The impact of ESG performance on green technological innovation in textile enterprises under the dual-carbon strategy

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ABSTRACT – REZUMAT

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Under the evolving paradigm shaped by China's "dual-carbon" goals, green technological innovation has emerged as a central driver for achieving sustainable development, particularly in the textile industry, a sector characterised by high resource consumption and significant environmental impact. Environmental, Social, and Governance (ESG) performance, widely recognised as a critical metric for assessing corporate sustainability, has received increasing attention for its influence on green innovation. This study investigated the relationship between ESG performance and green technological innovation using panel data from textile companies listed on the A-share markets in Shanghai and Shenzhen between 2015 and 2023. As a labour-intensive industry with intensive energy use and pollutant emissions, the textile sector faces unique pressures to transition toward low-carbon operations, making green technological innovation (e.g., clean production, circular economy technologies) pivotal for its sustainable development. Employing a fixed-effects model, the study revealed that strong ESG performance significantly promoted green innovation within textile firms, with the effect displaying notable heterogeneity across ownership types. Further analysis indicated that ESG performance facilitated green innovation by attracting heightened attention from analysts, thereby alleviating information asymmetry and enhancing external oversight. These findings contribute to the literature on ESG and corporate green innovation, offering theoretical and practical guidance for textile firms seeking to enhance green technological capabilities through improved ESG strategies in the context of China's dual-carbon policy agenda.

Keywords: *dual-carbon targets, ESG performance, green technological innovation, textile enterprises*

Impactul performanței ESG asupra inovării tehnologice ecologice în întreprinderile textile în cadrul strategiei duale privind carbonul

În contextul paradigmei în continuă evoluție, modelată de obiectivele „duale" ale Chinei în materie de emisii de carbon, inovarea tehnologică ecologică a devenit un motor central pentru realizarea dezvoltării durabile, în special în industria textilă, un sector caracterizat prin consumul ridicat de resurse și impactul semnificativ asupra mediului. Performanța în materie de mediu, socială și de guvernanță (ESG), recunoscută pe scară largă ca un indicator esențial pentru evaluarea durabilității corporative, a beneficiat de o atenție sporită datorită influenței sale asupra inovării ecologice. Acest studiu a investigat relația dintre performanța ESG și inovarea tehnologică ecologică utilizând date panel de la companii textile listate pe piețele de acțiuni A din Shanghai și Shenzhen între 2015 și 2023. Fiind o industrie cu utilizare intensivă a forței de muncă, cu un consum intensiv de energie și emisii poluante, sectorul textil se confruntă cu presiuni unice pentru a trece la operațiuni cu emisii reduse de carbon, ceea ce face ca inovarea tehnologică ecologică (de exemplu, producția curată, tehnologiile economiei circulare) să fie esențială pentru dezvoltarea sa durabilă. Utilizând un model cu efecte fixe, studiul a relevat că performanța ESG ridicată a promovat în mod semnificativ inovarea ecologică în cadrul firmelor textile, efectul prezentând o eterogenitate notabilă între tipurile de proprietate. Analize suplimentare au indicat că performanța ESG a facilitat inovarea ecologică prin atragerea unei atenții sporite din partea analiștilor, atenuând astfel asimetria informațională și îmbunătățind supravegherea externă. Aceste concluzii contribuie la literatura de specialitate privind ESG și inovarea ecologică corporativă, oferind îndrumări teoretice și practice pentru firmele textile care doresc să își îmbunătățească capacitățile tehnologice ecologice prin strategii ESG îmbunătățite în contextul agendei politice duale a Chinei privind emisiile de carbon.

Cuvinte-cheie: *obiective duble privind emisiile de carbon, performanța ESG, inovarea tehnologică ecologică, întreprinderi textile*

INTRODUCTION

Research background

Amidst the increasingly severe challenge of global climate change, contemporary society has faced unprecedented environmental crises [1]. Rising global temperatures, frequent extreme weather events, and ongoing sea-level rise have collectively constrained the prospects for sustainable socio-economic development [2]. In reply to these worldwide challenges, China clearly pledged to reach the peak of carbon emissions by 2030 and attain carbon neutrality by 2060. These ambitious targets aimed to reduce greenhouse gas emissions significantly, thereby promoting global climate stability and sustainable growth.

Driven by the dual-carbon goals, government reports have called for the manufacturing sector to pursue high-end, intelligent, and green development pathways [3]. As primary actors in economic activity, enterprises have increasingly borne responsibility not only for their own performance but also for their broader environmental impacts [4]. Consequently, corporate ESG performance has garnered extensive societal attention. ESG functions as a holistic indicator of a company's sustainability in three aspects: environmental conservation, social responsibility, and corporate management [5]. Excellent ESG performance enhances a firm's reputation and brand value while attracting investors and consumers, thereby generating greater commercial value and competitive advantage [6].

Nevertheless, within the context of the dual-carbon transition, reliance on traditional business models and conventional technological innovation has become insufficient to meet sustainability demands [7]. Green technological innovation has thus become a strategic imperative for firms to upgrade and transition towards sustainable operations [8].

Encompassing clean production technologies, energy-efficient systems, and circular economy solutions, green innovation aims to reduce both energy consumption and pollutant emissions, achieving environmental and economic gains simultaneously [9]. Despite its potential, green innovation faces significant barriers such as technological limitations, high capital requirements, and policy dependency. These challenges necessitate stronger ESG performance to help enterprises secure essential resources and external support [10].

Therefore, this study intended to investigate the impact of ESG performance on green technological innovation in the textile industry under China's dual-carbon framework. By analysing the distinct effects of different ESG dimensions, the study sought to uncover underlying mechanisms and heterogeneity in innovation outcomes. The findings intend to provide targeted strategic insights for enterprises and contribute to the development of ESG-driven innovation theory within the context of sustainable industrial transformation.

Research goals and significance

This research intends to thoroughly investigate the influence mechanisms of corporate ESG performance on green technological innovation under the backdrop of China's dual-carbon strategy.

Specifically, by constructing a scientific ESG performance evaluation index system, this research sought to measure corporate practices in the fields of environmental, social, and governance aspects. By employing empirical research approaches, the research investigated the intrinsic connections between ESG performance and both input and output of green technological innovation, identifying key factors and moderating variables that influence this relationship. The discoveries provide theoretical bases and practical directions for enterprises to formulate ESG-based green technological innovation strategies.

From a theoretical viewpoint, this research enriches and extends academic research in the fields of corporate social responsibility (CSR), sustainable development, and management of innovation. In the field of CSR, conventional research has mainly concentrated on the influence of individual CSR aspects on corporate performance. In contrast, this study incorporates multidimensional ESG factors into the analytical framework, providing a comprehensive examination of their effect on green technological innovation, thereby deepening theoretical understanding of the synergetic development of CSR practices and corporate innovation strategies. Within the field of sustainable development, the study reveals how companies, while pursuing economic objectives, can drive green technological innovation through ESG responsibilities, providing a micro-level theoretical support for achieving sustainable development goals and further refining the scope and connotation of sustainable development theory. In innovation management, this research breaks the limitations of previous studies, which predominantly focused on traditional factors such as technology and market conditions. By introducing ESG as a fresh perspective, the research broadens the scope of innovation management theory, facilitating the advancement of a more thorough and organised framework for corporate innovation management.

From a practical perspective, this research provides crucial decision-making insights for enterprises, investors, and government agencies. For companies, it assists managers in identifying the beneficial influence of ESG performance on green technological innovation, encouraging the integration of ESG principles into corporate strategic planning and daily operations. This approach facilitates increased investment in green technological innovation, enhancing the firm's sustainable development capacity and core competitiveness. By improving ESG performance, companies can appeal to consumers who are environmentally aware and socially accountable, thus expanding market share and establishing a favourable brand image. For investors, the study provides new evaluation standards and reference points for investment decisions. Investors can focus on companies with strong ESG performance to select investments with better growth prospects and sustainability, thus reducing investment risks and achieving long-term stable returns. For government agencies, this research provides empirical evidence that can inform the development of policies, helping authorities refine relevant laws and regulations. It also supports the enhancement of ESG practices and green technological innovation, promoting industrial structural upgrades and fostering green, sustainable economic development. For instance, the government may utilise fiscal incentives like tax cuts and subsidies to urge companies to enhance ESG performance and boost investment in green technological innovation. thereby creating a favourable policy and market environment for green innovation.

Research contributions

Theoretical significance

This research specifically focuses on the textile industry, a traditional manufacturing sector characterised by a long industrial chain, high pollution, high energy consumption, and unique ESG challenges (such as printing and dyeing wastewater and labour rights in the supply chain). By analysing the correlation between textile enterprises' ESG practices and green technological innovation (e.g., cleaner production and recycled fibre technologies), it reveals the driving mechanism of ESG performance on green innovation in this industry systematically for the first time. This study innovatively verifies the mediating role of "analyst attention": ESG performance indirectly promotes corporate green technological innovation by attracting analyst coverage (reducing information asymmetry and strengthening external supervision). The discovery of this mechanism enriches the "signal transmission" and "external governance" theories in the realm of ESG and innovation; it offers a fresh viewpoint for comprehending the indirect driving route of ESG on innovation.

Practical significance

Based on the outcomes of heterogeneity analysis, distinct ESG optimisation paths are put forward for state-owned enterprises (possessing policy and resource advantages), non-state-owned enterprises (primarily market-driven), and enterprises of different sizes (large enterprises with stronger resource conversion capabilities). Meanwhile, combined with the technical characteristics of textile sub-sectors (cotton textiles, chemical fibres, garment manufacturing), specific directions for the cooperation between ESG and green innovation are provided (e.g., chemical fibre enterprises should strengthen the layout of patents for recycling technologies). It offers the government a combined proposal of "ESG disclosure standards + industry incentive policies" (such as enhancing the transparency of ESG information in textile enterprises) and provides investors with a three-dimensional evaluation framework of "ESG scores + analyst coverage + green patents", helping to accurately identify enterprises with green transformation potential and promoting the textile industry toward low-carbon and sustainable development.

LITERATURE REVIEW

ESG performance research

Shaikh argued that ESG represents an investment ideology and corporate assessment criterion centred on a company's environmental, social, and governance performance instead of its financial performance [11]. It stresses the organic combination of economic and social benefits and acts as a vital mechanism for attaining high-quality economic growth and sustainable corporate progress. In current literature, academic studies on ESG performance have mainly focused on corporate value, financial performance, financing costs, and risk management. ESG performance can not only reduce information asymmetry inside and outside a company but also boost its long-term value [12, 13]. Zhou et al. discovered that ESG performance significantly enhanced both the book value and market value of enterprises [14]. Clementino and Perkins discovered that firms with superior ESG performance are able to convey more favourable signals to external stakeholders, improving corporate value and reducing financial and compliance risks [15]. Yu et al., analysing data from the A-share manufacturing sector, discovered a notable positive correlation between ESG disclosure and corporate value, with ESG disclosure only promoting corporate value after policy implementation [16]. Aydoğmuş et al. noted that strong ESG performance could significantly improve corporate value [17]. Zhang and You argued that the value-increasing effect of ESG performance was more prominent for non-state-owned enterprises in institutional settings with greater information transmission efficiency [18].

ESG disclosure enhances corporate transparency and reduces information asymmetry, while also shaping a firm's social obligation image and strengthening relationships with stakeholders, thereby increasing its credibility [19]. Therefore, A company's performance is significantly and positively influenced by its ESG performance [20]. Nirino et al. determined that companies boasting higher ESG ratings hold a competitive edge, having a positive effect on financial performance [21]. Crifo et al. put forward that ESG performance, related to corporate social responsibility and sustainable development, has emerged as a crucial driver of corporate performance [22]. It exerts a positive impact on economic performance and long-term competitiveness via brand image improvement, operational optimisation, risk mitigation, and capital attraction.

Positive ESG performance helps companies reduce their debt financing costs [23]. From the perspectives of market risk and financing costs, existing research has confirmed that ESG performance reduces both total and systematic risks [24] and that improved ESG performance can lower financing costs, thereby enhancing corporate value [25]. Furthermore, Studies have investigated the influence of ESG performance on market risks after an initial public offering (IPO). Research shows that ESG performance and disclosure assist companies in building reputational capital with investors post-listing, thus enhancing the firm's ability to withstand risk [26].

Relevant research on green technological innovation

Green innovation centres around and primarily consists of green technological innovation. Green technology denotes technologies, processes, or products that cut down environmental pollution and the consumption of raw materials and energy [27]. Lv et al. contended that the outcomes of green technological innovation can effectively relieve the financial constraints of enterprises [28]. Yuan and Zhang indicated that the enforcement of environmental regulations in China had a notable inhibitory impact on green technological innovation, whereas digital transformation could positively moderate the influence of environmental regulations on green technological innovation by lowering production costs [29]. Hao et al. stated that the digital economy could boost green technological innovation in advanced manufacturing sectors, with resource optimisation and industrial upgrading acting as vital intermediary channels [30]. Digital finance can spur green technological innovation by alleviating financing constraints, driving industrial improvements, and stimulating market demand [31]. Moreover, digital transformation can not only enhance the quantity of a firm's green technological innovation but also substantially improve the quality of these innovations.

Research on corporate ESG performance and its impact on green technological innovation

Long et al. discovered that corporate ESG performance was able to boost green technological innovation activities. Moreover, their research showed that company size and revenue growth rate had notable positive impacts on green technological innovation [32]. Xu et al. pointed out that corporate ESG performance could improve a firm's green technological innovation ability, and this effect was more evident in state-owned enterprises, companies situated in the eastern regions, and high-tech industries. Mechanism analysis proposed that reducing financing restrictions and increasing research and development expenditure were the two main ways through which ESG performance could encourage green technological innovation [33]. Yang et al. contended that corporate ESG performance mainly enhanced green technological innovation via intermediary means such as cutting debt financing costs, lessening information asymmetry, and enhancing the quality of information disclosure [34]. Qian and Liu determined that ESG ratings could significantly stimulate green technological innovation, and the effect was more prominent in state-owned enterprises and high-pollution industries [35]. Mechanism analysis demonstrated that ESG ratings could enhance green technological innovation by easing financing constraints and increasing analyst focus. Fan et al. maintained that ESG performance and green technological innovation were positively related, with better ESG performance resulting in more widespread green technological innovation activities [36]. Tan et al. hypothesised that corporate ESG performance spurred green technological innovation, having a significant positive influence on green technological innovation [37]. Even after taking endogeneity problems into account, the research findings remained reliable. Tan and Zhu argued that ESG performance mainly promoted green technological innovation by intensifying environmental investments, alleviating financing constraints, and improving the internal control quality of firms. ESG performance was found to promote green technological innovation, and digital transformation could positively moderate the impact of ESG performance on green technological innovation [38]. Human capital structure played a mediating part in the relationship between ESG performance and green technological innovation. Sun et al., in their study of the listed company Sun Paper, found that outstanding performance in environmental, social, and governance (ESG) aspects not only promoted green technological innovation and enhanced competitiveness but also contributed to the company's long-term viability [39].

Although scholars have made significant progress in understanding the relationship between ESG and green technological innovation, some gaps remain in the existing literature. First, current research mainly focuses on the direct effects of ESG performance on green technological innovation, yet there is a lack of in-depth analysis of the underlying mechanisms. For example, how ESG performance promotes the development of green technological innovation through influencing factors such as financing constraints and innovation efficiency still requires further exploration. Second, existing studies face certain limitations in sample selection and data acquisition. For instance, some studies have conducted empirical analyses on enterprises in specific industries or regions, limiting the generalisability of the findings. Additionally, challenges in data collection have affected the accuracy and reliability of the results. Future research could further expand the study of the relationship between ESG and green technological innovation.

For instance, it can investigate the mechanisms through which ESG performance affects green technological innovation and examine the disparities in the effect of different dimensions of ESG performance on innovation. Moreover, cross-industry and cross-regional research could be reinforced to improve the generalizability and precision of the results. Additionally, future studies could integrate emerging topics like digital transformation and sustainable development to explore novel trends and routes in the relationship between ESG and green technological innovation.

The three dimensions of ESG have differential impacts on green technological innovation

In the context of the "dual-carbon" strategy, the effects of the three aspects of ESG – Environmental, Social, and Governance on enterprises' green technological innovation are not homogeneous. Instead, they exert influence through differentiated mechanisms and pathways.

Environmental dimension (E): The core driver directly propelling green technological innovation

The environmental dimension focuses on enterprises' impacts on the ecological environment, including pollutant emission control, energy efficiency improvement, and green investment. It is the dimension most directly linked to green technological innovation.

Improvements in environmental performance (such as emission reduction targets and cleaner production requirements) directly stimulate demand for green technologies. For instance, to reduce carbon emissions or meet environmental regulations, enterprises will proactively invest in R&D of cleaner production technologies and circular economy technologies (e.g., wastewater recycling technologies in the textile industry). This highly aligns with the core goals of green technological innovation, which aim to cut down energy usage and pollutant discharges [9].

Enterprises with excellent environmental performance tend to place greater emphasis on green investments, such as establishing environmental R&D funds and introducing environmental protection equipment. These resource inputs are directly transformed into outputs of green technological innovation [38]. Studies have shown that increased environmental investment is a crucial route by which ESG fosters green innovation, especially in high-pollution sectors (such as the textile industry), where enhancements in the environmental aspect have a more substantial influence on green patent outputs [35].

Strong performance in the environmental dimension is more aligned with dual-carbon Policies and environmental rules, enabling enterprises to have a higher chance of getting policy support like government subsidies and tax incentives, which further reduces the costs of green technological innovation [10]. For example, enterprises with high environmental ratings are more likely to be included in green credit support lists, providing financial guarantees for their green technology R&D.

Social dimension (S): Indirectly enabling green innovation through reputation and resource integration

The social dimension focuses on enterprises' responsibilities to stakeholders (employees, communities, consumers, etc.), including the fulfilment of social responsibilities, protection of employees' rights and interests, and fairness in the supply chain. Its impact on green is indirect.

Enterprises with excellent social performance (e.g., ensuring employee welfare and participating in public welfare projects) can enhance their brand reputation and social recognition, attracting consumers and investors with environmental awareness [6]. This "social identity" will drive enterprises to strengthen their "responsible" image through green technological innovation, forming a positive cycle of "social reputation → increased market share → increased investment in green innovation". For example, if a textile enterprise performs well in the social dimension (e.g., ensuring labour rights in the supply chain), it is more likely to gain consumers' recognition for its green products (e.g., eco-friendly fabrics), thereby motivating it to continuously develop green textile technologies.

Good performance in the social dimension helps enterprises build stable stakeholder networks. For instance, positive interactions with communities and non-governmental organisations can provide access to more environmental technology information; investment in employee training (a key indicator of the social dimension) can enhance the green technological innovation capabilities of internal R&D teams [39].

Stability in the social dimension (e.g., high employee satisfaction and smooth supply chain collaboration) can reduce operational risks for enterprises, providing a stable internal environment for long-term green technological innovation. For example, reducing labour disputes or supply chain disruptions can ensure the continuity of green R&D projects.

Governance dimension (G): Ensuring the efficiency and sustainability of green innovation through institutional optimisation

The governance dimension focuses on enterprises' internal management mechanisms, including board structure, quality of information disclosure, and internal controls. Its core role is to reduce agency problems and improve resource allocation efficiency through institutional optimisation, providing institutional guarantees for green technological innovation.

Improvements in the governance dimension (e.g., high board independence and strong decision-making transparency) can reduce "short-sighted behaviour", ensuring that enterprises prioritise resource allocation to green technological innovation projects with higher long-term value rather than short-term profit projects [33]. For example, independent boards are more likely to support high-investment, long-cycle green R&D, preventing management from cutting innovation investments due to short-term performance pressures.

High-quality performance in the governance dimension (e.g., Standardized information disclosure and strict internal controls can decrease information asymmetry between enterprises and investors, facilitating the acquisition of financial support like green credit and equity financing. thereby solving the funding bottleneck for green technological innovation [34].

Supervision mechanisms in the governance dimension (e.g., audit committees and ESG performance assessments) can ensure that green innovation resources are not misused, improving innovation efficiency. For example, incorporating green technological innovation indicators into management evaluation systems can strengthen their motivation to promote innovation [22].

In summary, the environmental dimension is the "direct engine" of green technological innovation, the social dimension is the "indirect enabler", and the governance dimension is the "institutional guarantor". Enterprises need to differentially improve their performance in each ESG dimension based on their industry characteristics (e.g., asset-intensive industries need to strengthen the environmental dimension, while technology-intensive industries need to optimise the governance dimension) and development stages, so as to more accurately promote green technological innovation.

THEORETICAL ANALYSIS AND RESEARCH HYPOTHESES

ESG performance and green technological innovation

In the context of China's pledge to reach the "carbon peak" and "carbon neutrality" goals, enterprises ought to implement development strategies focused on green innovation to meet environmental regulations and advance the actual process of green transformation. First, the theory of sustainable development highlights the equilibrium among economic growth, environmental protection, and social welfare. This theory contends that firms should not merely pursue economic gains but also take environmental protection and social responsibility into account to attain long-term sustainable development. Under the ESG framework, by boosting environmental performance, increasing social responsibility, and fortifying corporate governance, companies can elevate their reputation and competitiveness in the market, thereby drawing more investors and consumers. Robust ESG performance reflects a firm's dedication to sustainable development, which not only aids in reducing environmental burdens but also strengthens the company's long-term competitiveness. Excellent ESG performance can spur investments in sustainable development, thus promoting green innovation.

Additionally, signalling theory indicates that companies communicate their real value and development prospects to the market via various signals like financial reports, dividend policies, and corporate social responsibility initiatives. Under the ESG framework, strong ESG performance acts as a crucial signal, transmitting to the market the company's determination to fulfil social responsibilities, prioritise environmental protection, and improve governance. Good ESG performance (such as better environmental performance, greater social responsibility, and stronger corporate governance) can signal to the market that the company is committed to sustainable development. These signals can improve the company's reputation and competitiveness, attracting more investors and consumers, thus offering funding and market incentives for green innovation.

Based on the above analysis, the following hypothesis is put forward:

H1: Strong ESG performance can facilitate corporate green innovation.

The mediating effect of analyst attention

As crucial information intermediaries in the capital market, analysts offer professional guidance to investors by thoroughly examining specific company information. Based on the information asymmetry theory, excellent ESG performance conveys extra information to the market, suggesting that the company has substantial growth potential and investment worth, thus drawing more attention from analysts. Moreover, because of the preference for companies with high ESG ratings in China, enterprises with remarkable ESG performance are more prone to attract analysts' notice. Hence, robust ESG performance transmits incremental information that lures more focus from analysts. Relying on the hypothesis of information asymmetry, analysts' professional analysis of ESG incremental information can effectively lessen the information asymmetry between investors and the company. Via analysts' reports, investors can obtain a more comprehensive knowledge of the company's green innovation endeavours, preventing undervaluation of the value of green innovation, thereby motivating managers to engage in more innovative activities.

According to the market pressure hypothesis, continuous analyst attention exerts pressure on companies and supervises the entire process of corporate green innovation. On the one hand, analysts, through field research and face-to-face communication, can identify potential issues within companies and directly supervise company managers, reducing speculative behaviour. On the other hand, sustained analyst attention may trigger a "supervision spillover effect", attracting the attention of other external supervisors, which means the company's green innovation activities will be subject to broader external oversight. This improves the efficiency of green innovation financing and speeds up the green innovation process.

In summary, strong ESG performance helps to attract analyst attention, and analysts' focus, through information interpretation and external supervision, enhances management's innovation motivation and the efficient use of green innovation funds, ultimately driving the achievement of green innovation.

Based on this, the following hypothesis is put forward:

H2: ESG performance improves corporate green innovation levels by drawing analyst attention.

RESEARCH DESIGN

Sample selection and data sources

Sample Selection: After screening, the total number of valid observations of textile enterprises from 2015 to 2023, the number of those listed on the Shanghai and Shenzhen A-shares is 668. According to the "Guidelines for the Classification of Listed Companies' Industries" of the China Securities Regulatory Commission and textile industry practices, the sample enterprises are divided into the following segments:

- Cotton textile and printing & dyeing industry: accounting for 38%, mainly covering enterprises engaged in spinning, weaving, printing and dyeing of natural fibres such as cotton and linen, including cotton yarn production and grey fabric manufacturing.
- Chemical fibre manufacturing industry: accounting for 27%, including enterprises producing chemical fibre raw materials such as polyester, nylon and viscose, as well as filaments and staple fibres.
- Garment and apparel manufacturing industry: accounting for 25%, covering enterprises producing terminal products such as clothing, shoes, hats

and home textiles, focusing on clean production processes (such as waterless dyeing) and low-carbon supply chain management.
- Other textile segments: accounting for 10%, including textile machinery manufacturing and industrial textiles (such as medical and filtering materials). These segments have relatively high technological intensity, and green innovation focuses on material improvement and energy efficiency enhancement.

Financial industry companies were excluded from the sample. Companies at risk of delisting or under special treatment due to significant risks were removed. Companies with missing data for specific years were excluded. The bottom and top 1% of all continuous variables were truncated.

ESG rating data were obtained from the Wind database; data regarding green patent applications and the overall number of patent applications were sourced from the green patent database and the listed company patent database on the China Research Data Service Platform (CNRDS). Other company characteristic data, such as company scale, profitability, debt-to-equity ratio, board size, proportion of independent directors, and company age, were obtained from the Guotai'an (CSMAR) database.

Variable selection

Independent variable: Corporate ESG performance

Following Jiao et al., ESG rating data were used. The Huazheng ESG evaluation system was employed, where scores from 1 to 9 were assigned based on the performance level. Higher scores signify better ESG performance [40].

In the robustness checks, Bloomberg's ESG performance scores were employed as alternative independent variables to guarantee the robustness of the study's outcomes. The reason for choosing the Huazheng Index is as follows:
- The Huazheng Index updates its data quarterly since 2019 and discloses ratings retrospectively, providing continuous and authoritative ESG ratings for the majority of China's listed companies.
- The continuous release of ESG ratings by the Huazheng Index increases investor trust and loyalty towards the rating information.
- Other mainstream ESG rating agencies in China, such as Shandao Ronglv and Shetou Meng, generally align with the Huazheng Index in terms of overall rating trends. Thus, this study uses the Huazheng Index ESG ratings as the source of data for the event study method.

Dependent variable: Green Technological Innovation (GTI)

In measuring corporate green technological innovation, both input and output methods are commonly used. However, given that it is challenging to distinguish the proportion of resources allocated to green technological innovation from the input perspective, this study adopts an output-based approach, employing the quantity of green patents filed by listed firms in a specific year as an indicator of their green technological innovation achievement. As per Li et al., the quantity of green patent applications was logarithm-transformed, adding 1 to prevent zero values in the computation [41].

Control variables

Given that other economic characteristics at the firm level may also impact green technological innovation, this study selects several relevant factors as control variables [42–44]. The size of the firm (Size) is gauged by the natural logarithm of total assets. Profitability (ROA) is shown by the return on assets, which mirrors the firm's capacity to earn profits from its total assets. Firms with greater profitability might have more resources to put into green technological innovation. The debt-to-equity ratio (Lev) shows the firm's ability to fulfil its debt obligations and its financial risk, which impacts its financing ability and operational stability, thus influencing green technological innovation. The size of the board (Board) is measured by the total number of directors on the board. The proportion of independent directors (Index) is computed by dividing the number of independent directors by the total number of board members. The age of the firm (Age) is measured by the natural logarithm of the company's years of operation, with 1 added to prevent taking the logarithm of zero. Industry dummy variables (Industry) are set in line with the China Securities Regulatory Commission's industry classification standards to control the heterogeneous impact of different industries on corporate results [45–47]. Year dummy variables (Year) are set to control for factors such as macroeconomic conditions and policy changes that vary over time and may influence the company's performance [48–50].

Mediating variable

Analyst attention (ANA) is chosen as the mediating variable. It is gauged by the natural logarithm of the quantity of analysts following the company (table 1).

Modelling

To examine the influence of corporate ESG performance on green technology innovation and the role of financing constraints between them, this paper successively constructs the following regression models [51–53]. For hypothesis 1, the following regression equation is built for testing:

$$Envrpat_{i,t} = \beta_0 + \beta_1 ESG_{i,t} + \beta_2 \Sigma Controls_{i,t} + \Sigma Year + \Sigma Industry + \varepsilon_{i,t} \quad (1)$$

where i and t denote the enterprise and the year, respectively, and $Envrpat_{i,t}$ stands for the logarithm of the quantity of green patents applied for by listed companies during period t, after adding 1. $ESG_{i,t}$ indicates the quantity of green patents applied for by listed companies during period t, and $ESG_{i,t}$ represents the value of the quantity of green patents applied for by listed companies during period t, after adding 1. $ESG_{i,t}$ denotes the ESG ratings of listed firm i in period t. $Controls_{i,t}$ represents the matrix of control variables for economic features of listed firms, including

Table 1

DATA SOURCES AND EXPLANATIONS			
Variable type	**Variable name**	**Variable symbol**	**Variable explanation**
Explained variables	Green Technology Innovation	GTI	Take the logarithm after adding 1 to the number of firms' green patent applications.
Explanatory variables	Corporate ESG Performance	ESG	Huazheng ESG Score
Mediating variables	Analyst Focus	ANA	Natural log of the quantity of analysts followed
Control variables	Firm size	lnTA	Natural logarithm of total assets
	Firm age	Age	Natural logarithm of the number of years of the company's existence plus 1 to take the natural logarithm
	Total Return on Assets	ROA	Ratio of net profit to total assets
	Gearing	Lev	Ratio of total liabilities to total assets
	Board size	Board	Total number of the board of directors
	Percentage of independent directors	Index	Number of independent directors/total number of board of directors
	Industry	Industry	Dummy variable for industry
	Annual	Year	Dummy variable for age

firm scale, debt-to-equity ratio (Lev), firm age, profitability, board size, and the proportion of independent directors (Index). Σ*Year* and Σ*Independent* directors are the two crucial variables. Σ*Year* and Σ*Industry* are year and industry control variables, respectively, and $\varepsilon_{i,t}$ are residual terms. When the regression coefficient β_1 of $ESG_{i,t}$ in Model 1 satisfies $\beta_1 > 0$ and is significant, it shows that the ESG performance of enterprises has a significant positive influence on green technological innovation, and the hypothesis 1 holds.

ANALYSIS OF EMPIRICAL RESULTS

Descriptive statistics

STATA18 was used to analyse the descriptive statistics of the explanatory variables and control variables selected in this paper, as presented in table 2.

Table 2 presents the descriptive statistics of the main variables employed in this research. The mean value of corporate green technological innovation was 0.058, having a minimum value of 0 and a maximum value of 1.792. This shows that there was substantial variation in green technological innovation among the sample firms. The average ESG performance score was 3.996, with a minimum of 1 and a maximum of 7, implying that the ESG performance of the sample companies was generally at a B-level rating.

Table 2

DESCRIPTIVE STATISTICS ANALYSIS TABLE					
Variable	**Obs**	**Mean**	**Standard deviation**	**Min**	**Max**
ESG	668	3.996	1.103	1	7
GTI	668	0.058	0.231	0	1.792
lnTA	668	21.916	0.95	19.893	25.114
Board	668	2.1	0.181	1.609	2.639
Index	668	0.379	0.057	0.308	0.6
Age	668	2.976	0.278	2.079	3.638
Lev	668	0.36	0.172	0.049	0.925
ROA	668	0.039	0.07	–0.353	0.244
ANA	668	1.275	1.189	0	3.664

Correlation analysis

The table of correlation analysis indicates that there exists a notable correlation between the chosen independent and dependent variables. The key independent variable (ESG) displays a significant positive correlation with the dependent variable (GTI), which aligns with the research anticipations (table 3).

Multicollinearity analysis

To further avoid interference from correlations between variables, this study conducted a multicollinearity analysis. As shown in table 4, the Variance Inflation Factor (VIF) was used before conducting the baseline regression. The VIF values of all variables were under 10, suggesting that there was no serious multicollinearity among the variables.

F-Test and Hausman Test

A fixed effects model or a pooled (mixed) effects model was more appropriate. An F-test was carried out to figure out which one. The test gave an F-value of $F(110, 550) = 2.35$ and a p-value of 0.0000, showing statistical significance. As a result, the pooled effects model was discarded in favour of the fixed effects model.

After that, a Hausman test was done to choose between the fixed effects model and the random effects model. The outcomes, presented in table 5, showed a p-value of 0.0000, which was lower than the 0.1 threshold. This outcome supported the choice of the fixed effects model.

Table 3

CORRELATION ANALYSIS TABLE									
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
(1) GTI	1.000								
(2) ESG	0.154*	1.000							
	(0.000)								
(3) InTA	0.135*	0.263*	1.000						
	(0.000)	(0.000)							
(4) Board	0.162*	0.184*	0.204*	1.000					
	(0.000)	(0.000)	(0.000)						
(5) Index	–0.056	–0.078*	–0.144*	–0.709*	1.000				
	(0.149)	(0.043)	(0.000)	(0.000)					
(6) Age	0.070	0.146*	–0.021	0.027	0.056	1.000			
	(0.072)	(0.000)	(0.591)	(0.492)	(0.148)				
(7) Lev	0.034	–0.131*	0.348*	0.077*	–0.109*	0.016	1.000		
	(0.386)	(0.001)	(0.000)	(0.046)	(0.005)	(0.677)			
(8) ROA	0.019	0.238*	0.093*	0.082*	–0.015	–0.116*	-0.421*	1.000	
	(0.627)	(0.000)	(0.016)	(0.034)	(0.701)	(0.003)	(0.000)		
(9) ANA	0.020	0.293*	0.424*	–0.005	0.052	–0.245*	–0.091*	0.421*	1.000
	(0.601)	(0.000)	(0.000)	(0.902)	(0.182)	(0.000)	(0.018)	(0.000)	

Note: *** p<0.01, ** p<0.05, * p<0.1.

Table 4

MULTICOLLINEARITY ANALYSIS		
Variables	**VIF**	**1/VIF**
Board	2.137	0.468
Index	2.067	0.484
ANA	1.69	0.592
InTA	1.641	0.609
Lev	1.547	0.646
ROA	1.525	0.656
ESG	1.269	0.788
Age	1.151	0.869
Mean VIF	1.628	

Table 5

RESULTS OF THE HAUSMAN TEST	
	Coef.
Chi-square test value	6.506
P-value	0.482

These results verified that the model specification was suitable, enabling the regression analysis to continue.

Benchmark regression analysis

Table 6 shows the benchmark regression outcomes by taking textile industry enterprises as samples. It systematically validates the influence of ESG performance (ESG) on green technological innovation (GTI) in textile enterprises through gradually bringing in control variables. In the basic Model 1 that merely contains enterprise, individual, and year fixed effects, the coefficient of ESG is 0.078, which is significant at the 1% level, suggesting a notable positive correlation between ESG performance and green technological innovation in textile industry enterprises. As control variables are gradually included (Models 2 to 7), the coefficient of ESG stays stable between 0.078 and 0.080, and the significance doesn't weaken in the least. This result firmly demonstrates that in the context of the textile industry, the promoting effect of ESG performance on green technological innovation has extremely high robustness, and the impact of the core explanatory variable is not disrupted by other potential factors.

Regarding control variables, the coefficient of enterprise size (InTA) is positive (0.012–0.017) in Models 2 to 7, but none reach a statistically significant level (p > 0.1). This suggests that the expansion of enterprise size in the textile industry does not significantly promote green technological innovation, which may reflect that the resource advantages brought by size are partially offset by industry characteristics (such as the inertia of traditional production modes). The coefficient of enterprise age (Age) is positive (0.110–0.204) in Models 3 to 7, but it is also not significant (p>0.1), indicating that the length of enterprise survival has a limited contribution to green technological innovation in the textile industry, and the industry pays more attention to current practices rather than historical accumulation. The return on total assets (ROA) coefficient is negative (ranging from –0.097 to –0.125) in Models 4 to 7, but all are not significant (p>0.1), implying that the improvement

Table 6

BENCHMARK STEPWISE REGRESSION RESULTS							
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
	GTI	**GTI**	**GTI**	**GTI**	**GTI**	**GTI**	**GTI**
ESG	0.078***	0.078***	0.078***	0.079***	0.079***	0.080***	0.080***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
lnTA		0.017	0.014	0.016	0.012	0.012	0.012
		(0.027)	(0.027)	(0.028)	(0.031)	(0.031)	(0.031)
Age			0.204	0.177	0.172	0.110	0.111
			(0.270)	(0.272)	(0.273)	(0.279)	(0.279)
ROA				–0.125	–0.104	–0.101	–0.097
				(0.159)	(0.175)	(0.175)	(0.177)
Lev					0.031	0.039	0.040
					(0.108)	(0.108)	(0.109)
Board						–0.113	–0.134
						(0.103)	(0.153)
Index							–0.073
							(0.389)
_cons	–0.229***	–0.588	–1.094	–1.062	–0.974	–0.570	–0.490
	(0.046)	(0.589)	(0.892)	(0.893)	(0.943)	(1.013)	(1.101)
Individual firm fixed effects	YES	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES	YES
Observations	668	668	668	668	668	668	668
R^2	0.118	0.119	0.120	0.121	0.121	0.123	0.123

Note: *, **, and *** denoted Significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors were presented in parentheses; the same rule applied below.

of short-term financial profitability in the textile industry has not effectively driven green technological innovation, possibly because green technology investment is long-term and has a certain conflict with short-term profit goals. The coefficient of asset-liability ratio (Lev) is positive (0.031–0.040) in Models 5 to 7, but all are not significant (p>0.1), It shows that the direction of the impact of liability level on the green patent output of textile enterprises is unclear, and financial leverage is neither a key constraint nor a promoting factor for green technological innovation. In Models 6 and 7, the coefficient of board size (Board) is negative (–0.113 to –0.134). Among them, the coefficient of Model 6 is close to the 10% significance level, but overall, it is still not significant (p > 0.1). This might reflect that an overly large board size in the textile industry has a certain inhibitory effect on green technological innovation investment because of reduced decision-making efficiency, yet the effect is weak. In Model 7, the coefficient of the proportion of independent directors (Index) is –0.073 (p > 0.1), which fails to reach significance, suggesting that the proportion of independent directors has no significant influence on the green technological innovation of textile enterprises, and the independent director mechanism in the corporate governance structure plays a limited role in green innovation decision-making.

Then we construct figure 1 based on the synergistic effect of the three dimensions (the document confirms that ESG promotes green innovation through analyst attention), the index is constructed using a weighted composite method:

$$\text{ESG Innovation Index} = (\text{Standardized ESG Score} \times 40\%) + (\text{Standardized Analyst Coverage} \times 30\%) + (\text{Standardized Green Patent Quality} \times 30\%) \quad (2)$$

A higher score indicates better synergistic performance between ESG and green innovation. For example, state-owned enterprises may have higher scores due to better ESG performance (consistent with the document's heterogeneity analysis), while non-state-owned enterprises may need to improve patent quality to enhance the index.

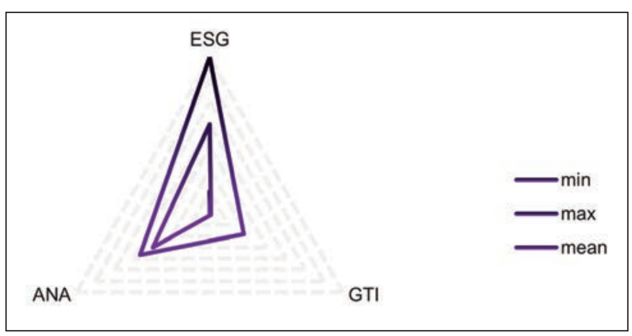

Fig. 1. Textile ESG-Innovation radar chart

Robustness tests

Winsorisation

Table 7 reports the regression results after winsorising all continuous variables at the 1 per cent tails [54, 55]. The positive and significant ESG coefficient persisted, confirming that the findings were not driven by outliers.

Table 7 shows the outcomes of Robustness Test 1 (winsorization) for the textile industry sample. It aims to validate the robustness of the benchmark regression conclusions by eliminating extreme values. In Model (1), which only controls for firm-specific and year fixed effects, the coefficient of corporate ESG performance (ESG) is 0.075 (t-statistic = 7.5), significant at the 1% level. This is very close to the positive influence of ESG on green technological innovation (GTI) in the benchmark regression (0.078), initially suggesting that the core conclusion remains unaffected by extreme values after winsorization. As control variables are gradually included (Models 2 to 7), the ESG coefficient stays stable between 0.075 and 0.078, with no significant changes in significance. This further validates the robust positive correlation between ESG performance and green technological innovation in the textile industry, enhancing the reliability of the main findings.

Regarding control variables: The coefficient of firm size (lnTA) varies between –0.006 and 0.015 in Models 2 to 7, none of which reach statistical significance ($p > 0.1$). Consistent with the benchmark regression results, this shows that the expansion of firm size has a limited driving effect on green technological innovation in the textile industry, as industry features (e.g., inertia of traditional production modes) may weaken the resource advantages brought by scale. The coefficient of firm age (Age) becomes negative (–0.048 to –0.193) in Models 3 to 7 but remains insignificant ($p > 0.1$). This reflects a slight change in the direction of the impact of firm age on green technological innovation after winsorization, though the statistical significance is still unclear, indicating that green innovation in the textile industry depends more on current ESG practices than historical accumulation. The coefficient of return on total assets (ROA) is negative (–0.201 to –0.283) in Models 4 to 7, with Model 4 approaching the 10% significance level (t-statistic ≈ –1.5) but overall remaining insignificant ($p > 0.1$). This implies that the inhibitory effect of short-term financial profitability on green technological innovation is slightly strengthened after winsorization, though not significantly, showing that corporate investment in green technology in the textile industry still needs to break free from the restrictions of short-term profit goals. The coefficient of asset-liability ratio (Lev) turns positive (0.124 to 0.137) in Models 5 to 7 but remains insignificant ($p > 0.1$), consistent with the benchmark regression results. This indicates that the direction of the impact of liability levels on green patent output of textile firms remains unclear, and financial leverage is not a key constraint or driver of green innovation. The coefficient of board

Table 7

REGRESSION RESULTS OF THE ROBUSTNESS TEST FOR THE REDUCED-TAIL TREATMENT

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	GTI	GTI	GTI	GTI	GTI	GTI	GTI
ESG	0.075***	0.075***	0.075***	0.076***	0.077***	0.078***	0.078***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
lnTA		0.013	0.014	0.015	–0.003	0.001	–0.006
		(0.031)	(0.031)	(0.031)	(0.035)	(0.035)	(0.036)
Age			–0.048	–0.074	–0.088	–0.192	–0.193
			(0.269)	(0.269)	(0.269)	(0.276)	(0.275)
ROA				–0.283	–0.226	–0.220	–0.201
				(0.189)	(0.196)	(0.196)	(0.196)
Lev					0.124	0.129	0.137
					(0.111)	(0.111)	(0.111)
Board						–0.180*	–0.354**
						(0.107)	(0.158)
Index							–0.605
							(0.405)
_cons	–0.232***	–0.521	–0.405	–0.339	0.044	0.614	1.340
	(0.046)	(0.672)	(0.935)	(0.935)	(0.996)	(1.050)	(1.157)
Individual firm fixed effects	YES	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES	YES
Observations	613	613	613	613	613	613	613
R^2	0.128	0.128	0.128	0.132	0.135	0.139	0.143

size (Board) is negative (–0.180* to –0.354**) in Models 6 and 7, with Model 6 significant at the 10% level (t-statistic ≈ –1.7) and Model 7 significant at the 5% level (t-statistic ≈ –2.2). Compared with the insignificant results in the benchmark regression, the inhibitory effect of board size becomes more evident after winsorization, suggesting that in the textile industry, excluding extreme values reveals a more significant inhibitory effect of overly large board sizes on green technological innovation investment due to reduced decision-making efficiency. The coefficient of the proportion of independent directors (Index) is –0.605 in Model 7 ($p > 0.1$), failing to reach significance, consistent with the benchmark regression results, showing that the ratio of independent directors has no notable influence on green technological innovation in textile companies.

Excluding epidemic effects

Table 8 shows the outcomes of Robustness Test 2 (excluding the influence of the pandemic years) for the textile industry sample, to verify the applicability of the core conclusions in non-pandemic periods. In the basic Model 1 that only controls for firm-specific and year fixed effects, the coefficient of corporate ESG performance (ESG) is 0.077, significant at the 1% level, which is very close to the benchmark regression result (0.078). This initially implies that after excluding the pandemic years, the positive impact of ESG on green technological innovation (GTI) remains stable. As control variables are gradually included (Models 2 to 7), the ESG coefficient stays stable between 0.077 and 0.079, and there is no substantial alteration in significance. This further validates the stable positive correlation between ESG performance and green technological innovation in the context of the textile industry, verifying the cross-period applicability of the core conclusion.

Regarding control variables, the coefficient of firm size (lnTA) is positive (0.010 to 0.016) in Models 2 to 7, but none of them reaches the statistical significance level ($p > 0.1$). Consistent with the results of the benchmark regression and the winsorization test, this shows that the expansion of firm size has a limited driving impact on green technological innovation in the textile industry. Industry characteristics (such as the inertia of traditional production modes) may continue to diminish the resource advantages brought by scale.

The coefficient of firm age (Age) is positive (0.084 to 0.163) in Models 3 to 7, but still not significant ($p > 0.1$). This reflects that after excluding the pandemic years, the direction of the impact of firm survival time on green technological innovation has not changed notably, and green innovation in the textile industry still depends more on current ESG practices rather than historical accumulation.

The coefficient of return on total assets (ROA) becomes positive (0.015 to 0.044) in Models 4 to 7, but the values are small, and all are significant ($p > 0.1$). This suggests that in non-pandemic periods, the inhibitory effect of short-term financial profitability on green technological innovation weakens,

Table 8

ROBUSTNESS REGRESSION RESULTS EXCLUDING EPIDEMIC EFFECTS

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	GTI	GTI	GTI	GTI	GTI	GTI	GTI
ESG	0.077***	0.077***	0.077***	0.077***	0.077***	0.079***	0.079***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.011)	(0.011)	(0.011)
lnTA		0.016	0.014	0.013	0.011	0.011	0.010
		(0.028)	(0.028)	(0.028)	(0.032)	(0.031)	(0.032)
Age			0.160	0.163	0.160	0.084	0.086
			(0.274)	(0.276)	(0.277)	(0.284)	(0.284)
ROA				0.015	0.029	0.034	0.044
				(0.186)	(0.206)	(0.206)	(0.208)
Lev					0.018	0.028	0.031
					(0.113)	(0.113)	(0.114)
Board						–0.134	–0.177
						(0.107)	(0.159)
Index							–0.146
							(0.399)
_cons	–0.225***	–0.568	–0.960	–0.963	–0.915	–0.428	–0.263
	(0.048)	(0.608)	(0.905)	(0.907)	(0.957)	(1.031)	(1.126)
Individual firm fixed effects	YES	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES	YES
Observations	597	597	597	597	597	597	597
R^2	0.122	0.123	0.124	0.124	0.124	0.127	0.127

but it is not significant. The contradiction between corporate investment in green technology and short-term profit goals in the textile industry still demands attention.

The coefficient of asset-liability ratio (Lev) is positive (0.018 to 0.031) in Models 5 to 7, but all are not significant ($p > 0.1$). In line with the benchmark regression outcomes, this shows that the direction of the influence of liability levels on the green patent output of textile companies remains unclear, and financial leverage is not a crucial limiting or facilitating factor for green innovation.

The coefficient of board size (Board) is negative (–0.134 to –0.177) in Models 6 and 7, among which the coefficient of Model 6 is close to the 10% significance level (t-value is about –1.25), but overall it is still not significant ($p > 0.1$). Compared with the insignificant results in the benchmark regression, the inhibitory effect of board size slightly strengthens after excluding the pandemic years, which may reflect that in normal periods, an overly large board size has a more prominent inhibitory effect on investment in green technological innovation due to decreased decision-making efficiency.

The coefficient of the proportion of independent directors (Index) is –0.146 in Model 7 ($p > 0.1$), which does not reach significance. This indicates that, in line with the benchmark regression results, the proportion of independent directors has no significant impact on the green technological innovation of textile firms.

Substitution with the IV-GMM model

Table 9 showcases the outcomes of Robustness Test 3 (utilising the IV-GMM model) for the textile industry sample. This test, by applying the instrumental variable generalised method of moments (IV-GMM) approach, intends to alleviate possible endogeneity problems (like reverse causality between ESG practices and green technological innovation or omitted variable bias) and further confirm the dependability of the core conclusions. In the IV-GMM Model 1 with firm and year fixed effects, the coefficient of corporate ESG performance (ESG) is 0.065, significant at the 1% level. After incorporating all control variables in Model 2, the ESG coefficient drops to 0.046 but still stays significant at the 5% level. Even though the coefficient is smaller than that in the benchmark regression (0.078***), the significance is maintained, suggesting that the positive influence of ESG performance on green technological innovation in the textile industry remains stable after dealing with endogeneity. The reliability of the core conclusion is verified via a more strict econometric method.

Regarding control variables, in Model 2, the coefficient of firm size (lnTA) is 0.022 (t-value = 2.0), significant at the 5% level. Different from the non-significant outcome in the benchmark regression, under the IV-GMM model, the positive influence of firm size on green technological innovation becomes more obvious. This might indicate that after dealing with endogeneity, larger firms in the textile industry can better utilise their resource advantages (such as R&D

Table 9

REPLACEMENT MODEL ROBUSTNESS REGRESSION RESULTS

Variables	IV-GMM Model	IV-GMM Model
	GTI	GTI
ESG	0.065***	0.046**
	(0.021)	(0.021)
lnTA		0.022**
		(0.011)
Age		0.047
		(0.039)
ROA		–0.032
		(0.129)
Lev		0.060
		(0.062)
Board		0.258**
		(0.116)
Index		0.471
		(0.319)
_cons	–0.250***	–1.543***
	(0.088)	(0.458)
Individual firm fixed effects	YES	YES
Year fixed effects	YES	YES
Observations	552	552
R^2	0.153	0.170

investment capabilities) to promote green technological innovation.

The coefficient of firm age (Age) is 0.047 (t-value ≈ 1.2), non-significant, implying that the impact of a firm's longevity on green technological innovation is still unclear. The industry still depends more on current ESG practices rather than historical accumulation.

The coefficient of return on total assets (ROA) is –0.032 (t-value ≈ –0.25), non-significant, showing that the inhibitory effect of short-term financial profitability on green technological innovation remains non-significant under the IV - GMM model. The conflict between green technology investment and short-term profit goals in the textile industry still deserves attention.

The coefficient of asset-liability ratio (Lev) is 0.060 (t-value ≈ 0.97), non-significant, suggesting that the impact direction of liability levels on green patent output is still unclear, and financial leverage is not a crucial constraint or promoter of green innovation.

In Model 2, the coefficient of board size (Board) is 0.258 (t-value = 2.2), significant at the 5% level, which is contrary to the non-significant negative effect in the benchmark regression. Under the IV-GMM model, board size has a positive impact on green technological innovation. This may reflect that after handling endogeneity, a larger board size supports green technology investment because of its richer professional resources or diverse decision-making capabilities, which may be related to industry characteristics (e.g., the requirement for diverse expertise in complex technological decisions).

The coefficient of the proportion of independent directors (Index) is 0.471 (t-value ≈ 1.5), non-significant, indicating that the proportion of independent directors exerts no significant impact on green technological innovation in textile firms.

In summary, The IV-GMM results not only confirmed the notable positive influence of corporate ESG performance on green technological innovation, but also showed a considerably increased ESG coefficient after instrument adjustment, further strengthening the causal effect of ESG investment on the boost of green patent output.

HETEROGENEITY ANALYSIS

Firm nature heterogeneity

Table 10 shows the outcomes of the property rights heterogeneity analysis for the textile industry sample [56–58]. By differentiating between state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs), it uncovers the disparities in the influence of ESG performance on green technological innovation (GTI) among enterprises with distinct property rights. In the SOE sample, the coefficient of ESG is 0.124, significant at the 5% level, suggesting that the ESG performance of SOEs has a notably positive effect on green technological innovation. In the non-SOE sample, the coefficient of ESG is 0.077, significant at the 1% level; the direction of impact is consistent with that of SOEs, but the coefficient value is smaller. This result suggests that although ESG practices promote green technological innovation in both types of enterprises, SOEs have a stronger ability to convert ESG practices into technological innovation due to their resource endowments, policy support, or governance characteristics (such as greater pressure from stricter ESG assessment).

Regarding control variables, in the state-owned enterprise (SOE) sample, the coefficient of the board size (Board) is –2.531 (t-value = –2.37), significant at the 5% level. This shows that the enlargement of the board size in SOEs has a notably inhibitory influence on green technological innovation. It might be because the decision-making process of SOE boards is intricate and inefficient, thus impeding the allocation of resources to green technology investment. In the non-SOE sample, the coefficient of Board is 0.013 ($p > 0.1$), not significant, which means the board size of non-SOEs has no significant effect on green technological innovation. The proportion of independent directors (Index) in the SOE sample is –3.738 (t-value = –1.86), significant at the 10% level. It implies that an increase in the proportion of independent directors in SOEs may restrain green technological innovation because of excessive decision-making supervision or lack of professionalism. In the non-SOE sample, the coefficient of Index is 0.397 ($p>0.1$), not significant, indicating that there is no

Table 10

FIRM NATURE HETEROGENEITY		
Variables	State-owned enterprises	Non-state-owned enterprises
	GTI	GTI
ESG	0.124**	0.077***
	(0.055)	(0.009)
lnTA	0.136	–0.009
	(0.197)	(0.033)
Age	–0.736	0.023
	(1.286)	(0.267)
ROA	0.088	–0.248
	(0.966)	(0.162)
Lev	–0.339	0.084
	(0.846)	(0.099)
Board	–2.531**	0.013
	(1.067)	(0.134)
Index	–3.738*	0.397
	(2.009)	(0.366)
_cons	5.791	–0.311
	(6.727)	(1.090)
Individual firm fixed effects	YES	YES
Year fixed effects	YES	YES
Observations	83	583
R^2	0.309	0.157

significant association between the proportion of independent directors in non-SOEs and green technological innovation [59–61].

The coefficient for firm size (lnTA) is 0.136 ($p > 0.1$) in the SOE sample and –0.009 ($p > 0.1$) in the non-SOE sample, both of which are not significant, indicating that the influence of enterprise size on green technological innovation under property-rights heterogeneity remains unclear. The coefficients of enterprise age (Age), return on total assets (ROA). Asset-liability ratio (Lev) is all insignificant ($p > 0.1$) in both types of enterprises, suggesting that the impact of these factors on green technological innovation shows no significant differences under property rights heterogeneity, consistent and weak marginal effect on GTI across both ownership types.

Integration into assessment mechanisms: Under the dual-carbon strategy, state-owned enterprises (SOEs), as the “main force” in policy implementation, have explicitly incorporated green development indicators (such as energy consumption per unit of output, carbon emission intensity, and the number of green patents) into their performance appraisal systems. For example, the Guidelines on Encouraging Central Enterprises to Speed up the Development of Green and Low-carbon Industries, issued by the State-owned Assets Supervision and Administration Commission of the State Council (SASAC) in 2022, mandate SOEs to “associate ESG performance with the salaries and career advancement of responsible individuals”, directly motivating SOEs to spur green technological innovation by enhancing ESG performance. (e.g., increasing environmental protection investment and disclosing social responsibility reports). Resource inclination support: SOEs are more likely to obtain policy resources such as government special subsidies and green credit. The document mentions that “SOEs can utilise policy directions and resource advantages to increase green R&D investment”, and high ESG scores serve as an important credential for them to access these resources, forming a positive cycle of “ESG improvement → acquisition of policy resources → acceleration of green innovation”.

Non-state-owned enterprises (non-SOEs) face stricter market financing reviews. The mechanism analysis in the document notes that “ESG performance can alleviate information asymmetry by attracting analysts’ attention”, but the impact of ESG on non-SOEs is weaker, reflecting that their green innovation relies more on market recognition rather than policy-driven forces. For example, investors (especially institutional investors) pay more attention to the ESG of non-SOEs, but due to limited financial strength, non-SOEs have lower efficiency in converting ESG inputs into green patents.

Non-SOEs need to break through differentiated competition. The document suggests that they “leverage scale advantages and ESG to build brands”, but constrained by higher financing costs (such as bond interest rates and equity financing thresholds), their green innovation is more dependent on short-term market returns, resulting in a weaker long-term driving effect of ESG on innovation compared to SOEs.

In summary, in the institutional context, the policy incentives (for SOEs) and market pressures (for non-SOEs) jointly result in the heterogeneity of ESG’s influence on green innovation. This supplement further explains the behavioural differences among different types of textile enterprises in the sample and enhances the institutional adaptability of the research conclusions.

Firm size

Table 11 shows the outcomes of the firm size heterogeneity analysis for the textile industry sample. It divides the sample into two groups: small-scale enterprises and large-scale enterprises, and then probes into the differences in the influence of ESG performance on green technological innovation (GTI) among enterprises of varying sizes. In the small-scale enterprise group, the coefficient of ESG is 0.049, significant at the 1% level; in the large-scale enterprise group, the coefficient of ESG is 0.106, also significant at the 1% level. Even though ESG has a notably positive impact on GTI in both kinds of enterprises, the ESG coefficient of large-scale enterprises (0.106) is markedly higher than that of small-scale enterprises (0.049). This suggests that as the scale of enterprises grows, the driving effect of ESG practices on green technological innovation gets stronger. This might be because large-scale enterprises have more ample resources (such as R&D investment ability and technical cooperation capabilities) to turn ESG concepts into practical innovation results.

Table 11

HETEROGENEITY ANALYSIS OF FIRM SIZE

Variables	Small-scale enterprises	Large-scale enterprises
	GTI	GTI
ESG	0.049***	0.106***
	(0.011)	(0.019)
lnTA	0.021	0.138
	(0.055)	(0.093)
Age	–0.043	0.335
	(0.300)	(0.543)
ROA	–0.075	–0.371
	(0.155)	(0.443)
Lev	0.025	–0.086
	(0.129)	(0.226)
Board	–0.051	0.035
	(0.177)	(0.300)
Index	–0.011	0.176
	(0.414)	(0.781)
_cons	–0.338	–4.431
	(1.351)	(2.692)
Individual firm fixed effects	YES	YES
Year fixed effects	YES	YES
Observations	334	334
R^2	0.126	0.139

In terms of control variables, the coefficients of firm size (lnTA) in both groups are not significant (0.021 for small-scale enterprises and 0.138 for large-scale enterprises, $p > 0.1$). This suggests that after grouping, the impact of the enterprises’ own size on GTI is no longer prominent. It may be because the grouping is based on size, and the lnTA in the control variables more reflects other unclear size-related characteristics. The coefficients of firm age (Age), Total asset return (ROA) and asset-liability ratio (Lev) are both insignificant in both groups ($p > 0.1$), suggesting that under the firm-size heterogeneity, the influence of these factors on GTI has no significant differences. The coefficients of board scale (Board) and the proportion of independent directors (Index) are also not significant in both groups ($p > 0.1$), indicating that the impact of governance structure on green technological innovation is weak in enterprises of different sizes.

In summary, capital-intensive firms, owing to their asset and capital-intensive nature, were the most responsive to ESG-driven innovation. Supported by their reliance on human capital, labour-intensive industries also presented a notable positive correlation between ESG and GTI. Conversely, even though technology-intensive companies had a robust R&D basis, the marginal impact of ESG on green technological innovation was comparatively moderate. This analysis provided empirical support for developing industry-specific strategies for green development.

Further discussion of the impact of the mediating mechanism of analysts' concerns

Table 12 shows the outcomes of the mediating effect test for the textile industry sample. By conducting a two-stage regression analysis, it initially confirms the possible mediating function of analyst attention (ANA) between ESG performance and green technological innovation (GTI). In Model 1, where GTI serves as the explained variable, the coefficient of corporate ESG performance (ESG) is 0.080, significant at the 1% level. This shows that ESG practices in the textile industry have a notable positive influence on green technological innovation, which aligns with the findings of the benchmark regression. Concerning control variables, the coefficients of firm size (lnTA), firm age (Age), return on total assets (ROA), asset-liability ratio (Lev), board size (Board), and the proportion of independent directors (Index) are all non-significant ($p > 0.1$). This implies that in the textile industry, these conventional factors have restricted driving effects on green technological innovation, and ESG performance is the key influencing factor [62–64].

In Model 2, where ANA serves as the explained variable, the coefficient of ESG is 0.093, significant at the 1% level. This indicates that more active ESG performance of textile enterprises draws greater analyst attention. Among the control variables, the coefficient of firm size (lnTA) is 0.557, presenting a significant positive correlation, meaning that larger enterprises are more prone to attract analyst attention. The coefficient of return on total assets (ROA) is 2.062, showing a significant positive correlation, which implies that enterprises with high profitability receive more analyst attention. The coefficient of firm age (Age) is –1.933, significantly negatively correlated at the 5% level, suggesting that enterprises with a longer existence time may have less analyst attention because of their relatively stable business models. The coefficients of other variables (Lev, Board, Index) are all non-significant ($p > 0.1$) [65–67].

Combining the results of the two stages, it can be preliminarily inferred that analyst attention is an important mediating path through which ESG affects green technological innovation [68, 69, 70]: improved ESG performance attracts more analyst attention (Model 2), and analysts, through information mining and dissemination, may force enterprises to strengthen green technological innovation to meet market expectations (Model 1). In the textile industry, a traditional high-pollution and high-energy-consumption field, the above findings have important practical significance: corporate ESG practices not only directly promote green technological innovation but also form external supervision pressure by increasing analyst attention, further promoting green transformation [71–73]. Policy makers may consider strengthening ESG information disclosure requirements and guiding analysts to pay attention to green technological innovation indicators, thereby building a positive cycle of "ESG practices–analyst supervision–green innovation" to help the textile industry achieve the goal of low-carbon development [74–77].

Table 12

TWO-STEP MEDIATED EFFECTS REGRESSION RESULTS

Variables	(1)	(2)
	GTI	ANA
ESG	0.080***	0.093***
	(0.010)	(0.030)
lnTA	0.012	0.557***
	(0.031)	(0.094)
Age	0.111	–1.933**
	(0.279)	(0.846)
ROA	–0.097	2.062***
	(0.177)	(0.537)
Lev	0.040	–0.045
	(0.109)	(0.329)
Board	–0.134	0.108
	(0.153)	(0.462)
Index	–0.073	0.618
	(0.389)	(1.179)
_cons	–0.490	–6.009*
	(1.101)	(3.335)
Individual firm fixed effects	YES	YES
Year fixed effects	YES	YES
Observations	668	668
R^2	0.123	0.279

CONCLUSIONS

This research examines the influence of ESG performance on green technological innovation (GTI) in Chinese textile enterprises within the dual-carbon strategy, utilising panel data of A-share listed textile firms from 2015 to 2023. By means of fixed-effects models, robustness checks, heterogeneity analyses, and mediating effect tests, the main findings are summarised as follows:

ESG performance notably boosts green technological innovation in textile enterprises. Benchmark regression outcomes indicate that ESG performance has a steadily positive and significant effect on GTI (coefficient range: 0.078–0.080), with this effect remaining robust after winsorization, excluding pandemic years, and addressing endogeneity via the IV-GMM model. This confirms that strong ESG practices directly drive green innovation in the textile industry, a traditional high-pollution and high-energy-consumption sector. Heterogeneity in the impact of ESG performance, by ownership, state-owned enterprises (SOEs) exhibit a stronger positive effect of ESG on GTI (coefficient: 0.124) compared to non-SOEs (0.077), likely due to SOEs' superior resource endowments, policy support, and stricter ESG assessment pressures. By firm size: large-scale enterprises show a more pronounced ESG-driven GTI effect (coefficient: 0.106) than small-scale enterprises (0.049), reflecting that larger firms' abundant resources (e.g., R&D capacity, technical cooperation) better convert ESG concepts into innovation outcomes. Analyst attention acts as a critical mediating mechanism. ESG performance enhances analyst attention (coefficient: 0.093), and analysts, through information dissemination and external supervision, incentivise enterprises to strengthen green technological innovation to meet market expectations. This forms an "ESG practices–analyst supervision–green innovation" transmission path. Limited role of traditional control variables. Factors such as firm size, age, profitability (ROA), leverage (Lev), board size, and independent director ratio generally show insignificant impacts on GTI in textile enterprises, indicating that ESG performance is a core driver of green innovation in this sector, outweighing traditional firm characteristics.

Overall, this study verifies that enhancing ESG performance is an efficient strategy for textile enterprises to boost green technological innovation under the dual-carbon goal. The results offer theoretical backing for comprehending ESG-driven green innovation and practical advice for enterprises, investors, and policymakers to facilitate sustainable industrial transformation.

POLICY RECOMMENDATIONS

For firms: Integrate ESG into core strategy and enhance green innovation capability

Strengthen ESG management systems: Implement a comprehensive ESG indicator framework covering environmental, social, and governance dimensions. Highlight crucial areas like environmental investment and social responsibility disclosure. Through enhancing ESG ratings, companies can draw more analyst interest and obtain external resources. For instance, following the Huazheng ESG evaluation framework, firms should identify and address weaknesses (e.g. environmental performance), develop improvement plans, and regularly disclose progress to build market confidence.

Formulate differentiated strategies based on firm type and industry characteristics: SOEs should leverage policy direction and resource advantages to increase investment in green technology R&D and establish best□practice models for ESG-innovation synergy. Private firms can utilise the benefits of scale expansion and differentiate their brand through ESG, using green patent portfolios to enhance competitiveness. Asset-intensive firms (e.g., chemical, energy sectors) should integrate ESG into equipment upgrades and process optimisation. Labour-intensive firms (e.g., textiles) should focus on innovations in clean production, and technology-intensive firms (e.g., electronics) should embed ESG-oriented goals into existing R&D frameworks.

For investors: Develop an ESG Analyst attention investment framework

Prioritise firms with high ESG ratings and rising analyst coverage, especially in asset intensive sectors, where green innovation potential more readily translates into long-term value. For example, in the energy sector, take into account companies that have ESG ratings of B or higher and steadily growing analyst coverage across three quarters, combined with growth in green patenting, to assess investment appeal.

Track ESG-related commentary in analyst reports to identify breakthrough green innovation initiatives and avoid underestimating their value due to information asymmetry. A dynamic monitoring framework could include "ESG rating → analyst coverage → green patents". When a firm's ESG rating improves and analyst coverage surges, closely evaluate its green innovation projects for commercial potential.

For government: Improve the ESG-Innovation Ecosystem

Enhance ESG disclosure and rating standards by promoting the adoption of authoritative ESG rating systems like Huazheng's. Require quarterly disclosure of key ESG metrics (e.g., carbon emissions, green R&D investment) by listed companies to enhance transparency and improve the effectiveness of analyst attention. For example, provide subsidies to companies that meet disclosure standards, and include consistently improving firms in green financing programmes.

Implement industry-specific incentive policies by introducing ESG-innovation subsidies for asset-intensive sectors (e.g., a 10 per cent subsidy for every RMB 10,000 of green R&D expenditure), and tax incentives for clean-production technology in labour-intensive sectors. Facilitate cross-department collaboration across finance, environment, and industry ministries to create a virtuous cycle of "policy incentives → ESG improvement → innovation drive".

Suggestions for refining ESG strategies in sub-sectors of textile enterprises

Cotton Textile Enterprises should focus on cleaner production technology innovation and water resource management. Align ESG environmental goals with the high water consumption and high pollution pain points of the cotton textile industry. Prioritise R&D investments in advanced clean production technologies, such as in-depth printing and dyeing wastewater treatment technologies (e.g., membrane separation, advanced oxidation) and low liquor ratio dyeing processes. Enhance ESG environmental scores through the layout of green patents. For example, establish quantifiable ESG indicators such as "wastewater reuse rate" and "energy consumption per unit output value", and link them to R&D investments. Set up a cross-departmental ESG management team, with production, R&D, and environmental protection departments collaborating to formulate a roadmap for cleaner production technologies.

Regularly disclose progress in technological upgrades (e.g., reductions in wastewater treatment costs, proportion of green processes applied) to strengthen analysts' recognition of their ESG performance.

Chemical fibre enterprises should strengthen circular economy patent layout and raw material substitution innovation. Addressing the chemical fibre industry's reliance on fossil resources and the difficulty of waste, focus ESG environmental goals on R&D of circular regeneration technologies (e.g., PET bottle chip recycling, spinning, chemical depolymerisation) and bio-based chemical fibres (e.g., PLA, PHA). Enhance the synergy between ESG and green innovation by patenting technologies in areas such as "recycled fibre preparation" and "degradable material modification". Highlight achievements in low-carbon supply chain transformation in ESG disclosures – for instance, collaborating with upstream petrochemical enterprises to develop low-carbon raw materials and publicly disclosing the proportion of recycled fibres in products. This will attract brand customers focused on sustainable consumption (e.g., sportswear companies), forming a positive cycle of "ESG improvement → increased market demand → greater innovation investment".

Garment manufacturing enterprises should promote green supply chain management and low-carbon design innovation.

Focus on energy conservation and emission reduction in garment production (e.g., waterless printing technology) and the construction of a waste garment recycling system. Refine ESG indicators into metrics such as "low-carbon fabric utilisation rate" and "product recycling rate", and protect eco-friendly designs (e.g., detachable, easily degradable garment structures) through green patents. Integrate labour rights protection (e.g., reasonable working hours, skill training) into the ESG framework, especially in labour-intensive garment processing links. By improving employee satisfaction to reduce turnover rates, it indirectly ensures the stable implementation of green production processes.

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