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ESG disclosure and technological innovation capabilities of the Chinese listed companies

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ABSTRACT

The main objective of this study is to explore how ESG disclosure effectively promotes technological innovation capabilities (TIC) and also in different industries (green vs. high-tech). Further, examine the role of financing constraint (FC) in the relationship between the ESG disclosure and TIC. We employed the panel regression model, Causal step approach, Bootstrap mediation effect test, 2SLS, and GMM model. We used Bloomberg's ESG disclosure score of China's A-share listed companies from 2011 to 2019 (1); we found that the ESG disclosure has a significant relationship with corporate innovation indicators (OTI, STI, NSTI) and play a significant role in promoting TIC at different levels of corporate innovation (2) ESG disclosure of non-green (high-tech) industry is more effectively promote TIC than green (non-high tech) industry (3) ESG disclosure can promote corporate innovation by reducing the level of corporate financing constraints, and FC has a partial intermediary role between ESG and TIC.

1. Introduction

China's economy is shifting from high-speed growth to a high-quality development stage. The long-standing extensive development mode needs to be adjusted to a more ecological mode, allocating resources more effectively and introducing new management concepts into enterprise strategy. China is closely following the forefront of international ESG development, communicating and cooperating to build a global ESG ecosystem. In 2018, China Securities Regulatory Commission (CSRC) revised "sustainable and green development" as guiding principles, stipulating that listed companies disclose ESG information. Subsequently, the Asset Management Association of China (AMAC) issued the first "Green Investment Guidelines and ESG Evaluation System" for listed companies, further encouraging fund managers to engage in green investment practices and supporting listed firms to enhance information disclosure. China's 15th National Congress target commitment of "strive to peak China's carbon dioxide emissions by 2030, achieving carbon neutrality by 2060", later in 2021, "carbon peak and neutrality" was also written into the government work report.

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ESG concept has recently been recognized as a vital management strategy for company's survival. ESG refers to how enterprises and investors integrate environmental, social, and governance problems into their business models (i.e., the inclusion of non-financial elements into business strategy that have financial implications) in order to achieve certain objectives, for instance, customer satisfaction and environmental protection (Gillan et al., 2021). Recently, it has been a thriving trend globally for enterprises to voluntarily disclose ESG information using frameworks and standards from the Sustainability Accounting Standards Board (SASB) and Global Reporting Initiative (GRI). Global ESG investment continued to grow rapidly in 2021. As of the second quarter of 2021, sustainable investment mutual funds in just five major markets (US, EU, Japan, Canada, and Australia) totaled \$2.24 trillion, more than double the amount of 2020. Bloomberg Intelligence (2021) predicts that by 2025, total worldwide ESG assets would amount to \$53 trillion, or more than 30% of the \$140.5 trillion in total assets under management (AMU). Nowadays, more enterprises have realized that ESG is a key driver for competitive advantage, reputation establishment, and operational efficiency (Aouadi and Marsat, 2018; Buallay, 2019; Filbeck et al., 2019). Recognized rating agencies have focused their efforts on developing metrics that might represent a company's level of environmental and social responsibility (Tomo and Landi, 2017). Recent research underlines the need to achieve corporate sustainability through the harmonious growth of the economy, society, and environment (Alkaraan et al., 2022; Dey et al., 2020; Henderson, 2021). Given that stock exchanges have taken measures to improve the level of ESG disclosure (Bizoumi, Lazaridis, and Stamou, 2019). On the other hand, the global sustainable investment assets were over \$30.7 trillion in 2018, a 34% increase from 2016 (GSA, 2018). Therefore, institutional investors are becoming more aware that long-term financial performance is now influenced by ESG performance (Bai et al., 2022; Khurram et al., 2023).¹ Dasgupta (2022) stated that companies are always motivated to improve ESG actions, especially for those financial performance shortfalls, possibly maintaining future legitimacy. Existing studies focus on ESG ratings' impact on corporate financial performance, while other potential channels such as technological innovation capabilities should also be considered.²

Recently, the Chinese government has vigorously promoted technological innovation capabilities within companies at the national level, i.e., China's 14th Five-Year Plan (2021) proposes to "transition towards innovation-driven development and boost companies' technological innovation capabilities (TIC, hereafter)." Yam et al. (2004); Yam et al. (2011) explain that TIC is a comprehensive set of characteristics/capabilities (i.e., learning, R&D, resource allocation, manufacturing, marketing, organization, and strategic planning) of an enterprise that facilitates and supports its technological innovation strategies. Yam et al. (2011) and Tu et al. (2023) argued that with the increasingly fierce market competition, technological innovation capabilities is not only the prerequisite for a firm to keep its market share and increase its core competitiveness; it is also the assurance of the improvement of the company's profitability, capacity for expansion (growth ability), and financial performance. Balsalobre-Lorente et al. (2021) revealed that technological innovation capability is a stimulus for enterprises to retain prolonged competitive advantage, has a direct or indirect effect on macroeconomic growth and company performance. However, technological innovation capabilities are generally costly and risky; several studies revealed certain internal and external factors affect the TIC and are the leading cause of financial constraints (FC).³

Harhoff (2000) and Myers and Majluf (1984) explain that TIC activities are more susceptible to financing constraints and more challenging to obtain external financing because of the complexity and uniqueness of the innovation process, the high risk and accumulation of R&D activities, and the uncertainty surrounding the benefits of innovation. In China, enterprises technological innovation capabilities investment is highly dependent on external financing like bank loans (Ge et al., 2020) and FC make it challenging to grab external financing for import technology and independent research.⁴ It has an adverse impact on corporate innovation (TIC) decision-making and hinders enterprise performance (Gorodnichenko and Schnitzer, 2013). Yam et al. (2011) and Tu et al. (2023) argue that the imperfections in the financing function and the stock market's immature development hinder the formation of an environment conducive to TIC. Indeed, the main obstacle to economic growth and entrepreneurial success in developing countries is a lack of access to finance (Boermans and Willebrands, 2018). In this regard, the ESG criterion guides companies in implementing the idea of sustainable development by pushing them to use energy-saving and environmentally friendly technology. It would help strengthen the connection between the company and stakeholders and also get stakeholder support, alleviate information asymmetry,

¹ ESG portfolios may not give a strong diversification advantage for traditional stock portfolios, but they can bring long-term benefits.

² Several academicians confirmed that technological innovation capabilities within firms plays a significant role in sustainable economic development (i.e., Yam et al. 2004; 2011). Annual China's Central Economic Work Conference (2021) also emphasized the need to "strengthen the key position of the enterprise technological innovation capabilities, expand support for the real economy besides green development.

³ According to Tu et al. (2023), the transformation guarantee capacities and input-output are the main factors which influencing the enterprises technological innovation capabilities (TIC). However, Ge et al. (2020) reveal that government subsidies, internal capital accumulation, external financing, and information asymmetry are the main causes of financial constraints (FC) for corporate innovation or TIC (Bai et al., 2022).

⁴ Ang et al. (2014) explain that financing is considered a major impediment to corporate innovation (TIC) in China, and it continues to be a significant issue. Jin et al. (2019) document that the degree of corporate financial constraint is significantly different in China owing to listed firms varying ownership status, region, age, and size. On the other hand, enterprises have very few financing options because of the Chinese bank-dominated financial system. Banks with high nationalization rates tend to favor lending to sizable state-owned corporations due to political asylum. Additionally, the Sci-Tech Innovation Board (STAR Market), which is dedicated to resolving high-tech enterprises financing and investment problems, is still in the research and development stage. According to Yuan et al. (2021), financial reform has become critical in supporting TIC. Therefore, the 19th CPC Central Committee (5th Plenary Session 2020) highlighted "support for green financial development and green technological innovation." Wang and Li (2022) further elaborate those credits are typically given to innovative firms, particularly those with a high technological innovation capability, allowing firms with financial constraints to innovate (Tu et al., 2023). Zhang et al. (2020) reported that the interaction between environmental information disclosure and technological innovation had been demonstrated to help alleviate financial constraints.

reduce agency conflicts, better firms' long-term financial performance and market value, build a reputation, reduce financing costs and generate positive market reactions. Therefore, firms that pursue ESG development will benefit in terms of improving technological innovation capabilities, enhancing employee satisfaction, and increase investor attractiveness (In et al., 2019), and reducing financial constraints for corporate innovation (Zhang et al., 2023). In light of the aforementioned empirical evidence, our study attempts to answer the following questions: (1) Can better ESG disclosure effectively promote technological innovation capabilities? (2) Can better ESG disclosure effectively promote the TIC in different industries (green vs. high-tech)? (3) What is the role of FC in the association between ESG disclosure and technological innovation capabilities?

This paper's main motivation and contributions are as follows: Firstly, the existing research on ESG disclosure is insufficient to pay attention to technological innovation capabilities (TIC). This study uses long-term samples of the Chinese listed firms from 2011 to 2019 to test the relationship between ESG disclosure and TIC and enriches the research in this field (i.e., recent studies Atif and Ali, 2021; Bolognesi and Burchi, 2023; Buallay et al., 2022; Cheng and Lin, 2012; Duan and Zhuang, 2021; Khan, 2022; Lozano and Martínez-Ferrero, 2022; Raimo et al., 2021; Arvidsson and Dumay, 2022; Harasheh and Provasi, 2022; Meng-tao et al., 2023; Tu et al., 2023). We find that ESG disclosure plays a significant role in promoting TIC at different levels of corporate innovation. These results provide theoretical insights into the dynamics through which corporate pro-social decision-making stimulates and promotes green innovation, as well as there, are managerial repercussions for entities like companies, regulators, index agencies and investors, to grasp how ESG practices could support technological innovation in a sustainability-focused setting. Secondly, we observe the moderating effect of corporate characteristics (Green and non-green industry; Song and Yu, 2018; Tolliver et al., 2021; Wang and Li, 2022; Yuan et al., 2021; Zhai et al., 2022; Zhang and Xu, 2019; Zhang et al., 2020; Zheng et al., 2022, and high-tech and non-high tech industry; Ang et al., 2014; Tu et al., 2023) on the relationship between ESG disclosure and TIC. We revealed that ESG disclosure of non-green industries more effectively promotes TIC than the green industry, while ESG disclosure has a stronger role in high-tech enterprises in promoting TIC, especially for high-end substantive innovation. Therefore, based on exploring the function mechanism of green credit policy on the sustainable development indicators of Chinese listed companies, these findings attempt to provide scientific policy and decision support for regulators. Thirdly, we introduces financing constraints (Bae et al., 2021; Bai et al., 2022; Boermans and Wilibrands, 2018; Ge et al., 2020; Gorodnichenko and Schnitzer, 2013; Hadlock and Pierce, 2010; Harhoff, 2000; Jin et al., 2019; Lin et al., 2017; Ma et al., 2018; Tang, 2022; Wan et al., 2020; Zhai et al., 2022; Zhang et al., 2020; Zhang et al., 2023) as an intermediary variable of the relationship between ESG disclosure (Arvidsson and Dumay, 2022; Atif and ali, 2021; Bizoumi et al., 2019; Bissoondoyal-Bheenick et al., 2023; Bolognesi and Burchi, 2023; Brooks and Oikonomou, 2018; Buallay, 2019; Fatemi et al., 2018; Harasheh and Provasi, 2022; Husted and Sousa-Filho, 2018; Khan, 2022; Li, Gong et al., 2018; Meng-tao et al., 2023; Raimo et al., 2021; Yu and Van Luu, 2021) and technological innovation capabilities (Cheng and Lin, 2012; Duan and Zhuang, 2021; Tu et al., 2023; Wang et al., 2008; Yam et al., 2004; Yam et al., 2011) which provides a new foothold for relevant research. We find that ESG disclosure can promote corporate innovation by reducing the level of corporate financing constraints. Further, the financing constraints have a partial intermediary role in the association between ESG and TIC. However, even though existing studies have found that the financing structure can affect the innovation activities of enterprises, its internal mechanism is not clear, especially the mechanism of sustainable development performance remains to be explored, providing broader space and practical reference for future research in related fields.

The rest of this paper is organized as follows: Section 2 explains the literature review and hypothesis development. Section 3 presents the Methodology, which includes sample selection and data sources, the definition of the main and control variables of the study, model construction, and hypothesis testing. Section 4 demonstrates the empirical findings based on several regression analyses and robustness tests. Section 5 concludes the study with a summary of our findings, policy enlightenment, and limitations with future prospects.

2. Literature review

As one of the world's greatest economies, China is struggling with environmental and energy issues; there are increasing calls for green development to mitigate the negative effect of carbon dioxide emissions and lack of oil and gas resources on sustainable development (Lin et al., 2021). According to Tolliver et al. (2021), economic growth must be maintained while tackling environmental externalities and climate change, and also the degree to which stimulate the ESG information corresponds to the impacts on the transition to sustainable growth perspectives. ESG performance is an assessment tool that urges investors to concentrate on the environmental, social, and corporate governance performance (Bissoondoyal-Bheenick et al., 2023; Zhang et al., 2023); several studies highlighted that these three factors mainly impact on the enterprise innovation (Khan, 2022). Given that Chinese financial analysts' oversight of corporate governance and their informational role in the market can reduce the decoupling of corporate sustainability, trigger favorable market responses, and motivate managers to invest more in green innovation—particularly for polluting companies and companies with greater information asymmetry (Bissoondoyal-Bheenick et al., 2023; Zhang, 2022).

In view of traditional agency theory, overemphasis on corporate social responsibility (CSR) is recognized as an abuse of power for manager's own reputation (Jensen and Meckling, 1976), occupying the resources allocation originally planned for technological innovation and upgrading (Friedman, 2007). The negative externalities of innovation activities of moral and ethical crises (Buhmann and Fieseler, 2021) and environmental pollution (Karim, Albitar, and Elmarzouky, 2021), have also triggered the implementation of responsible innovation in academic and industrial circles. The concept of responsible innovation was listed as a critical section of the EU Horizon 2020 framework plan, requiring firms and their stakeholders to fully consider the unknown risks and negative effects. These negative effects may arise from innovation activities while pursuing the commercial value of innovation based on factors such as business ethics, social, moral acceptance, and social expectation and satisfaction. Responsible innovation provides new opportunities for the sustainable development of firms by amplifying and promoting the positive external effects of innovation and reducing or

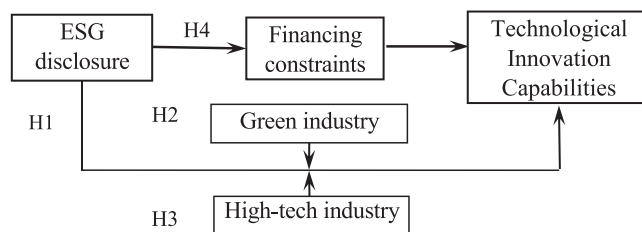


Fig. 1. Research concept.

avoiding the negative external effects of innovation. With the diversified development of internal control mechanism for shareholder, recent researches also document that stakeholder highly relates to firms' ESG disclosure with greater adherence to ESG actions (Li et al., 2018; Fatemi et al., 2018), where board diversity is positively correlated with ESG disclosure (Nadeem et al., 2017; Husted and Sousa-Filho, 2018; Bualalay et al., 2022; Lozano and Martínez-Ferrero, 2022). Therefore, ESG practices may cultivate organizational learning (Duque-Grisales and Aguilera-Caracuel, 2021), organizational capabilities (Cornell, 2021; Cornell and Shapiro, 2021; Espahbodi et al., 2019), and enhance the corporate governance structure (Song and Yu, 2018; Khan, 2022) for corporate innovation (Khurram et al., 2023). Those ESG practices effectively improved the social responsibility and governance level of Chinese listed companies (Li, Zhang, and Zhao, 2022; Zhai et al., 2022), thus improving R&D investment and technological innovation (Lin et al., 2017; Zhang et al., 2023). Therefore, this paper puts forward the following hypothesis:

H1. : ESG disclosure can effectively promote technological innovation capability.

Green industry can be roughly divided into innovation from environmental enterprises (EEs) and resource enterprises (REs). RE and EE samples were selected from resource exploitation, heavily-polluting industries, or green businesses. Specifically, EEs are firms whose scope of business includes environmental pollution or protection, for instance, chemical materials, waste materials recycling and processing, paper-making, energy equipment manufacturing etc. (Hendrickson and Tuttle, 1997). Where REs are firms whose main businesses involve in natural resources, for instance, forests, oil, minerals, energy, waste and metallurgy (Oltra and Jean, 2009). Green industries lack the drive to innovate in areas like environmental protection and energy efficiency, which are obvious signs of externalities and common public goods from which other businesses or society at large might freely benefit by the innovation of these industries (e.g., cleaner water and air). Since green enterprises could not get all the benefits of innovation (Zhang and Xu, 2019), the lack of internal motivation for innovation may weaken the overall impact mechanism on TIC.

Green enterprises are highly related to ESG performance (Zhang et al., 2023; Khurram et al., 2023), while high-tech enterprises are always derived from TIC (Tu et al., 2023). Innovation in technology-intensive high-tech industries faces high upfront costs as well as substantial uncertainty (Wan et al., 2020; Tu et al., 2023). Specifically, the TIC of high-tech industries is intended to be affected differently by economic policy, where high-tech companies obtaining government subsidies and advantageous tax regimes improve their economic benefits and give a positive signal outside the firms that assisting them to attract external financing (Liu et al., 2020; Meng-tao et al., 2023). Therefore, improving corporate governance, increasing information disclosure, and alleviating financing constraints would certainly improve high-tech industries' product quality (Wang, 2020).

Given the aforementioned literature, this paper posits the following hypotheses to identify the impact of industrial heterogeneity:

H2. : Among green industries, ESG disclosure has a weaker role in promoting technological innovation capability.

H3. : Among high-tech industries, ESG disclosure has a stronger role in promoting technological innovation capability.

Previous studies have shown that the financing constraints during the daily R&D process may have a restraining effect on innovation investment in the short term, but it still has a promoting effect in the long term (Ma and Hou, 2018). However, financial constraints might result in R&D underinvestment, whereas agency costs could result in R&D over-investment (Lin et al., 2017), and the upsurge in the difficulty of assessing R&D could be a source of financing frictions (He and Ciccone, 2020). According to modern corporate finance theory—agency problems and information asymmetry cause the cost of external financing to be greater than that of internal capital, leading to the issue of financing constraints (Bai et al., 2022). Based on signal theory, firms that disclose non-financial information to the market can decrease the degree of information asymmetry between them and investors, promote stakeholder participation and transparency, and decrease the propensity of enterprise opportunistic behavior (Bénabou and Tirole, 2010; Bai et al., 2022; Hanson, Lyons et al., 2017; Bolognesi and Burchi, 2023). Given sustainable development theory,⁵ the financing constraints depend on firm's long-term operation, while the financing cost directly affects the relevant indicators of ESG performance (Tang, 2022; Zhang et al., 2023). Raimo et al. (2021), companies with higher degrees of openness in disclosing ESG information gain access to third-party financial resources (i.e., venture capital, public finance, bank loans) under better conditions. Friede et al. (2015) and Nekhili et al. (2021) ESG actions may increase enterprise value by improving cash flows, maximize shareholder utility, and lowering the discount rate. Enterprises with stronger ESG performance have lower equity capital costs and higher credit ratings (Henriksson

⁵ The sustainable development theory suggest that companies can alleviate financing constraints and agency cost, thereby promoting the quantity and quality of corporate innovation output (Tang, 2022).

et al., 2019); positive market reactions and negative impact on default risk, results in lower financing costs (Atif and Ali, 2021; Bae et al., 2021; Bissoondoyal-Bheenick et al., 2023; Gillan et al., 2021; Li et al., 2022; Zhang et al., 2023) and alleviate financing constraints to provide financial guarantees for enterprise R&D and technological innovation (Tu et al., 2023; Zhang et al., 2020). In short, better ESG disclosure reduces financing constraints, and more enterprises tend to strengthen their investment in TIC. Based on the aforementioned theoretical analysis, we carry out the experimental design as shown in Fig. 1 and propose the following hypotheses for the mediating models:

H4. : ESG disclosure can promote technological innovation capability by easing corporate financing constraints.

3. Methodology

3.1. Sample and data source

This paper employed 7146 annual samples of China's Shanghai and Shenzhen A-share listed companies from 2011 to 2019 to construct a panel dataset. Those financial and patent-related data are collected from CSMAR, Wind, and DIB databases, and ESG disclosure scores are acquired from Bloomberg database. To ensure the reliability of the research samples, we performed the following data processing: (1) Exclude financial and real estate enterprises; (2) Exclude ST, ST*, PT, and IPO samples during the research period; (3) Exclude samples with missing values. All variables excluding dummy variables were winsorized by 1% to reduce the influence of outlier fluctuations.

3.2. Variables

3.2.1. Explained variables

Since China's economy is shifting towards high-quality development, R&D activities has become a spontaneous investment behavior within the context of fierce global market competition. Previous studies focus more on R&D input to measure technological activities of enterprises, but the actual technological innovation with typical high-risk characteristics is difficult to effectively convert the R&D input into innovation output, thus overestimating the technological innovation capability by using those indicators. From the perspective of financial management, the impact of ESG performance on corporate innovation mainly lies in promoting green transformation and alleviating financing constraints, i.e., the pre-innovation activities (Zheng et al., 2022). Due to the essential characteristics of innovation activity cycle and patent disclosure system, the number of patent application is more comprehensively disclosed than the number of patent grant. Based on previous literature (Zhang et al., 2021; Li and Yang, 2022), this paper adopted the application number of patents as the proxy variable to measure technological innovation capabilities (TIC), dividing TIC indicators into three levels: overall technological innovation (OTI), substantial technological innovation (STI), and non-substantial technological innovation (NSTI), respectively. In view of the huge deviation of patent count among enterprises, we conducted natural logarithm processing on these patent indicators.

3.2.2. Explanatory variables

China has proposed its need to build a more market-oriented green technology innovation system, developing green finance to strengthen energy conservation and environmental protection industries. Meanwhile, China markets as a net receiver rather than a net transmitter that abide by the ESG criteria are closely linked, with a sizeable increase in their connectedness during turmoil periods (Zaghum et al., 2020), which is related to the fact that companies issued ESG report are more advanced in information disclosure. This geographic reconfiguration of ESG rating construction expanded from financial agglomerations to technological and digital innovation spaces (Zhang et al., 2021; Tu et al., 2023). It is believed that ESG disclosure plays an important role in enhancing brand reputation, demonstrating social responsibility, building investor confidence, and helping companies identify opportunities and challenges. ESG disclosure can more realistically represent the company's ESG actions as well as being easily transformable into a quadratic score to identify the key driver of innovative activities. The improvement of listed companies' ESG awareness, regulatory policy requirements, and the promotion of investment institutions are the main driving forces for the ESG disclosure of the Chinese A-share listed companies. By June 2021, 26% of China's A-share listed companies had released their 2020 ESG reports; recently, the State-owned Assets Supervision and Administration Commission (SASAC) issued the "work plan for improving the quality of listed companies", where clearly demand those listed companies of central enterprises to achieving "full coverage" of ESG report disclosure by 2023. Since China has not issued mandatory disclosure requirements, and Bloomberg's ESG score by construction considers both sustainability and ethical impacts (Nollet et al., 2016), this paper employed Bloomberg's ESG disclosure scores as quantitative indicators in our empirical research.

3.2.3. Moderating variables

3.2.3.1. Green industry. In line with the industry classification of the China Statistics Bureau, 22 sub-classifications of industries were screened due to the availability of relevant data. We further compared the 18 subcategories of (Zhang and Xu, 2019) after the consolidation of analogous industries. The following sub-classification of industries was obtained as the treatment group of the green industry. Finally, we obtained 2626 observations from 379 Environmental enterprises (EEs) and resource enterprises (REs) after removing samples of "other industries" (see Table A1).

3.2.3.2. High-tech industry. With the rapid development of digital manufacturing and services, the high-tech industry is changing the production process of enterprises as well as the lifestyle of humans. According to the Organization for Economic Cooperation & Development (OECD) classification standards, the high-tech industry can be roughly divided into 6 subcategories: aerospace, computer, pharmaceutical, scientific, electrical, and communication equipment manufacturing. Besides, “High-tech Industry Classification (2018)” of the State Council of China (SCC) further classified high-tech industry into 9 service industries as follows: e-commerce services, information services, inspection, and testing services, R&D services, technology transfer services, environmental governance services, professional services, intellectual property services, and other high-tech services. Drawing on the research of Wang (2020) and Tu et al. (2023) this paper classified the following 13 industries as high-tech industry (see Table A2).

3.2.4. Mediating variable

Financing constraints could be calculated by financial-related indicators such as cash flow sensitivity coefficient (Hadlock and Pierce, 2010) but may cause more endogenous issues. The financing constraint index (FCI) is constructed from two dimensions, including firm size and age; both have strong exogenous properties and are not significantly affected by the time effect. In order to avoid endogeneity, this paper chooses the financing constraint index (FCI) of Hadlock and Pierce (2010) to measure corporate financing constraints (FC). The specific formula is as follows:

$$FCI = -0.737 * Size + 0.043 * Size^2 - 0.04 * Age$$

Since all values calculated from the above formula are negative, the smaller FCI value implied the greater financing constraint dilemma faced by enterprises.

3.2.5. Control variables

We introduced a set of firm-level factors that influence TIC and ESG disclosure based on previous literature. Those firm characteristic variables are control variables, including Firm size, Return on total assets, Patent maintenance period, First shareholder concentration, Assets and liabilities, Fixed assets, and Internal control. Due to the transformation of macro policy and the external environment, both industry effect (industry) and time effect (year) are controlled to fix the divergence of TIC at the level of year and industry (see Table A3).

3.3. Panel regression model

3.3.1. Benchmark model

To analyze the impact of ESG on corporate technological innovation, the following panel econometric model is set based on the theoretical analysis and research hypotheses in the previous section:

$$\ln TIC_{it} = \alpha_0 + \alpha_1 ESG + \Sigma Control_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

In model (1), the subscripts i and t denote the individual firm and year, respectively. The explanatory variable is ESG disclosure score, and the explained variable of technological innovation capability (TIC) includes overall technological innovation (OTI), substantial technological innovation (STI), and non-substantial technological innovation (NSTI). Control Contains a set of control variables that affect firm technological innovation, and ε_{it} represents the random error of the model. We also include industry fixed effect μ_i and year fixed effect γ_t to eliminate the effects of firm characteristics that unchanged over time and macroeconomic environment.

3.3.2. Moderating effect model

To further verify the influence mechanism of corporate characteristics related to TIC and ESG, different grouping methods of EERE (Green Industry Classification) and TECH (High Technology Industry Classification) are introduced into our baseline regression model. The following moderating models are constructed, where the interaction coefficient β_3 is our main concern. If the coefficient β_3 of the interaction term of ESG*EERE in model (2) is negative and significant, that indicates ESG disclosure is more effective in promoting corporate innovation among non-green firms (in comparison with green firms). If the coefficient φ_3 of the interaction term of ESG*TECH in model (3) is positive and significant, that indicates ESG disclosure is more effective in promoting corporate innovation among high-tech firms (in comparison with non-high-tech firms).

$$\ln TIC_{it} = \beta_0 + \beta_1 ESG + \beta_2 EERE + \beta_3 ESG * EERE + \Sigma Control_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (2)$$

$$\ln TIC_{it} = \varphi_0 + \varphi_1 ESG + \varphi_2 TECH + \varphi_3 ESG * TECH + \Sigma Control_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (3)$$

3.3.3. Mediating effect model

Drawing on the “causal step approach” of Preacher and Hayes (2008), we adopt financing constraints index (FCI) as the mediating variable to further explore the path mechanism of ESG influencing firms’ technological innovation. So the following recursive equation is set, where FCI in models (4) and (5) denotes the mediating variable of financing constraint, and the meanings of μ_i , γ_t , ε_i are consistent in Model (1)-(5).

$$FCI_{it} = \lambda_0 + a ESG + \Sigma Control_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (4)$$

Table 1
Variables descriptive statistics.

variable	N	Mean	Median	S. D.	Min	Max
OTI	7146	2.942	3.045	1.916	0	6.967
STI	7146	2.164	2.079	1.740	0	6.168
NSTI	7146	2.377	2.398	1.823	0	6.314
ESG	7146	20.45	20.25	5.810	10.33	38.43
EERE	7146	0.367	0	0.482	0	1
TECH	7146	0.358	0	0.480	0	1
FCI	7146	-3.803	-3.811	0.231	-4.275	-3.223
SIZE	7146	22.93	22.85	1.185	20.66	25.86
ROA	7146	0.0510	0.0420	0.0510	-0.075	0.194
PMP	7146	1.401	1.354	0.864	0.386	3.992
FSC	7146	37.88	36.45	16.14	10.45	74.57
AL	7146	0.457	0.466	0.195	0.0880	0.829
FA	7146	0.238	0.195	0.174	0.0110	0.692
IC	7146	6.484	6.520	0.171	5.716	6.740

Notes: This table shows the summary statistic between the study variables which defined in [Table A3](#).

$$\text{LnTIC}_{it} = \lambda_0 + c \cdot \text{ESG} + b \text{FCI}_{it} + \Sigma \text{Control}_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (5)$$

If the coefficient a of ESG in the model (4) is significant and the coefficient b of mediator in the model (5) is significant, the mediating effect exists. Moreover, supposing the coefficient c' of ESG in model (5) is significantly positive, that indicates a partial mediating effect of the above financing constraint in driving the role of ESG on TIC.

4. Empirical results

4.1. Descriptive statistics and correlations

[Table 1](#) demonstrates that the mean value of the OTI of the samples is 2.942 and the standard deviation is 1.916, indicating enough variety within the patent counts among enterprises. The green industry (high-tech) mean value is 0.367 (0.356), indicating that most samples are non-green or non-high-tech industries. The average ESG score of 20.45 with the S.D. of 5.810, showing that the average ESG rating of the firms between 10.33 and 38.43. The average value of the financing constraint index of the sample firms is -3.803 , and the standard deviation is 0.231, implying that the sample Chinese firms generally have financing constraints. It can be seen from the descriptive statistics that there are no outliers within samples to affect the follow-up research.

[Table 2](#) reports the Pearson's correlation coefficients between ESG disclosure and innovation indicators (OTI, STI, NSTI) are 0.251, 0.250, and 0.249, respectively, and statistically significant at 1%, which can preliminary verify the correctness of hypothesis 1&4. Since the OTI includes two aspects of STI and NSTI, the correlation between these three is relatively high. From the correlation analysis of other variables, all correlation coefficients between variables are below 0.5, indicating that each variable is relatively independent, and there are no multicollinearity issues on subsequent regression. Further, we also apply the variance inflation factor (VIF) test and find that there is no multicollinearity between variables (all results of VIF are less than 0.7).

4.2. Results of the regression analysis

4.2.1. ESG disclosure and Enterprise Innovation

The results of the Hausman test show that the p-value is less than 0.05 ($\text{Prob} > \chi^2 = 0.0000$), therefore we choose the fixed-effect (FE) regression model while controlling the fixed effects of time and industry. [Table 3](#) reports the regression results of the benchmark test of ESG disclosure on TIC. Columns (1)-(3) report the effect of ESG disclosure on corporate innovation without control variables. The regression coefficients of ESG disclosure are 0.062, 0.058, and 0.057, respectively, with all coefficients statistically significant at a 1% level. The FE test shows that ESG disclosure has a significant impact on promoting OTI, STI, and NSTI. Similarly, shown in [Fig. 2](#) that co-movement exists between ESG disclosure and corporate innovation (i.e., when ESG has an upward trend, then corporate innovation also moves upward and vice versa), which indicates that enterprises with more ESG disclosure information have a positive impact on the promotion of corporate innovation and vice versa. Columns (4)-(6) report the effect of ESG disclosure on corporate innovation combined with relevant control variables. Both stability of coefficient and significance show that ESG disclosure has a significant role in promoting TIC at different levels of corporate innovation, which supports Hypothesis 1 (inline with [Bai et al., 2022](#); [Buallay, 2019](#); [Brooks and Oikonomou, 2018](#); [Fatemi et al., 2018](#); [Husted and Sousa-Filho, 2018](#); [Li et al., 2018](#); [Yu and Van Luu, 2021](#)).

4.2.2. The moderating effect of corporate characteristics

[Table 4](#) reports the moderating effect of association attributes within the promotion of innovation by ESG disclosure. Where EERE represents the green-association attribute, and both coefficients of ESG disclosure and ESG*EERE in column (2) are significant at the 1% level. Meanwhile, the increase of Adj. R^2 in comparison with column (1), this green attribute has a significant moderating effect on

Table 2
Correlation matrix.

	OTI	STI	NSTI	ESG	EERE	TECH	FCI	SIZE	ROA	PMP	FSC	AL	FA
OTI	1												
STI	0.925 ***	1											
NSTI	0.937 ***	0.786 ***	1										
ESG	0.251 ***	0.250 ***	0.249 ***	1									
EERE	-0.106 ***	-0.091 ***	-0.135 ***	0.144 ***	1								
TECH	0.229 ***	0.295 ***	0.114 ***	-0.046 ***	0.007	1							
FCI	0.115 ***	0.114 ***	0.110 ***	-0.018	-0.046 ***	0.009	1						
SIZE	0.345 ***	0.342 ***	0.359 ***	0.417 ***	0.037 ***	-0.164 ***	0.151 ***	1					
ROA	0.028 **	0.028 **	-0.001	-0.090 ***	-0.011	0.126 ***	0.045 ***	-0.144 ***	1				
PMP	0.002	0.130 ***	-0.135 ***	0.062 ***	0.077 ***	0.283 ***	-0.050 ***	-0.022 *	0.058 ***	1			
FSC	-0.00600	-0.036 ***	0.033 ***	0.073 ***	0.088 ***	-0.185 ***	0.226 ***	0.221 **	0.071 ***	-0.105 ***	1		
AL	0.134 ***	0.128 ***	0.175 ***	0.185 ***	0.015	-0.219 ***	0.002	0.508 ***	-0.493 ***	-0.106 ***	0.066 ***	1	
FA	-0.142 ***	-0.166 ***	-0.098 ***	0.130 ***	0.351 ***	-0.185 ***	0.005	0.149 ***	-0.180 ***	-0.116 ***	0.155 ***	0.155 ***	1
IC	0.079 ***	0.086 ***	0.067 ***	0.094 ***	-0.024 **	0.001	0.128 ***	0.137 ***	0.267 ***	0.022 *	0.070 ***	-0.054 ***	-0.049 ***

Notes: This table shows the Pearson correlation between the main and control variables of this study which defined in [Table A3](#).

Table 3
The promotion effect of ESG disclosure on corporate innovation: fixed effect regression.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	OTI	STI	NSTI	OTI	STI	NSTI
ESG	0.062 *** (19.16)	0.058 *** (19.36)	0.057 *** (18.28)	0.026 *** (8.25)	0.023 *** (7.95)	0.026 *** (8.51)
SIZE				0.619 *** (31.71)	0.575 *** (32.02)	0.551 *** (29.31)
ROA				1.256 *** (3.42)	1.211 *** (3.59)	1.038 *** (2.93)
PMP				-0.097 *** (-4.79)	0.123 *** (6.57)	-0.310 *** (-15.79)
FSC				-0.005 *** (-4.77)	-0.006 *** (-5.78)	-0.004 *** (-3.34)
AL				-0.123 (-1.02)	-0.067 (-0.61)	0.011 (0.10)
FA				-0.936 *** (-7.57)	-1.013 *** (-8.89)	-0.650 *** (-5.45)
IC				0.058 *** (2.72)	0.050 *** (2.58)	0.053 *** (2.60)
Constant	1.683 *** (24.54)	0.986 *** (15.54)	1.216 *** (18.34)	-11.582 *** (-28.16)	-11.537 *** (-30.49)	-10.454 *** (-26.37)
Year Fix	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fix	Yes	Yes	Yes	Yes	Yes	Yes
Obs	7146	7146	7146	7146	7146	7146
Adj. R ²	0.398	0.377	0.378	0.493	0.481	0.479

Notes: This table shows the ESG disclosure impact on promoting TIC and also at different levels of corporate innovation (OTI, STI, and NSTI). The t-statistics in parentheses, * p < 0.1, ** p < 0.05, *** p < 0.01

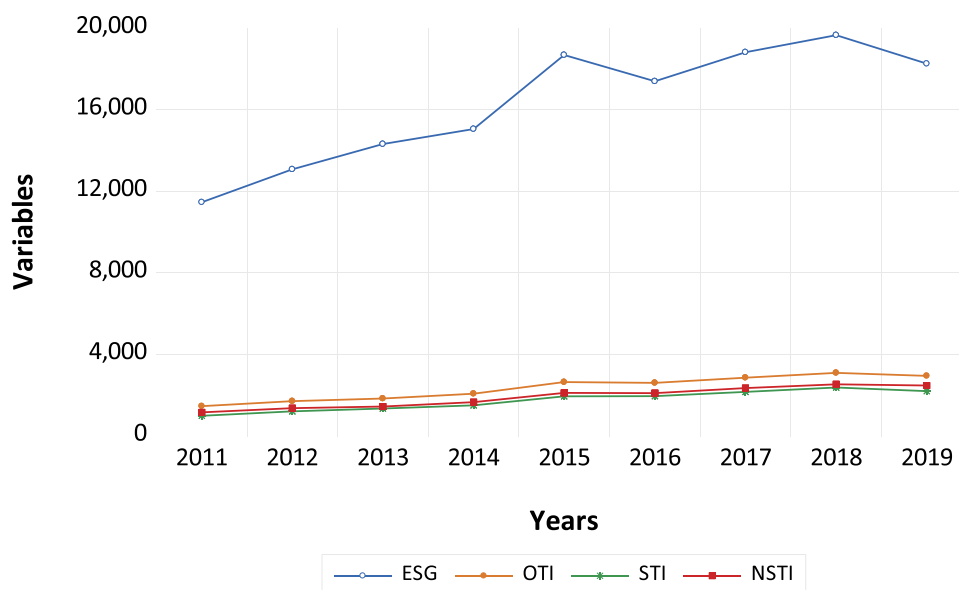


Fig. 2. ESG disclosure impact in promoting TIC at a different level of corporate innovation.

the relationship between ESG disclosure and TIC. Further, ESG disclosure in the green industry plays a weaker role in promoting the overall innovation of enterprises. In addition, similar results were obtained from the fixed effect regression of STI and NSTI. The analysis above shows that ESG disclosure of non-green industry is more effective in promoting TIC than green industry, which supports Hypothesis 2 (consistent with Song and Yu, 2018; Tolliver et al., 2021; Wang and Li, 2022; Xu et al., 2020; Bai et al., 2022; Yu and Van Luu, 2021; Yuan et al., 2021; Zhai et al., 2022; Zhang and Xu, 2019; Zhang et al., 2020; Zheng et al., 2022).

Table 5 reports the results of the moderating effect of high-tech attributes on promoting corporate innovation by ESG disclosure. The ESG disclosure coefficient in columns (2) and (4) are 0.033 and 0.028, both significant at the 1% level, while the interaction term coefficient is 0.016 and 0.012, with significance at the 5% level. Compared with columns (1) and (3), the increase of Adj. R² also indicates that the technical attributes of enterprises have a moderating effect within the promotion of ESG disclosure on OTI and STI, and it is more notable in the high-tech industry. The coefficient of ESG disclosure in column (6) is 0.033, which is statistically

Table 4
Moderating results of corporate green attributes.

VARIABLES	(1) OTI	(2) OTI	(3) STI	(4) STI	(5) NSTI	(6) NSTI
ESG	0.026 *** (8.33)	0.034 *** (8.35)	0.023 *** (8.03)	0.030 *** (8.08)	0.026 *** (8.59)	0.033 *** (8.60)
EERE	-0.847 *** (-3.69)	-0.523 *** (-2.04)	-0.771 *** (-3.64)	-0.476 ** (-2.03)	-0.742 *** (-3.35)	-0.420 * (-1.70)
ESG*EERE		-0.017 *** (-2.90)		-0.015 *** (-2.85)		-0.017 *** (-2.99)
SIZE	0.617 *** (31.67)	0.613 *** (31.40)	0.574 *** (31.97)	0.570 *** (31.71)	0.550 *** (29.26)	0.546 *** (29.00)
ROA	1321 *** (3.60)	1331 *** (3.63)	1270 *** (3.76)	1279 *** (3.79)	1095 *** (3.10)	1.104 *** (3.12)
PMP	-0.098 *** (-4.84)	-0.099 *** (-4.86)	0.122 *** (6.53)	0.122 *** (6.51)	-0.311 *** (-15.84)	-0.311 *** (-15.87)
FSC	-0.005 *** (-4.73)	-0.005 *** (-4.62)	-0.006 *** (-5.74)	-0.006 *** (-5.63)	-0.004 *** (-3.29)	-0.004 *** (-3.18)
AL	-0.106 (-0.88)	-0.105 (-0.88)	-0.052 (-0.47)	-0.052 (-0.47)	0.026 (0.22)	0.026 (0.23)
FA	-0.933 *** (-7.55)	-0.925 *** (-7.48)	-1.010 *** (-8.87)	-1.002 *** (-8.81)	-0.647 *** (-5.43)	-0.639 *** (-5.36)
IC	0.056 *** (2.63)	0.056 *** (2.65)	0.049 ** (2.50)	0.049 ** (2.52)	0.051 ** (2.52)	0.052 ** (2.54)
Constant	-11.245 *** (-26.71)	-11.296 *** (-26.82)	-11.231 *** (-28.99)	-11.278 *** (-29.10)	-10.159 *** (-25.03)	-10.210 *** (-25.15)
Year Fix	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fix	Yes	Yes	Yes	Yes	Yes	Yes
Obs	7146	7146	7146	7146	7146	7146
Adj. R ²	0.494	0.495	0.482	0.483	0.480	0.480

Notes: This table shows the moderating effect of green industries within the promotion of corporate innovation by ESG disclosure. The *t*-statistics in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5
The results of the moderating effect of enterprise technology attributes.

VARIABLES	(1) OTI	(2) OTI	(3) STI	(4) STI	(5) NSTI	(6) NSTI
ESG	0.032 *** (9.24)	0.033 *** (9.43)	0.027 *** (8.55)	0.028 *** (8.70)	0.033 *** (9.91)	0.033 *** (9.88)
TECH	-0.667 *** (-12.07)	-0.660 *** (-11.93)	-0.671 *** (-13.34)	-0.666 *** (-13.22)	-0.415 *** (-7.78)	-0.414 *** (-7.76)
ESG*TECH		0.016 ** (2.42)		0.012 ** (1.97)		0.001 (0.12)
SIZE	0.554 *** (27.51)	0.553 *** (27.46)	0.504 *** (27.50)	0.503 *** (27.45)	0.496 *** (25.51)	0.496 *** (25.50)
ROA	2216 *** (5.25)	2206 *** (5.23)	2064 *** (5.38)	2057 *** (5.36)	1931 *** (4.74)	1.930 *** (4.74)
PMP	-0.156 *** (-7.17)	-0.154 *** (-7.07)	0.097 *** (4.88)	0.098 *** (4.95)	-0.374 *** (-17.79)	-0.374 *** (-17.77)
FSC	-0.004 *** (-3.16)	-0.003 *** (-3.08)	-0.004 *** (-4.11)	-0.004 *** (-4.04)	-0.002 ** (-2.25)	-0.002 ** (-2.25)
AL	0.133 (1.11)	0.143 (1.18)	0.206 * (1.88)	0.213 * (1.94)	0.234 ** (2.01)	0.234 ** (2.01)
FA	-0.714 *** (-5.70)	-0.711 *** (-5.67)	-0.810 *** (-7.10)	-0.807 *** (-7.08)	-0.461 *** (-3.81)	-0.461 *** (-3.81)
IC	0.236 ** (2.29)	0.232 ** (2.25)	0.249 *** (2.66)	0.245 *** (2.62)	0.173 * (1.74)	0.173 * (1.74)
Constant	-11.179 *** (-15.60)	-11.159 *** (-15.58)	-11.117 *** (-17.05)	-11.102 *** (-17.03)	-10.017 *** (-14.49)	-10.016 *** (-14.49)
Year Fix	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fix	Yes	Yes	Yes	Yes	Yes	Yes
Obs	7146	7146	7146	7146	7146	7146
Adj. R ²	0.483	0.484	0.473	0.474	0.468	0.468

Notes: This table shows the moderating effect of high tech industries within the promotion of corporate innovation by ESG disclosure. The *t*-statistics in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6
Mediating role of financing constraints.

VARIABLES	(1) OTI	(2) FCI	(3) OTI	(4) STI	(5) STI	(6) NSTI	(7) NSTI
ESG	0.0283 *** (8.66)	0.0014 *** (3.03)	0.0291 *** (8.96)	0.0246 *** (8.21)	0.0254 *** (8.50)	0.0286 *** (9.12)	0.0294 *** (9.38)
FCI			0.6455 *** (7.53)		0.5761 *** (7.32)		0.5496 *** (6.65)
SIZE	0.5953 *** (29.75)	-0.0632 *** (-22.85)	0.5545 *** (26.85)	0.5503 *** (29.95)	0.5139 *** (27.09)	0.5326 *** (27.65)	0.4979 *** (25.02)
ROA	1.4331 *** (3.57)	0.1343 ** (2.42)	1.5198 *** (3.80)	1.3676 *** (3.71)	1.4450 *** (3.93)	1.2530 *** (3.24)	1.3269 *** (3.44)
PMP	-0.1045 *** (-5.02)	-0.0041 (-1.42)	-0.1072 *** (-5.17)	0.1235 *** (6.47)	0.1212 *** (6.37)	-0.3208 *** (-16.02)	-0.3230 *** (-16.18)
FSC	-0.0052 *** (-4.55)	-0.0019 *** (-12.15)	-0.0065 *** (-5.60)	-0.0057 *** (-5.42)	-0.0068 *** (-6.43)	-0.0036 *** (-3.26)	-0.0047 *** (-4.19)
AL	-0.0935 (-0.77)	0.2149 *** (12.81)	0.0452 (0.37)	-0.0237 (-0.21)	0.1001 (0.89)	0.0417 (0.36)	0.1598 (1.36)
FA	-0.8262 *** (-6.65)	0.0180 (1.05)	-0.8146 *** (-6.58)	-0.9224 *** (-8.09)	-0.9120 *** (-8.03)	-0.5572 *** (-4.66)	-0.5473 *** (-4.59)
IC	0.2624 ** (2.52)	-0.0317 ** (-2.20)	0.2419 ** (2.33)	0.2769 ** (2.89)	0.2586 ** (2.71)	0.1917 * (1.91)	0.1743 * (1.74)
Constant	-12.4767 *** (-17.48)	5.3991 *** (54.74)	-8.9916 *** (-10.60)	-12.5502 *** (-19.15)	-9.4395 *** (-12.11)	-11.0292 *** (-16.06)	-8.0617 *** (-9.86)
Year Fix	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fix	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7146	7146	7146	7146	7146	7146	7146
Adj. R ²	0.485	0.324	0.489	0.474	0.478	0.473	0.476

Notes: This table shows the mediating role of financing constraints within the promotion of corporate innovation by ESG disclosure. The t-statistics in parentheses, * p < 0.1, ** p < 0.05, *** p < 0.01

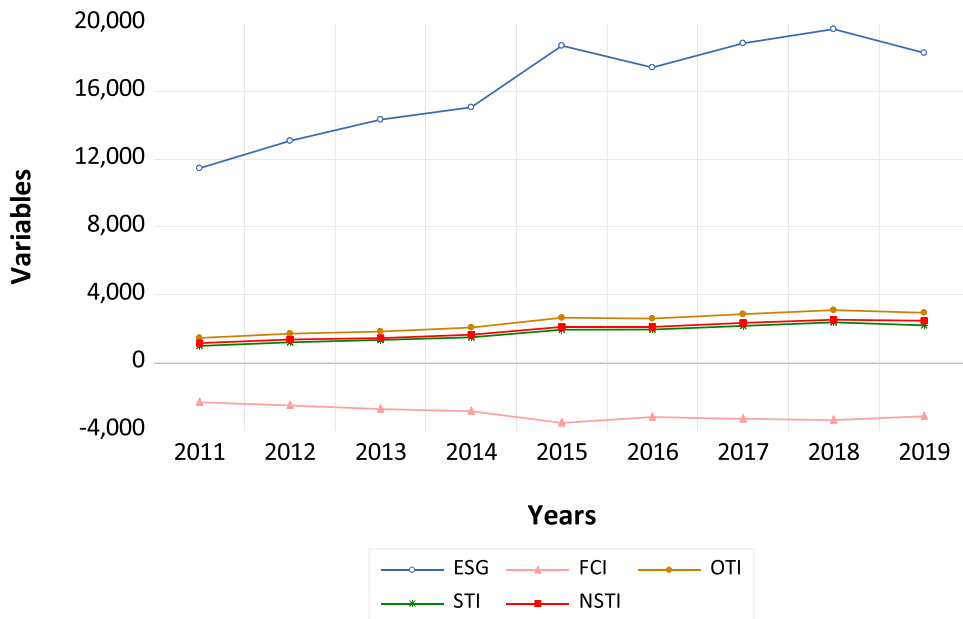


Fig. 3. Mediating role of the corporate financing constraints (FCI) between ESG disclosure and corporate innovation (OTI, STI, NSTI).

significant at 1% level, but the coefficient of the interaction term of ESG*TECH is 0.001 and statistically insignificant, indicating the high-tech attribute of enterprises have a certain impact on ESG disclosure to promote non-substantive innovation, but it is not significant. In general, ESG disclosure has a stronger role in high-tech enterprises in promoting technological innovation, especially for high-end substantive innovation, which partially supports Hypothesis 3 (inline with Ang et al., 2014; Bai et al., 2022; Tu et al., 2023).

4.2.3. Mediating role of financing constraints

Table 6 reports the results of the mediation test of financing constraints within the promotion of corporate innovation by ESG

Table 7
Robustness test of the Bootstrap method.

	Effect	Obs.	Coef.	Std.Err.	z	P > z	[95% Conf. Interval]
OTI	bs_1(ind_eff)	7146	-0.0020342	0.0004411	-4.61	0	-0.0028988 – 0.0011695
	bs_2(dir_eff)	7146	0.0457098	0.0034339	13.31	0	0.0389796.0524401
STI	bs_1(ind_eff)	7146	-0.0020814	0.0004453	-4.67	0	-0.0029542 – 0.0012087
	bs_2(dir_eff)	7146	0.040124	0.0032133	12.49	0	0.0338262.0464219
NSTI	bs_1(ind_eff)	7146	-0.0016	0.0003762	-4.25	0	-0.0023373 – 0.0008627
	bs_2(dir_eff)	7146	0.0419343	0.0034488	12.16	0	0.0351748.0486939

Notes: Sampling number = 1000

Table 8
Robustness test of the 2SLS method.

VARIABLES	First stage	Second stage		
	ESG	OTI	STI	NSTI
L2. ESG	0.743 * ** (81.389)			
ESG		0.039 * ** (7.294)	0.032 * ** (6.523)	0.040 * ** (7.834)
SIZE	0.578 * ** (10.666)	0.612 * ** (25.128)	0.570 * ** (25.190)	0.547 * ** (23.045)
ROA	2.466 * * (2.106)	0.947 * (1.875)	0.947 * * (2.018)	0.835 * (1.699)
PMP	0.124 * * (2.207)	-0.099 * ** (-4.069)	0.127 * ** (5.613)	-0.310 * ** (-13.103)
FSC	0.002 (0.776)	-0.005 * ** (-3.681)	-0.006 * ** (-4.581)	-0.003 * * (-2.469)
AL	-0.048 (-0.145)	-0.141 (-0.980)	-0.035 (-0.261)	-0.006 (-0.041)
FA	0.273 (0.813)	-0.898 * ** (-6.186)	-0.996 * ** (-7.386)	-0.627 * ** (-4.440)
IC	0.758 * (1.928)	0.491 * ** (2.886)	0.481 * ** (3.043)	0.352 * * (2.126)
Constant	-13.118 * ** (-5.100)	-15.367 * ** (-13.705)	-15.446 * ** (-14.835)	-13.211 * ** (-12.105)
Year Fix	Yes	Yes	Yes	Yes
Industry Fix	Yes	Yes	Yes	Yes
Obs	5141	5141	5141	5141
Adj. R ²	0.671	0.492	0.482	0.473
Kleibergen-Paap rk LM statistic	48.615			
Cragg-Donald Wald F statistic	132.427			
Kleibergen-Paap rk Wald F statistic	54.752			

Notes: This table using the 2SLS technique to avoid the endogeneity issues by take ESG disclosure by 2-period lag as an instrumental variable. The t-statistics in parentheses , * p < 0.1, ** p < 0.05, *** p < 0.01

disclosures. In column (2), the coefficient of ESG disclosure is significantly positive (0.0014) at the 1% level. Since the financing constraint index (FCI) is a reverse indicator, the positive coefficient indicates that ESG disclosure can significantly reduce the level of corporate financing constraints. These findings indicate that firms better ESG performance can reduce the degree of information asymmetry and financing costs, as well as alleviate the financing constraints (consistent with the findings of Bai et al., 2022; Zhai et al., 2022; Tang, 2022; Zhang et al., 2023). In column (3), the coefficient of ESG and FCI are 0.0291 and 0.6455, with a significance level of 1%, indicating ESG disclosure can promote enterprises' overall innovation capacity by reducing financing constraints. Moreover, the same results can be obtained from columns (5) and (7) on STI and NSTI. All these finding shows that financing constraints have a partial mediation effect within ESG disclosure promoting corporate innovation; that is, ESG disclosure can promote corporate innovation by reducing the level of corporate financing constraints, which can also be seen in Fig. 3, fully supporting Hypothesis 4 (also in line with the findings of Bae et al., 2021; Bai et al., 2022; Boermans and Willebrands, 2018; Ge et al., 2020; Gorodnichenko and Schnitzer, 2013; Hadlock and Pierce, 2010; Harhoff, 2000; Jin et al., 2019; Lin et al., 2017; Ma et al., 2018; Tang, 2022; Wan et al., 2020; Zhai et al., 2022; Zhang et al., 2023; Zhang et al., 2020).

In order to make an interval estimation, the Bootstrap test has become a necessary methodology in mediation effect verification (Lu and Sun, 2022). The regression results of OTI, STI, and NSTI are shown in Table 7, all confidence intervals of direct effects and indirect effects do not contain 0, indicating significant intermediary path of financing constraints. So, the mediating effect of FCI within the positive impact of ESG disclosure on TIC is further verified, which fully support our Hypothesis 4 (Bai et al., 2022; Tang, 2022; Zhai et al., 2022).

Table 9
Robustness test of the GMM method.

VARIABLES	FCI	OTI	STI	NSTI	OTI	STI	NSTI
ESG	0.001 *** (3.25)	0.032 *** (3.86)	0.028 *** (3.92)	0.030 *** (3.33)	0.029 *** (3.59)	0.024 *** (3.46)	0.029 *** (3.24)
FCI					0.465 *** (2.79)	0.783 *** (5.48)	0.360 * (1.91)
SIZE	0.002 (0.76)	0.009 (0.30)	0.006 (0.24)	0.026 (0.74)	0.110 ** (2.38)	0.157 *** (4.32)	0.097 * (1.93)
ROA	0.017 (0.64)	3.172 *** (3.23)	2.689 *** (2.99)	2.765 *** (2.59)	2.932 *** (2.96)	2.408 *** (2.67)	2.843 *** (2.67)
PMP	-0.001 (-0.67)	0.171 *** (1.70)	0.181 *** (4.50)	0.141 *** (3.07)	0.189 *** (4.31)	0.216 *** (5.41)	0.154 *** (3.38)
FSC	0.001 (0.83)	-0.0152 *** (-2.74)	-0.005 (-1.12)	-0.018 *** (-2.99)	-0.012 ** (-2.14)	-0.005 (-1.11)	-0.016 ** (-2.54)
AL	0.021 * (1.93)	0.859 * (1.79)	0.576 (1.53)	0.974 * (1.74)	0.721 (1.58)	0.262 (0.77)	1.050 ** (2.04)
FA	-0.062 *** (-4.32)	-0.945 * (-1.89)	-1.108 *** (-2.88)	-1.107 ** (-2.09)	-1.311 *** (-2.82)	-1.291 *** (-3.59)	-1.377 *** (-2.77)
IC	-0.005 * (-2.08)	0.064 (0.75)	0.020 (0.32)	-0.010 (-0.11)	-0.013 *** (-0.16)	-0.028 (-0.53)	-0.064 (-0.71)
Constant	1.017 *** (113.49)	0.598 *** (16.02)	0.599 *** (18.41)	0.506 *** (12.83)	0.577 *** (15.54)	0.580 *** (18.57)	0.496 *** (12.62)
Year Fix	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fix	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	5133	5133	5133	5133	5133	5133	5133
AR (1)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AR (2)	0.642	0.001	0.003	0.005	0.001	0.004	0.005
Sargan	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hansen	0.092	0.307	0.146	0.477	0.527	0.276	0.655

Notes: This table used the GMM technique to verify the main regression results of the study. The t-statistics in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.3. Robust test

To avoid the endogeneity caused by the mutual causality between ESG disclosure and corporate innovation, we referred to (Hs and Fei, 2021; Duan and Zhuang, 2021) to take ESG disclosure by 2-period lag as an instrumental variable. A two-stage lagged instrumental variable is not high-correlated with the current period disturbance term since it already happened, which can effectively satisfy the requirement on exogeneity of correlation. Table 8 reports the regression results of the two-stage least squares (2SLS) method by instrumental variable, which shows the coefficient of one-stage regression L2. ESG in column (1) is 0.743 and passes the significance test at 1% level. Meanwhile, the Kleibergen-Paap LM statistic is 48.615, corresponding to a p -value of 0, indicating that the instrumental variable is identifiable. And the Cragg-Donald Wald F-statistic of 132.427 is much greater than the Stock-Yogo critical judgment value of 16.38 at the 10% level, so there is no weak instrumental variable issue. The regression coefficients of ESG on all three levels of TIC in columns (2)-(4) are significantly positive at the 1% level, which is consistent with the baseline regression results, further verifying the robustness of our main regression (consistent with Bai et al., 2022; Buallay, 2019; Brooks and Oikonomou, 2018; Fatemi et al., 2018; Husted and Sousa-Filho, 2018; Li et al., 2018; Yu and Van Luu, 2021).

Our study scientific contribution involves the two-step generalized method of moments (GMM) method based on the weak instrumental variable test of 2SLS first order regression. We further introduce the mediating variable of FCI to conduct the dynamic panel data estimation by GMM regression. The robustness results of Table 9 are consistent with the main test, where the effect of FCI on NSTI is significant at 1%, and the mediating effect of FCI on NSTI is lower than that of STI and OTI.

5. Discussion

Several recent studies discuss the significant impact of ESG disclosure on default risk (Atif and Ali, 2021), firm performance (Bizoumi et al., 2019; Bissoondoyal-Bheenick et al., 2023; Buallay, 2019; Khan, 2022), sell-side analyst's prices (Bolognesi and Burchi, 2023), Firm value (Brooks and Oikonomou, 2018; Fatemi et al., 2018; Li et al., 2018), Board structure (Husted and Sousa-Filho, 2018), cost of debt financing (Raimo et al., 2021), reporting quantity, quality, and performance (Arvidsson and Dumay, 2022), cost of internal control system (Harasheh and Provasi, 2022), Board diversity (Buallay et al., 2022; Husted and Sousa-Filho, 2018; Nadeem et al., 2017; Lozano and Martínez-Ferrero, 2022), stock liquidity (Meng-tao et al., 2023), firm characteristics, corruption, and political rights (Yu and Van Luu, 2021); and technological innovation capabilities impact on uncertainty (Wang et al., 2008), regional and firm innovation system (Yam et al., 2011), Financial investment (Duan and Zhuang, 2021), innovation audit (Yam et al., 2004), firm Performance (Cheng and Lin, 2012), High-tech industries development (Tu et al., 2023). Given that, our study contributes to this piece of evidence by analyzing the impact of ESG disclosure on technological innovation capabilities by taking the data of Chinese listed firms from 2011 to 2019. We find that ESG disclosure has a significant association with corporate innovation and plays an important

role in promoting firms' technological innovation capabilities at different levels of corporate innovation, which is in line with the studies (Bai et al., 2022; Buallay, 2019; Brooks and Oikonomou, 2018; Fatemi et al., 2018; Husted and Sousa-Filho, 2018; Li et al., 2018; Yu and Van Luu, 2021). Further, we analyze whether the corporate characteristics (Green vs. high-tech industry) can modify the relationship between ESG disclosure and TIC. We find that ESG disclosure of non-green industry more effectively promotes TIC than the green industry, consistent with Tolliver et al. (2021); Wang and Li (2022); Bai et al., 2022; Yu and Van Luu, 2021; Yuan et al. (2021); Zhai et al., 2022; Zhang and Xu (2019); Zhang et al., 2020; Zheng et al. (2022). However, ESG disclosure has a stronger role in high-tech enterprises in promoting technological innovation capabilities, especially for high-end substantive innovation, in line with the findings of (Ang et al., 2014; Bai et al., 2022; Tu et al., 2023). Finally, recently many scholars have explored the connection between financing constraints and R&D investment (Harhoff, 2000), ESG firm performance (Zhang et al., 2023), borrowing behavior, microfinance and firm productivity (Boermans and Willebrands, 2018), Chinese environmental regulation and export green-sophistication (Ge et al., 2020), corporate innovation (Gorodnichenko and Schnitzer, 2013; Wan et al., 2020), alternative KZ index measures (Hadlock and Pierce, 2010), firm productivity (Jin et al., 2019), agency costs and corporate R&D investment (Lin et al., 2017); firm technological innovation (Ma and Hou, 2018), ESG performance (Zhang et al., 2023), ESG performance and corporate innovation (Tang, 2022; Zhai et al., 2022), green innovation (Zhang et al., 2020), ESG and stock price crash risk (Bae et al., 2021), ESG and institutional investors' preference (Bai et al., 2022), so we examine whether ESG disclosure improve technological innovation capabilities by alleviating financing constraints. Our findings indicate that ESG disclosure can promote corporate innovation by reducing the level of corporate financing constraints, and the financing constraints have a partial intermediary role between the relationship of ESG and TIC, which is in line with the findings of (Bae et al., 2021; Bai et al., 2022; Boermans and Willebrands, 2018; Ge et al., 2020; Gorodnichenko and Schnitzer, 2013; Hadlock and Pierce, 2010; Harhoff, 2000; Jin et al., 2019; Lin et al., 2017; Ma et al., 2018; Tang, 2022; Wan et al., 2020; Zhai et al., 2022; Zhang et al., 2023; Zhang et al., 2020). Overall, our findings align with developed markets (i.e., USA, Europe) or emerging markets (i.e., China). Since sustainable development performance mainly involves environmental performance and social responsibility performance (Alexopoulos et al., 2018), this study explores the mechanism by which the guidelines affect the ESG (Sustainable Development) performance of innovation-driven start-ups through financing costs, enriching and expanding the sustainable development theory that emerged at the end of the last century. Further, our study contributes to a better understanding of ESG practices in emerging countries.

6. Conclusions, policy enlightenment, limitations, and future prospects

6.1. Conclusions and policy enlightenment

Nowadays, ESG is receiving greater attention from businesses, investors, and regulators due to the global ESG investment market's rapid growth. ESG performance can be used to evaluate a firm's commitment to sustainable business practices. However, the validity of ESG performance is still debatable in the current literature, with most of these studies concentrating on the effects of ESG performance in developed economies (Khan, 2022). Nevertheless, there is a lack of studies investigating the function of ESG performance and its connection to corporate technological innovation in emerging economies. This study contributes to the current literature on developed and emerging economies about corporate innovation behavior and sustainable development. Our framework provides further theoretical and empirical support for the prior research on the efficacy of ESG practices and corporate innovation. Given that, by using the Bloomberg's ESG disclosure score of the China's A-share listed companies from 2011 to 2019, we explore the impact of ESG disclosure on technological innovation capabilities (TIC) promotion and the mediating effect of financial constraints index (FCI). The findings show that 1) better ESG promoting TIC at different levels of corporate innovation, which is more effective in the non-green than green industry. 2) better ESG can significantly promote technological innovation in high-tech enterprises, especially for high-end substantive innovation. 3) better ESG disclosure can promote corporate innovation by reducing the level of corporate financing constraints, and FCI has a partial intermediary role in their relationship. Since the high-risk nature of innovative behavior and the instability of related return, investors cannot accurately evaluate sustainability prospects, which in turn exposes firms to higher financing constraints (Bai et al., 2023; Zhang et al., 2023). ESG disclosure provides critical information to assess sustainability performance by adding value for internal and external decision-making (Harasheh and Provasi, 2022), which enables firms to facilitate corporate technological innovation (Tu et al., 2023) by alleviating financing constraints (Zhang et al., 2023). Meanwhile, ESG disclosure has a more significant impact on technological innovation within non-green and high-tech industries, and this fact may be because listed companies among those industries have stronger technological motivation and higher technological requirements in China (Zhang and Xu, 2019; Wang, 2020). In general, our findings verified the internal mechanism of financing constraints on the relationship between ESG and TIC by exploring the differential moderating effect of the affiliated nature of enterprises. As the key driving factor for firms to enhance their business value and maintain their core competitiveness, ESG action has become a general consensus in society to promote firm transformation, upgrading, and high-quality development by implementing innovation strategies. Therefore, investors have begun to emphasize evaluating the link between non-financial information—including ESG disclosure—and firms' exposure to both opportunities and risks. Along with this trend, it has become even more crucial for enterprises to generate value for all stakeholders and communicate with their investors and other stakeholders about the value-creation process. In order to address sustained economic growth, climate change, and environmental externalities (Tolliver et al. (2021) suggest that enterprises' promotion of ESG disclosure and environmentally adjusted multi-factor productivity growth has an impact on the transitions toward sustainable growth paradigms. Our results reveal that better ESG disclosure might foster greater enterprise technological innovation by lifting enterprise financing constraints in the quest for sustainable development. Relevant managerial and policy implications are as follows:

First, enterprises should strengthen their ESG practices and improve their ESG ratings. Enterprises should endorse the ESG concept

in project investment, staff training, and product development; actively engage in social responsibility, cultivate environmental awareness, strengthen internal governance and enhance investment efficiency that increase their competitiveness and help them achieve sustainable development. Additionally, enterprises should make a concerted effort to enhance capital investment in the ESG field and vigorously work to improve the ESG disclosure and use its related information in order to improve enterprise ESG performance, achieve higher market evaluation, ease financing constraints, strengthen enterprise reputation and then enhance the efficiency of enterprise investment. Moreover, the enterprises should expand their information disclosure to gain a better return on their ESG investment; so, the creditors, investors, and other stakeholders can better understand the enterprise's ESG rating in a timely and appropriate manner and support their further growth. This initiative can strengthen the firm's core competitiveness and enhance long-term value (Bolognesi and Burchi, 2023). According to Arvidsson and Dumay (2022), analysts are placing more demands on Chinese enterprises to give higher-quality ESG data⁶ in order to modify the link between information asymmetry and sustainable corporate performance; ultimately, capital flows will be redirected and accelerated toward business investments that support to attain sustainable growth (i.e., green innovation). Lastly, the firms should strive to accomplish technological innovation in line with high-quality development; then they should have a forward-looking perspective on technological innovation and realize transformation and upgrading as soon as conceivable (all the above arguments consistent with the sustainable development theory).

Second, in order to tackle the financial constraints, the banks and other financial institutions should implement responsible investing based on ESG concepts; strictly following the relevant regulations of the guidelines, and conduct a scientific and systematic comprehensive evaluation of the enterprises and projects to be loaned and restrict the loans of green enterprises and finally act as external regulators of enterprises to promote sustainable corporate development. In ESG policy assessment, they should track the loan receiving enterprises and loan projects, check the use of funds throughout the process, strictly prevent the diversion of green credit funds to other non-green projects, and truly ensure that green credit funds are used for green innovation and promote the green transformation of enterprises. According to Meierrieks (2015), a country's ability for innovation may be strengthened by economic measures that enhance its financial system. Given that governments may encourage foreign and social capital in firm innovation via financial advice and pertinent regulations. To expand financing options, the government should foster financial organizations (i.e., finance and leasing firms and trust; Ge et al., 2020), along with supporting different approaches (i.e., industry chain finance and Internet finance etc.) to ease the firm's financial constraints and as a result, decrease the firms financing cost (all these above consistent with the stakeholder theory and resource theory).

Third, the governments encourage investment in green financial infrastructure by prioritizing the dual functions of green financial products (i.e., debt financing in environmental conservation and economic development, Feng and Shen, 2022). Many international organizations, stock exchanges, and government regulatory authorities have developed mature ESG information disclosure standards, such as the United Nations Sustainable Development Goals (SDGs) and GRI Standards, which are widely used internationally. Given that to provide more efficient financial services in sustainable fields (i.e., green innovation), the Chinese government must steadily strengthen ESG laws and rules and efficiently stimulate investors, analysts, and other relevant stakeholders to engage in sustainable and low-carbon production and life. However, the external system has to be further upgraded as the Chinese market is currently in an emerging and transitional stage. The policy-making and regulatory agencies must enhance and upgrade the ESG information disclosure system of listed firms and establish an evident and viable green financial standard system with global standards, ESG ratings, local units, and pertinent information disclosure requirements. Meanwhile, apart from government efforts, social participation—including that of non-governmental entities, the media, the public, and other stakeholders—must be eased in order to observe corporate ESG conduct and foster a sense of mutual collaboration among all participants.

Lastly, the capital market system has to be enhanced to stimulate the efficient flow of information between the enterprises and the capital market; support the efficient and thorough dissemination of information about corporate governance, social responsibility, and the company environment to the capital market; decrease capital allocation frictions; reduce information asymmetry both internally and externally, overcome firm financial issues; and decisively promote companies technological innovation (in line with the signalling theory). These initiatives can accelerate corporate innovation and ignite the microscale underpinnings of high-quality economic growth.

6.2. Research limitations and future prospects

As for this study's limitation and future direction, we focused on Chinese-listed firms so that future research may be extended to green development studies of other emerging economies and compare the findings. Additionally, our sample firms are Chinese-listed firms, so future researchers can extend the analysis to non-listed firms (i.e., private companies or family businesses). Further, the financial constraint mediates the positive association of ESG and TIC, so future studies may consider other mediating factors (i.e., CEO characteristics and investors' reactions, etc.) for Chinese or international enterprises. Finally, future researchers can alter the model to consider the present pandemic scenario and empirically investigate how COVID-19 will affect technological innovation and ESG disclosure.

⁶ The majority of corporate ESG data are provided by data providers, which significantly impacts the data's usefulness given the various ESG standards adopted. Therefore, in China, to better exhibit the true ESG condition of enterprises; the Chinese ESG rating agencies should gradually enhance two-way communication with the experienced international ESG rating agencies and encourage the formation of an ESG assessment system that complies with national conditions and also internationally compatible.

Table A1
Subcategories of the green industry.

N	Code	Industry	No. of firms	Percent (%)
1	A01, A03, A04, A05	Agriculture, forestry, animal, and fishery	20	5.27%
2	B06, B08, B09, B11	Mining industry	29	7.65%
3	C15	Liquor, beverage, and refined tea manufacturing	22	5.80%
4	C21	Wood processing	1	0.26%
5	C22	Paper making and paper products	12	3.17%
6	C23	Printing and recording media copying	4	1.27%
7	C25	Oil and gas processing, cooking, and nuclear fuel processing	8	2.11%
8	C26	Chemical materials and products	68	17.94%
9	C27	Pharmaceutical products	74	19.53%
10	C28	Chemical fibers	10	2.64%
11	C29	Rubber and plastic products	14	3.69%
12	C31	Metallurgy industry of black metals	17	4.49%
13	C32	Metallurgy industry of nonferrous metals	32	8.44%
14	C33	Metallic mineral products	10	2.64%
15	C35	Special equipment manufacturing sector	16	4.22%
16	D44	Electric power and hot power production	34	8.97%
17	D45	Gas production and supply industry	5	1.32%
18	D46	Waste resources and materials recycling and processing	3	0.79%
TOTAL			379	100%

Table A2
Subcategories of the high-tech industry.

N	Code	Industry	No. of firms	Percent (%)
1	C26	Chemical raw materials and chemical products manufacturing	85	23.88%
2	C27	Pharmaceutical industry	70	19.66%
3	C35	Special equipment manufacturing	62	17.42%
4	C37	Manufacturing of railway, marine, aerospace, and other transportation equipment	42	11.80%
5	C39	Computer communications and other electronic equipment manufacturing	38	10.67%
6	C40	Instrument manufacturing	17	4.78%
7	I63	Telecommunications, radio, television and satellite transmission services	13	3.65%
8	I64	Internet and related services	9	2.53%
9	I65	inspection and testing services	8	2.25%
10	M73	Research and experimental development	7	1.97%
11	M74	Professional technology service	3	0.84%
12	M75	Science and technology extension and application services	1	0.28%
13	N77	Ecological protection and environmental management	1	0.28%
TOTAL			356	100%

Table A3
Variable definition.

Type	Symbol	Variable	Description
Explained variable	OTI	Overall technological innovation	Ln (total number of patents application + 1)
	STI	Substantial technological innovation	Ln (number of invention patents + 1)
Explanatory variables	NSTI	Non-substantial technological innovation	Ln (utility model patent + design patent + 1)
	ESG	ESG disclosure	Scores from 0 to 100
Moderator	EERE	Green industry	Green industry= 1, Else= 0
	TECH	High-tech industry	High-tech industry= 1, Else= 0
Mediating variable	FCI	Financing Constraint Index	$FCI = -0.737 * Size + 0.043 Size^2 - 0.04 Age$
Control variable	SIZE	Firm size	The natural log of total assets
	ROA	Return on total assets	Net Profit/total Asset
	PMP	Patent maintenance period	Time from patent application to termination
	FSC	First shareholder concentration	The ownership of the largest shareholder
	AL	Assets and liabilities	Total liabilities/Total assets
	FA	Fixed assets	Fixed assets/Total assets
	IC	Internal control	Natural logarithm of internal control scores

Ethics approval statement

This article does not contain any studies with human participants or animals performed by any of the authors.

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Declaration of Competing Interest

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

Data Availability

Data will be made available on request.

Appendix A

See Tables A1-A3.

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