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Article

The impact and mechanism of green finance on the ESG performance of China's manufacturing enterprises from biomechanics perspectives

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Abstract: Biomechanics boost human health and performance. Sports not only promote the improvement of national physical fitness, but also promote the development of fitness equipment manufacturing industry. Sports injuries, such as fractures, require the consultation of orthopedic doctors, and fitness requires the guidance of coaches, which to a certain extent promotes the employment of biomechanics researchers. Therefore, the potential of biomechanics is for improving human health and Environmental, Social and Governance (ESG) performance is well established. Green finance can provide financial support for the sustainable development of the manufacturing industry. Whether green finance, as a financial tool that combines healthy, environmental and economic benefits, has a significant impact on the ESG performance of enterprises that are highly concerned by government departments and investors at present still requires in-depth research. This paper, from bio-mechanics perspectives, based on data from listed manufacturing companies in China from 2013 to 2022, examines the impact of green finance on the ESG performance of manufacturing enterprises (especially, sports facilities manufacturing enterprises) by constructing a fixed-effects model. The research findings are as follows: First, green finance prompts citizens choose low-carbon transport, such as cycling, running, or new energy vehicles. It is not only conducive to improving citizens' physical fitness and the environment, but also conducive to the development of sports facility manufacturing companies and auto-mobile manufacturing companies. Second, green finance significantly enhances the ESG performance of manufacturing enterprises, and this conclusion has been robustly tested through methods such as replacing the explained variable, incorporating dummy variables, and employing instrumental variable techniques. Third, green finance improves the ESG performance of enterprises by alleviating financing constraints and promoting green technological innovation in the manufacturing sector. Finally, green finance has a more significant impact on enhancing the ESG performance of non-state-owned manufacturing enterprises and technology-intensive manufacturing enterprises. This study provides an in-depth exploration of the extent and mechanisms through which green finance influences the ESG performance of Chinese manufacturing enterprises, offering policy references for accelerating the green transformation and up-grading of China's manufacturing sector.

Keywords: green finance; biomechanics perspectives; running economy; China's manufacturing; corporate ESG performance; financing constraints; green technological innovation

1. Introduction

According to the data released by the World Bank, China's manufacturing sector has maintained its position as the world's largest in terms of added value since 2010, earning the title of "manufacturing powerhouse." However, as China's economy shifts towards high-quality development, manufacturing enterprises are facing new challenges. The low-end manufacturing sector is grappling with issues

such as overcapacity and poor environmental performance, while high-end manufacturing enterprises lack sustained momentum for green transformation. Moreover, the global manufacturing sector is undergoing a profound green transformation. For instance, the European Union has launched a series of green policies, aiming to make the EU the world's first climate - neutral region. These initiatives involve numerous requirements and support measures for the manufacturing industry's green transition. Currently, global manufacturing is evolving towards being cleaner, more energy - efficient, and more intelligent. So to promote the green transformation of manufacturing enterprises, the "14th Five-Year Plan" issued by the Central Committee of the Communist Party of China in 2020 proposed to "strengthen legal and policy support for green development, develop green finance, support green technology innovation, promote clean production, develop environmental protection industries, and advance green transformation in key industries and critical areas." Green finance not only optimizes the allocation of financial capital but also serves as a tool for environmental regulation. It effectively addresses the shortcomings of traditional environmental policies and explores new ways to use financial regulation and other market mechanisms in environmental management [1]. The scale of the global green finance market is expanding robustly, with a ceaseless outpouring of innovative products. Amidst the backdrop of economic globalization, countries around the world are intensifying their collaboration and communication in the realm of green finance. Thus, it is of utmost urgency to vigorously propel the development of green finance, as it represents a critical step towards a sustainable future. However, as a financial tool that combines environmental and economic benefits [2], whether green finance significantly impacts the ESG performance of enterprises, which is highly regarded by both government departments and investors, remains a topic for further research.

ESG refers to Environment, Social, and Governance. The ESG concept emphasizes that enterprises should focus on ecological environmental protection, fulfill social responsibilities, and improve governance levels. This concept not only expands the connotation of green investment but also extends its boundaries [3] and serves as a key indicator to assess whether a company has long-term development potential [4]. ESG ratings can evaluate a company's commitment, achievements, business strategies, and structure in achieving sustainability goals, while also helping enterprises gain deeper insights into their strengths, weaknesses, risks, and opportunities. Recent studies have found that factors such as green taxation [5], environmental risks [6], and institutional investors [7] significantly impact corporate ESG performance, but research from the perspective of green finance is relatively scarce.

Therefore, based on the research of scholars both domestically and internationally, this paper examines the impact of green finance on the ESG performance of Chinese listed manufacturing enterprises from 2013 to 2022, as well as the underlying mechanisms. The marginal contributions of this study are: first, it enriches the research on the impact of green finance on corporate ESG performance, providing empirical support for understanding the mechanisms of this impact; second, it offers new insights for accelerating the green transformation and upgrading of China's listed manufacturing enterprises; third, it provides policy

implications for government departments to improve green finance and ESG-related policies, and lays the foundation for third-party ESG rating agencies to develop industry-specific and localized ESG rating systems.

2. Literature review

2.1. Research on green finance

Research on green finance in China has lagged behind that in foreign countries. Existing literature can be broadly categorized into three areas. The first focuses on green financial instruments, such as green credit, which can influence the investment and financing behavior of highly polluting enterprises [8], incentivize corporate green innovation [9], and promote the transformation of corporate environmental governance [10]. Additionally, companies that issue green bonds not only enhance their operational performance but also pave the way for long-term value growth [11]. The second area examines the economic consequences of green finance development, such as promoting economic growth [12], driving the optimization and upgrading of industrial structures [13], and boosting high-quality economic development [14]. The third area explores the environmental benefits of green finance, such as improving overall environmental quality [15], enhancing environmental performance [16], and effectively reducing carbon emissions [17]. However, most empirical studies on the impact of green finance on enterprises focus on a single green financial instrument or policy. The literature has not yet reached a consensus on the impact of green finance as a direct financing tool on the ESG performance of manufacturing enterprises. Therefore, it is necessary to conduct research on the relationship between green finance and the ESG performance of manufacturing enterprises.

Running biomechanics is considered an important determinant of running economy (RE) [18]. Running economy (RE) is a determinant of performance in endurance sports and is a complex multi-factorial measure which reflects the combined functioning of bio-mechanical, neuro-muscular, metabolic and cardio-respiratory factors some of which are hereditary or adapt to coaching [19]. Ye presents a novel approach to financial decision-making by integrating biomechanical principles with neural network architectures [20].

2.2. Research on ESG

With the increasing application of ESG investment principles in corporate management practices and development strategies, the body of research on corporate ESG performance has been enriched. The research can be broadly categorized into three areas. The first focuses on the connotation and application of ESG performance, such as its role as an important indicator for institutional investors to assess companies in capital markets [21] and its impact on foreign direct investment [22]. The second area examines the economic consequences of corporate ESG performance, such as its impact on corporate value [23], operational performance [24], financing constraints [25], investment risks [26], and mismatches in investment and financing horizons [27]. The third area explores the factors influencing corporate ESG performance, such as environmental regulation policies [28], environmental

risks [29] and common institutional investors [30], all of which significantly affect corporate ESG performance.

3. Research hypothesis

Green finance fundamentally represents credit allocation based on environmental constraints, meaning that under the same capital pricing conditions, it tends to allocate funds to green projects. This mechanism not only fulfills the resource allocation function of traditional financial instruments but also supplements the role of environmental regulation. Through the research of domestic and international scholars on the driving factors of green finance's impact on the ESG performance of manufacturing enterprises, this paper argues that green finance enhances the ESG performance of manufacturing enterprises through two mechanisms: alleviating financing constraints and incentivizing green technological innovation.

Firstly, green finance helps alleviate the financing constraints of manufacturing enterprises, thereby improving their ESG performance. Currently, Chinese manufacturing enterprises are in the transition phase of green development, and these enterprises urgently need financial support and investment [31]. Compared to heavily polluting projects, green finance is more inclined to support environmental protection projects [32], thereby compelling manufacturing enterprises to shift towards green projects and actively disclose environmental information. This shift in manufacturing enterprises helps improve the completeness and accuracy of their information disclosure mechanisms, reducing information asymmetry with external stakeholders. The reduction in information asymmetry attracts more attention, understanding, and supervision from external fund providers, alleviating the financing constraints of enterprises [33]. The alleviation of financing constraints not only motivates enterprises to improve their ESG performance but also provides them with the ability to do so. The release of financing constraints allows enterprises to obtain more financial support, which, to maintain a good green image, naturally leads to increased investment in environmental responsibility, social responsibility, and corporate governance, thereby helping enterprises achieve better ESG performance.

Secondly, green finance incentivizes green technological innovation in manufacturing enterprises, thereby improving their ESG performance. The Neoclassical School argues that the financial burden on enterprises can easily lead to a shortage of funds for green technological innovation [34]. Green finance injects substantial funds into energy-saving and environmentally friendly manufacturing enterprises through various financial instruments, effectively stimulating technological innovation and providing long-term momentum for innovation through opportunities sharing and risk diversification [35]. Additionally, due to the information disclosure function of green finance, enterprises that release environmental signals will attract attention and supervision from capital market investors. Under external pressure, to meet the demands of external investors and enhance corporate value, enterprises tend to actively increase investment in green technological innovation, comprehensively reduce environmental costs, and gain the

trust of external investors [36]. By enhancing green technological innovation, manufacturing enterprises achieve higher resource utilization efficiency, thereby improving environmental performance; simultaneously, they achieve lower production costs, providing financial support for enterprises to voluntarily fulfill social responsibilities and improve governance systems, laying the foundation for enhancing ESG performance.

Based on the above analysis, the following hypothesis is proposed:

H1: Under the condition of other factors remaining unchanged, green finance significantly promotes the ESG performance of manufacturing enterprises.

4. Materials and methods

4.1. Data sources

This paper selects Chinese listed manufacturing companies from 2013 to 2022 as the research sample. Drawing on data processing methods from existing literature, samples classified as ST and ST* are excluded, along with those with missing key variables. ESG performance data for enterprises is sourced from ESG rating scores published by China Securities Index and SynTao Green Finance. Green finance data is obtained from information released on the official websites of the National Bureau of Statistics, the Ministry of Science and Technology, and the People's Bank of China, as well as from annual statistical reports. Relevant variables for listed manufacturing companies are sourced from the CSMAR database.

4.2. Model specification and variable description

To examine the impact of green finance on the ESG performance of manufacturing enterprises, the following econometric model is constructed:

$$ESG_{it} = \beta_0 + \beta_1 green_{ct} + \gamma control_{it} + \delta_j + \varphi_t + \varepsilon_{it} \quad (1)$$

Among them, δ_j represents the industry fixed effect; φ_t represents the time fixed effect; ε_{it} represents the random error term. The focus of this paper is β_1 that if this coefficient is positive, it indicates that green finance has a positive impact on the ESG performance of manufacturing enterprises; conversely, it has a negative impact.

4.2.1. Dependent variable

The dependent variable in this paper is "esg", representing the ESG performance of manufacturing enterprises in a given year. This article utilizes Huazheng's comprehensive ESG indicators, which covers the three systems of environmental responsibility, social responsibility, and governance responsibility, including 26 key indicators and over 130 sub-indicators. The Huazheng rating system has extensive data coverage. It comprehensively and precisely reflects enterprises' ESG performance, with timely data updates. Therefore, this paper chooses China Securities Index. The Huazheng index system ranks the ESG performance of all listed companies from high to low into 9 categories: AAA, AA, A, BBB, BB, B, CCC, CC, and C. For the convenience of research, this paper assigns values 1–9 to the nine rating categories from C to AAA, with higher values

indicating better ESG performance. Additionally, in the robustness test section, the ESG rating index from SynTao Green Finance is selected as an alternative variable.

4.2.2. Explanatory variable

The core explanatory variable in this paper is "green", representing the green finance index of a city in a given year. This paper selects green finance data from 421 prefecture-level cities across the country and uses the entropy method for measurement. The entropy method sets weights from an objective perspective. It determines the contribution degree of each indicator by calculating the entropy value and the difference coefficient of each indicator, effectively avoiding the interference of subjective factors on the results. The evaluation system of green finance involves a large number of complex indicators, so it is even more important to eliminate the interference of subjective factors. In addition, the entropy method can analyze and process data with normal and non-normal distributions, which well adapts to the characteristics and distribution patterns of data of different indicators in green finance. Many scholars have chosen the entropy method when constructing the evaluation system of green finance and achieved satisfactory results. Therefore, this paper also selects the entropy method. The evaluation indicators include green credit, green investment, and green insurance, among others. The comprehensive evaluation system is shown in **Table 1**.

Table 1. Green finance evaluation indicator system.

Variable	Indicators	Connotation	Calculation method
Green Finance	Green Credit	Proportion of Environmental Protection Project Loans	Total Environmental Protection Project Loans in the Province/Total Loans in the Province
	Green Investment	Proportion of Environmental Pollution Control Investment to GDP	Environmental Pollution Control Investment/GDP
	Green Insurance	Promotion Level of Environmental Pollution Liability Insurance	Revenue from Environmental Pollution Liability Insurance/Total Premium Income
	Green Bonds	Development Level of Green Bonds	Total Issuance of Green Bonds/Total Issuance of All Bonds
	Green Support	Proportion of Fiscal Environmental Protection Expenditure	Fiscal Environmental Protection Expenditure/General Budget Expenditure
	Green Funds	Proportion of Green Funds	Total Market Value of Green Funds/Total Market Value of All Funds
	Green Equity	Depth of Green Equity Development	Carbon Trading, Energy Use Rights Trading, Emission Rights Trading/Total Equity Market Trading Volume

4.2.3. Control variables

The control variables selected for this study are shown in **Table 2**.

Table 2. Control variable indicators and their meanings.

Variable name	Variable Symbols	Variable Meaning
Corporate ESG Performance	esg	Huazheng Rating Index
Green Finance	green	Green Finance Index of Prefecture-Level Cities
Free Cash Flow	cfo	Net Operating Cash Flow/Total Assets
Corporate Size	size	Natural Logarithm of Total Assets
Debt-to-Equity Ratio	der	Total Liabilities/Net Assets

Table 2. (*Continued*).

Variable name	Variable Symbols	Variable Meaning
Return on Total Assets	Roa	Net Profit/Total Assets at the End of the Period
Corporate Growth	growth	Revenue Growth Rate
Corporate Value	tob	Market Value of the Enterprise/Replacement Cost of the Enterprise
Board Size	board	Total Number of Board Members
Unified Role of Chairman and CEO	dual	Chairman and CEO Positions Held by the Same Person (1 if true, 0 otherwise)
Institutional Investor Ownership Ratio	inst	Measures of Enterprise Equity Characteristics
Equity Concentration	top1	Shareholding Ratio of the Largest Shareholder
Independent Director Ratio	indep	Proportion of Independent Directors in the Total Number of Board Members

4.3. Descriptive statistics

The descriptive statistics for the main variables in this paper are presented in **Table 3**. The mean value of green finance is 0.423 with a standard deviation of 0.113, indicating that the level of green finance in prefecture-level cities across the country is still in a developmental stage, with certain variations among regions. The mean ESG performance of manufacturing enterprises is 4.139, suggesting that the ESG performance of most manufacturing enterprises is average, primarily falling between BB and B, and there are significant differences in ESG levels among enterprises. It can be seen from the results that the distributions of the other variables do not exhibit extreme values and are all within reasonable ranges.

Table 3. Descriptive statistics of key variables.

Variables	*N*	mean	sd	min	max
esg	16,417	4.139	1.016	1.000	8.000
green	14,655	0.423	0.113	0.098	0.632
cfo	16,417	0.050	0.065	−0.136	0.242
size	16,417	22.00	1.131	19.970	25.520
der	16,417	0.819	0.828	0.053	5.25
roa	16,417	0.042	0.067	−0.225	0.232
growth	16,417	0.159	0.354	−0.479	2.079
tob	16,417	2.188	1.407	0.000	8.860
board	16,417	2.096	0.191	1.609	2.565
dual	16,417	0.349	0.477	0.000	1.000
inst	16,417	0.407	0.249	0.002	0.904
top1	16,417	0.326	0.138	0.087	0.693
indep	16,417	0.377	0.054	0.333	0.571

5. Empirical results and analysis

To verify the validity of hypothesis H1, this paper first employs a fixed-effects model for regression analysis, exploring the impact of green finance on the ESG performance of manufacturing enterprises while controlling for time and industry

fixed effects. Subsequently, a series of robustness tests are conducted to validate the reliability of the basic regression analysis. Finally, to delve into the heterogeneity and mechanisms of the impact of green finance on corporate ESG performance, heterogeneity analysis and mechanism studies are performed respectively.

5.1. Benchmark regression

Table 4 presents the regression results of the impact of green finance on the ESG performance of manufacturing enterprises. The results in Equation (1) show that, after including firm-level control variables, the coefficient of green finance (green) is 0.482, which is significantly positive at the 5% level. Equation (2) further controls for regional GDP growth, and the coefficient of green finance (green) is 0.406, also significantly positive at the 5% level. This indicates that when manufacturing enterprises participate in green finance projects, their ESG performance significantly improves. Therefore, hypothesis H1 is validated.

$$ESG_{it} = \beta_0' + \beta_1' green_{ct} + \beta_3 gdp + \gamma' control_{it} + \delta_j' + \varphi_t' + \varepsilon_{it}' \quad (2)$$

Table 4. Baseline regression results.

	(1)	**(2)**
	esg	**esg**
green	0.482***	0.406**
	(0.185)	(0.195)
cfo	0.143	0.153
	(0.143)	(0.143)
size	0.179***	0.179***
	(0.009)	(0.009)
der	−0.213***	−0.213***
	(0.012)	(0.012)
roa	2.934***	2.881***
	(0.166)	(0.166)
growth	−0.196***	−0.194***
	(0.025)	(0.025)
board	0.384***	0.392***
	(0.052)	(0.053)
dual	−0.033**	−0.031*
	(0.017)	(0.017)
tob	−0.044***	−0.045***
	(0.006)	(0.006)
inst	−0.0001	−0.0001
	(0.0001)	(0.0001)
top1	0.006***	0.005***
	(0.001)	(0.001)
indep	0.021***	0.021***
	(0.002)	(0.002)

Table 4. (*Continued*).

	(1)	(2)
	esg	**esg**
gdp		0.033
		(0.025)
Constant	−1.599***	−1.954***
	(0.242)	(0.354)
N	14655	14545
R^2	0.198	0.198
Industry	YES	YES
Year	YES	YES

* Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively; robust standard errors are reported in parentheses. The same applies below.

5.2. Robustness test

To verify the reliability of the benchmark regression results, a series of robustness tests were conducted, including sample replacement, control for time trends, and exclusion of external shocks. To validate the reliability of the corporate ESG performance indicators, the method of replacing the explained variable was used for verification; to control for sample time and regional trend effects, province and year interaction fixed effects were added for regression; considering the omitted variable problem in data processing, the winsorization treatment was canceled for testing; to alleviate the impact of external environment shocks, the sample period was adjusted for verification; considering the impact of policy effects on empirical results, policy dummy variables were included for regression; to test the endogeneity issue of the core variables, appropriate instrumental variables were considered to test the robustness of the empirical results.

1) Replacement of Explained Variables. The main ESG performance evaluation institutions for domestic listed companies are HuaZheng, Bloomberg, and SynTao. Compared to the others, HuaZheng has a broader coverage, more comprehensive, and detailed data, hence China Securities Index were used as the explained variable in the benchmark regression. In the robustness test, SynTao's ESG scores were used to measure the ESG performance of manufacturing enterprises, with a smaller sample size, but the regression results still support the conclusions of this paper, see **Table 5** Model (1).

2) Change of Fixed Effects. The benchmark regression results in the previous text were controlled for industry and time fixed effects within the fixed effects model, and the interaction term fixed effects of province and year were added for regression. In **Table 5** Model (2), the regression coefficient for green finance (green) is 0.399, which is significantly positive at the 10% level, further verifying the robustness of the results of this paper.

3) Winsorization Treatment. The impact of green finance on the ESG performance of manufacturing enterprises may still have an omitted variable problem. In response to the above issue, the winsorization treatment performed in the previous basic regression was canceled, and a regression analysis was conducted on

all data of all variables. The results are shown in **Table 5** Model (3), where the regression coefficient for green finance (green) is 0.441, significantly positive at the 5% level, and the previous conclusions remain robust.

4) Change of Sample Period. Due to the impact of the COVID-19 pandemic from the end of 2019 to 2022, the development of the real economy was slow, and the manufacturing industry suffered from labor shortages, forced shutdowns, and product backlogs, etc. Therefore, the sample from 2020 to 2022 was deleted and the regression was rerun. In **Table 5** Model (4), the regression coefficient for green finance (green) is 0.430, significantly positive at the 10% level.

5) Exclusion of Policy Influence. On 14 June 2017, the State Council's executive meeting decided to select some areas in Zhejiang, Jiangxi, Guangdong, Guizhou, and Xinjiang provinces (regions) to create green finance reform and innovation pilot zones with different focuses and distinct characteristics, and to explore beneficial and promotable successful experiences in the institutional mechanisms of these pilot zones. Therefore, a dummy variable for pilot cities was added, with pilot cities assigned a value of 1 and other cities assigned 0, for regression. In **Table 5** Model (5), the regression coefficient for green finance (green) is 0.401, significantly positive at the 5% level, further supporting the conclusions of this paper.

Table 5. Robustness test results.

	(1)	(2)	(3)	(4)	(5)
	esg	**esg**	**esg**	**esg**	**esg**
green	1.545***	0.399*	0.441**	0.430*	0.401**
	(0.593)	(0.189)	(0.194)	(0.239)	(0.188)
policy					0.107***
					(0.040)
controls	YES	YES	YES	YES	YES
constants	−4.714***	−1.589***	−1.817***	−1.482***	−1.574***
N	1848	14655	14545	8733	14655
R^2	0.308	0.202	0.197	0.198	0.198
Industry	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES
Pro&year	NO	YES	NO	NO	NO

6) Instrumental Variable Test. This paper uses the average green finance development level of the three provinces with the most similar economic development levels to province p, where enterprise *i* is located, as the instrumental variable. On one hand, neighboring provinces with similar economic scales are likely to have similar green finance development levels, which satisfies the relevance requirement for selecting instrumental variables. On the other hand, the green finance development levels of neighboring provinces are unlikely to influence the ESG performance of enterprises within the province, meeting the exogeneity requirement for instrumental variables.

Table 6 reports the 2SLS regression results of the instrumental variable (IV) constructed earlier. Equation (1) presents the results of the first-stage regression, where the instrumental variable's regression coefficient is significantly positive at the 1% level. Equation (2) shows the results of the second-stage regression, where the estimated coefficient of green finance on corporate ESG performance remains significantly positive. From the statistical tests of the instrumental variable, the K-P rk LM statistic is 24.824, passing the test for unidentifiable instrumental variables. The values of the C-D Wald *F* and K-P rk Wald *F* both indicate that the instrumental variable is not a weak instrument. In addition, the Hansen J result passes the over-identification test for the instrumental variable. In summary, the instrumental variable selected in this paper has a certain degree of rationality. That is, after controlling for potential endogeneity issues with instrumental variables, the benchmark regression results remain robust.

Table 6. Regression results using the instrumental variable method.

	(1)	**(2)**
	I	**II**
	gf	**esg**
IV	0.047***	
	(0.015)	
gf		0.488**
		(0.227)
controls	YES	YES
K-P rk LM		24.824***
C-D Wald *F*		26.875
K-P rk Wald *F*		25.138 <16.38>
Hansen J		0.000
N	12,323	12,323
Province	YES	YES
Industry	YES	YES
Year	YES	YES

5.3. Heterogeneity analysis

The previous discussion primarily focused on the overall effects of green finance. However, the impact of green finance should vary across entities with different characteristics. Therefore, it is necessary to analyze the effects of green finance on different entities from the perspective of heterogeneity. This paper will examine two aspects: property right heterogeneity and factor intensity heterogeneity.

First, property right heterogeneity test. All manufacturing listed companies were divided into state-owned enterprises and non-state-owned enterprises. State-owned enterprises were assigned a value of 1, while non-state-owned enterprises were assigned a value of 0. Regression analysis was conducted based on this data, with the results shown in **Table 7**. The regression results indicate that green finance has an insignificant impact on the ESG performance of state-owned manufacturing enterprises. This may be due to the inherent advantages of state-owned enterprises,

which can enjoy abundant fiscal support from the government and extensive support from financial institutions. As a result, they are less dependent on green financial tools, and green finance provides insufficient impetus for their ESG performance. Non-state-owned manufacturing enterprises, on the other hand, due to a lack of financial support, have limited ability to improve their ESG performance and need to rely on green financial tools for support.

Second, factor intensity heterogeneity test. All manufacturing enterprises were divided into three groups: Technology-intensive, labor-intensive, and capital-intensive enterprises. Regression analysis was conducted on these groups, with the results shown in the table below. Among them, green finance has a significant positive impact on the ESG performance of technology-intensive manufacturing enterprises, while the impact on labor-intensive and capital-intensive enterprises is not significant. The reason for this is that technology-intensive manufacturing enterprises use green financial tools to create more external innovation advantages, addressing the issue of insufficient innovation motivation, thereby encouraging enterprises to improve their ESG performance. At the same time, the financial support required for technological innovation by technology-intensive enterprises has been strongly boosted by the green finance market. This not only broadens the financing channels for technology-intensive manufacturing enterprises but also improves their financing efficiency, making these enterprises more inclined to invest resources to enhance their ESG performance.

Table 7. Results of heterogeneity test.

Variable	Property Heterogeneity		Factor Intensity		
	State-Owned Enterprises	Non-State-Owned Enterprises	Technology-Intensive	Labor-Intensive	Capital-Intensive
	esg	esg	esg	esg	esg
green	0.104	1.524***	0.695***	−0.283	−0.165
	(0.208)	(0.396)	(0.212)	(0.476)	(0.655)
constants	−0.346	−3.958***	−1.934***	−1.462**	−0.523
	(0.312)	(0.423)	(0.282)	(0.627)	(0.757)
controls	YES	YES	YES	YES	YES
N	10921	3734	10553	2044	2057
R^2	0.192	0.286	0.205	0.296	0.180
Industry	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES

5.4. Mechanism analysis

Based on the theoretical analysis in the previous section, this paper posits that green finance may enhance the ESG performance of manufacturing enterprises by alleviating financing constraints and promoting green technological innovation. Therefore, this paper constructs the following model:

$$sa_{it} = \alpha_0 + \alpha_1 green_{ct} + \gamma controls_{it} + \delta_j + \emptyset_t + \varepsilon_{it} \quad (3)$$

$$envrpat_{it} = \alpha_0 + \alpha_1 green_{ct} + \gamma controls_{it} + \delta_j + \emptyset_t + \varepsilon_{it} \quad (4)$$

First, the financing constraint (sa) impact channel. This paper selects the SA index to measure corporate financing constraints. The absolute value of the calculated SA index is taken, with a larger absolute value indicating a higher level of financing constraints faced by the enterprise. The regression results are shown in **Table 8**. In Equation (1), the coefficient of financing constraints (sa) is significantly negative at the 1% level, indicating that the development of green finance helps alleviate financing constraints. Financing constraints have become one of the important factors restricting the transformation and upgrading of manufacturing enterprises. Information asymmetry is a fundamental characteristic of financial transactions, which can easily lead to difficulties in corporate financing. The development of green finance has improved the environmental information disclosure mechanism, addressed the information asymmetry flaws inherent in traditional finance, reduced transaction costs, and thus alleviated the financing constraints faced by manufacturing enterprises. After alleviating financing constraints, manufacturing enterprises have sufficient funds for daily production and business operations. To gain a good reputation, manufacturing enterprises have both the motivation and ability to take on environmental, social, and governance responsibilities, thereby achieving sustainable development.

Table 8. Results of mechanistic testing.

	(1)	**(2)**
	sa	**envrpat**
green	−0.192***	0.450***
	(0.046)	(0.163)
controls	YES	YES
constants	−3.518***	−4.530***
	(0.063)	(0.240)
N	14655	14643
R^2	0.189	0.166
Industry	YES	YES
Year	YES	YES

Second, the green technological innovation (envrpat) impact channel. This paper f uses the sum of the number of green invention patent applications and green utility model patent applications to obtain the total green innovation, then adds 1 to the total and takes the logarithm to obtain green technological innovation (envrpat). The results are shown in **Table 8**, Equation (2). The coefficient of green finance is significantly positive and passes the significance test at the 1% level, indicating that green finance helps enhance corporate green technological innovation. Green technological innovation is characterized by high investment risks, long investment cycles, and slow investment returns. For manufacturing enterprises whose goal is to maximize profits, the investment cost-effectiveness is not high. However, with the development of green finance, the government has introduced a series of green policies, strengthening financial support for green bond financing and other areas, along with stricter regulatory pressures. Manufacturing enterprises will widely

engage in more green technological innovations, thereby achieving the dual effect of reducing resource utilization and environmental pollution rates while improving production efficiency. After conducting more green technological innovations, manufacturing enterprises naturally improve their environmental performance, contributing to the green transformation of manufacturing enterprises and enhancing their ESG performance.

6. Conclusions

This paper conducts an in-depth and comprehensive exploration of the impact of green finance on the ESG performance of manufacturing enterprises. The main conclusions are as follows: First, green finance can significantly enhance the ESG performance of manufacturing enterprises. This conclusion remains robust after various robustness tests, including replacing the explained variable, changing fixed effects, and using instrumental variable methods. Second, mechanism tests reveal that green finance improves the ESG performance of manufacturing enterprises by alleviating their financing constraints and incentivizing green technological innovation. Third, this enhancing effect is more pronounced in state-owned manufacturing enterprises and technology-intensive manufacturing enterprises. These research findings hold significant theoretical and practical value for the country's policy goals of achieving "carbon peaking and carbon neutrality." Furthermore, this study is not without its limitations. For instance, data for certain years in some prefecture - level cities are absent. Moreover, it falls short of delving deeply into the variances in how green finance impacts the ESG performance of manufacturing enterprises across diverse institutional and cultural settings. These areas undeniably call for continued research efforts to gain a more comprehensive understanding.

1) The government should accelerate the improvement of the green finance system, encourage innovation in the green finance system, guide traditional financial institutions to engage with, understand, and provide green financial services, and lay the foundation for manufacturing enterprises to access higher-quality green financial services and accelerate their green transformation. Additionally, the government should promptly improve relevant laws and regulations on green finance, establish industry norms, and curb "greenwashing" behaviors among enterprises.

2) The government should increase fiscal support, as insufficient funding remains one of the key constraints on the green transformation of current manufacturing enterprises. The government should diversify green finance support methods, potentially adopting differentiated supportive policies for different entities. For non-state-owned manufacturing enterprises, the government can collaborate with financial institutions to provide more convenient approval processes and greater financial support, thereby stimulating the enthusiasm of manufacturing enterprises to participate in green transformation. Furthermore, manufacturing enterprises should focus on attracting high-quality talent to provide intellectual support for the green transformation of China's manufacturing sector.

3) The sustainable operation of the green finance system depends on a targeted financial regulatory framework. In the development of green finance, equal emphasis

should be placed on establishing information disclosure and regulatory systems to reduce information asymmetry between financial institutions and manufacturing enterprises, thereby facilitating better cooperation and accelerating the achievement of policy goals for high-quality development of China's manufacturing enterprises.

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