finance and industrial structure. In addition, there may be some unobservable regional characteristics or institutional Variables that are missed, further exacerbating the estimation bias. Therefore, this study adopts the double correction LASSO regression and the tool Variable method to identify and control the potential endogenous problems from different perspectives, so as to enhance the robustness and causal explanatory power of the empirical results.

This study selects the extreme rainfall index as a tool Variable, mainly based on its exogeneity to regional environmental pressure and its impact mechanism on green financial supply. As a typical climate shock, extreme rainfall has strong suddenness and exogenousness, which does not directly affect the adjustment path of regional industrial structure, but will aggravate the vulnerability of local ecological environment and improve the level of environmental risk exposure, thus prompting local governments, financial institutions and enterprises to more actively promote the development of green finance and the allocation of resources to cope with climate risks and disaster losses.

As can be seen from table 7, column (1) shows that the tool Variable is significant in the first stage of regression, indicating that it has a strong correlation with the green financial Variable ; the second-stage regression results of Column (2) are also consistent with the benchmark regression, and have passed the unrecognizable test and the weak tool Variable test, indicating that the variable setting of the tool is reasonable and has good recognition ability. After effectively alleviating the potential endogenous problems, the promotion effect of green finance on the transformation of industrial structure is still robust, which further verifies the reliability of the benchmark regression conclusion. In addition, the double selection LASSO method is used to test the robustness, and the results are also consistent with the main regression direction, which further enhances the robustness and credibility of the empirical conclusions.

Table 7: Endogenous test[b]

Variable	（1） gfi First stage	（2） IND Second stage	（3） IND DDL
gfi		4.8388	1.7723
		{1.4257}	{0.2147}
		[3.39]	[8.26]
		(0.001)	(0.000)
IV	-0.0283		
	{0.0046}		
	[-6.10]		
	(0.000)		

[b] In Column (3), [ ] is the Z value in parentheses.

Cragg-Donald Wald rk F statistic		38.42		
Kleibergen-Paap rk LM statistic		22.15		
Control variables	YES		YES	YES
Year fixed effect	YES		YES	YES
Province fixed effect	YES		YES	YES
N	600		600	600
R^2	0.4739		0.4476	-

4.4 Mechanism analysis

To explore the mechanism by which green finance drives industrial upgrading, this study introduces green technological innovation and carbon emissions as mediators, applying a dual-path analysis. Green finance, through credit allocation and policy incentives, fosters eco-innovation and adoption of cleaner technologies, enhancing resource efficiency and guiding industries toward low-carbon transformation. Simultaneously, it imposes tighter financing constraints on high-emission sectors while supporting sustainable industries, thus reducing carbon intensity. These mediators reflect the dual mechanism of innovation-led advancement and emission-driven restructuring in the green finance-industry nexus.

Table 8: Mediating effect test result**s**

Variable	Green technology innovation		Total carbon emissions	
	（1）	（2）	（3）	（4）
	IND	lngi	IND	lncei
gfi	3.5432	1.6912	3.5432	-1.3853
	{0.3895}	{0.7512}	{0.3895}	{0.2079}
	[9.10]	[3.67]	[9.10]	[-6.67]
	(0.000)	(0.025)	(0.000)	(0.000)
Control variables	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES
N	600	600	600	600
R^2	0.9418	0.9746	0.9418	0.9957

Table 8 indicates that green finance significantly affects both green technology innovation and carbon emissions. These results show that green finance influences industrial structure transformation not only directly but also indirectly, by fostering green innovation and curbing emissions, thus supporting its role in promoting green development and high-quality industrial transformation.

Table 9: Mediating effect test results[c]

Variable	Green technology innovation			Total carbon emissions		
	（1）	（2）	(3)	（4）	（5）	(6)
	IND	lngi	IND	IND	lncei	IND
gfi	1.7723	6.5606	1.5750	1.7723	-2.1921	1.1823
	{0.2147}	{0.4403}	{0.2964}	{0.2147}	{0.0725}	{0.1827}
	[8.26]	[14.89]	[5.31]	[8.26]	[-30.22]	[6.47]
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lngi			0.0305			
			{0.0178}			
			[1.71]			
			(0.087)			
lncei						-0.034
						{0.0168}
						[-2.07]
						(0.038)
Control variables	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES	YES	YES
N	600	600	600	600	600	600

In order to ensure the robustness of the mediating effect, this study also introduces DDL regression and uses three-step method to explore the mediating effect. As shown in Table 9, the conclusion is the same as the two-step method, which proves that the mediating effect still exists.

4.5 Heterogeneity analysis

4.5.1 Classified by region

Given China's significant regional economic disparities, green finance's effect may vary across regions. Therefore, regional grouping is necessary in empirical analysis to explore these regional differences in green finance's impact on industrial structure transformation. Specifically, variations in economic development, industrial base, and financial system maturity across China's regions may cause differences in green finance's efficiency and pathways for promoting industrial structure upgrading. Regression analysis of the eastern, central, western, and northeastern regions reveals green finance's regional adaptability. The results are shown in Table 10.

[c] In Table 9, [ ] is the Z value in parentheses.

Table 10: Regional heterogeneity

Variable	（1） IND Eastern	（2） IND Central	（3） IND Western	（4） IND Northeastern
gfi	-2.0652	0.4760	2.4434	6.8629
	{1.2081}	{0.6905}	{0.5507}	{2.4533}
	[-1.71]	[0.69]	[4.44]	[2.80]
	(0.089)	(0.492)	(0.000)	(0.009)
Control variables	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES
N	200	120	220	60
R^2	0.9661	0.9359	0.7608	0.9196

The results of heterogeneity analysis show that green finance has a significant role in promoting the upgrading of industrial structure in the western and northeastern regions, but has no significant impact in the central region, and shows a negative significant relationship in the eastern region. This result may be closely related to the economic structure and development stage of each region. The western and northeastern regions have long relied on the industrial structure dominated by resource-based and heavy industry. Green finance is easier to intervene in these areas in the form of policy finance, which plays a key role in eliminating backward production capacity and guiding the development of green industry. Especially under the policy guidance and resource tilt, the marginal effect of green finance is more obvious. In contrast, although the financial system in the eastern region is more developed, its industrial structure has been in a higher stage. Green finance may flow more to mature industries with green labelling or be used for formal green financing, but it will inhibit the substantive transformation, and may even crowd out effective transformation investment in traditional industries, resulting in " green mismatch " phenomenon ; however, the development of green finance in the central region is still in its infancy, with insufficient institutional supply and limited application of green financial instruments, which has not yet formed effective support for the transformation of industrial structure.

4.5.2 Divided by climate risk level

Climate risk has become a key factor affecting the sustainable development of regional economy. The level of climate risk faced by different regions is significantly different, which may affect the allocation efficiency and policy response of green financial resources. In addition, green finance is essentially an institutional arrangement to guide the flow of funds to environmentally friendly industries. Its effect is more likely to be promoted by policies, markets and public environmental awareness in areas with high climate risks, thus showing stronger guidance and incentives. Therefore, this study divides the samples into high climate risk group (TOP25%) and low climate risk group (BOTTOM25%) according to the level of climate risk, and

conducts empirical tests. The results are helpful to identify the actual effect of green finance under different environmental vulnerability backgrounds and enhance the pertinence of research conclusions.

Table 11: Climate risk heterogeneity

Variable	（1） IND High climate risk	（2） IND Low climate risk
gfi	3.2751	1.399632
	{0.6828}	{0.9089}
	[4.80]	[1.54]
	(0.000)	(0.127)
Control variables	YES	YES
Year fixed effect	YES	YES
Province fixed effect	YES	YES
N	148	149
R^2	0.9598	0.9473

As shown in Table 11, green finance significantly drives industrial structure transformation in regions with high climate risk levels, but it is not significant in regions with low climate risk levels. The results show that climate risk, as an external pressure mechanism, has an amplification effect in promoting the role of green finance. On the one hand, high climate risk areas often face more severe environmental governance challenges, local governments and enterprises pay more attention to green development, and green finance is easier to obtain policy support and achieve effective resource delivery; on the other hand, the public, financial institutions and enterprises in high-risk areas are more sensitive to climate issues, the demand for green financial products is stronger, and the financing efficiency is higher, which is more conducive to guiding the adjustment of industrial structure to a green and low-carbon direction. In contrast, low climate risk areas have less environmental pressure, and the urgency and policy priority of green finance are low, which leads to its insignificant guiding effect on industrial structure, indicating that the regulatory role of climate risk in the structural transformation promoted by green finance cannot be ignored.

4.5.3 Divided by the intensity of environmental regulation

As an important institutional means to promote green development and industrial upgrading, environmental regulation largely determines the degree of attention and response behavior of enterprises and financial institutions to environmental constraints. There are obvious differences in the implementation of environmental regulation, the diversity of policy tools and the effectiveness of regulatory mechanisms in different regions. This difference in institutional environment will affect the resource allocation efficiency and policy guidance ability of green finance. Therefore, this study divides the samples into two groups according to the intensity of environmental regulation : high regulation intensity (TOP25%) and low

regulation intensity (BOTTOM25%) for heterogeneity analysis, which can reveal the regulatory effect of institutional environment in the process of green finance.

Table 12: Heterogeneity of environmental regulation intensity

Variable	（1） IND High environmental regulation	（2） IND Low environmental regulation
gfi	4.9414	-0.5599
	{0.6807}	{1.4197}
	[7.26]	[-0.39]
	(0.000)	(0.694)
Control variables	YES	YES
Year fixed effect	YES	YES
Province fixed effect	YES	YES
N	147	146
R^2	0.9512	0.9776

In areas with high environmental regulation intensity, green finance has a significant positive effect on industrial structure transformation. In areas with weak environmental regulation, the role of green finance is not significant. This difference shows that the effectiveness of green finance depends largely on the support of external institutional constraints. In areas with strong environmental regulations, the government has strengthened the pressure and motivation of enterprises ' green transformation through strict emission standards, environmental law enforcement, tax incentives and other means. Therefore, green financial instruments can more accurately identify, screen and support environmental-oriented projects and enterprises, and form a mechanism of ' regulation + finance ' to promote the optimization of industrial structure. In areas with weak regulations, environmental constraints are low, and green finance lacks sufficient institutional support. It is easy to become a mere formality, and it is difficult to have enough forced effects on high-energy-consuming and high-polluting industries, which in turn affects its substantive role in promoting the transformation of industrial structure.

5 Conclusions and recommendations

5.1 Conclusion

Based on the panel data of 30 provinces in China from 2003 to 2022, this paper systematically examines the impact of green finance on the transformation and upgrading of industrial structure and its mechanism of action. It uses fixed effect model, instrumental variable method, double correction LASSO method and mediating effect analysis to ensure the robustness and explanatory power of the results. The study found that green finance can significantly promote the optimization and upgrading of industrial structure, and its role is particularly evident in the two mechanism channels of green technology innovation and carbon emission constraints. Further heterogeneity analysis shows that the promotion effect of green finance is

more significant in the western and northeastern regions, high climate risk areas, and high environmental regulation areas, while it even shows a certain negative effect in the eastern region. In the central and low-risk, low-regulation areas, the effect is not significant, reflecting that there are great differences in the spatial distribution and institutional environment of green financial development.

5.2 Policy recommendations

Tailor green finance frameworks to regional comparative advantages by designing spatially-differentiated financial instruments that align local ecological modernization needs with sustainable transition priorities. The government should formulate sub-regional green finance support strategies according to the differences in regional economic foundation, industrial structure and environmental carrying capacity, especially to increase the supply and system construction of green finance in central, low climate risk and low environmental regulation areas.

Strengthen the coordination of green finance and environmental policy. By improving the environmental regulation system, strengthening the green credit guidance and green information disclosure system, guiding financial institutions to form endogenous green preferences, and improving the accurate guidance ability of green finance to industrial structure adjustment.

Encourage green technology innovation and low-carbon transformation. We can reduce the investment threshold of green innovation and clean technology by means of financial subsidies, tax relief, risk sharing, etc., while strengthening the cultivation of green patents and consolidating the technical foundation of green finance to promote structural upgrading.

Improve the assessment and supervision capabilities of the green financial system. Establish a green assessment standard and dynamic supervision mechanism covering the whole life cycle of the project, prevent ' green shuffle ' or resource mismatch, and ensure that green finance truly serves the high-quality development goals.

6 Declarations

6.1 Research limitations and future prospects

Although this paper has made some explorations in theoretical construction and empirical identification, there are still the following limitations :

(1) There is subjectivity in the construction of indicators. Although the green financial development index is weighted by the entropy weight-TOPSIS method, the data acquisition limitation and weight setting are still subjective, which may affect the measurement accuracy.

(2) There are spatial estimation errors in carbon emission data. The carbon emission Variable in this paper comes from the EDGAR database. Although it is authoritative, it is a national-level estimate and may not accurately reflect the actual emission characteristics of each province.

(3) The study did not include more fine-grained micro-mechanism analysis. This paper is mainly based on the provincial panel. Future research can further introduce micro data at the enterprise or industry level,

and combine the spatial econometric model and the dynamic panel model to deeply analyze the spatial and temporal diffusion effect of green finance and its dynamic feedback mechanism.

Future research can also explore the impact path of green finance on the structural evolution of emerging industries such as digitalization and intelligence, and provide more systematic policy basis and theoretical support for promoting the integration of Chinese-style modernization and green transformation.

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6.4 Competing Interests

Declare any potential conflict of interest exist in this publication.

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Appendix. Green finance development index system

Primary Indicator	Secondary Indicator	Tertiary Indicator	Measurement Method
Green Finance	Green Credit	Proportion of Credit for Environmental Protection Projects	Total credit for environmental protection projects in the province / Total credit in the province
	Green Investment	Investment in Environmental Pollution Control as a Share of GDP	Investment in environmental pollution control / GDP
	Green Insurance	Promotion Level of Environmental Liability Insurance	Revenue from environmental liability insurance / Total insurance premium income
	Green Bonds	Development Level of Green Bonds	Total issuance of green bonds / Total issuance of all bonds
	Green Support	Proportion of Government Expenditure on Environmental Protection	Government expenditure on environmental protection / General public budget expenditure
	Green Funds	Proportion of Green Funds	Total market value of green funds / Total market value of all funds
	Green Equity Instruments	Depth of Green Equity Market	Total transaction volume of carbon trading, energy-use rights trading, and emission rights trading / Total equity market transaction volume