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The Impact of Green Finance on Manufacturing Resilience: Perspectives from Technological Innovation and Energy Structure

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Abstract: *This study examines the impact of green finance on manufacturing resilience and its underlying mechanisms using panel data from 30 Chinese provinces between 2012 and 2022. By constructing a comprehensive evaluation system for manufacturing resilience that encompasses three dimensions and introducing technological innovation and energy structure transition as mediating variables, the empirical analysis reveals the following findings: (1) Green finance has a significantly positive effect on manufacturing resilience. (2) Both technological innovation and energy structure transformation serve as partial mediators in the relationship between green finance and manufacturing resilience. (3) Regional heterogeneity analysis indicates that the positive impact of green finance is most pronounced in eastern China, while its effects are weaker in other regions.*

Keywords: *Green finance; Manufacturing Resilience; energy structure transition*

1. Introduction

China's manufacturing sector boasts a comprehensive and vast industrial system, having achieved undeniable success in quantitative growth. However, there remains a qualitative gap compared to developed countries. The 20th CPC National Congress emphasized advancing manufacturing toward higher-end, smarter, and greener development while enhancing industrial chain resilience and security. This highlights the significance of transitioning from quantity to quality and strengthening manufacturing resilience in the new era. Since Comfort introduced the concept of resilience into economics[1], academic research on economic resilience has expanded. Foreign scholars often analyze it through dimensions like social capital and industrial development[2,3], while domestic scholars focus on economic vulnerability and adaptability[4,5]. Industrial resilience, a subset of economic resilience, has been explored in terms of risk resistance, recovery capacity, and adaptability[6,7]. Green finance, which provides funding for green projects, not only develops green credit products but also encourages industrial adjustments in manufacturing. Although existing studies have examined green finance's impact on ecological resilience[8,9], its effect on manufacturing resilience remains unclear. Thus, investigating the mechanism of green finance's influence on manufacturing resilience holds significant theoretical and practical value.

2. Theoretical analysis and research hypothesis

Green finance enhances the resilience of the manufacturing sector through three key mechanisms. First, it strengthens manufacturing robustness. By implementing differentiated credit policies based on firms' pollution levels or emission-reduction efforts, green finance incentivizes green transformation and innovation while restricting overcapacity production[10]. This promotes high-quality manufacturing through targeted financing. Moreover, the environmentally conscious, technology-driven nature of green finance aligns with the future trajectory of manufacturing. It fosters new business models, technologies, and products that mitigate adverse shocks from environmental degradation and market volatility. Additionally, green finance mobilizes social resources—technology, talent, and equipment—to enhance labor productivity and production efficiency[11]. Second, green finance improves recovery capacity. Through leverage effects, it redirects capital from polluting, energy-intensive industries to eco-friendly and high-tech sectors[12]. This financial support ensures operational continuity by meeting manufacturers' transactional[13], short-term debt, and working capital needs. Crucially, it provides funding for emerging technologies that boost production efficiency and reduce resource waste when adopted. Third, green finance enhances adaptive capacity by accelerating industrial transformation. Under green financing

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pressures, high-pollution manufacturers must transition toward energy-efficient production or face competitive disadvantages[14]. Firms slow to adapt risk downsizing or obsolescence, whereas agile adopters gain market competitiveness, ensuring sustainable growth. This dynamic reinforces the sector's ability to evolve with environmental and market demands. Based on this, the following research hypothesis is proposed.

H1: Green finance exerts a statistically significant positive effect on manufacturing resilience.

Green finance employs differentiated credit policies and environmental rights trading mechanisms to directly constrain high-pollution energy consumption while simultaneously incentivizing clean energy investments[15]. The application of distributed renewable energy systems can reduce supply disruption risks and enhance supply chain stability. Energy structure optimization enables enterprises to proactively adapt to trade barriers such as carbon border adjustment mechanisms, mitigating the impacts of sudden policy changes[16]. This process inevitably reshapes corporate energy input portfolios, making energy structure transformation a crucial intermediate channel for green finance policy transmission.

Technological innovation enhances production efficiency and capital allocation by optimizing factor utilization and product value-added. It accelerates the phase-out of high-pollution, energy-intensive firms while fostering industrial upgrading and sustainable development. By driving cross-sector technology diffusion[17], it cultivates new growth engines and strengthens market competitiveness through innovation-driven value creation. This transformation facilitates industrial restructuring and coordinated economic development[18]. Based on this, the following research hypothesis is proposed.

H2: Energy restructuring and technological innovation mediate green finance's positive impact on manufacturing upgrading.

3. Econometric modeling and Variable Definition

3.1 Model setup

$$\boldsymbol{MR_{it} = \alpha_0 + \alpha_1 Df_{it} + \sum \beta CV_{it} + \mu_i + \nu_t + \varepsilon_{it}} \quad (1)$$

Among them MR represents manufacturing resilience, Df denotes digital finance, and CV indicates the control variables. The terms μ and ν capture unobserved regional fixed effects and time fixed effects respectively, while ε represents the stochastic error term.

To investigate the mechanisms through which green finance influences the resilience of the manufacturing sector, this paper constructs the following mediating effect model based on Equation (1).

$$\mathrm{Df_{it}} = \alpha_0 + \alpha_1 \mathrm{Med_{it}} + \sum \beta \mathrm{CV_{it}} + \mu_i + \nu_t + \varepsilon_{it} \quad (2)$$

$$\mathrm{MR_{it}} = \alpha_0 + \alpha_1 \mathrm{Df_{it}} + \gamma \mathrm{Med_{it}} + \sum \beta \mathrm{CV_{it}} + \mu_i + \nu_t + \varepsilon_{it} \quad (3)$$

Here, Med represents the mediating variables, including technological innovation and consumption upgrading, while the meanings of the other variables remain consistent with those in Equation (1).

3.2 Core explanatory variables

The core explanatory variable is green finance (GF). China's green finance system comprises multiple dimensions including green securities, green insurance, green credit, and carbon finance, forming a comprehensive development framework that requires a multi-indicator integrated evaluation system. Accordingly, this study constructs a green finance index (gf) using five sub-indicators through the entropy method: green credit (measured inversely by interest expense ratio of energy-intensive enterprises), green investment (environmental protection expenditure ratio in local budgets), green securities (market share of eco-friendly A-share companies), green insurance (ratio of agricultural to property insurance premiums), and carbon finance (inversely measured by CO2 emissions per GDP). Data sources include statistical yearbooks, China Industrial Statistical Yearbook, RESSET Financial Database, and CEADs Carbon Emissions Database.

3.3 Explained Variables

Manufacturing resilience (MR) reflects the sector's capacity to withstand shocks (maintaining stability), recover from disruptions (restoring production), and transform through innovation (achieving sustainable growth). The evaluation system incorporates these three dimensions (see Table 1), with

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measurements MR_s (entropy method) and MR_cv (coefficient of variation method).

3.4 Mediating variables

Mediating variables include technological innovation (Create), measured by the logarithm of valid invention patents in industrial enterprises, and energy structure transition (EM), represented by the electricity consumption ratio to reflect reduced carbon costs and fossil fuel dependence.

3.5 Control variables

Control variables cover government intervention (Gov, fiscal expenditure/GDP ratio), urbanization (Urb, urban population share), population density (PD, log of people per km²), employment (Employ, log of manufacturing workers), and transportation infrastructure (Traffic, log of highway mileage). This comprehensive framework enables systematic analysis of green finance's impact on manufacturing resilience through innovation and energy transition pathways while controlling for key socioeconomic factors.

Table 1: Manufacturing Industry Resilience Evaluation Index System

Primary indicator	Secondary indicator	Indicator Explanation	Indicate attribute
Resilience And Stability capacity	Per Capita Number of Invention Patents	Number of Invention Patents/R&D Personnel in Large-scale Industrial Enterprises	Positive
	Profit Margin of Manufacturing Enterprises	Total Profits of Large-scale Industrial Enterprises/Main Business Costs of Large-scale Industrial Enterprises	Positive
	Labor Productivity in Manufacturing	Industrial Value Added/Average Number of Manufacturing Employees	Positive
	Proportion of Manufacturing Output Value	Industrial Value Added/GDP	Positive
	Advanced Manufacturing Industrial Structure	Revenue of High-tech Industries/Revenue of Large-scale Industries	Positive
Absorption And Recovery Capacity	Degree of Foreign Trade Openness	Total Import and Export Volume of Goods	Positive
	Degree of Foreign Investment Openness	Foreign Direct Investment Amount	Positive
	Proportion of Tertiary Industry Value Added	Regional Marketization Index	Positive
	Manufacturing Growth Rate	Current Year Industrial Value Added/Previous Year Industrial Value Added	Positive
Transformation And Upgrading Capacity	Energy Consumption per Unit of Value Added	Coal Physical Consumption/Industrial Value Added	Negative
	CO2 Emissions per Unit of Value Added	Sulfur Dioxide Emissions/Industrial Value Added	Negative
	Industrial Solid Waste Generated per Unit of Value Added	Industrial Solid Waste Utilization/Industrial Value Added	Negative
	Chemical Oxygen Demand in Wastewater per Unit of Value Added	Chemical Oxygen Demand in Wastewater/Industrial Value Added	Negative
	R&D Investment Intensity	R&D Expenditure of Large-scale Industrial Enterprises/Main Business Income of Large-scale	Positive
	R&D Personnel Investment Effort	Number of R&D Personnel in Large-scale Industrial Enterprises	Positive

3.6 Data sources

This study utilizes panel data from 30 Chinese provinces, municipalities, and autonomous regions (excluding Hong Kong, Macao, Taiwan, and Tibet) spanning the period 2012-2022. The primary data sources include the official website of the National Bureau of Statistics, China Industrial Statistical Yearbook, China Statistical Yearbook, China Financial Statistical Yearbook, China Insurance Statistical Yearbook, China Energy Statistical Yearbook, China Labor Statistical Yearbook, China Science and Technology Statistical Yearbook, China High-Tech Industry Statistical Yearbook, provincial statistical yearbooks, as well as the WIND database and CEInet Statistics Database.

4. Estimation results and analysis

4.1 Descriptive Statistics

Descriptive statistics of key variables are presented in Table 2. The green finance index (GF) shows

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an average value of 3.391, ranging from 2.202 to 4.416, indicating relatively underdeveloped green finance systems across provinces. While China has long prioritized environmental protection, systematic development of green finance remains in its early stages, with significant regional variations due to differences in geographical advantages, financial/technical support, and environmental priorities. The technological innovation index (Create) averages 9.316 (range: 5.136-13.258) with substantial regional disparities, reflecting the high-cost, high-risk nature of R&D activities that often exceed firms' financial capacities while facing prohibitive external financing costs.

Table 2: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
mr_s	330	.162	.119	.044	.71
mr_cv	330	.227	.102	.087	.688
gf	330	3.391	.503	2.202	4.146
urb	330	.608	.117	.36	.9
gov	330	.249	.102	.107	.643
pd	330	5.475	1.291	2.068	8.275
traffic	330	2.458	.077	2.245	2.558
employ	330	100277.5	140250.48	1157	772585
create	330	9.316	1.522	5.136	13.258
em	330	.033	.023	.004	.094

4.2 F-test and Hausman test

This study employs both F-test and Hausman test to determine the appropriate model specification between fixed-effects and random-effects models in Table 3. The test results show statistically significant p-values (<0.05) for both manufacturing resilience measurement methods (entropy weighting and coefficient of variation approaches), leading to the rejection of the null hypothesis. The test results indicate that the fixed-effects model is more appropriate for this study.

Table 3: Results of F and Hausmann test

	mr_s-p	mr_cv-p
F test	0.0000	0.0000
Hausman test	0.0000	0.0029

4.3 Baseline regression result

Table 4: Baseline Regression Results

	(1)	(2)	(3)	(4)
	mr_s	mr_s	mr_cv	mr_cv
gf	0.237***	0.179***	0.245***	0.162***
	(14.677)	(5.916)	(15.529)	(5.397)
pd		0.326***		0.290***
		(6.021)		(5.410)
traffic		-1.715***		-1.364***
		(-6.525)		(-5.231)
urb		0.278***		0.308***
		(3.988)		(4.450)
gov		-0.231***		-0.236***
		(-4.692)		(-4.829)
employ		0.000***		0.000**
		(3.165)		(2.557)
_cons	-0.643***	1.864***	-0.604***	1.304**
	(-11.724)	(3.146)	(-11.289)	(2.218)
N	330	330	330	330
R2	0.419	0.572	0.446	0.578

***p<0.01,**p<0.05,*p<0.10

The results in Table 4 baseline regression results demonstrate that the coefficient of digital finance on manufacturing resilience remains consistently positive and statistically significant at the 1% level, regardless of whether control variables are included. This robust finding confirms that green finance

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exerts a significantly positive impact on enhancing manufacturing resilience, indicating that the development of green financial instruments effectively strengthens the sector's capacity to withstand shocks, recover from disruptions, and achieve sustainable transformation.

4.4 Robustness test

This study conducts robustness tests using three approaches: (1) Instrumental variable regression using first-order lagged green finance variables (Table 5 columns 1-2)[19], (2) Winsorization at the 1% level (Table 5 columns 3-4), and (3) Sample adjustment by excluding municipalities [20](Table 5 columns 5-6). The results consistently demonstrate green finance's positive impact on manufacturing resilience, confirming the reliability of our baseline findings and supporting Hypothesis 1.

Table 5: Robustness Test Results

	(1)	(2)	(3)	(4)	(5)	(6)
	mr_s	mr_cv	mr_s	mr_cv	mr_s	mr_cv
gf	0.145***	0.127***	0.145***	0.132***	0.158***	0.138***
	(4.484)	(3.959)	(4.950)	(4.468)	(4.312)	(3.740)
pd	0.369***	0.341***	0.246***	0.218***	0.397***	0.325***
	(5.749)	(5.385)	(4.811)	(4.210)	(6.891)	(5.586)
traffic	-1.721***	-1.423***	-1.506***	-1.169***	-2.058***	-1.633***
	(-5.823)	(-4.882)	(-6.083)	(-4.669)	(-7.088)	(-5.579)
urb	0.371***	0.407***	0.306***	0.333***	0.375***	0.392***
	(4.606)	(5.129)	(4.529)	(4.874)	(4.330)	(4.489)
gov	-0.257***	-0.261***	-0.259***	-0.261***	-0.252***	-0.237***
	(-4.785)	(-4.930)	(-5.475)	(-5.453)	(-4.727)	(-4.409)
employ	0.000***	0.000**	0.000***	0.000***	0.000***	0.000**
	(2.796)	(2.175)	(3.509)	(2.780)	(2.983)	(2.499)
_cons	1.710**	1.241*	1.888***	1.309**	2.293***	1.777**
	(2.528)	(1.861)	(3.369)	(2.310)	(3.364)	(2.586)
N	300	300	330	330	286	286
R2	0.548	0.555	0.574	0.575	0.611	0.593

***p<0.01,**p<0.05,*p<0.10

4.5 Mediation test

Table6: Mediation Effect Test Results

	(1)	(2)	(3)	(4)	(5)	(6)
	create	mr_s	mr_cv	em	mr_s	mr_cv
gf	1.928***	0.147***	0.135***	-0.009***	0.163***	0.145***
	(7.394)	(4.509)	(4.159)	(-2.932)	(5.401)	(4.855)
pd	-0.027	0.326***	0.291***	-0.002	0.323***	0.287***
	(-0.058)	(6.081)	(5.447)	(-0.325)	(6.046)	(5.435)
traffic	8.558***	-1.855***	-1.483***	-0.004	-1.722***	-1.373***
	(3.772)	(-6.952)	(-5.585)	(-0.166)	(-6.644)	(-5.348)
urb	10.109***	0.112	0.167*	0.023***	0.317***	0.349***
	(16.798)	(1.160)	(1.739)	(3.177)	(4.528)	(5.044)
gov	0.923**	-0.247***	-0.249***	-0.006	-0.241***	-0.247***
	(2.167)	(-5.001)	(-5.080)	(-1.151)	(-4.949)	(-5.117)
employ	0.000**	0.000***	0.000**	-0.000	0.000***	0.000**
	(2.205)	(2.853)	(2.285)	(-0.141)	(3.184)	(2.572)
create		0.016**	0.014**			
		(2.448)	(2.083)			
em					-1.697***	-1.816***
					(-3.028)	(-3.273)
_cons	-24.550***	2.267***	1.645***	0.073	1.988***	1.436**
	(-4.799)	(3.715)	(2.709)	(1.195)	(3.393)	(2.476)
N	330	330	330	330	330	330
R2	0.920	0.581	0.584	0.613	0.572	0.580

***p<0.01,**p<0.05,*p<0.10

The regression results for the technological innovation mechanism are presented in columns (1)-(3) of Table 6. Column (1) shows that green finance has a statistically significant positive effect on technological innovation at the 1% level, indicating that green finance development significantly

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promotes technological progress. Columns (2)-(3) demonstrate that when both technological innovation and green finance are included in the regression equation, the coefficient of green finance decreases compared to the baseline regression while remaining significant, with both variables showing positive coefficients. This confirms that technological innovation plays a partial mediating role, suggesting green finance enhances manufacturing resilience partly by facilitating technological innovation.

For the energy structure mechanism shown in columns (4)-(6) of Table 5, column (4) reveals green finance significantly promotes energy structure transformation at the 1% significance level. Columns (5)-(6) indicate that when incorporating both energy structure and green finance in the regression, green finance's coefficient increases relative to the baseline while maintaining significance, with both variables exhibiting positive effects. This demonstrates energy structure transformation partially mediates the relationship, meaning green finance improves manufacturing resilience in part by accelerating energy structure optimization. These findings collectively validate Hypothesis 2, establishing both technological innovation and energy structure transformation as significant transmission channels through which green finance enhances manufacturing resilience. The results remain robust across different model specifications, confirming the dual-pathway mechanism of green finance's impact on manufacturing sector resilience.

4.6 Heterogeneity estimation results

Given significant regional variations in green finance development and manufacturing resilience levels across China's provinces due to geographical differences, this study conducts separate regression analyses for eastern, central, western, and northeastern regions according to the National Bureau of Statistics' classification framework. The regional regression results presented in Table 7 reveal distinct spatial patterns in how green finance influences manufacturing resilience, with coefficient magnitudes and significance levels varying substantially across different geographical zones.

Table7: Regression Results of Region heterogeneity ananlysis

	(1) eastern	(2) central	(3) western	(4) northeastern
gf	0.258***	0.104	0.021	0.348
	(3.969)	(1.005)	(0.515)	(1.007)
pd	0.108	0.181	0.250***	0.309
	(0.711)	(1.461)	(3.357)	(1.095)
traffic	-1.718***	-1.180*	-2.469***	-1.554
	(-2.902)	(-1.770)	(-6.636)	(-1.093)
urb	0.170	0.162	0.696***	0.170
	(1.194)	(0.729)	(6.747)	(0.126)
gov	-0.446***	-0.357*	-0.417***	-0.276
	(-3.768)	(-1.837)	(-5.684)	(-0.855)
employ	0.000***	0.000	-0.000*	-0.000
	(3.265)	(1.267)	(-1.699)	(-0.463)
_cons	2.755**	1.742	4.585***	0.776
	(2.113)	(1.063)	(4.869)	(0.198)
N	110	66	121	33
R2	0.651	0.553	0.702	0.516

***p<0.01,**p<0.05,*p<0.10

The regression results of green finance's impact on manufacturing resilience across China's four major regions are presented in Models (1)-(4). The eastern region shows a statistically significant coefficient of 0.258 for green finance at the 1% level, while the coefficients for central, western, and northeastern regions are insignificant. Financial development scale and urbanization level demonstrate certain significance, whereas other variables remain insignificant. This regional disparity primarily stems from structural characteristics - most central, western and northeastern provinces are energy and raw material bases dominated by high-pollution, high-emission, and energy-intensive industries. These regions suffer from irrational industrial structures and weak independent innovation capacity, resulting in underdeveloped green finance systems that minimally impact high-quality manufacturing development. The western region faces particularly severe challenges due to its remote geographical location, inadequate transportation infrastructure, and educational resource shortages, which constrain economic exchanges and information flows with more developed areas. This geographical disadvantage creates significant developmental hurdles for green finance from the outset. Furthermore, the lack of advanced

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and innovative industries in the west limits opportunities for diversified green financial products and services. Technological backwardness also hinders environmental protection and clean technology R&D, leaving the region with insufficient innovation capacity and competitiveness in green finance. These compounded factors - structural, geographical, and technological - collectively restrict the development and application of green finance in China's less developed regions, creating substantial regional imbalances in green finance's effectiveness for enhancing manufacturing resilience.

5. Conclusion and Policy Recommendations

This study examines the impact of green finance on manufacturing resilience using panel data from 30 Chinese provinces (2012-2022), constructing a comprehensive evaluation system that measures resilience through three dimensions: resistance and stability maintenance capacity, absorption and recovery capacity, and transformation and upgrading capacity. With technological innovation and energy structure transition as mediating variables, the key findings reveal: (1) Green finance significantly enhances manufacturing resilience, demonstrating its positive role in empowering industrial adaptability; (2) Both technological innovation and energy structure transformation serve as partial mediators in this empowerment process; (3) Regional heterogeneity analysis using fixed-effects models shows green finance's effect is strongest in eastern China (statistically significant), while maintaining positive but weaker correlations in central, western, and northeastern regions.

Based on the above conclusions, the following policy recommendations are put forward: First, strengthen the legal safeguards for green insurance and improve the green finance system and legal framework. Currently, China's green finance sector lacks comprehensive laws and policy frameworks, creating regulatory gaps and implementation challenges. Second, innovate guarantee financing support policies for green industry projects to inject vitality into green finance development. A multi-tiered third-party guarantee platform incorporating loans, insurance and securities should be established to meet industrial development needs, helping disperse financial institution risks and improve green loan accessibility to incentivize corporate participation in green industries.

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