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Exploring the impact of ESG ratings on enterprises' green technology innovation

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Abstract
Green technology innovation (GTI) is a crucial factor in the global quest for sustainability. This study examines the impact of environmental, social, and governance (ESG) ratings provided by SynTao Green Finance on the GTI of Chinese A-share listed enterprises from 2007 to 2022. By utilizing the time-varying difference-in-differences (DID) model and examining the promotion effect of GTI in application and authorization, the study demonstrates a positive relationship between higher ESG ratings and enterprises' GTI. This conclusion is substantiated through rigorous robustness tests. The findings indicate that ESG ratings facilitate enterprises' GTI by addressing financing constraints, mitigating agency issues, and fostering research and development investment. Moreover, ESG ratings are found to be beneficial for enterprises operating in highly competitive markets and garnering significant analytical attention, while not being conducive to GTI in heavily polluting or manufacturing enterprises. By overcoming the limitations of the traditional Ordinary Least Square model in dealing with time trends and persistence effects, this study elucidates the influencing factors of ESG ratings on enterprises' GTI. Consequently, it provides valuable insights for enterprises to develop targeted sustainable strategies and achieve a mutually beneficial outcome for the economy and the environment.

Keywords ESG ratings · Green technology innovation · Green development · Sustainability

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1 Introduction

Global sustainable development faces significant challenges, such as climate change, resource depletion, and environmental damage (Sreeharsha & Venkata, 2021). In this context, enterprises are crucial sustainable development drivers (Mio et al., 2020), particularly GTI (Wu et al., 2023). China, one of the major manufacturing nations in the world, is in a critical position concerning innovation for global environmental sustainability (Wu et al., 2015). ESG ratings have gained prominence in investment and enterprise decisions and are becoming essential for assessing enterprises' performance (Ahmad et al., 2023; Wu & Li, 2023). Green and sustainable development is necessary for long-term human development (Adomako & Tran, 2022). With ESG ratings integrated into regulations, enterprises must adhere to minimize legal risks (Shen, 2023). Additionally, ESG ratings engage consumers by providing long-term growth and returns (Bissoondoyal-Bheenick et al., 2023). The ESG rating system positively evaluates enterprises' GTI, thereby enhancing its reputation and brand value, which are crucial for the enterprise's long-term green development.

The complexity of GTI encompasses various factors such as technology, sustainability, and social responsibility, with a focus on environmental friendliness and resource efficiency (Mandas et al., 2023). The relationship between ESG ratings and GTI has gained significant attention in the academic community. Scholars have utilized ESG ratings to examine their impact on enterprises' investment fields to enhance financial conditions (Abdi et al., 2022; Kim & Li, 2021; Ruan & Liu, 2021). Furthermore, ESG ratings have shown predictive value in the finance domain (Das, 2023), highlighting the intricate interplay between ESG ratings and economic outcomes, shaping responsible investment and enterprise sustainability practices. Some studies have explored the positive impact of ESG ratings on enterprise innovation, particularly in the context of financial investment and listed enterprises' inventions (Dmuchowski et al., 2023; Forcadell et al., 2021; Hu et al., 2020; Mukhtar et al., 2024; Wang & Sun, 2022; Wang et al., 2023; Zhang & Chen, 2023). However, the perspective of environmental regulation suggests that it may not be conducive to incentivizing GTI and could impose limitations. Conversely, from a non-environmental regulatory standpoint, positive relationships between ESG ratings and enterprises' GTI have been studied (Liu & Lyu, 2022), with only a few scholars exploring the internal mechanisms between ESG ratings and GTI. In this context, this study examines the mechanism through which ESG ratings influence enterprises' GTI from a non-environmental regulatory perspective, aiming to bridge existing research gaps and assist governments and enterprises in allocating limited resources effectively to ensure economic success. Consequently, there is a relatively limited body of research on the impact of ESG ratings on enterprises' GTI (Zhang & Liu, 2023). By investigating aspects such as property rights, technical level, and market experience, this study explores the role of ESG ratings in promoting enterprises' GTI capabilities. However, it is crucial to note that the impact of ESG ratings on GTI is often indirect and requires intermediary factors. This study delves into the internal mediation process (Del Vitto et al., 2023; Fan et al., 2023; Habib, 2023b; Shen et al., 2023) to examine the relationship between ESG ratings and enterprises' GTI comprehensively. However, only a few scholars have explored the mediating variables between ESG ratings and GTI, making this article a valuable reference for further research in the field.

There is no denying the impact of ESG ratings on enterprises' GTI (Berg et al., 2022; Qiang et al., 2023). How to explore the corresponding relationship has always been a hot topic among scholars. If the regression model is directly used, the impact of time trends

will be ignored, and there will be a certain degree of endogeneity. Therefore, this paper adopts a time-varying DID model to reasonably deal with the endogeneity problem of model selection (Sun & Cao, 2023). So far, not many scholars have studied the impact of ESG ratings on enterprises' GTI through the time-varying DID model.

Although the above concepts are conceptually interlinked broadly, empirical findings are scattered, and linkages remain understudied in prior literature. Against this backdrop, this paper adopts stakeholder theory, agency theory and dynamic capabilities view, starting from the perspective of non-environmental regulation, and adopts a time-varying DID model to improve the robustness of the research results while integrating ESG ratings with enterprises' GTI. Creating a unique framework that analyzes the impact mechanism of ESG ratings on enterprises' GTI. Examining enterprises' financing constraints, enterprise agency issues, and enterprise R&D investment through the internal intermediary effect provides profound insights into the impact of ESG ratings on enterprises' GTI and fills the gaps in existing research. Finally, the relevant factors of ESG rating enhancement of GTI, such as market competition, industry attributes, and market attention are discussed, which helps to clarify the specific conditions for ESG ratings to promote enterprises' GTI.

This study of findings demonstrated that ESG ratings positively influence the growth of environmentally friendly GTI, providing a solid empirical basis for formulating and enhancing development strategies. Furthermore, the unique methodology and insightful conclusions of this study provide valuable theoretical and practical guidance for enterprises to deepen their green industry development and sustainable innovation.

This paper is organized as described below: the following section offers the pertinent conceptual foundation and predictions. The section after depicts the data processing and measurement development. The fourth section details depicts the research design.The fifth section outlines the empirical findings that will be discussed. The sixth section details the conduct of the mechanical tests. The seventh section analyzes heterogeneity. The eighth section discusses the results and the ninth section summarizes the research.

2 Theoretical foundation and predictions development

2.1 Theoretical foundation and predictions

Recently, ESG ratings have attracted widespread attention from stakeholders (Esposito De Falco et al., 2021). Stakeholder theory articulates that enterprises' success and reputation are profoundly affected by a variety of different stakeholder types who play an essential role in its development (Mahajan et al., 2023) and that enterprises must carefully consider and fulfill the demands and anticipations of various parties (Bridoux & Stoelhorst, 2022), which has important implications for the evaluation and quantification of the sustainability performance of enterprises (Silva et al., 2019). Similarly, this study argues that enterprises' ESG ratings may affect stakeholders and enterprises' GTI.

Agency theory indicates that principals and agents typically have different levels of information, which can create inconsistencies between the agent's behavior and the principal's expectations (Cabrales et al., 2022). The principal cannot fully understand the agent's behavior and decision-making and thus cannot effectively monitor the agent's behavior (Bergh et al., 2018). Agency theory emphasizes appropriate incentives and tracking mechanisms, which, to some extent, can resolve the knowledge unevenness issue, ensure that the way the agent acts is in line with the expectations of the principal, and protect the interests

of shareholders (Habib, 2023a; Shahwan & Habib, 2023). This study argues that ESG ratings can help ease enterprises' agency issues and boost enterprises' GTI.

The dynamic capability view means having the capacity to predict the future and recognize trends and movements. This ability helps enterprises and individuals make informed choices in a changing environment (Ye et al., 2022). Applying the dynamic capability view is necessary for market analysis, and fully utilizing it in strategic planning to improve the quality of decision-making has been a topic of close attention for many enterprises (Ojha et al., 2020). Similarly, this study contends that ESG can dynamically influence enterprises' GTI development.

2.2 Hypotheses development

ESG ratings are an analytical framework for measuring enterprises' commitment to sustainable development and social responsibility, which aids in increasing enterprises' environmental consciousness while supporting green and sustainable development (Li & Li, 2022). Initially, ESG ratings were intimately tied to sustainability, inspiring enterprises to focus on developing and applying GTI to reduce environmental issues (Barbieri et al., 2023). Second, ESG ratings are essential to enterprises' reputation and sustainability initiatives. Therefore, enterprises aggressively seek green patents to demonstrate dedication to environmental preservation and sustainability (Hu et al., 2023). Therefore, we make the subsequent theory:

H1 ESG ratings benefit green applications and authorization, encouraging enterprises' green technology innovation.

Information transparency is an essential environmental characteristic influencing finance (Hoang et al., 2020). Overall, ESG ratings positively impact enterprises' reputation, examining enterprises' sustainability performance and increasing, their attractiveness to investors and financial institutions (Zahid et al., 2023), growing the proportion of financiers who take ESG ratings factored in when making financial choices to improve their ability to predict financial distress (Citterio & King, 2023). According to experts, ESG ratings encourage enterprises to be more proactive in resolving social issues, which can help reduce their financing limitations. For example, those suffering financial difficulties due to environmental problems should appropriately boost environmental protection expenditures to improve their financing prospects. Consequently, ESG ratings align enterprises, societal, and environmental issues, and reduce the impact of enterprises' financial risk. In comparison, they support the development of enterprises' GTI. Therefore, we make the subsequent theory:

H2 ESG ratings promote enterprises' green technology innovation by encouraging enterprises' financial limits.

Agency issues are possible conflicts concerning interests between the leadership team and investors or other parties involved. ESG ratings lower agency costs and moderately influence information asymmetry. Furthermore, ESG ratings assist decision-makers in managing enterprises and mitigating enterprises' agency issues (Li & Xu, 2024). This reduces agency costs (Agosto et al., 2023). Furthermore, ESG ratings assist decision-makers in managing enterprises and mitigating enterprise agency issues. As investors' interest in sustainability and the overall effect grows, so does the importance of ESG ratings as a non-negligible component in investment decision-making. Enterprises with low ESG ratings are often explicitly excluded from ESG funds (Kim & Park, 2023), while enterprises

with excellent ESG ratings have more opportunities. ESG ratings help align management's interests with those of shareholders and stakeholders, and their impact on the long-term viability of enterprises. Therefore, we make the subsequent theory:

H3 ESG ratings promote enterprises' green technology innovation by mitigating enterprises' agency issues.

The total amount of money and resources that enterprises devote to research and development. An inverted U is seen between research and development expenditures and green breakthroughs in enterprises, and moderate R&D expenditures may support green electronic device creation in enterprises. Investing more in R&D can help enterprises innovate their GTI (Li et al., 2023), and investors are more likely to favor enterprises that have superior ESG ratings (Jámbor & Zanócz, 2023), potentially increasing R&D. Enterprises that increase R&D spending can foster environmental sustainability and green enterprises' creativity concerning one another (Hao et al., 2020). Therefore, we make the subsequent theory:

H4 Green technology innovation is encouraged by ESG ratings by boosting the enterprises' R&D investments.

Typically, ESG ratings have a moderating effect on enterprises' competition (Rabaya & Saleh, 2022). Increased market competitiveness causes enterprises to prioritize innovation and sustainable development, making them more inclined to work on innovative GTI devices (Crowley & Jordan, 2017). First, enterprises with green technological breakthroughs can distinguish themselves in competitive markets, and GTI is a significant strategy for resolving environmental challenges. Second, ESG ratings boost market rivalry (Li et al., 2022), especially in environmental protection and green innovation (Martins, 2022). Finally, to increase environmental regulation enforcement, the government and regulatory bodies should stimulate GTI and encourage enterprises to use environmentally friendly solutions (Chen et al., 2022). Therefore, we make the subsequent theory:

H5 The greater the ESG ratings, the greater the probability of promoting enterprises' green technology innovation.

Given increasingly severe environmental concerns, the sustainability of environmentally polluting enterprises has a significant beneficial relationship with the caliber of the dissemination of their social duties (Dhar et al., 2022). Heavy polluters and manufacturing enterprises are the main contributors to carbon emissions (Yuan et al., 2022). Typically, they face a wide range of environmental and social risks, including legal, reputational, and supply chain risks that are receiving attention (Guo & Shi, 2022). By improving their ESG ratings, these enterprises' risks can be mitigated, and their sustainability improved (Garcia et al., 2017). Therefore, we make the subsequent theory:

H6 ESG ratings significantly inspire green technology inventiveness among heavy polluters and manufacturing enterprises.

ESG ratings are a substantial aspect of global nonfinancial assessments (Park & Oh, 2022). More and more investors, particularly long-term investors, perceive analysts' concerns as potentially representing investment risk and return (Harper, 2020; Park & Jang,

2021). High ESG ratings can attract more investors and increase enterprises' market capitalization (Chen & Xie, 2022). Therefore, we make the subsequent theory:

H7 ESG ratings attract enterprise analysts' attention, encourage enterprise investment, and facilitate enterprises' green technology innovation.

3 Data processing and measurement development

3.1 Data processing

Based on the ESG ratings information provided by SynTao Green Finance first made public in 2015, China's listed enterprises are crucial financial systems. In this paper, a sample of publicly traded enterprises from the A-share market between 2007 and 2022 was chosen for the study, and the sample treatment process is as follows. (1) Financial enterprises and enterprises that were Special Treatment (ST), suspended (ST*), or Suspended for Rectification (PT) during the study year were excluded. (2) Enterprises listed in the current year were excluded to prevent discrepancies in disclosure due to shorter listing periods. (3) Severely missing data were removed to ensure that the research sample contained high-quality data. Finally, 334,549 sample observations were obtained, covering all Chinese A-listed enterprises from 2007 to 2022, except the financial industry, with a certain degree of stability and representativeness, providing sufficient data for an in-depth analysis. (4) Tailoring was used to exclude the interference of extreme values, ensure that the statistical analysis was not affected by outliers, and raise the model outcomes' credibility. Enterprises' GTI data used in this study came from the China Research Data Service Platform (CNRDS) database, while the Wind database provided the ESG rating data. The CSMAR database provided all other pertinent data.

3.2 Measurement development

Explained variable: For enterprises' GTI. Chen and Chen (2021) use (GTI1) to measure the number of green applications, moreover, Xu et al. (2021) use (GTI2) to measure the number of green authorizations.

Control Variables: Regarding the control variables of enterprises' GTI, some studies have constructed a comprehensive index evaluation system (Linton, 2021). For example, the data may include the security code, year of application, and type of variable.

ESG ratings are the primary explanatory factor. Various types of Wind databases contain ESG ratings information, including SynTao Green Finance, China Securities Index (CSI), FTSE Russell, and the Social Value Investment Alliance, among which SynTao Green Finance is highly authoritative. Therefore, the ESG ratings information of SynTao Green Finance is the core explanatory variable and refers to the methodology (Tan & Zhu, 2022). If SynTao Green Finance releases the rating data of the enterprise i in the year t, then $ESG_{it} = 1$, otherwise $ESG_{it} = 0$. In addition, this study uses CSI ESG data as a proxy for these variables to emphasize the robustness of the core variables. The results shown in Table 1 display comprehensive definitions of the variables.

Table 1 Detailed variable definitions

Type	Name	Symbol	Definition
Explained variables	Total number of green patents filed for inventions	GTI1	Ln (1 + Total number of green patents filed for inventions)
	Total number of green invention patents granted	GTI2	Ln (1 + Total number of green patents granted for inventions)
Core explanatory variables	ESG rating	ESG	0–1 variable, defined according to whether BDR publishes ESG rating data for the company or not
	CSI ESG rating	ESG_rate	CSI ESG rating
Control variables	Enterprise size	Size	Natural logarithm of annual total assets
	Return on assets	ROA	Net profit/Average balance of total assets
	Leverage ratio	Lev	Total liabilities/Total assets
	Enterprise age	LnAge	Natural logarithm of the age of the listed enterprise
	Operating income growth rate	Growth	(Operating income for the current period—Operating income for the previous period)/Operating income in the prior period
	Shareholding concentration	Top1	Top1 shareholdings among shareholders
	Net fixed assets per capita	PFixA	Ln (Net fixed assets/Total employees)
	Operating sale per capita	PSales	Ln (Operating sale/Total number of employees)

4 Research design

ESG ratings significantly affect financial markets and investment choices, in addition to reporting on the governance, social, and environmental performance of an enterprise. Therefore, it is becoming more widely acknowledged that ESG ratings provide enterprises with a competitive edge in addition to being an ethical obligation. The SynTao Green Finance initial release of ESG rating data for listed enterprises has attracted significant interest. This endeavor may lead to several external shocks in financial markets and provide investors with more information about the sustainability performance of enterprises. This study constructed a baseline regression model to better understand how listed enterprises and financial markets are affected by publishing SynTao Green Finance of ESG ratings.

$$Y_{it} = \beta_0 + \beta_1 ESG_{it} + \rho X_{it} + \gamma_i + \delta_t + \varepsilon_{it}, \tag{1}$$

where the variable that explains, Y_{it} is the enterprise's green applications or authorization i in the year t and ESG_{it} is the primary variable used to explain. X_{it} is a group of variables under control, γ_i is the individual fixed impact, δ_t is the designated time, and ε_{it} is a term for random error.

To accurately assess the dynamic relationship between ESG ratings and green with envy technology filing and licensing by listed enterprises and to conduct parallel trend tests, this study constructed the following time-varying DID:

$$\begin{aligned} Y_{it} = {} & \lambda + \delta_s^{\text{precut}} \left[D_i \times I\left(t - T_D < -8\right)\right] + \sum_{s=-8}^{-2} \delta_s^{\text{pre}} \left[D_i \times I\left(t - T_D = s\right)\right] \\ & + \sum_{s=0}^{7} \delta_s^{\text{post}} \left[D_i \times I\left(t - T_D = s\right)\right] + \delta_s^{\text{postcut}} \left[D_i \times I\left(t - T_D > 7\right)\right] \\ & + \rho X_{it} + \gamma_i + \delta_t + \varepsilon_{it}, \end{aligned} \tag{2}$$

where $D_i = 1$ is the therapeutic unit enterprise and $D_i = 0$ is the group under control enterprise i.$I(\bullet)$ is the indicative function, T_D is the current ESG ratings, and $(t - T_D = s)$ is the relative time of ESG ratings release as a reference, where $s = -1$ is the base time frame, δ reflects the dynamic shifts in the significance of ESG ratings on enterprises' green applications or authorization. If δ_s^{precut} and δ_s^{pre} are not significantly different from 0, δ_s^{post} and $\delta_s^{\text{postcut}}$ are substantially different from 0, all the variables are the same as in Eq. (1).

The measuring model that follows was developed to look into how enterprises' ESG influences its financing constraints, agency issues, and R&D investment:

$$N_{it} = \alpha_0 + \alpha_1 ESG_{it} + \rho X_{it} + \gamma_i + \delta_t + \varepsilon_{it}, \tag{3}$$

$$N_{it} = d_0 + d_1 ESG_{it} + \rho X_{it} + \gamma_i + \delta_t + \varepsilon_{it}, \tag{4}$$

$$N_{it} = g_0 + g_1 ESG_{it} + \rho X_{it} + \gamma_i + \delta_t + \varepsilon_{it}, \tag{5}$$

where N_{it} is the mechanism variable regarding agency issues, financial limitations, and R&D investment, whereas, and all the variables are the same as in Eq. (1).

The transmission mechanism between the two has not been further discussed. Therefore, the following financing constraints, agency issues, and R&D investment

intermediary measurement models, respectively, for mediation are created using the previously developed model as the foundation.

$$Y_{it} = e_0 + e_1 ESG_{it} + e_2 N_{it} + \rho X_{it} + \gamma_i + \delta_t + \varepsilon_{it}, \tag{6}$$

$$Y_{it} = f_0 + f_1 ESG_{it} + f_2 N_{it} + \rho X_{it} + \gamma_i + \delta_t + \varepsilon_{it}, \tag{7}$$

$$Y_{it} = k_0 + k_1 ESG_{it} + k_2 N_{it} + \rho X_{it} + \gamma_i + \delta_t + \varepsilon_{it}, \tag{8}$$

where N_{it} is the mediating variable in the above equation, regarding financing constraint, agency issues, and R&D investment, and all the variables are the same as in Eq. (1).

The measuring model that follows was developed to look into how enterprises' ESG ratings influence their market competition, industry attributes, and market concerns:

$$Y_{it} = b_0 + b_1 ESG_{it} + b_2 ESG_{it} R_{it} + b_3 R_{it} + \rho X_{it} + \gamma_i + \delta_t + \varepsilon_{it}, \tag{9}$$

$$Y_{it} = j_0 + j_1 ESG_{it} + j_2 ESG_{it} R_{it} + j_3 R_{it} + \rho X_{it} + \gamma_i + \delta_t + \varepsilon_{it}, \tag{10}$$

$$Y_{it} = h_0 + h_1 ESG_{it} + h_2 ESG_{it} R_{it} + h_3 R_{it} + \rho X_{it} + \gamma_i + \delta_t + \varepsilon_{it}, \tag{11}$$

where R_{it} is the regulating variable and all the variables are the same as in Eq. (1).

5 Data analytics and discussion

5.1 Model analytics

Table 2 below displays the findings of the variables' descriptive statistics. With a mean ESG value of 0.215, 21.5% of the sampled enterprises offered ESG rating information. Regarding the control variables, the sample size had a mean value of approximately 22.250, with maximum and minimum values of 26.720 and 19.600, In addition, the enterprises' average return on total assets was approximately 4.4%, and its average gearing ratio was approximately 41.5%. This indicates that enterprises' liability accounts for half of their

Table 2 Descriptive statistics of variables

Variable	N	Mean	SD	Min	Max
GTI1	33,549	0.272	0.641	0.000	4.159
GTI2	33,549	0.570	0.968	0.000	5.063
ESG	33,549	0.215	0.411	0.000	1.000
Size	33,549	22.250	1.310	19.600	26.720
ROA	33,549	0.044	0.060	−0.458	0.240
Lev	33,549	0.415	0.201	0.028	0.876
LnAge	33,549	2.614	0.652	0.000	3.434
Growth	33,549	0.260	0.560	−0.746	3.564
Top1	33,549	0.351	0.150	0.082	0.768
PFixA	33,549	12.550	1.163	8.752	17.400
PSales	33,549	13.830	0.875	11.640	17.280

assets, the proportion of liabilities is relatively reasonable, and every value of the other elements falls between acceptable bounds.

The following are the precise impacts of ESG ratings on enterprises' GTI: Table 3 displays the regression results of the model that was first estimated. The firm's regression analysis controls and year-fixed effects and uses firm-level clustered standard errors.

Table 3 of the results for regression demonstrates that all of the ESG ratings' correlation coefficients are extremely positive, suggesting that ESG ratings have the potential to encourage advancements in GTI for the enterprise. The number of enterprise applications for GTI on the regression coefficient of ESG rating is 0.270 after adapting for certain variables, as indicated in column (2) of the table. This means that the ESG ratings increase the average amount of enterprises' applications for GTI 27.0% the following year. According to Table 3 and column 4, the regression coefficient between the number of green inventions awarded to enterprise creations and the ESG rating is 0.162. This means that, on average, ESG ratings result in a 16.2% increase in enterprises' green authorization the following year. To a certain extent, ESG ratings facilitate enterprises' GTI.

The enterprise size (Size) coefficient was significantly positive when compared to the other variables used for control. Larger enterprises are more inclined to submit an

Table 3 Regression results

Variable	Gti1	GTI1	GTI2	GTI2
	(1)	(2)	(3)	(4)
ESG	0.333***	0.270***	0.211***	0.162***
	(0.029)	(0.028)	(0.025)	(0.024)
Size		0.313***		0.239***
		(0.023)		(0.022)
ROA		0.176		0.102
		(0.114)		(0.101)
Lev		0.014		0.021
		(0.070)		(0.066)
LnAge		− 0.565***		− 0.510***
		(0.215)		(0.192)
Growth		0.010		0.015*
		(0.010)		(0.009)
Top1		0.004		0.058
		(0.131)		(0.122)
PFixA		0.012		0.037***
		(0.014)		(0.013)
PSales		− 0.035*		− 0.044**
		(0.019)		(0.017)
Observations	0.776***	− 4.375***	− 0.504***	− 3.227***
	(0.006)	(0.788)	(0.006)	(0.716)
Constant	33,173	33,173	33,173	33,173
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
R^2	0.693	0.704	0.702	0.696

Robust standard errors in parentheses: ***$p<0.01$, **$p<0.05$, *$p<0.1$

application for and be granted GTI, because the development of GTI is an extremely dangerous, high-input endeavor. Furthermore, the coefficients about the annual growth rate of operating income (Growth) and operating sale per capita (PSales) in the regression study of GTI in technology exhibit a noteworthy positive correlation, indicating that enterprises with fast growth efficiency and high operating revenue are more likely to apply for and be authorized by GTI.

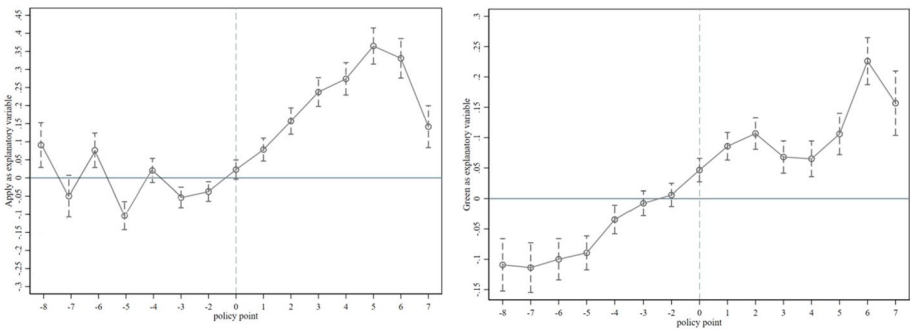
5.2 Robustness test and discussion

5.2.1 Parallel trend test result

A parallel trend test can profoundly investigate the dynamic characteristics of ESG ratings by utilizing Model (2), with GTI1 and GTI2 as explanatory variables. We investigated how ESG ratings affected the filing and granting of green by enterprises, Fig. 1 presents the findings. The difference between enterprise petitions for GTI applications and authorizations were not statistically significant before the implementation of ESG ratings. However, after ESG ratings in 2015, GTI is above the horizontal axis in the subsequent period and both GTI applications and GTI authorizations for the treatment group show a significant upward trend in relative terms, suggesting that ESG ratings have a contributing effect on enterprises' GTI with some persistence.

5.2.2 Placebo test

To verify that the impact of ESG ratings on the ability to innovate GTI is not coincidental, to increase the causal relationship between variables (Hartman & Hidalgo, 2018). In this paper, the placebo test is used to identify the effect of ESG ratings by introducing a dummy placebo variable to verify that the observed relationship exceeds the randomized level. We utilized the technique of processing (La Ferrara et al., 2012), according to the different distribution of the regression's ratings of the ESG process, 500 times randomly selected to construct the dummy policy variables, and then conducted regression estimation of the model and tested its p-value and coefficient distribution Fig. 2 presents the findings. The regression coefficients' average value of the listed enterprises' GTI on "dummy policy variables" is close to 0. This result is far from the benchmark regression coefficient.



(a) Application as an explanatory variable (b) Green as an explanatory variable

Fig. 1 Parallel trend test chart results

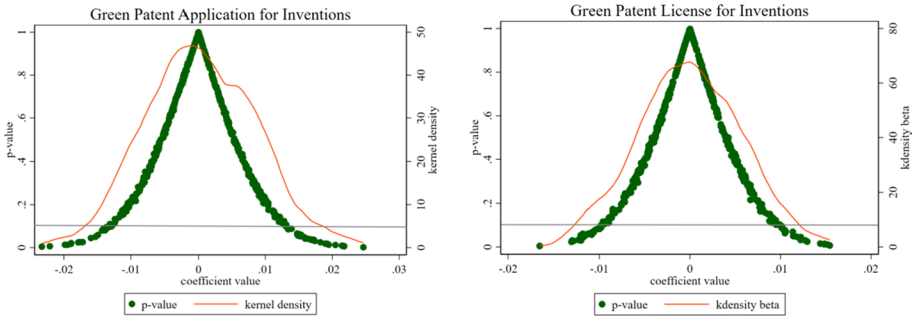


Fig. 2 Placebo test chart results

The distribution of the estimated coefficients is similar to the favorable distribution, and the *p* value is more significant than 0.10 in most cases, at the 10% level, which is not noteworthy. Put differently, the policies that are put into place are what lead to how the ESG rating affects the technological advancement of greens in listed enterprises, which verifies the above conclusion for reliability.

5.2.3 PSM-DID method

SynTao Green Finance of enterprises' ESG ratings may favor larger enterprises with better disclosure. To reduce the presence of individual factors, reduce the effect of potential confounding variables, increase the internal validity of causal inference, and avoid possible bias in the selection of the sample data, this paper ensures that the treatment and control groups are balanced in terms of pre- and post-trait characteristics using the PSM-DID. Using the kernel matching method, controlling factors like the gearing ratio (Lev) and operating income growth rate (Growth) can be used as covariates to guarantee consistency between both the control and treatment groups. Then, some unmatched samples were removed, and the matched data were rechecked using the DID model to ensure the findings from the regression analysis are provided in Table 4. All of the ESG regression findings are positive. Indicating that ESG ratings promote enterprises' GTI.

PSM-DID applies to cross-sectional data for which the literature generally adopts two methods: cross-sectional matching and period-by-period matching. Bckerman and Ilmakunnas (2009) took the panel data were transformed them into matched periods for the PSM test. The method is as follows: (1) The matching variables were economic level, financial support, industrial structure, and market size. (2) To match the ideal control group with uniform support conditions for all enterprises, they used nearest-neighbor matching, containing the number of invented green fields. They also eliminated these uncommon conditions to obtain a new sample set. (3) They conducted a balance test on the obtained data and further analyzed the corresponding outcome.

The cross-sectional PSM balance test results are displayed in Fig. 3, where the matched data's standardized mean value variance is less than 10%, strictly meeting the requirements of the balanced test.

Figure 4 displays the spatial distribution of the fictitious sample, where the sample's propensity score values are clustered around 0, and most of the pieces in the control and experimental groups are within the common area.

Table 4 Robustness test results of PSM-DID

Variable	GTI1	GTI2
	(1)	(2)
ESG	0.339***	0.225***
	(0.029)	(0.023)
Size	0.234***	0.083***
	(0.022)	(0.015)
ROA	0.138	− 0.028
	(0.100)	(0.065)
Lev	0.055	0.028
	(0.060)	(0.042)
LnAge	− 0.350*	− 0.215*
	(0.185)	(0.126)
Growth	0.007	0.013**
	(0.009)	(0.006)
Top1	− 0.007	− 0.022
	(0.116)	(0.083)
PFixA	− 0.002	0.018*
	(0.012)	(0.009)
PSales	− 0.025	− 0.027**
	(0.016)	(0.011)
Constant	− 3.397***	− 0.893*
	(0.708)	(0.490)
Observations	29,936	29,936
Industry FE	YES	YES
Year FE	YES	YES
R^2	0.716	0.639

Robust standard errors in parentheses: ***$p<0.01$, **$p<0.05$, *$p<0.1$

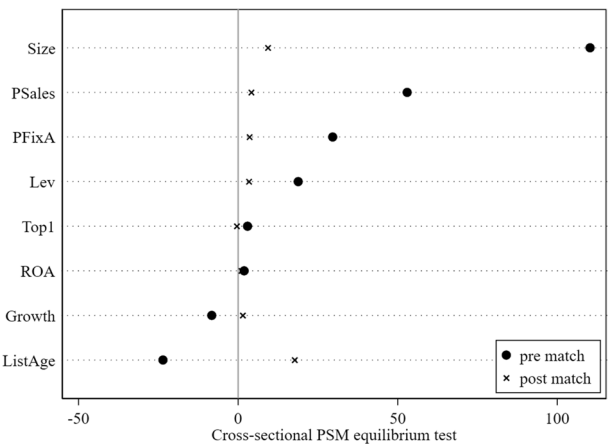


Fig. 3 Cross-sectional PSM equilibrium test results

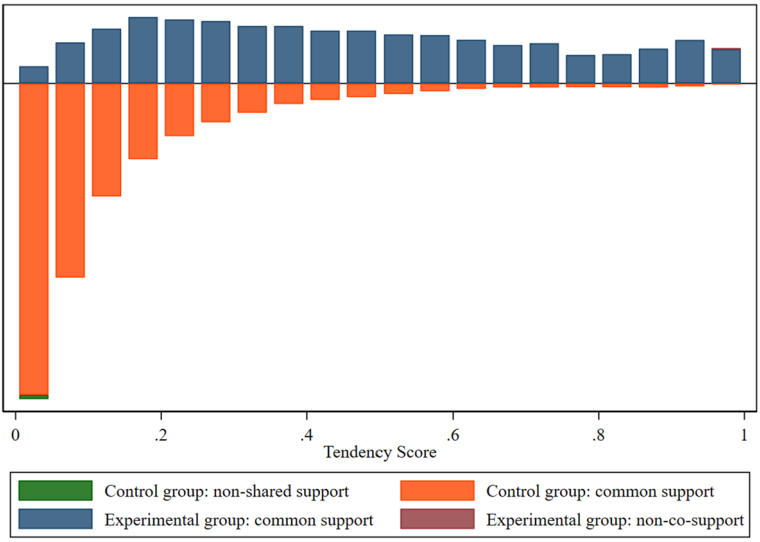


Fig. 4 Propensity score results

Assessing Figs. 3 and 4 together, according to the fact that most of the coefficient values are reduced after matching and the R^2 values of the regression coefficients are significantly reduced, we can see that, to some extent, the possibility of systematic bias in matched samples at different times is low and it satisfies the test of equilibrium.

Figure 5 displays the kernel density distribution before and after comparing longitudinal PSM and year-by-year PSM.

It is not difficult to find that, compared with the pattern of distribution of kernel density before matching, there is a noticeable reduction in the distance between the density of the kernel distribution's mean lines between the curves is significantly closer after matching. To a certain extent, this indicates the processing effect of the cross-section PSM in reducing the sample selection bias.

5.2.4 Substitution variables, models, and (t + 1) period test

The primary explaining the stability of ESG ratings on the promotion of enterprises' GTI, this paper replaces the core explanatory variables. Referring to the methodology (Lin et al., 2021), according to the size of the CSI ESG rating, a larger value indicates a higher ESG. The regression results are shown in Table 5 below. The regression coefficients of CSI ESG for both invention green applications and authorization in columns (1) and (2) are significant, indicating the robustness of the above findings. In addition, to further verify the significance of the time-varying DID model, the text is replaced by the OLS model. The regression results are shown in columns (3) and (4) of Table 5. It can be seen that the time-varying DID is more significant than the OLS model, indicating the superiority of time-varying DID. Furthermore, the effect of enterprises' GTI and ESG ratings is persistent, green applications and authorization take time to materialize. For these reasons, this study uses the t + 1 period to validate GTI1 and GTI2; the outcomes of the regression are displayed in columns (5) and (6). The robustness of the outcomes is further demonstrated

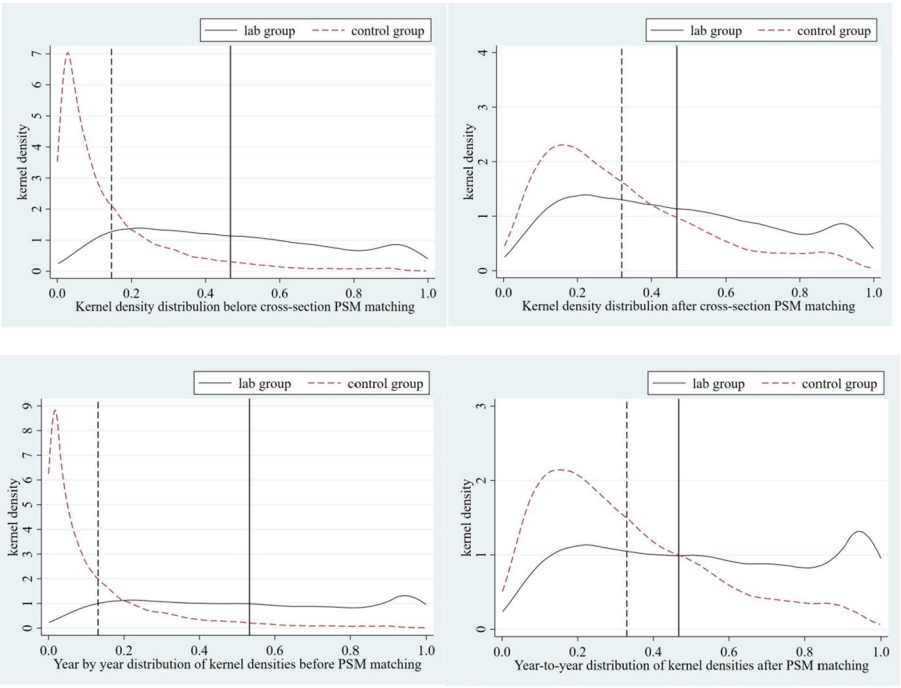


Fig. 5 Kernel density distribution before and after cross-section PSM, and year-by-year PSM matching

by Table 5, where the ESG regression values are favorable and significant at the 1% level, respectively.

5.2.5 Segmental discussion

To investigate the relationship between enterprises' GTI and ESG ratings, and to determine whether the New Crown epidemic influences this relationship, this study excludes the 2020–2022 data to eliminate possible interference from the New Crown epidemic, leaving 24,495 observations. On this basis, the explanatory variables are adjusted accordingly, in which enterprises' green application is adapted to GTI12, and enterprises' green authorization is adjusted to GTI22.

Table 6 columns (1) and (2) present a linear regression equation of ESG ratings on enterprise requests for GTI both before and following the removal of the new crown epidemic data. Correspondingly, Columns (3) and (4) show the regression of green awards to enterprises before as well as after removing the data. By comparing and analyzing these two sets of data, it is evident that the impact of ESG ratings on enterprises' GTI remains significantly positive, even after removing data from the epidemic years. This finding provides strong evidence that the pandemic did not significantly change the impact of commercial green breakthroughs on ESG ratings.

Consequently, the impact of ESG ratings on enterprises' GTI for demonstrates strong stability, further highlighting the significance of ESG ratings for enterprises' GTI. Therefore, when facing a severe test of the global pandemic, enterprises should pay more attention to

Table 5 Robustness test results of variable substitution, and (t + 1) period test

Variables	GTI1	GTI2	GTI1	GTI2	GTI1 ($t+1$)	GTI2 ($t+1$)
	(1)	(2)	(3)	(4)	(5)	(6)
ESG_mark	0.009*	0.038**				
	(0.018)	(0.016)				
time-varying DID			0.236***	0.096***		
			(0.040)	(0.030)		
OLS DID			0.068*	0.060*		
			(0.040)	(0.031)		
ESG					0.275***	0.217***
					(0.033)	(0.025)
Size	0.344***	0.169**	0.238***	0.105***	0.109***	0.093***
	(0.075)	(0.067)	(0.021)	(0.015)	(0.023)	(0.018)
ROA	− 0.048	− 0.012	0.076	− 0.032	0.609***	0.275***
	(0.261)	(0.182)	(0.096)	(0.065)	(0.150)	(0.098)
Lev	− 0.022	− 0.109	0.000	− 0.035	0.051	0.023
	(0.228)	(0.162)	(0.059)	(0.042)	(0.078)	(0.057)
Growth	− 0.030	0.011	− 0.358*	− 0.246*	0.015	0.003
	(0.029)	(0.026)	(0.189)	(0.134)	(0.012)	(0.008)
Top1	0.351	− 0.026	0.008	0.011*	− 0.104	− 0.028
	(0.444)	(0.312)	(0.008)	(0.006)	(0.138)	(0.095)
PFixA	− 0.017	0.001	0.022	0.029	− 0.004	0.010
	(0.048)	(0.031)	(0.112)	(0.084)	(0.014)	(0.009)
PSales	0.023	− 0.015	− 0.007	0.015*	− 0.030	− 0.016
	(0.055)	(0.036)	(0.012)	(0.009)	(0.018)	(0.013)
LnAge	− 0.105	− 0.024	-0.018	-0.020*	− 0.281	− 0.145
	(0.182)	(0.095)	(0.016)	(0.011)	(0.186)	(0.136)
Constant	− 7.118***	− 3.202**	− 3.540***	− 1.354***	− 0.523	− 1.259**
	(1.791)	(1.531)	(0.697)	(0.504)	(0.755)	(0.581)
Observations	4887	4887	33,173	33,173	21,034	21,034
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.845	0.827	0.673	0.592	0.746	0.697

Robust standard errors in parentheses: ***$p<0.01$, **$p<0.05$, *$p<0.1$

improving ESG ratings. It will help encourage enterprises to innovate with green technologies and be an essential way to realize sustainable development.

The above five robustness tests confirm the real impact of ESG ratings on GTI by eliminating the interference of possible factors. We conclude that ESG ratings positively influence enterprises' green applications and authorization, which promotes enterprises' GTI and has a certain degree of robustness. Thus, H1 is verified.

Table 6 Segmental discussion results

Variable	GTI1 (1)	GTI11 (2)	GTI2 (3)	GTI21 (4)
ESG	0.339***	0.225***		
	(0.029)	(0.023)		
			0.336***	0.220***
			(0.031)	(0.024)
Size	0.234***	0.083***	0.211***	0.065***
	(0.022)	(0.015)	(0.022)	(0.014)
ROA	0.138	− 0.028	0.226**	− 0.018
	(0.100)	(0.065)	(0.104)	(0.070)
Lev	0.055	0.028	0.092	0.066
	(0.060)	(0.042)	(0.062)	(0.041)
LnAge	− 0.350*	− 0.215*	− 0.367**	− 0.230**
	(0.185)	(0.126)	(0.170)	(0.115)
Growth	0.007	0.013**	0.007	0.013**
	(0.009)	(0.006)	(0.009)	(0.006)
Top1	− 0.007	− 0.022	− 0.151	− 0.055
	(0.116)	(0.083)	(0.118)	(0.082)
PFixA	− 0.002	0.018*	0.006	0.024***
	(0.012)	(0.009)	(0.012)	(0.009)
PSales	− 0.025	− 0.027**	− 0.034**	− 0.036***
	(0.016)	(0.011)	(0.016)	(0.010)
Constant	− 3.397***	− 0.893*	− 2.805***	− 0.426
	(0.708)	(0.490)	(0.695)	(0.465)
Observations	29,936	29,936	24,495	24,495
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
R^2	0.716	0.639	0.709	0.628

Robust standard errors in parentheses: ***$p<0.01$, **$p<0.05$, *$p<0.1$

6 Mechanism testing

6.1 ESG ratings and financing constraints

The connection between financing and ESG ratings constraints is becoming increasingly important in current financial markets. Investors are increasingly focusing on sustainable investments and are more willing to support enterprises with good ESG ratings. enterprises increase their ESG performance to improve their advantages in the financing market, reduce financing costs, and attract investors and capital, which are essential for long-term sustainability and value growth. Financing constraints are measured using the SA index as well as the price of equity financing (CEF). The results of the financing constraint tests for regression are displayed in Table 7. The overall favorable findings of the ESG ratings regression analysis are shown in column (1), indicating that ESG ratings have a facilitating influence on financing challenges. The effect of enterprise finance limitations on enterprises' green developments is displayed in columns (3) and (4). Their statistically

Table 7 Mechanism test 1: ESG ratings, financing constraints, and enterprises green technology innovation

Variable	SA	CEF	GTI1	GTI2
	(1)	(2)	(3)	(4)
ESG	0.057***	− 0.008***		
	(0.004)	(0.002)		
SA			1.005***	0.891***
			(0.205)	(0.155)
Size	− 0.004	0.005***	0.300***	0.141***
	(0.005)	(0.001)	(0.032)	(0.023)
ROA	0.014	− 0.009	− 0.161	− 0.192*
	(0.020)	(0.011)	(0.171)	(0.115)
Lev	− 0.082***	0.024***	0.134	0.112*
	(0.012)	(0.004)	(0.085)	(0.058)
LnAge	− 0.067	− 0.049**	− 0.479	− 0.553**
	(0.062)	(0.024)	(0.371)	(0.242)
Growth	0.000	− 0.001	− 0.015	− 0.003
	(0.002)	(0.001)	(0.014)	(0.011)
Top1	0.091***	− 0.009	− 0.148	− 0.102
	(0.030)	(0.008)	(0.164)	(0.114)
PFixA	0.004	− 0.001	0.026	0.028**
	(0.002)	(0.001)	(0.016)	(0.011)
PSales	− 0.004	0.000	− 0.050**	− 0.026*
	(0.004)	(0.001)	(0.023)	(0.015)
Constant	− 3.511***	0.144**	− 0.755	1.859**
	(0.196)	(0.071)	(1.354)	(0.909)
Observations	12,855	12,855	12,855	12,855
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
R^2	0.963	0.432	0.701	0.637

Robust standard errors in parentheses: ***$p<0.01$, **$p<0.05$, *$p<0.1$

significant positive regression coefficients suggest that enterprises' green with-envy technological innovation increases with increasing financing constraints; in other words, enterprises with green applications and authorization are positively impacted by financing constraints. Conclusion: H2 was confirmed, and the ESG ratings encourage enterprises' financing constraints that support green breakthroughs in technology.

6.2 ESG ratings and agency issues

Agency issues can cause enterprise managers to act in a shortsighted manner, which is not beneficial to enterprises' GTI. ESG ratings can reveal enterprises' governance structures and protect shareholder rights, thus helping investors understand enterprises' agency issues. Good ESG ratings are essential for investors. The enterprises' agency issues are calculated by dividing the profit from enterprises by management and selling expenses (MS). The findings of the regression are shown in Table 8. Because the ESG ratings regression

Table 8 Mechanism test 2: ESG ratings, agency issues, and company's green technology innovation

Variable	MS	GTI1	GTI2
	(1)	(2)	(3)
ESG	0.004**	0.144***	0.050**
	(0.002)	(0.035)	(0.025)
MS		− 0.205	− 0.499***
		(0.288)	(0.168)
Size	− 0.008***	0.295***	0.134***
	(0.002)	(0.033)	(0.023)
ROA	− 0.099***	− 0.168	− 0.229*
	(0.017)	(0.179)	(0.121)
Lev	− 0.027***	0.046	0.026
	(0.006)	(0.087)	(0.060)
LnAge	0.004	− 0.546	− 0.611**
	(0.023)	(0.368)	(0.244)
Growth	0.001	− 0.015	− 0.002
	(0.001)	(0.014)	(0.011)
Top1	− 0.019**	− 0.060	− 0.029
	(0.009)	(0.168)	(0.116)
PFixA	0.010***	0.032**	0.036***
	(0.001)	(0.016)	(0.011)
PSales	− 0.032***	− 0.060**	− 0.046***
	(0.003)	(0.026)	(0.017)
Constant	0.598***	− 4.160***	− 0.972
	(0.072)	(1.196)	(0.838)
Observations	12,855	12,855	12,855
Industry FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
R^2	0.812	0.698	0.632

Robust standard errors in parentheses: ***$p<0.01$, **$p<0.05$, *$p<0.1$

coefficients are significantly positive, ESG ratings positively impact enterprises' agency issues. Column (2) is not entirely negative, and column (3) is negative, suggesting that green breakthrough technology is hampered by agency issues; the more management short-sightedness that exists, the more barriers and the fewer green breakthroughs in technology there are. Thus, by resolving the agency issues, ESG ratings encourage enterprises to continue developing their green technological advances. thus, H3 is verified.

6.3 ESG ratings and R&D investment

R&D has a mutually beneficial relationship between investments and ESG ratings. Enterprises increase R&D, whereas high ESG ratings may increase their competitiveness and attractiveness, and further support R&D and innovations. This study selected R&D and R&D ratio (RDR) two variables to measure R&D investment Table 9 indicates the regression analysis results about the expenditures on research and development systems. The regression results

Table 9 Mechanism test 3: ESG ratings, R&D investment, and company's green technology innovation

Variable	R&D (1)	RDR (2)	GTI1 (3)	GTI2 (4)
ESG	0.090***	0.400**		
	(0.031)	(0.160)		
R&D			0.000***	0.000***
			(0.000)	(0.000)
Size	0.718***	0.341**	0.281***	0.107***
	(0.031)	(0.156)	(0.034)	(0.023)
ROA	1.115***	− 6.612***	− 0.212	− 0.216*
	(0.210)	(1.222)	(0.183)	(0.120)
Lev	− 0.089	− 3.532***	0.102	0.090
	(0.100)	(0.520)	(0.093)	(0.065)
LnAge	1.114	− 1.821	0.573	0.005
	(1.050)	(9.942)	(0.684)	(0.347)
Growth	− 0.055***	− 0.077	− 0.031*	− 0.015
	(0.019)	(0.120)	(0.017)	(0.012)
Top1	0.075	− 1.081	− 0.009	− 0.010
	(0.271)	(1.121)	(0.176)	(0.135)
PFixA	− 0.060***	0.348**	0.033*	0.034***
	(0.023)	(0.150)	(0.018)	(0.013)
PSales	− 0.019	− 2.399***	− 0.070**	− 0.032*
	(0.043)	(0.320)	(0.027)	(0.018)
Constant	0.507	33.200	− 6.504***	− 2.135**
	(2.697)	(24.462)	(1.792)	(0.970)
Observations	11,436	10,981	11,436	11,436
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
R^2	0.895	0.852	0.715	0.653

Robust standard errors in parentheses: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

for financing allocated to research and development in addition to R&D investment as a percentage of operating revenue from ESG are displayed in columns (1) and (2). The substantial positive coefficients for regression show that ESG ratings encourage enterprises to invest in R&D. Research and development's effects expenditures on enterprises' GTI is highlighted in coefficients of regression show a substantial positive trend, suggesting that research and development spending can promote the creation of novel green obvious technologies and increase the total amount of enterprises with green developments increases with investment in research and development. Therefore, by increasing spending on research and development, ESG ratings support enterprises' GTI, thus, H4 was verified.

7 Heterogeneity analysis

7.1 ESG ratings, market competition, and enterprises' green technology innovation

For a highly competitive enterprise, good ESG helps them stand out in the market and gain support from stakeholders. Therefore, more enterprises invest in ESG ratings to achieve sustainable enterprise growth. Based on this, this study evaluates the level of market competition using the Huffington Index (HHI), where HHI is the principal operating revenue. The size of HHI shows the intensity of competition in the market. Table 10 columns (1) and (2) present the HHI regression analysis and ESG ratings, which are overwhelmingly favorable. The HHI and green applications and authorization have completely negative coefficients for regression. It indicates that the smaller the HHI of enterprises, the greater the market competition, and the more conducive the goal is to increase the beneficial effects of ESG ratings on how innovative enterprises' GTI. Further, since ESG ratings positively promote enterprises' GTI by strengthening market competition, this study found that enterprise competitiveness relates to operating income. Enterprises with good ESG ratings are more likely to increase their operating incomes, and listed enterprises can utilize ESG ratings to strengthen market competition. Thus, research H5 was verified.

Table 10 Regression results of market competition and industry attributes on the company's green technology innovation

Variable	GTI1	GTI2	GTI1	GTI2	GTI1	GTI2
	(1)	(2)	(3)	(4)	(5)	(6)
ESG	0.302***	0.193***	0.234***	0.073***	0.285***	0.104***
	(0.039)	(0.032)	(0.042)	(0.028)	(0.047)	(0.034)
HHI	− 0.292**	− 0.122***				
	(0.086)	(0.060)				
ESG*HTI			0.141**	0.215***		
			(0.058)	(0.047)		
ESG*MFI					0.029	0.127***
					(0.060)	(0.048)
Size						
	0.238***	0.099***	0.234***	0.093***	0.243***	0.101***
	(0.027)	(0.021)	(0.027)	(0.020)	(0.028)	(0.021)
ROA	− 0.052	− 0.152	− 0.062	− 0.164*	− 0.067	− 0.182*
	(0.140)	(0.095)	(0.140)	(0.094)	(0.139)	(0.095)
Lev	− 0.029	− 0.038	− 0.019	− 0.029	− 0.024	− 0.034
Constant	− 3.616***	− 1.253*	− 3.486***	− 1.104*	− 3.806***	− 1.342**
	(0.933)	(0.683)	(0.924)	(0.664)	(0.928)	(0.669)
Observations	19,368	19,368	19,368	19,368	19,368	19,368
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.748	0.678	0.748	0.680	0.748	0.679

Robust standard errors in parentheses: ***$p<0.01$, **$p<0.05$, *$p<0.1$

7.2 Industry attributes, enterprises' green technology innovation, and ESG ratings

According to Morgan Stanley Capital International (MSCI), a multinational supplier of services and instruments for investment decision support, the ESG rantings and climate trends outlook report shows that ESG ratings construction is crucial for attracting investors. As investors value enterprises' sustainability and environmental performance, a heavily polluting enterprise that actively improves their ESG ratings performance can attract more investors. Therefore, if an enterprise is heavily polluting, it is (HTI = 1), otherwise, it is (HTI = 0), and if it is manufacturing, it is (MFI = 1), otherwise it is (MFI = 0). Table 10 removes column (5), which is insignificant but still positive. The cross-multiplier in terms of ESG ratings, the outcomes of the regression of ESG*HPI and ESG*MFI, and industry attributes are displayed in Columns (3), (4), and (6) respectively. These coefficients of correlation are significantly positive, suggesting that is the significance of ESG ratings in encouraging green breakthroughs in the technology of manufacturing enterprises and heavy polluters. Thus, H6 was verified.

7.3 Green technology innovation in corporations, market concerns, and ESG ratings

ESG ratings and market attention can be mutually reinforced. Good ESG ratings attract analysts' attention, whereas analysts' research and recommendations attract more institutional investors, increasing the market value of an enterprise. Based on this, this study sets capital market attention as measured by the amount of analysts' attention (lnANAL) and shares held by instructor holdings (INST). Table 11 displays the results of a regression of market attention and ESG ratings, where the product of green authorizations and applications and analysts' attention, ESG*lnANAL is insignificant and still positive. The creation of GTI and the amount of analyst attention, ESG*lnANAL, are trivial and optimistic. The product of the number of ESG*lnANAL was significantly positive. The quantity of analyst attention, ESG*lnANAL, and the development of green breakthroughs in technology are meaningless and upbeat. The number of ESG*lnANAL produced a substantially positive product. The cross-multiplier ESG*INST and the combination of the ESG rating and the percentage of institutional investor shareholding have regression coefficients that are both substantially positive. This means that more enterprise analysts pay attention to the enterprise. The more attention the capital market pays attention to it, the more favorable the environment is to reinforce the beneficial effect of ESG ratings on enterprises' GTI. In other words, ESG ratings attract enterprise analysts' attention, promote enterprise investment, and are conducive to enterprises' GTI. Thus, H7 is supported. Analysts are more likely to pay attention to good market value, thus introducing capital investment and promoting GTI.

8 Discussion

This study examines the relationship between ESG ratings and GTI by taking Chinese A-listed enterprises from 2007 to 2022 as a sample. Measuring GTI from both the application and authorization aspects ensures the authority and authenticity of the impact of ESG ratings on it, we used time-varying DID models, regression models, and other models to complete the research objectives. The results show that: (1) ESG ratings have a positive

Table 11 Market concerns and company's green technology innovation

variables	GTI1 (1)	GTI2 (2)	GTI1 (3)	GTI2 (4)
ESG	0.240***	0.027		
	(0.067)	(0.052)		
ESG*lnANAL	0.026	0.064***		
	(0.026)	(0.022)		
lnANAL	0.032***	− 0.004		
	(0.011)	(0.008)		
ESG*INST			0.005***	0.004***
			(0.001)	(0.001)
Size	0.221***	0.093***	0.235***	0.100***
	(0.028)	(0.021)	(0.028)	(0.021)
ROA	− 0.159	− 0.173*	− 0.123	− 0.187**
	(0.142)	(0.096)	(0.137)	(0.094)
Lev	− 0.010	− 0.041	− 0.022	− 0.040
	(0.084)	(0.060)	(0.083)	(0.059)
LnAge	− 0.224	− 0.167	− 0.261	− 0.179
	(0.240)	(0.164)	(0.237)	(0.162)
Growth	0.008	0.019**	0.005	0.017**
	(0.011)	(0.008)	(0.011)	(0.008)
Top1	− 0.040	− 0.056	− 0.123	− 0.077
	(0.150)	(0.117)	(0.153)	(0.120)
PFixA	− 0.004	0.014	− 0.009	0.011
	(0.016)	(0.013)	(0.016)	(0.013)
PSales	− 0.034	− 0.025*	− 0.025	− 0.020
	(0.021)	(0.015)	(0.020)	(0.015)
Constant	− 3.246***	− 1.117	− 3.452***	− 1.261*
	(0.946)	(0.689)	(0.931)	(0.683)
Observations	19,198	19,198	19,368	19,368
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
R^2	0.749	0.679	0.749	0.679

Robust standard errors in parentheses: ***$p<0.01$, **$p<0.05$, *$p<0.1$

impact on GTI. Specifically, ESG ratings performance can promote GTI. This is consistent with Stakeholder theory, Agency theory, dynamic capability view, and previous research results (Bai et al., 2024; Khan & Liu, 2023; Li & Pang, 2023). The ESG ratings reflect its sustainable development and normative management (de Souza Barbosa et al., 2023; Tsang et al., 2023), and GTI represents its outstanding performance in environmental protection and sustainable innovation (Aftab et al., 2022), as well as its luster and leading position in the field of sustainable development (Miao et al., 2021). Stakeholder theory emphasizes that enterprises should consider meeting the expectations of stakeholders, promote GTI, and assume social responsibility (Perino et al., 2019). Agency theory requires management to represent the interests of shareholders and ensures that ESG ratings are not short-term surface (Hitt et al., 2021). The dynamic capability view emphasizes that enterprises need

to have the ability to adapt learn and innovate flexibly to maintain a competitive advantage in GTI (Kevill et al., 2020). (2) The study found that ESG ratings affect enterprises' GTI through the intermediary effect (Ha et al., 2023; Lee, 2023), which highlights the importance of financing constraints, agency issues, and R&D investment in the pursuit of ESG ratings. The mediating effect plays a crucial role in the correlation between ESG rating and GTI (Wang & Sarkis, 2017). (3) The study points out that the contribution of ESG ratings to GTI is influenced by external factors, including HHI, heavy pollution or manufacturing, and analyst attention. High HHI may indicate market monopolization, and attention needs to be paid to reduce competition (Dave et al., 2017; Javeed et al., 2020). In heavy pollution or manufacturing industries, enterprises may face greater ESG ratings challenges and need to be more environmentally conscious (Rossi et al., 2024). Clean energy or green tech sectors, on the other hand, are more likely to have good ESG ratings (Asl et al., 2022). As analysts are predictable in making decisions with discretionary budgetary implications (Chakravarty & Grewal, 2016), increased analyst attention could incentivize enterprises to excel in GTI to meet investor expectations. These results are consistent with the above theory and confirm that ESG ratings are expected to lead to more GTI.

9 Conclusions and policy recommendations

As the idea of ESG investing has gained traction, more and more enterprises realize that ESG ratings are moral responsibility and a key factor for enterprises' success. This stimulates enterprises' efforts in sustainability and GTI and is also a crucial means for enterprises to fulfill the objectives of carbon neutrality and carbon peak through GTI. Therefore, it is vital to conduct investigations into the relationship between enterprises' GTI and ESG ratings. First, a panel data analysis of the GTI of the Chinese enterprise with A-share listings between 2007 and 2022, combined with time-varying DID, was conducted to establish a unique analytical framework for studying this issue from multiple perspectives. Second, the study examined how ESG ratings affect enterprises' GTI. Analyzing agency issues, R&D investment, and enterprise financing constraints shows how different innovation activity levels are affected by ESG ratings, such as finance, management, and development. Finally, this study explores the factors related to enhancing ESG ratings for GTI, such as market competition, industry attributes, and market attention.

The empirical analysis yields the following main conclusions. (1) From the standpoint of enterprises' GTI for application and authorization, ESG ratings facilitate enterprises' GTI. Following several robustness tests, this conclusion is still valid. (2) According to the procedure for the test, ESG ratings can influence enterprises' GTI through enterprises' financing constraints, agency issues, and R&D investments. (3) The results of the variability examination indicate that the enterprise' GTI is more significantly impacted by ESG ratings in highly competitive marketplaces and heavily polluting industries. Concern and market competition highlight the advantages of ESG ratings for enterprises' creativity in GTI.

According to this study, ESG ratings help to promote the effect of ESG ratings on green-related breakthroughs in technology, through their significant impact on green applications and authorization. This result is in line with previous studies, which further suggest that improving the degree of innovation in GTI (Long et al., 2023), as well as the demands of the market and society can be better understood by strengthening the efforts of enterprises' applications and authorization to satisfy ESG ratings needs. The mechanism

analysis shows that ESG ratings provide corresponding funds for enterprises to obtain GTI and accelerate it by facilitating the alleviation of enterprises' financing constraints, which is consistent with the views of Nie et al. (2022) and Zhai et al. (2022). Based on this, the study's findings demonstrate that ESG ratings encourage enterprises' GTI by lowering the cost of equity financing. In addition, ESG ratings can raise the bar for GTI by supporting enterprises' invention of green applications and authorization. Furthermore, enterprises' agency issues are resolved by ESG ratings, which support enterprises' GTI. These findings show that ESG ratings assist investors and stakeholders, correct management myopia, and motivate enterprises to concentrate on GTI.

Enterprises' R&D investment is increased by ESG ratings, which in turn encourages enterprise green breakthroughs in technology, thereby providing greater possibilities for further development. The present study discovers, from the point of view of the diversity analysis, that the greater the market competition, the more favorable the ESG ratings are in promote enterprises' GTI. Enterprises are subjected to multiple pressures from market competition, such as competition for intellectual property rights. ESG ratings help them succeed in this fiercely competitive environment and bring new solutions to the market through GTI. Additionally, ESG ratings significantly promote GTI in heavy enterprises of polluters and manufacturing. ESG ratings create favorable conditions for GTI by improving the governance standards of the enterprises.

This study broadens our understanding of the connection between enterprises' GTI and ESG ratings promoting GTI has become a common goal for the enterprise and is crucial for global environmental sustainability. This study argues that from a governmental perspective, by offering suitable incentives, more enterprises ought to be urged to actively engage in GTI, tax reduction policies, or other incentives. At the same time, strengthening environmental regulatory mechanisms to ensure that enterprises' behavior in green innovation is sustainable and green will help. From an enterprise perspective, enterprises should emphasize ESG ratings and improve their performance in terms of ethical and moral enterprise governance, and protecting the environment to promote innovation and development of GTI. An enterprise should also increase its R&D investments, especially in GTI, to improve its core competitiveness.

This study has limitations but opens possibilities about opportunities for more research. This study's scope is restricted to Chinese A-share-listed enterprises it does not conduct a benchmark examination of enterprises in other nations. Therefore, further analysis can be optimized by (1) expanding the research parameters to international scope and investigating enterprises in different international locations for a more comprehensive comparative study, and (2) looking into the potential impact of ESG ratings on additional facets of enterprises' GTI, such as managerial competence and enterprise ethics, which are critical areas for continuous enterprise improvement.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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