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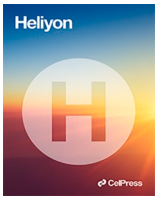

Research article

Can ESG ratings promote green total factor productivity? Empirical evidence from Chinese listed companies

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ABSTRACT

Against the backdrop of frequent extreme climates and international consensus on green and low-carbon development, Environmental, Social, and Governance (ESG) has progressively drawn increasing attention. Integrating the perspectives of stakeholder theory and signaling theory, this study employed the Malmquist-Luenberger productivity index, fixed-effects regression model, mediating effect model, propensity matching score difference-in-differences model, and a two-stage least squares method. Using the research sample of Chinese A-share listed companies between 2011 and 2021, the mechanisms linking ESG ratings and each component (the individual scores of E, S, and G) with the green innovation and green total factor productivity (GTFP) of enterprises were investigated. This study conducted heterogeneity analysis integrating regional, industry, and enterprise dimensions, fully considered the potential endogeneity issues, and conducted multiple robustness tests by exploring alternative approaches, replacing the measures of indicators, and reducing the research sample. The results demonstrated that higher ESG ratings significantly improved the green innovation and GTFP of enterprises. This improvement was achieved through the stakeholders and signaling mechanisms, and was more prominent in economically underdeveloped regions, patent-intensive industries, and industries with lower environmental risk. In addition, the impact varied among enterprises with different property rights. The findings elucidate the pathways through which soft regulation influences micro-level corporate decision-making, making significant contributions to the literature. Furthermore, this study provides a theoretical foundation and policy reference for constructing a positive feedback loop mechanism for ESG ratings and promoting the green transformation and upgrading of enterprises.

1. Introduction

Environmental, Social, and Governance (ESG) originated from the "Principles for Responsible Investment" issued by the United Nations in 2006. This suggests that enterprises should emphasize environmental performance, social responsibility, and corporate governance more in their development strategies. ESG is an enrichment and extension of Corporate Social Responsibility (CSR) and an important criterion for measuring the level of green and sustainable development of enterprises. In recent years, ESG disclosures and ratings have received widespread attention from global investors and governments. However, China's ESG system remains in an exploratory stage, providing normative pressure through environmental regulatory tools [1]. A considerable number of listed

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companies in China have only begun to disclose ESG information in recent years. In September 2020, China clearly proposed the goals of carbon peaking and carbon neutrality. The ESG concept is highly consistent with the spiritual core of China's high-quality development goals. Thus, the government has continuously strengthened and improved an institutional environment conducive to enterprises practicing ESG and sustainable development. Although the ESG systems in developed countries are relatively mature, their indicator systems and information disclosure frameworks are mostly based on Western countries. Consequently, they are quite different from China's concepts and practices. For example, the international mature capital market is mainly composed of institutional investors, thus, its ESG rating system mainly considers institutional investors and pays less attention to individual investors [2]. Meanwhile, due to different social and cultural backgrounds and levels of economic development, foreign mature ESG systems are not suitable for China's social development requirements. Taken together, this provides a good starting point for exploring the effectiveness of ESG given the unique background of China.

With continuous improvements in the ESG system, the academic community has conducted extensive research. Numerous studies have consistently demonstrated that ESG positively affects enterprises' financial performance and market value [3–5] and that the relationship between ESG and stock prices is significant in environmentally sensitive industries [6]. However, some scholars have proposed a negative or nonlinear relationship between ESG and firm value [7,8]. In terms of capital costs, studies generally believe that good ESG performance by enterprises can reduce both debt [9] and equity capital costs and improve financing channels [10,11]. In terms of financial risk, scholars have pointed out that complete ESG disclosure can help reduce default risk [12], stock price crash risk [13], and financial risk [14].

Green innovation is the cornerstone and catalyst for the sustainable development of enterprises. Scholars have noticed the impact of ESG on green innovation but have not reached consistent conclusions. Most scholars believe that there is a positive linear relation between ESG ratings and the driving force and achievement of green innovation [15,16]. However, Cohen et al. [17] found a negative correlation between ESG and green innovation, such as oil and natural gas, in energy companies in the United States. Huiyun et al. [18] found a U-shaped relationship between ESG and green innovation performance in heavily polluting enterprises in China. Therefore, will the contradictory conclusions on green innovation further affect their role in green total factor productivity (GTFP)? This study conducts exploratory research on the mechanism of the interaction among ESG ratings, green innovation, and GTFP.

This study aims to construct a theoretical model that combines stakeholder and signaling theories, including ESG ratings, green innovation, and GTFP. Using Chinese A-share listed companies between 2011 and 2021 as the research sample, this study empirically examined the impact of ESG ratings on the green innovation and GTFP of enterprises using the ESG rating data. The possible mechanisms of action were verified, and the heterogeneous effects of relevant factors were explored from regional, industry, and enterprise dimensions. This study fully considered the potential endogeneity issues and conducts various robustness tests.

This study makes two major contributions. First, it focuses on subdivided areas, green innovation, and GTFP, enriching research on the economic consequences of ESG. Existing research has primarily analyzed the economic consequences of ESG in terms of financial performance, market value, capital cost, financial risk, and other aspects. Although some studies have focused on the superficial impact of ESG on innovation, they have not deeply analyzed the influence chain and underlying mechanisms. Following the SOR theory, this study concretized the action chain according to the path of stimulus (ESG ratings) — response (green innovation) — result (GTFP), not only expanding the results in the field of green innovation at the theoretical level but also helping to understand the decision-making value of ESG in the sustainable development process of enterprises, which was an important supplement to existing research. Second, this study has advantages in terms of data use and variable selection. Currently, studies on total factor productivity (TFP) mainly use regional- and industry-level data, lacking potential micro-mechanism exploration of the impact of ESG on GTFP at the enterprise level. This study uses the Slacked-Based Measure (SBM) super-efficiency model to construct an indicator system for GTFP at the micro-enterprise level that included both input indicators (capital, labor, and energy inputs) and output indicators (expected and unexpected outputs). This will help identify and compare the differences in green innovation behavior among enterprises and explore the relationship between macro conditions and micro paths.

2. Hypotheses

External stakeholders pay more attention to companies with high ESG ratings. Unlike Western countries, where "top-down" policies are mostly used to mandate enterprises that disclose ESG information, China's ESG construction started relatively late and is primarily evaluated by third-party institutions through research and assessment on various aspects of corporate performance. An increasing number of investors tend to assign higher valuations to companies with better performance in environmental protection, social responsibility, and other aspects [19], and consumers are also more inclined to choose environmentally friendly products [20]. Higher ESG ratings improve the social image of enterprises and eliminate information asymmetry between enterprises and stakeholders. Moreover, information exchange and trust-building can help companies acquire critical resources, gain external support, reduce financing and operational costs [21,22], improve corporate performance [23], and meet government supervision, environmental regulations, and social requirements.

This study posits that higher ESG ratings can elevate enterprises' green innovation levels through resource coordination and market-catering effects. Specifically, the resource coordination effect refers to the fact that the higher an enterprise's ESG ratings, the stronger its resilience to high-risk, high-cost innovative activities, and less constrained innovation resources. Managers have greater autonomy in conducting green innovation activities, which results in a higher level of green innovation. The market-catering effect holds that green innovation, with its dual attributes of environment and innovation, is the most congruent decision for companies to achieve a "win-win" of economic efficiency and environmental protection [24]. This forces managers to cater to the market for ESG ratings [25], thereby improving the level of green innovation. Overall, higher ESG ratings can prompt managers to enhance green

innovation based on the effects of innovation resource coordination and market catering. Based on this, Hypothesis 1 was proposed.

H1. The higher the ESG rating, the higher the level of green innovation in enterprises.

Green innovation is a key driving force for the sustainable development of enterprises, and GTFP is a crucial criterion for assessing the quality of enterprise development [26]. Extending the research chain from green innovation to GTFP can help clarify the specific role of ESG ratings in the sustainable development process of enterprises.

Combined with the perspective of stakeholder theory, it can be known that the higher the ESG ratings, the more actively the enterprise can respond to government environmental regulations, support local economic development [27], and focus on ensuring employee rights and interests [28]. This will win the trust and support of stakeholders [29], providing enterprises with more resources to increase R&D investment and improve green innovation capabilities and factor productivity. Simultaneously, the higher the ESG ratings, the more perfect the design of internal governance mechanisms, such as supervision, balances, and feedback in the enterprise; the more effectively it can maintain healthy connections among stakeholders, such as the board of directors, managers, and shareholders; and alleviate the phenomenon of an insufficient supply of green innovation resources caused by adverse selection and moral hazard. This will help correct the defensive tendency of managers to deliberately avoid risks, encourage them to pay attention to green innovation, and increase innovation investment, thereby accelerating the improvement of GTFP in enterprises and promoting their sustainable development.

According to the signaling theory, higher ESG ratings imply that a company is more inclined to use renewable energy and clean equipment [30], develop green and environmentally friendly products, donate to charitable organizations, and have a higher level of workplace safety. These factors contribute to conveying signals of altruism and sustainable development to external stakeholders [31, 32]. Such positive signals help increase a company's information transparency, enhance reputation capital, reduce information asymmetry risks and external financing costs associated with technological innovation [33], and provide higher-quality innovative talents and resources for green innovation activities, thereby improving the GTFP of enterprises [34].

In summary, this study suggests that enterprises with higher ESG ratings gain more support from stakeholders, have better access to innovation resources, and have lower financing costs, which incentivize them to proactively engage in green transformation. However, higher ESG ratings improve stakeholder supervisory engagement. Analysts and financial regulatory institutions may pay attention to enterprises' ESG development strategies and communicate their implementation to the market, which makes enterprises more concerned and forces them to enhance the efficiency of innovation resource allocation under external public pressure. Both proactive and reactive innovation activities ultimately lead to improvements in an enterprise's GTFP. Based on this, Hypothesis 2 was proposed.

H2. The higher the ESG rating, the higher the level of GTFP in enterprises.

The research framework diagram is illustrated in Fig. 1.

3. Materials and methods

3.1. Research sample and data selection

The statistical caliber of emission-related data in the China Environmental Statistical Yearbook has changed since 2011. This study used 2011 as the starting point and selected A-share listed companies that traded on the Shanghai and Shenzhen stock exchanges between 2011 and 2021 as research samples to explore the mechanism of ESG ratings on green innovation and GTFP of enterprises. In accordance with the research needs, the following data screening was conducted in this study: (1) Considering that the China Environmental Statistical Yearbook only discloses emission data for four industries: agriculture, forestry, animal husbandry, and fishery (category code A); mining (category code B); manufacturing (category code C); and electricity, heat, gas, and water production and supply (category code D); other industries were excluded from the study. (2) Research samples with special treatments were excluded.[1] (3) Research samples with missing data were excluded. (4) Winsorization treatment was applied to all continuous variables in the 1 % quantile, and all the original data were standardized to ensure dimensional uniformity. A total of 14,421 valid samples were obtained.

3.2. Variable definitions and model construction

3.2.1. Explained variables

(1) Green innovation (GInv)

Previous studies have mostly measured enterprises' innovation levels through the number of patent applications and authorizations. Considering that patent authorization may be affected by external forces and is not a comprehensive reflection of an enterprise's innovation willingness and ability, while application data are relatively more stable, reliable, and timely [35], this study used the number of patent applications for measurement. Furthermore, in the process of identifying green patent applications, this study classified green technology into seven major fields, namely, alternative energy, transportation, waste management, and energy

[1] A company's stock name will be given special treatment when it suffers losses in consecutive accounting periods, indicating a potential risk of being delisted.

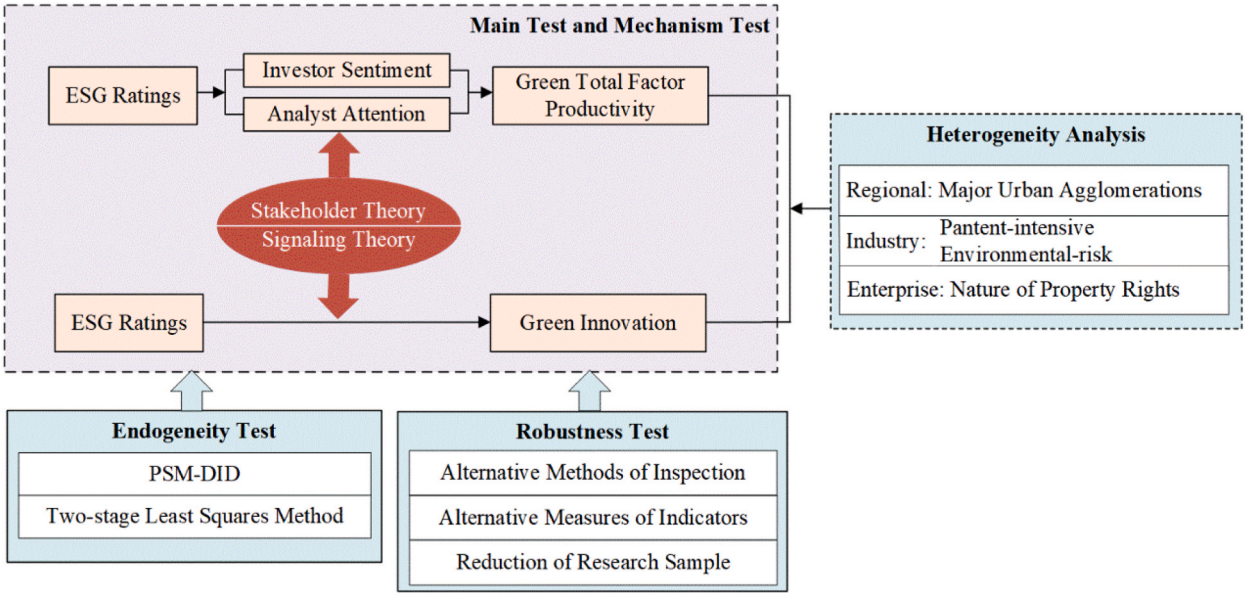

Fig. 1. Research framework diagram.

conservation, based on the International Patent Classification Index for Environmentally Friendly Technology released by the World Intellectual Property Organization (WIPO) in 2010. The corresponding relationship between the patents applied for by the research sample from 2011 to 2021 and the classification index was identified and calculated, and the number of green patent applications from the sample enterprises was obtained. Therefore, this study drew on the measurement method of Liao et al. [36] to measure the level of green innovation in enterprises (GInv) using the proportion of green patent applications to all patent applications.

(2) GTFP

Compared with TFP, which only focuses on economic development benefits, GTFP not only measures technological change but also incorporates resource and environmental factors, such as energy consumption and environmental pollution, into the scope of assessment, making it an essential criterion for assessing the quality of enterprise development. Chung et al. [37] introduced both expected and unexpected outputs into the productivity measurement framework and constructed the Malmquist-Luenberger productivity index (hereafter, the ML productivity index) using the directional distance function. However, the presence of non-zero slack variables will lead to deviations in the measurement results of productivity. Tone [38] proposed the Slacked-Based Measure (SBM) method to solve the problem of overestimating efficiency due to not considering non-zero slack variables. This study adopts the approach proposed by Oh [39] and Bruni et al. [40] and uses the SBM directional distance function to measure the GTFP using the ML productivity index (see Equation (1)).

$$GTFP = \frac{1 + D_0^t(x^t, y^t, b^t; y^t, -b^t)}{1 + D_0^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}\right)} \tag{1}$$

where D_0 represents the directional distance function and t represents time. x, y, and b represent the factors of input, expected output, and unexpected output, respectively. The index system of GTFP is shown in Table 1. Inspired by the basic ideas of inclusive TFP in macroeconomic research, this study divides the index system of GTFP at the micro-enterprise level into two dimensions: input and output. The input dimensions included labor, capital, and energy inputs. The output dimension included expected and unexpected outputs. In the index system, measuring the energy input is difficult. This study follows the approach of Pei et al. [41] and calculates this by multiplying the industry's total energy consumption by the proportion of the enterprise's operating costs to the industry's overall operating costs. The same principle is applied to calculate the unexpected output.

3.2.2. *Explanatory variable*

ESG ratings are the core explanatory variables in this study. Currently, disclosing ESG reports is not mandatory for listed companies in China. Some security firms and rating agencies rate and rank enterprises' ESG performance. Representative ESG ratings include the Huazheng Index ESG Ratings, FTSE Russell ESG Ratings, and Bloomberg Consulting ESG Ratings. Considering that the Huazheng Index ESG ratings system has fast update speed and wide coverage [42], which better aligns with the actual conditions of the Chinese market and has high credibility and research value, this study selected the ESG ratings index published by Shanghai Huazheng Index Information Service Co., Ltd. (abbreviated as "Huazheng Index") to measure the ESG performance of enterprises. This indicator was obtained from the Wind database, with higher values indicating higher ESG ratings for the sample enterprises.

Table 1
Index system of GTFP at the micro-enterprise level.

Dimension	Code	Name	Measurement
Input Index	x	Labor Input	Number of employees
		Capital Input	Net value of fixed assets
		Energy Input	Converted quantity of standard coal (Unit: ten thousand tons)
Output Index	y	Expected Output	Operating income of enterprises
	b	Unexpected Output	Comprehensively calculated based on the emission data of atmospheric pollutant SO_2, chemical oxygen demand of water quality (COD), and solid waste discharge

3.2.3. Control variables

This study incorporated the following control variables into the model based on previous studies to reduce bias in model estimation caused by omitted variables. As Hongsen et al. [43] argue, high capital intensity means that the company's funds are mainly used for large-scale equipment procurement, which may constrain its investment and innovation with regard to environmental protection. Moreover, the debt ratio and company growth may also affect enterprises' green transformation intentions. Therefore, we have controlled for debt ratio (Debt), company growth (Growth), and capital intensity (CI). Internal cash flow and firm value will significantly affect GTFP of enterprises [44], so we added cash holdings (Cash), firm value (FV), and individual stock return (IST) to control for the impact. In addition, there is a correlation between the governance structure characteristics and GTFP [45]. Therefore, we have controlled for the independent director ratio (INDE), equity balance (Z), internal control deficiency (ICD), and industry- and year-fixed effects. The annual reports of listed companies, the National Intellectual Property Administration database, and the China Environmental Statistics Yearbook are the main data sources for the explained variables. The data for the explanatory variables are primarily from the Wind database, while the CSMAR database and annual reports of listed companies generally provide the data for the control variables. Table 2 shows the statistical descriptions of these variables.

3.2.4. Model construction

Considering the differences among individual enterprises, this study drew on the approach by Rui et al. [46] and constructed fixed-effects regression models (2) and (3) to test the impact of ESG ratings on green innovation and GTFP. In addition, this study also controlled for industry- and year-fixed effects. According to the theoretical analysis, ESG ratings may positively impact the level of green innovation and GTFP of enterprises through the stakeholder path. If the regression coefficients α_1 and β_1 were significantly positive, the hypotheses have been preliminarily validated.

$$GInv_{i,t} = \alpha_0 + \alpha_1 ESG_{i,t} + \sum \alpha_2 X_{i,t} + \varepsilon_{i,t} \tag{2}$$

$$GTFP_{i,t} = \beta_0 + \beta_1 ESG_{i,t} + \sum \beta_2 X_{i,t} + \theta_{i,t} \tag{3}$$

where i and t represent the research sample individuals and time, $GInv_{i,t}$ represents green innovation, $GTFP_{i,t}$ represents green total factor productivity, and $ESG_{i,t}$ represents ESG ratings. ε and θ are the residuals of the regression model, and $X_{i,t}$ represents the control variables. The specific indicators and measurement methods of the control variables are shown in Table 2.

Table 2
Statistical description of the main variables.

Classification	Code	Mean	Minimum	Maximum	Standard Deviation
Explained Variables	GInv	0	1	0.03	0.10
	GTFP	0.00	750.22	22.14	92.04
Explanatory Variable	ESG	56.71	84.27	72.98	5.45
Control Variables	Debt	0.06	0.90	0.43	0.19
	Growth	−0.67	3.60	0.23	0.54
	CI	0.02	0.70	0.25	0.15
	Cash	0.01	2.97	0.24	0.42
	FV	0.86	8.73	2.01	1.29
	IST	−0.57	2.13	0.15	0.49
	INDE	0.33	0.57	0.37	0.05
	Z	0.03	2.66	0.70	0.57
	ICD	0	1	0.36	0.481

Notes: Debt ratio (Debt) was determined by dividing total liabilities by total assets; company growth (Growth) was calculated by the growth rate of operating income; capital intensity (CI) was determined by dividing fixed assets by total assets; cash holdings (Cash) was measured by the ratio of cash and cash equivalents to total assets; firm value (FV) was determined by dividing market value by total assets; individual stock return (IST) was measured by the annual stock return taking into account the reinvestment of cash dividends; independent director ratio (INDE) was calculated by dividing the number of independent directors by total number of directors; equity balance (Z) was determined by dividing the shareholding ratios of the second to fifth largest shareholders by the shareholding ratio of the largest shareholder; and internal control deficiency (ICD) was determined by whether the report disclosed the existence of internal control deficiencies.

4. Results

4.1. Main test

Table 3 presents the results of the main test. Columns (1) and (5) present that ESG ratings have a beneficial influence on enterprises' green innovation (GInv) and GTFP (with significance levels of 1 %), supporting H1 and H2. In addition, this indicates that higher ESG ratings can enhance the green innovation and GTFP of enterprises through resource coordination and market-catering effects. To further investigate which dimension has a stronger improvement effect, we included each component of the ESG ratings (the individual scores of E, S, and G) in the model for testing. The test results are shown in columns (2)–(4) and (6)–(8), suggesting that individual scores of Environmental (E), Social(S), and Governance (G) all have a significant positive impact on the green transformation process of enterprises. Relatively speaking, E and S have a more significant impact on green innovation, while G has a stronger promoting effect on GTFP. The above results further demonstrate that ESG ratings can influence a company's green transformation process by releasing favorable signals to the market. Among them, the higher the scores of E and S, the more signals the company attaches importance to sustainable development and conveys to the outside. This can reduce the financing costs and thereby improve the level of green innovation to some extent. The higher the score of G, the higher the company's information transparency, which has a significant impact on the overall improvement of GTFP.

4.2. Mechanism test

Incorporating the above analysis, the perspectives of stakeholder theory and signaling theory have laid a theoretical foundation for exploring the interaction mechanism between ESG ratings and GTFP. On the one hand, the higher the ESG ratings, the higher the trust of stakeholders in the enterprise, which will provide support for the improvement of GTFP. On the other hand, the higher the ESG ratings, the more signals the company will convey to the outside that it values sustainable development and altruism; also, the more external attention it will receive, thereby providing more possibilities for improving GTFP. Furthermore, to verify whether this mechanism is valid, this study drew on the research of Zhonglin and Baojuan [47]and constructed the mediating effect models (4), (5), and (6).

$$GTFP_{i,t} = \beta_0 + \beta_1 ESG_{i,t} + \sum \beta_2 X_{i,t} + \theta_{i,t} \quad (4)$$

Table 3
Main test results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	GInv	GInv	GInv	GInv	GTFP	GTFP	GTFP	GTFP
ESG	0.045***				0.029***			
	(6.607)				(3.386)			
E		0.073***				0.015*		
		(10.625)				(1.716)		
S			0.028***				0.021**	
			(3.668)				(2.551)	
G				0.015**				0.026***
				(2.044)				(3.074)
Debt	0.063***	0.050***	0.058***	0.060***	0.035***	0.030***	0.032***	0.038***
	(7.663)	(6.092)	(7.077)	(7.192)	(3.980)	(3.427)	(3.663)	(4.209)
Growth	0.032***	0.033***	0.031***	0.031***	0.003	0.002	0.003	0.002
	(3.459)	(3.542)	(3.349)	(3.280)	(0.360)	(0.285)	(0.298)	(0.278)
CI	0.008	0.004	0.011	0.009	−0.008	−0.008	−0.007	−0.008
	(0.844)	(0.434)	(1.072)	(0.918)	(-0.855)	(-0.879)	(-0.695)	(-0.877)
Cash	0.015***	0.018***	0.018***	0.016***	0.001	0.003	0.003	−0.000
	(3.502)	(4.189)	(4.239)	(3.689)	(0.092)	(0.242)	(0.261)	(-0.015)
FV	−0.039***	−0.034***	−0.043***	−0.045***	−0.014	−0.016*	−0.017*	−0.016*
	(-5.029)	(-4.397)	(-5.558)	(-5.693)	(-1.491)	(-1.667)	(-1.747)	(-1.699)
IST	0.002	−0.000	0.004	0.005	0.018	0.019	0.019	0.019
	(0.227)	(-0.010)	(0.481)	(0.553)	(1.423)	(1.516)	(1.539)	(1.510)
INDE	−0.025***	−0.020***	−0.022***	−0.024***	0.015	0.017*	0.017*	0.013
	(-3.392)	(-2.713)	(-2.924)	(-3.205)	(1.545)	(1.810)	(1.784)	(1.381)
Z	−0.021***	−0.021***	−0.023***	−0.021***	0.012	0.011	0.010	0.013
	(-2.719)	(-2.804)	(-3.030)	(-2.773)	(1.331)	(1.240)	(1.154)	(1.422)
ICD	−0.009	−0.006	−0.006	−0.009	0.034*	0.035*	0.036*	0.032*
	(-0.537)	(-0.363)	(-0.368)	(-0.535)	(1.830)	(1.902)	(1.938)	(1.735)
Constant	0.251***	0.205**	0.270***	0.223**	−0.056	−0.073	−0.041	−0.087
	(2.760)	(2.259)	(2.937)	(2.469)	(-0.608)	(-0.792)	(-0.444)	(-0.941)
Industry/Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	14421	14421	14421	14421	14421	14421	14421	14421
Adj. R^2	0.139	0.142	0.138	0.138	0.003	0.002	0.002	0.002

Notes: T-test values are in parentheses. ***, **, and * represent P < 0.01, P < 0.5, and P < 0.1, respectively.

$$Mediating_{i,t} = \gamma_0 + \gamma_1 ESG_{i,t} + \sum \gamma_2 X_{i,t} + \mu_{i,t} \quad (5)$$

$$GTFP_{i,t} = \delta_0 + \delta_1 ESG_{i,t} + \delta_2 Mediating_{i,t} + \sum \delta_3 X_{i,t} + \sigma_{i,t} \quad (6)$$

where $Mediating_{i,t}$ is the proxy indicator of the mediating variables, μ and σ are the residuals of the regression model, and the definitions of other variables remain consistent with the above.

This study selected two dimensions of mediating variables: analyst attention (Analyst) and investor sentiment (Investor). First, as important stakeholders of the enterprise, analysts will play the role of external supervision, checks and balances, feedback based on the ESG ratings, correct the company's short-sighted behavior [48], and provide evaluation and suggestions for the green transformation of the enterprise. Meanwhile, analysts serve as the front-end of enterprises' signal transmission. With their professional information search and interpretation capabilities, they can convey and interpret the ESG performance of enterprises to investors, reduce the degree of information asymmetry, and create a good external environment, thereby improving GTFP of enterprises. Therefore, this study used analyst attention (Analyst) as a mediating variable for mechanism testing, measured by the number of analysts (analysis teams) who followed and analyzed the enterprise within one year.

Furthermore, to consolidate the existence of this mechanism, this study selected investor sentiment (Investor) as an alternative indicator of the mediating variable. Unlike analyst attention, investor sentiment can better reflect the end effects of the signal transmission process. Specifically, investor sentiment refers to the systematic deviation of future expectations caused by the irrational behavior of investors, which can lead to market valuation of a company deviating from its basic value. The proportion of individual investors in China's capital market is relatively high, and they are easily affected by environmental and psychological factors, and investor sentiment characteristics are obvious [49]. The higher the company's ESG ratings, the stronger the stock price deviation reflected by investor sentiment, which will maximize the stock price, thereby reducing financing constraints and motivating companies

Table 4
Mechanism test results.

Panel A: Reliability of statistical results on mediating effects

Variables	Effects	Estimate	Standard error	Z	P
Analyst	Indirect effect	0.015	0.003	5.699	0.000
	Direct effect	0.014	0.009	1.556	0.120
	Total effect	0.029	0.009	3.427	0.001
Investor	Indirect effect	0.012	0.002	6.298	0.000
	Direct effect	0.017	0.009	1.964	0.050
	Total effect	0.029	0.009	3.427	0.001

Panel B: Regression results of mediating effect

Variables	(1) GTFP	(2) Analyst	(3) GTFP	(4) Investor	(5) GTFP
ESG	0.029***	0.296***	0.014	0.069***	0.017**
	(3.427)	(37.489)	(1.556)	(26.303)	(1.964)
Analyst			0.052***		
			(5.766)		
Investor					0.175***
					(6.487)
Debt	0.035***	0.097***	0.030***	0.240***	−0.007
	(3.901)	(11.596)	(3.333)	(86.234)	(-0.614)
Growth	0.003	−0.031***	0.005	−0.038***	0.010
	(0.371)	(-3.888)	(0.558)	(-14.546)	(1.149)
CI	−0.008	−0.009	−0.008	0.024***	−0.013
	(-0.852)	(-1.027)	(-0.803)	(8.207)	(-1.293)
Cash	0.001	0.053***	−0.002	−0.048***	0.009
	(0.096)	(5.040)	(-0.146)	(-13.642)	(0.828)
FV	−0.014	0.175***	−0.023**	1.035***	−0.196***
	(-1.477)	(19.450)	(-2.382)	(344.607)	(-6.613)
IST	0.018*	0.146***	0.010	0.028***	0.013
	(1.662)	(14.966)	(0.938)	(8.550)	(1.199)
INDE	0.015*	−0.000	0.015*	−0.001	0.015*
	(1.742)	(-0.008)	(1.745)	(-0.338)	(1.763)
Z	0.012	0.038***	0.010	−0.003	0.012
	(1.392)	(4.896)	(1.158)	(-1.150)	(1.456)
ICD	0.034*	0.000	0.034*	0.055***	0.024
	(1.896)	(0.030)	(1.897)	(10.086)	(1.349)
Constant	−0.056	0.226***	−0.068	0.252***	−0.100
	(-0.662)	(2.883)	(-0.801)	(9.637)	(-1.180)
Industry/Year	Yes	Yes	Yes	Yes	Yes
N	14421	14421	14421	14421	14421
Adj.R^2	0.003	0.148	0.005	0.905	0.005

Notes: T-test values are in parentheses. ***, **, and * represent $P < 0.01$, $P < 0.5$, and $P < 0.1$, respectively.

to further improve GTFP. Drawing on the research of Goyal and Yamada [50], this study used the method of decomposing Tobin'Q, and the residual between the fitted value and the actual value obtained by the regression as the proxy variable for investor sentiment (Investor), as shown in model (7).

$$Tobin'Q_{i,t} = \varphi_0 + \varphi_1 ROE_{i,t} + \varphi_2 Growth_{i,t} + \varphi_3 Debt_{i,t} + \varphi_4 Size_{i,t} + \vartheta_{i,t} \quad (7)$$

where $Tobin'Q_{i,t}$ represents the market value including pricing errors, $ROE_{i,t}$ represents return on equity, $Growth_{i,t}$ represents company growth, $Debt_{i,t}$ represents debt ratio, $Size_{i,t}$ represents company size, and the residual of the regression model $\vartheta_{i,t}$ represents investor sentiment (Investor).

Table 4 presents the results of the mechanism test. Combining the second row of Panel A and columns (1)–(3) of Panel B, it can be seen that in the mechanism of "ESG ratings—analyst attention—GTFP," analyst attention has a significant explanatory effect of 25.9 %; in addition, the coefficients of all key variables are significantly positive at the 1 % level, confirming the existence of this mechanism. The higher the company's ESG ratings, the more attention it will receive from analysts, which will send a stronger signal to the outside. Consequently, the innovation resources of stakeholders will be tilted towards the company, thereby promoting the improvement of GTFP. Combining the third row of Panel A and columns (1), (4), and (5) of Panel B, it can be observed that in the mechanism of "ESG ratings—investor sentiment—GTFP," investor sentiment has a significant explanatory effect of 20.5 %, and the coefficients of all key variables are significantly positive at the 1 % level. This further confirms the existence and significance of the mechanism of action. That is to say, a company's ESG ratings will release green transformation signals through investor sentiment and promote the improvement of GTFP.

4.3. Heterogeneity test

4.3.1. Regional heterogeneity analysis

Nowadays, urban agglomerations represent the mainstream and trend of urban development in the world [51]. In recent years, China's neighboring urban agglomerations have become increasingly interconnected. The Beijing-Tianjin-Hebei, Yangtze River Delta and Pearl River Delta urban agglomerations are among China's earliest and most representative urban agglomerations. Among them, the Beijing-Tianjin-Hebei urban agglomeration consists of Beijing, Tianjin, and Hebei Province. Beijing is the political and cultural center of China, and the enterprises in this urban agglomeration rely more on traditional industries and the domestic market, with strong policy dependence. The Yangtze River Delta urban agglomeration, comprising Shanghai and its surrounding provinces, is an

Table 5
Heterogeneity results of major urban agglomerations.

Variables	Beijing-Tianjin-Hebei		Yangtze River Delta		Pearl River Delta		Other Regions	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	GInv	GTFP	GInv	GTFP	GInv	GTFP	GInv	GTFP
ESG	0.056**	0.069*	0.044***	0.022	0.015	0.025	0.050***	0.028**
	(2.001)	(1.919)	(3.913)	(1.485)	(0.909)	(1.000)	(4.788)	(2.283)
Debt	0.067**	0.039	0.093***	0.048***	0.053**	0.026	0.053***	0.028**
	(2.408)	(0.944)	(5.628)	(3.588)	(2.465)	(1.045)	(4.496)	(2.113)
Growth	0.023	0.060	0.081***	−0.016*	0.070**	−0.023	0.012	0.002
	(0.663)	(1.100)	(3.953)	(-1.674)	(2.368)	(-1.394)	(1.036)	(0.198)
CI	−0.064*	−0.022	0.046**	−0.016	−0.027	0.013	0.021	−0.007
	(-1.843)	(-0.623)	(2.183)	(-0.791)	(-0.979)	(0.455)	(1.580)	(-0.487)
Cash	0.014	0.013	0.026***	−0.016	−0.000	0.006	0.019***	0.002
	(1.040)	(0.222)	(3.424)	(-1.037)	(-0.035)	(0.173)	(2.804)	(0.167)
FV	−0.040	−0.004	−0.022	−0.025**	0.002	−0.017	−0.054***	−0.013
	(-1.553)	(-0.126)	(-1.273)	(-2.123)	(0.083)	(-0.720)	(-5.687)	(-0.841)
IST	−0.043	0.069	−0.022	0.000	−0.016	0.037	0.022	0.018
	(-1.422)	(1.083)	(-1.487)	(0.009)	(-0.713)	(1.156)	(1.514)	(0.988)
INDE	−0.022	0.013	−0.034***	−0.001	−0.011	−0.037**	−0.025**	0.040***
	(-0.643)	(0.333)	(-2.654)	(-0.043)	(-0.638)	(-2.085)	(-2.236)	(2.616)
Z	−0.010	0.040	−0.031**	0.013	−0.036**	0.007	−0.008	0.006
	(-0.393)	(1.270)	(-2.520)	(0.717)	(-1.964)	(0.344)	(-0.693)	(0.539)
ICD	0.035	0.027	−0.042	0.013	0.083*	−0.007	−0.001	0.047*
	(0.607)	(0.383)	(-1.506)	(0.386)	(1.675)	(-0.136)	(-0.044)	(1.749)
Constant	0.346*	0.430	0.132	−0.514***	−0.099	0.164	0.234**	−0.051
	(1.951)	(0.769)	(1.429)	(-5.679)	(-0.828)	(0.578)	(2.229)	(-0.539)
Industry/Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1190	1190	4281	4281	2105	2105	6845	6845
Adj. R^2	0.225	0.009	0.156	0.003	0.133	0.003	0.124	0.002

Notes: The Beijing-Tianjin-Hebei urban agglomeration mainly includes Beijing, Tianjin, and Hebei Province; the Yangtze River Delta urban agglomeration mainly includes Shanghai, Jiangsu Province, Zhejiang Province, and Anhui Province; the Pearl River Delta urban agglomeration mainly includes Guangdong Province; other areas except the above are included in "Other Regions." T-test values are in parentheses. ***, **, and * represent $P < 0.01$, $P < 0.5$, and $P < 0.1$, respectively.

important intersection of the "Belt and Road" and the Yangtze River Basin. Its transportation and location advantages make this urban agglomeration a concentrated area for China's manufacturing industry. The Pearl River Delta urban agglomeration is the largest high-tech economic industrial zone in China. As a pioneer in reform and opening up, its advantages are that it is more open and innovative, and has a relatively high degree of marketization. As the urban agglomerations have varying development characteristics and evolutionary states, as well as significant differences in the levels of marketization and economic development, the relationships of ESG, green innovation, and GTFP may also vary. To verify the above analysis, this study drew on the research of Zhouyan et al. [52], considered China's three major urban agglomerations as the research object, and divided the research sample into four parts according to the registration location: Beijing-Tianjin-Hebei (see columns 1 and 2), Yangtze River Delta (see columns 3 and 4), Pearl River Delta (see columns 5 and 6), and other regions (see columns 7 and 8). Table 5 presents the grouping test results of regional heterogeneity analysis.

The results of the group test reveal significant regional heterogeneity among ESG ratings, green innovation and GTFP. The results in other regions are similar to the main test results (significant at 1 % and 5 %, respectively, see columns 7 and 8). The significance level for the Beijing-Tianjin-Hebei urban agglomeration is relatively low (significant at 1 % and 5 %, respectively, see columns 1 and 2). In the Yangtze River Delta urban agglomeration, ESG ratings have a promoting effect on green innovation at the 1 % level, but the impact on GTFP is not significant (see columns 3 and 4). ESG ratings in the Pearl River Delta urban agglomeration have no significant effect on green innovation or GTFP (see columns 5 and 6).

This can be attributed to the Yangtze River Delta and the Pearl River Delta being the lead in industrial green transformation, attracting technology-intensive enterprises, developing supportive service industries, and possessing mature market development mechanisms. The higher the degree of marketization, the higher the environmental regulations and low-carbon requirements for enterprises in the urban agglomeration, which will promote enterprises to spontaneously carry out green transformation. At this time, the green transformation and development of enterprises is mainly self-driven rather than externally driven. Therefore, the correlations among ESG ratings, green innovation, and GTFP may be relatively weak. In contrast, the industrial structure of the Beijing-Tianjin-Hebei urban agglomeration is dominated by capital-intensive industries such as heavy industry and chemical industry, with national policies playing a prominent role [53], and a relatively slow marketization process [54]. Thus, the external regulatory mechanism of ESG ratings will play a significant role. In addition, urban agglomerations with higher development levels entered the stage of high-quality development earlier, and GTFP grew slowly. Other regions, by comparison, have considerable room for improvement regarding the quality of development, and ESG ratings have a relatively stronger promoting effect on green innovation and GTFP.

4.3.2. Industry heterogeneity analysis

(1) Heterogeneity analysis of patent-intensive industries

Table 6
Heterogeneity results of patent-intensive industries.

Variables	Patent-Intensive Industries		Non-Patent-Intensive Industries	
	GInv	GTFP	GInv	GTFP
ESG	0.036***	0.036***	0.058***	0.021
	(3.901)	(3.165)	(5.738)	(1.557)
Debt	0.053***	0.036***	0.076***	0.035**
	(4.888)	(3.244)	(6.002)	(2.492)
Growth	0.062***	−0.000	−0.013	0.006
	(5.020)	(-0.030)	(-0.922)	(0.509)
CI	0.040***	−0.012	0.009	−0.003
	(2.658)	(-0.826)	(0.662)	(-0.226)
Cash	0.015***	−0.007	0.026***	0.012
	(2.840)	(-0.391)	(3.282)	(0.773)
FV	−0.040***	−0.006	−0.056***	−0.031*
	(-3.765)	(-0.531)	(-5.111)	(-1.677)
IST	−0.003	−0.005	0.012	0.047**
	(-0.282)	(-0.306)	(0.842)	(2.293)
INDE	−0.014	0.002	−0.038***	0.032*
	(-1.333)	(0.199)	(-3.841)	(1.949)
Z	−0.021**	0.008	−0.021*	0.017
	(-2.203)	(0.678)	(-1.779)	(1.261)
ICD	−0.013	0.021	−0.014	0.049*
	(-0.617)	(0.874)	(-0.507)	(1.687)
Constant	0.225***	−0.043	0.280***	−0.085
	(4.798)	(-1.161)	(2.679)	(-0.857)
Industry/Year	Yes	Yes	Yes	Yes
N	8363	8363	6058	6058
Adj. R^2	0.148	0.002	0.146	0.005

Notes: T-test values are in parentheses. ***, **, and * represent $P < 0.01$, $P < 0.5$, and $P < 0.1$, respectively.

Enterprises' green innovation is greatly impacted by their level of industrial innovation activity [55]. Compared to non-patent-intensive enterprises, patent-intensive enterprises are more inclined to improve their GTFP through R&D and new technology investments. In 2008, the State Council of the PRC implemented the "National Intellectual Property Strategy Outline," designating intellectual property-intensive industries as synonymous with industries with strong innovation capabilities and high value-added. In 2016, the State Intellectual Property Office issued the "Patent-Intensive Industries Catalog (2016)" (Trial), which provides authoritative guidance for the identification of patent-intensive enterprises. Based on this, this study drew on the research of Chengliang et al. [56], defined the industries of communication equipment manufacturing, pharmaceutical manufacturing, instrument and meter manufacturing, special equipment manufacturing, electrical machinery manufacturing, tobacco products, general equipment manufacturing, chemical raw material manufacturing, and transportation equipment manufacturing as patent-intensive industries, and conducted group tests with non-patent-intensive industries, the results of which are presented in Table 6.

Columns (1) and (2) show that the test results for patent-intensive industries were consistent with the original results. However, for non-patent-intensive industries (see the results in the last two columns), ESG ratings still have a beneficial influence on green innovation at the 1 % level; however, the impact on GTFP is not significant, although it is positive. This is mainly because non-patent-intensive enterprises are primarily labor-intensive and capital-intensive enterprises, with relatively low technological intensity. This results in a lower threshold for green innovation activities for such enterprises, and ESG ratings as an external governance mechanism have a significant positive impact on green innovation. However, given the simplicity of technology imitation and diffusion among enterprises, the improvement of GTFP in non-patent-intensive enterprises can be accounted for by labor and capital investments rather than the innovation activities. The relationship between ESG ratings and GTFP in non-patent-intensive enterprises is not significant due to weak stakeholder engagement and communication.

(2) Heterogeneity analysis of environmental risk

With the enhancement of environmental information transparency, the government and environmental protection departments are supervising and holding enterprises accountable for their pollution emissions. Different industries face different environmental risks. Industries with high environmental risk have relatively higher governance costs, and their motivation to actively engage in green transformations may be weaker. This study draws on the research of Xin and Ying [57] and divides the entire sample into high- and low-environmental-risk industries, based on the environmental risks faced by different industries. Table 7 presents the results.

Evidently, compared with low-environmental-risk industries (significant at the 1 % level), the significance in high-environmental-risk industries was relatively weaker (significant at the 5 % level), suggesting that the above chain of action was also established in these enterprises, although its effectiveness was reduced. This is because low-environmental-risk enterprises are more likely to gain

Table 7
Heterogeneity results of environmental risk.

Variables	High-Environmental-Risk Industries		Low-Environmental-Risk Industries	
	GInv	GTFP	GInv	GTFP
ESG	0.070**	0.068**	0.041***	0.026***
	(2.365)	(2.301)	(5.849)	(2.899)
Debt	0.101**	−0.018	0.057***	0.039***
	(2.351)	(-0.444)	(6.961)	(4.306)
Growth	−0.054*	0.023	0.046***	−0.000
	(-1.794)	(0.940)	(4.703)	(-0.023)
CI	0.081*	0.012	0.002	−0.007
	(1.878)	(0.410)	(0.242)	(-0.672)
Cash	0.074*	−0.002	0.009**	0.004
	(1.880)	(-0.039)	(2.165)	(0.326)
FV	−0.154***	−0.065**	−0.034***	−0.011
	(-3.202)	(-2.288)	(-4.366)	(-1.138)
IST	0.023	0.009	0.002	0.016
	(0.445)	(0.229)	(0.261)	(1.254)
INDE	−0.114***	0.037	−0.018**	0.013
	(-2.655)	(0.779)	(-2.440)	(1.391)
Z	−0.131***	−0.042*	−0.013*	0.017*
	(-3.252)	(-1.946)	(-1.742)	(1.790)
ICD	−0.083	0.006	0.004	0.036*
	(-0.924)	(0.095)	(0.259)	(1.856)
Constant	0.777***	−0.013	0.190**	−0.050
	(3.435)	(-0.167)	(2.118)	(-0.541)
Industry/Year	Yes	Yes	Yes	Yes
N	1013	1013	13408	13408
Adj.R^2	0.210	0.005	0.129	0.003

Notes: High-environmental risk industries include nuclear power generation, hydroelectric power generation, water conservancy and inland port engineering construction, coal mining and washing, petroleum and natural gas extraction, ferrous metal mining and dressing, nonferrous metal mining and processing, and non-metallic mining and dressing. T-test values are in parentheses. ***, **, and * represent $P < 0.01$, $P < 0.5$, and $P < 0.1$, respectively.

recognition from stakeholders, while high-environmental-risk enterprises face more environmental regulatory pressure, transformation difficulties, and pollution control costs. This requires greater investment in green transformation than for low-environmental-risk industries [58]. To meet various environmental regulatory requirements, some innovative resources may be occupied by environmental risk factors such as pollution control, resulting in a reduction in the improvement of ESG ratings on green innovation and GTFP.

4.3.3. Enterprise heterogeneity analysis

Enterprises with different property rights experience significant differences in organizational management, business objectives, social responsibilities, and political connections. Compared with non-state-owned enterprises, state-owned enterprises bear both economic and social effects. Therefore, this study divided the research sample into two categories: state-owned enterprises and non-state-owned enterprises. Table 8 presents the heterogeneity results at the enterprise level.

ESG ratings have a significant positive impact on green innovation (GInv) and GTFP in both state-owned and non-state-owned enterprises; however, the degree of impact varies. The impact of ESG ratings on green innovation (GInv) is more significant in non-state-owned enterprises (see columns 1 and 3), while the impact coefficient of ESG ratings on GTFP is larger and the significance level is higher in state-owned enterprises (see columns 2 and 4). This is mainly because state-owned and non-state-owned enterprises have different inherent motivations when fulfilling ESG responsibilities. The former have a stronger political will to fulfill ESG responsibilities and carry out green technological innovation. The higher the ESG ratings, the more motivated they will be to engage in multi-dimensional green transformation. Under the constraints of internal governance and external supervision, state-owned enterprises can effectively implement ESG practices to support high-quality development and promote the improvement of GTFP. Non-state-owned enterprises however, have strong profit incentives and hope to establish a good image through high ESG ratings, thereby obtaining stable economic returns. They are more inclined to adopt passive measures under policy constraints. Therefore, they are more concerned about improving the level of short-term green innovation. The promotion effect of ESG ratings on GTFP is thus relatively weaker than that of state-owned enterprises.

4.4. Endogeneity and robustness test

4.4.1. Endogeneity test

This study may have endogeneity issues, such as sample selection bias and bidirectional causality. Among them, sample selection bias is due to the non-randomness of sample selection, which may result in biased conclusions and cannot reflect the nature of the population. In response to this potential endogeneity issue, this study constructed a propensity score matching -difference-in-difference model (PSM–DID), aiming to randomly allocate research samples by searching for other external events [59] and avoid sample

Table 8
Heterogeneity results of nature of property rights.

Variables	State-Owned Enterprises		Non-State-Owned Enterprises	
	(1)	(2)	(3)	(4)
	GInv	GTFP	GInv	GTFP
ESG	0.053***	0.036**	0.043***	0.020*
	(3.867)	(2.317)	(5.427)	(1.867)
Debt	0.068***	0.023	0.060***	0.034***
	(4.711)	(1.516)	(5.807)	(3.051)
Growth	0.017	0.023	0.048***	−0.014
	(1.276)	(1.519)	(3.620)	(-1.449)
CI	0.020	−0.017	−0.002	−0.008
	(1.300)	(-1.168)	(-0.129)	(-0.652)
Cash	0.024***	−0.023	0.010*	0.013
	(3.087)	(-1.031)	(1.886)	(0.938)
FV	−0.041***	−0.050***	−0.037***	0.002
	(-2.699)	(-3.333)	(-4.041)	(0.151)
IST	0.007	0.005	−0.003	0.029*
	(0.370)	(0.267)	(-0.273)	(1.805)
INDE	−0.041***	0.048**	−0.018*	−0.004
	(-3.503)	(2.552)	(-1.914)	(-0.376)
Z	−0.030*	0.023	−0.019**	0.013
	(-1.828)	(1.236)	(-2.273)	(1.283)
ICD	0.008	0.006	−0.015	0.036
	(0.278)	(0.207)	(-0.782)	(1.559)
Constant	0.384**	−0.175	0.149	0.046
	(2.567)	(-1.491)	(1.408)	(0.323)
Industry/Year	Yes	Yes	Yes	Yes
N	5340	5340	9081	9081
Adj. R^2	0.157	0.007	0.121	0.002

Notes: T-test values are in parentheses. ***, **, and * represent $P < 0.01$, $P < 0.5$, and $P < 0.1$, respectively.

selection bias. Meanwhile, in order to avoid the interference of the main test indicators on the endogeneity test, this study used the ESG rating indicator (DESG) released by Bloomberg Consulting for analysis. The values of the experimental and control groups were as follows: If ESG ratings were performed for the enterprise for the first time, the value of the enterprise in that year and subsequent years was one; otherwise, it was zero. This study included all control variables in the logit model to determine the propensity score and retained paired samples that met the common support hypothesis, resulting in 9128 samples entering the DID test. Columns (1) and (2) of Table 9 show that the impact of DESG ratings on green innovation and GTFP is consistent with the original test, which supports the hypothesis proposed in the theoretical analysis and avoids the endogeneity problems that may be caused by sample selection bias.

In addition, endogeneity issues of bidirectional causality may exist between the explained and explanatory variables. On the one hand, significant positive relationships are evident among ESG ratings, green innovation, and GTFP in the main test. On the other hand, when the levels of green innovation and GTFP are high, a reverse impact on the enterprise's ESG ratings may occur. This endogeneity issue is mainly manifested as the correlation between the disturbance term and explanatory variable, which violates the basic assumption of Ordinary Least Squares (OLS). The common method to solve this problem is to find instrumental variables and obtain more consistent and effective estimation results through two-stage least squares (2SLS). The selection requirement of instrumental variables is that they are related to the explanatory variables and not to the disturbance terms. Referring to the approach of Fisman and Svensson [60], this study used the mean ESG ratings (ESG_City) of enterprises registered in the same city as the instrumental variable because they usually have a strong correlation, but are not related to the enterprises' own green innovation and GTFP, which is consistent with the exogenous characteristics of instrumental variables. Meanwhile, the results showed that the Cragg Donald Wald F statistic is 1762.884, passing the weak instrumental variable test, and thereby indicating that the instrumental variable has a strong correlation with the endogenous explanatory variable. Columns (3)–(5) of Table 9 report the results of the 2SLS, among which column (3) represents the first-stage regression, which shows that the instrumental variables have good explanatory power for the explanatory variable. Columns (4) and (5) show the second-stage regression. The results align with those of the main test after controlling for endogeneity issues, demonstrating the reliability of the findings.

4.4.2. Robustness test

(1) Alternative methods of inspection

First, the core explained variables of this study—green innovation (GInv) and GTFP—both exhibit typical left-censored data

Table 9
Results of the endogeneity test.

Variables	PSM-DID		2SLS		
	(1)	(2)	(3)	(4)	(5)
	GInv	GTFP	ESG	GInv	GTFP
DESG	0.050**	0.076***			
	(2.512)	(3.577)			
ESG_City			0.332***		
			(45.252)		
ESG				0.078***	0.048*
				(3.246)	(1.707)
Debt	0.054***	0.016	−0.096***	0.069***	0.035***
	(5.006)	(1.471)	(-10.866)	(7.625)	(3.680)
Growth	0.038***	−0.006	−0.035***	0.036***	0.004
	(3.233)	(-0.540)	(-4.167)	(3.731)	(0.487)
CI	0.010	−0.014	0.018**	0.012	−0.009
	(0.825)	(-1.202)	(1.966)	(1.151)	(-0.905)
Cash	−0.006	−0.001	0.056***	0.014***	−0.001
	(-0.510)	(-0.078)	(4.292)	(2.849)	(-0.063)
FV	−0.053***	−0.025**	−0.119***	−0.031***	−0.014
	(-5.053)	(-2.159)	(-11.932)	(-3.673)	(-1.430)
IST	0.016	0.010	0.070***	−0.003	0.011
	(1.331)	(0.637)	(6.575)	(-0.264)	(0.857)
INDE	−0.029***	0.017	0.071***	−0.028***	0.012
	(-3.254)	(1.447)	(8.964)	(-3.519)	(1.229)
Z	−0.014	0.030**	−0.029***	−0.017**	0.013
	(-1.359)	(2.569)	(-3.498)	(-2.146)	(1.458)
ICD	−0.012	0.014	0.028*	−0.009	0.036*
	(-0.570)	(0.624)	(1.675)	(-0.496)	(1.886)
Constant	0.161	−0.106	−0.211**	0.274***	−0.050
	(1.453)	(-0.974)	(-2.344)	(2.954)	(-0.521)
Industry/Year	Yes	Yes	Yes	Yes	Yes
N	9128	9128	13902	13902	13902
Adj.R^2	0.118	0.004	0.153	0.140	0.002

Notes: T-test values are in parentheses. ***, **, and * represent $P < 0.01$, $P < 0.5$, and $P < 0.1$, respectively.

characteristics. For this data structure, the Tobit model test can convert censored data into probability models for analysis, with high estimation accuracy and reliability. Therefore, this study used the Tobit model to re-test the main test (as shown in Table 10), which is consistent with the original results, and therefore confirms the robustness of the research conclusions.

In addition, this study used the traditional three-step method to test the mechanisms of analyst attention (Analyst) and investor sentiment (Investor). Combined with the research of Pituch and Stapleton [61], the Bootstrap method is an alternative method for mediating effect testing. Therefore, this study chose the Bootstrap method to verify the robustness of the mechanism tests. Among them, the repeated sampling sample size is set to 1000, and the confidence interval of the mediation effect coefficient is observed through a large number of repeated samplings. If the upper and lower limits of the confidence interval at the 95 % level do not include 0, it means that the mediating effect is significant. The results of the Bootstrap test are shown in Table 11. The mediating effect coefficients are significant at the 1 % level, and the confidence interval at the 95 % level do not include 0, indicating that the mediating effect mechanisms of analyst attention and investor sentiment exist and are significant, confirming the robustness of the mechanism test.

(2) Alternative measures of indicators

The academic community generally believes that the innovation quality of invention patents is higher than that of utility models and design patents, and their examination standards are relatively stricter. Therefore, drawing on Liao et al.'s approach [36], this study replaces the green innovation measurement method (GInvN) with the ratio of green invention patent applications to green patent applications for robustness tests, which can better reflect the substantive innovation of enterprises. As shown in Column (1) of Table 12, the results remain consistent with the original tests after the measurement indicator of the explained variable is replaced. To verify that ESG ratings have a broader impact on TFP, we replace the GTFP index used in the main test with a TFP indicator without adding unexpected output. In Column (2), the results are consistent with the original test. In addition, SynTao Green Finance is a professional service organization for green finance and responsible investment, which has been issuing ESG ratings since 2015. Drawing on the approach of Broadstock et al. [62], this study replaced the ESG ratings indicator with SynTao Green Finance's ESG ratings (SESG), and conducted a robustness test (see Columns 3 and 4). The research conclusions remain robust.

(3) Reduction of research sample

Table 10
Tobit test results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	GInv	GInv	GInv	GInv	GTFP	GTFP	GTFP	GTFP
ESG	0.006***				0.494***			
	(10.328)				(3.430)			
E		0.006***				0.189*		
		(13.130)				(1.783)		
S			0.002***				0.207**	
			(6.718)				(2.401)	
G				0.002***				0.339***
				(4.291)				(2.935)
Debt	0.178***	0.143***	0.163***	0.174***	16.957***	14.362***	15.400***	18.196***
	(10.569)	(8.603)	(9.775)	(10.187)	(3.904)	(3.318)	(3.572)	(4.100)
Growth	0.022***	0.022***	0.020***	0.020***	0.540	0.428	0.446	0.416
	(4.509)	(4.451)	(4.111)	(4.049)	(0.371)	(0.294)	(0.307)	(0.286)
CI	−0.056***	−0.071***	−0.044**	−0.059***	−5.018	−5.174	−4.087	−5.146
	(-2.585)	(-3.293)	(-2.036)	(-2.731)	(-0.852)	(-0.877)	(-0.694)	(-0.874)
Cash	−0.040	−0.015	−0.018	−0.029	0.237	0.629	0.678	−0.039
	(-1.265)	(-0.483)	(-0.588)	(-0.925)	(0.096)	(0.254)	(0.274)	(-0.016)
FV	−0.022***	−0.021***	−0.025***	−0.025***	−1.027	−1.150*	−1.200*	−1.169*
	(-7.626)	(-7.402)	(-8.743)	(-8.968)	(-1.478)	(-1.653)	(-1.735)	(-1.691)
IST	0.011	0.008	0.013*	0.013*	3.304*	3.527*	3.563*	3.502*
	(1.420)	(1.079)	(1.740)	(1.741)	(1.664)	(1.776)	(1.797)	(1.766)
INDE	−0.184***	−0.120**	−0.132**	−0.175***	25.317*	29.727**	29.260**	22.592
	(-3.358)	(-2.220)	(-2.421)	(-3.153)	(1.744)	(2.052)	(2.021)	(1.543)
Z	−0.017***	−0.018***	−0.019***	−0.017***	1.902	1.772	1.653	2.039
	(-3.205)	(-3.447)	(-3.592)	(-3.248)	(1.394)	(1.299)	(1.211)	(1.491)
ICD	−0.001	0.001	0.001	−0.002	3.104*	3.227**	3.282**	2.937*
	(-0.106)	(0.145)	(0.086)	(-0.257)	(1.898)	(1.972)	(2.006)	(1.793)
Constant	−0.507***	−0.421***	−0.216***	−0.227***	−34.458**	−11.794	−12.895	−27.189**
	(-8.071)	(-7.959)	(-4.244)	(-3.794)	(-2.412)	(-0.970)	(-1.124)	(-1.976)
Industry/Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	14421	14421	14421	14421	14421	14421	14421	14421
Pseudo R^2	0.604	0.611	0.597	0.594	0.001	0.001	0.001	0.001

Notes: T-test values are in parentheses. ***, **, and * represent $P < 0.01$, $P < 0.5$, and $P < 0.1$, respectively.

Table 11
Mechanism test results based on Bootstrap method.

Variables	Mediating effect coefficient			95 % confidence interval	
	Estimate	Standard error	P	upper	lower
Analyst	0.154	0.003	0.000	0.009	0.022
Investor	0.012	0.002	0.000	0.008	0.016

Table 12
Robustness test results for replacing indicator measures.

Variables	(1)	(2)	(3)	(4)
	GInvN	TFP	GInv	GTFP
ESG	0.144***	0.076***		
	(17.100)	(13.562)		
SESG			0.025**	0.050**
			(2.038)	(2.486)
Debt	0.150***	0.222***	0.047***	0.033*
	(17.634)	(33.082)	(3.468)	(1.909)
Growth	0.035***	−0.005	0.034**	0.002
	(4.221)	(-0.643)	(2.101)	(0.129)
CI	−0.063***	−0.484***	0.009	−0.016
	(-6.709)	(-69.185)	(0.622)	(-0.953)
Cash	0.036***	0.030***	0.023***	0.001
	(2.861)	(4.862)	(3.546)	(0.043)
FV	−0.074***	−0.079***	−0.060***	−0.031*
	(-8.377)	(-11.496)	(-5.866)	(-1.852)
IST	0.051***	0.056***	0.019	0.018
	(4.957)	(7.821)	(1.324)	(0.827)
INDE	−0.015*	0.005	−0.025**	0.038**
	(-1.910)	(0.957)	(-2.236)	(2.098)
Z	−0.013	−0.026***	−0.016	0.012
	(-1.485)	(-4.967)	(-1.290)	(0.707)
ICD	0.046***	0.014	0.048*	0.039
	(2.642)	(1.243)	(1.831)	(1.135)
Constant	−0.313***	−0.383***	0.484***	−0.205
	(-3.691)	(-9.864)	(3.496)	(-1.627)
Industry/Year	Yes	Yes	Yes	Yes
N	14421	19341	5066	5066
Adj.R^2	0.059	0.491	0.214	0.003

Notes: T-test values are in parentheses. ***, **, and * represent $P < 0.01$, $P < 0.5$, and $P < 0.1$, respectively.

Heavily polluting enterprises experience inertia when facing green innovation, and improvements in the external environment can encourage them to improve green innovation [63]. Therefore, compared with heavily polluting enterprises, ESG ratings' beneficial effects on green innovation and GTFP may be relatively weaker in non-heavily polluting enterprises. To confirm the validity of the conclusion, this study drew on the method of Qingyuan and Zehua [64] and used the directory of heavily polluting enterprises established in the "Environmental Information Disclosure Guidelines for Listed Companies" issued by the Ministry of Environmental Protection of the PRC in 2010 as the benchmark. Non-heavily polluting enterprises were selected for the robustness test, with a sample size of 9001 after screening. Table 13 presents the results. In non-heavily polluting enterprises, the direction and significance level of the impact of ESG ratings on green innovation and GTFP withstood the test, demonstrating that the findings of this study have enough explanatory power.

5. Conclusion

This study followed the SOR theory and the path of "stimulus (ESG ratings) — response (green innovation) — result (GTFP)" and selected A-share listed companies between 2011 and 2021 as the research sample. Using the Huazheng Index ESG rating data, an in-depth investigation was conducted on the association among ESG ratings, green innovation, and GTFP, as well as the underlying transmission mechanisms. First, we conducted an in-depth comparison and discussion of the results obtained in this study and those of past studies, and clearly explained the added value of this study to the existing literature as follows.

(1) The main test results show that an ESG rating and its components (individual scores of E, S, and G) have a significant improvement effect on green innovation and GTFP of enterprises. Relatively speaking, E and S have a more significant impact on green innovation, while G has a stronger promoting effect on GTFP. This supports the conclusion of most literature; that is, the improvement of ESG ratings will enhance the level of technological innovation of enterprises, thereby promoting green

Table 13
Robustness test results for non-heavily polluting enterprises.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	GInv	GInv	GInv	GInv	GTFP	GTFP	GTFP	GTFP
ESG	0.053***				0.031***			
	(6.669)				(2.660)			
E		0.086***				0.015		
		(10.041)				(1.250)		
S			0.028***				0.030***	
			(3.068)				(2.710)	
G				0.018**				0.024**
				(2.055)				(2.078)
Debt	0.061***	0.043***	0.055***	0.058***	0.035***	0.029**	0.032***	0.037***
	(5.704)	(4.078)	(5.153)	(5.349)	(2.919)	(2.445)	(2.687)	(3.035)
Growth	0.035***	0.036***	0.034***	0.033***	0.001	−0.000	0.000	−0.001
	(3.392)	(3.472)	(3.212)	(3.136)	(0.060)	(-0.046)	(0.017)	(-0.050)
CI	−0.038***	−0.039***	−0.037***	−0.037***	−0.017	−0.016	−0.016	−0.016
	(-2.837)	(-2.920)	(-2.708)	(-2.730)	(-1.291)	(-1.238)	(-1.222)	(-1.255)
Cash	0.003	0.006	0.007	0.005	−0.004	−0.002	−0.002	−0.005
	(0.470)	(1.024)	(1.224)	(0.841)	(-0.276)	(-0.130)	(-0.123)	(-0.301)
FV	−0.017	−0.011	−0.022**	−0.024**	−0.012	−0.014	−0.014	−0.015
	(-1.632)	(-0.997)	(-2.103)	(-2.247)	(-0.926)	(-1.080)	(-1.061)	(-1.151)
IST	−0.003	−0.005	−0.000	0.000	0.017	0.018	0.018	0.018
	(-0.308)	(-0.482)	(-0.029)	(0.041)	(0.987)	(1.085)	(1.047)	(1.077)
INDE	−0.012	−0.006	−0.008	−0.011	0.016	0.019	0.019	0.015
	(-1.226)	(-0.647)	(-0.776)	(-1.064)	(1.401)	(1.631)	(1.631)	(1.295)
Z	−0.016*	−0.017*	−0.019**	−0.017*	0.002	0.002	0.001	0.003
	(-1.816)	(-1.931)	(-2.086)	(-1.882)	(0.231)	(0.143)	(0.072)	(0.280)
ICD	−0.021	−0.015	−0.017	−0.021	−0.001	0.001	0.001	−0.003
	(-1.009)	(-0.727)	(-0.845)	(-1.017)	(-0.047)	(0.035)	(0.064)	(-0.131)
Constant	0.235**	0.181*	0.249***	0.201**	−0.050	−0.068	−0.026	−0.080
	(2.504)	(1.947)	(2.624)	(2.174)	(-0.524)	(-0.708)	(-0.269)	(-0.831)
Industry/Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	9001	9001	9001	9001	9001	9001	9001	9001
Adj. R^2	0.152	0.156	0.150	0.150	0.001	0.001	0.001	0.001

Notes: T-test values are in parentheses. ***, **, and * represent $P < 0.01$, $P < 0.5$, and $P < 0.1$, respectively.

transformation and development. As some studies suggest, ESG ratings can improve the level of technological innovation and green innovation [65] by enhancing learning capabilities [66] and improving corporate governance levels [67]. However, some studies suggest that ESG ratings may exacerbate managers' short-sighted behavior, thereby adversely affecting the long-term green transformation of enterprises [68]. This study's research responds to this and determined the following. With the continuous improvement of the capital market, ESG ratings can more comprehensively convey the true operating conditions of enterprises, reduce information asymmetry as much as possible, and managers' short-sighted behavior can be quickly identified, thereby greatly weakening the adverse impact of ESG ratings on GTFP.

(2) The mechanism test results indicate that the ESG ratings will release green transformation signals through analyst attention and investor sentiment, and thus promote the improvement of GTFP. This is a powerful supplement to the existing literature. Previous studies contend that stakeholders are an important force for enterprises to obtain sustainable competitive advantages [69]. Compared with other technological innovation processes, green transformation is more complex and has longer-term value output. Asymmetric information can easily trigger adverse selection behavior among investors, leading to distortion of capital allocation [70]. An enterprise's higher ESG rating is more likely to be recognized by stakeholders, which is conducive to conveying positive information on ESG [71], obtaining more funds, cooperation, and technical services, and significantly improving resource allocation efficiency [72]. This can help enterprises overcome the challenges of green transformation, correct distortions in capital allocation, and gain long-term momentum for green development [73].

Next, this study explored the heterogeneity analysis in detail by combining the major urban agglomerations, patent intensity and environmental risks of industries, and nature of property rights. The study determined that, at the regional level, compared with the performance of enterprises in other regions, the coefficients and significance levels of enterprises in major urban agglomerations (Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta) are relatively low. At the industry level, the promoting effect of ESG ratings is more pronounced in patent-intensive industries and industries with lower environmental risks. At the enterprise level, the impact of ESG ratings on green innovation is more significant in non-state-owned enterprises, while the impact coefficient of ESG ratings on GTFP is larger and the significance level higher in state-owned enterprises. In addition, this study conducted endogeneity tests through PSM-DID and 2SLS methods, avoiding various endogeneity issues that may be caused by sample selection bias and bidirectional causality. Meanwhile, we conducted multiple robustness tests by exploring alternative approaches, replacing the measures of indicators, and reducing the research sample. All results were consistent with the original test, confirming that the conclusions have sufficient explanatory power.

5.1. Theoretical contribution

This study's theoretical contributions are mainly reflected in two aspects. First, it advances pertinent research on the driving factors of green innovation. Previous studies on the green transformation of enterprises have mostly focused on the hard supervision of policies, paying less attention to the micro-mechanisms of soft regulation, such as ESG ratings. This study improves the theoretical model of ESG ratings and green transformation based on stakeholder theory, confirming the promoting effect of ESG ratings on green innovation and GTFP. These findings will help better understand the driving mechanisms of green innovation and the roots of transformation strategy selection. Second, it expands on the consequences of ESG research. Existing studies focus on ESG in developed Western markets with relatively mature systems. As a developing country in the later stages of modernization, China's ESG system is still in the exploration stage, and its effectiveness still lacks research. This study uses A-share listed companies that traded on the Shanghai and Shenzhen stock exchanges between 2011 and 2021 to explore the mechanism of ESG ratings on the green transformation of enterprises, deepening our understanding of ESG and providing empirical evidence from emerging markets.

5.2. Managerial implication

This study has several important managerial implications. Enterprises should fully recognize the promoting role of ESG ratings on green innovation and GTFP, regard ESG construction as a value investment rather than a cost expenditure, strive to practice new development concepts, actively accelerate green transformation, fulfill environmental and social responsibilities, strengthen internal governance efficiency, and fully demonstrate their comprehensive capabilities for sustainable development. This will absorb more strategic resources from the market and stakeholders while empowering green innovation, actualizing the win-win scenario of increasing economic and environmental advantages, and creating conditions to enhance GTFP.

This study suggests that government departments should fully recognize the role of ESG ratings in promoting enterprises' green transformation, establish and improve ESG information disclosure standards, support system frameworks that are in line with China's actual conditions, guide enterprises to standardize the disclosure of ESG information, actively fulfill ESG responsibilities, and promote the implementation of innovation-driven and environmentally friendly strategies at the micro level. Additionally, an environmental governance and innovation-driven system should be constructed with the government as the leader, enterprises as the main body, and social rating agencies as the participants. Full play should be given to the joint efforts of the proactive government and an effective market, forming a positive feedback loop mechanism for ESG ratings, giving certain policy preferences to enterprises with good ESG performance, transforming social responsibility into innovation advantages, and promoting the incremental improvement of green transformation.

5.3. Limitations and future research

This study had some limitations. First, due to data availability, this study only collected cross-sectional data from listed companies in four industries, which cannot fully represent the overall picture of Chinese enterprises. Therefore, the generalizability of these findings is limited. In the future, the sample scope will expand, and dynamic research will be conducted continuously. Second, in the mechanism test, this study employed analyst attention and investor sentiment as mediating variables for mechanism verification. In the future, further exploration will be conducted on the effects of other soft regulations on media, suppliers, and auditors. In addition, after the implementation of mandatory ESG disclosure policies, a comprehensive examination of the combined effects of hard and soft regulations can be conducted.

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Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Dengyun Niu: Writing – original draft, Software, Investigation, Conceptualization. **Zhihua Wang:** Writing – review & editing, Validation, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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