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The effect of ESG performance on open innovation: Evidence from China

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ABSTRACT

This study aims to explore the link between corporate Environmental, Social, and Governance (ESG) performance and the practices of open innovation within firms, as well as investigating the underlying mechanisms. It employs data from China's A-share listed companies spanning the period 2018–2023, comprising a final sample of 17,250 firm-year observations. This research relies primarily on fixed-effects OLS regressions for model estimation. The results reveal that stronger ESG performance significantly enhances corporate open innovation. Concurrently, that ESG performance promotes open innovation is partly mediated by alleviating financing constraints. Further investigation indicates that each dimension of ESG independently enhances open innovation capability, with financing constraints also mediating these individual linkages. These findings bear important implications for economic modeling: first, by internalizing ESG as a non-financial factor, they enrich theoretical models of corporate innovation decisions; second, by developing a resource-channel model with financing constraints as the core mediator, they strengthen the explanatory power of the green–innovation linkage. Accordingly, policy efforts should focus on integrating ESG criteria into national open innovation incentives, developing ESG-linked financial instruments to lower capital costs, and establishing mandatory ESG disclosure. These measures aim to fully harness ESG's direct and indirect benefits for open innovation.

Contribution/ Originality: This research stands out by filling the literature gap by linking ESG performance with open innovation, emphasizing financing constraints as a mediating pathway. To the best of our knowledge, this is the first study of its kind to introduce the perspective of open innovation into the model linking ESG performance to corporate innovation.

1. INTRODUCTION

Nowadays, open innovation (OI) has gradually become an important catalyst for companies seeking sustainable management (Gangi, Daniele, Tani, & Papaluca, 2025). It has attracted widespread attention from academia and deep involvement from the business community (Mariani, Trivellato, Martini, & Marafioti, 2022). Concurrently, the closed innovation paradigm poses significant challenges in addressing the mounting complexity of technological activities that have emerged from a century of progressive change. Consequently, open innovation has gradually become an important path to break through key core technologies and achieve high-quality development of firm performance (Al Nuaimi, Singh, & Ahmad, 2024; Audretsch, Belitski, Caiazza, & Siegel, 2023; Inauen & Schenker-Wicki, 2011). An increasing number of firms are choosing to build cooperative networks to share resources with

external entities to achieve complementary advantages in knowledge and technology, thereby enabling open innovation through integrating external expertise and resources into their innovations (Meng et al., 2023; Zou, Qi, & Xie, 2025).

According to the Open Innovation Barometer, 90% of companies will actively adopt or plan to deploy open innovation strategies through cross-border cooperation by 2025 (The Economist Group, 2022). Functioning as an effective means to obtain social capital from networks, open innovation accelerates the pace of innovation by using external resources to bridge internal capability gaps (Al Nuaimi et al., 2024; Battistella, Ferraro, & Pessot, 2023; Zou et al., 2025). Simultaneously, open innovation promotes risk sharing and cost sharing between enterprises and their partners, further driving sustained collaborative engagement (Liu, Deng, & Pan, 2025).

However, the implementation of open innovation continues to face persistent challenges, particularly related to partner incentive misalignment and unintended knowledge spillovers (Zou et al., 2025). The inherent multi-party collaboration and information-sharing characteristics of OI inevitably increase organizational coordination costs and management complexity (Dabić, Daim, Bogers, & Mention, 2023; Rossoni, de Vasconcellos, & de Castilho Rossoni, 2024).

Given the difficulty in constructing an innovation system that effectively balances the interests of multiple stakeholders, many corporate open innovation initiatives remain limited to non-core domains or short-term pilot projects, thereby constraining the realization of their theorized synergistic and value-added potential (Gegenhuber, Mair, Lührsen, & Thäter, 2023; Liu et al., 2025). Identifying the key drivers for the successful implementation of open innovation has therefore become a critical research objective (Tan, 2025).

In China, the national development strategy emphasizes open cooperation in science and technology innovation as a core element of its strategic priorities, highlighting the importance of open innovation (OI) (Chi, Ren, Li, & Yang, 2024). The proposal of "new-quality productive forces" by President Xi Jinping in September 2023 emphasizes growth driven by innovation and the pursuit of high-quality development. This is highly consistent with the guiding principles of the new development pattern, which prioritizes innovation, coordination, green development, openness, and shared benefits proposed in the 14th Five-Year Plan, highlighting the urgent need for China's economy to be driven by innovation and sustainable practices (Deng, Chen, & Zhang, 2023; Yang, Zhu, & Albitar, 2024).

Open innovation is identified as a strategic priority for development (Deng et al., 2023). Nowadays, OI has become not only the major form of enterprise innovation but also a core concept underpinning China's broader economic development strategy (Li, Xu, Wu, Hong, & Skare, 2023). Enhancing open innovation sustains a competitive advantage, constituting a critical research priority (Liang & Li, 2023). However, China ranked 11th in the 2024 Global Innovation Index, which is not in line with its standing as the world's second-largest economy. The innovative performance of enterprises, as the core driving force of the national innovation ecosystem, is crucial to enhancing national competitiveness (Agazu & Kero, 2024).

Compared with closed innovation, the transition to open innovation accelerates innovation output through the integration of external resources. This collaborative relationship with complementary partners has proven to be a key factor in achieving innovation outcomes of higher quality and greater influence (Majchrzak, Bogers, Chesbrough, & Holgersson, 2023). Consequently, investigating the critical determinants of open innovation in China holds paramount importance (Audretsch et al., 2023).

Concurrently, the widespread adoption of sustainable development principles has prompted researchers to closely examine the economic benefits of ESG practices and their role in corporate innovation models (Hao, Alharbi, Hunjra, & Zhao, 2025). ESG originated from the concept of socially responsible investment (SRI) and represents an investment strategy and set of values that integrate environmental, social, and corporate governance performance as central components of decision-making (Ahmad, Yaqub, & Lee, 2024; Richardson, 2009). Integrating ESG factors into innovation decision-making not only drives innovation and sustainable progress but also is essential for

addressing global challenges, facilitating national economic transformation, and fostering international cooperation (Yang, Li, Qiu, Wang, & Liu, 2024). An effective ESG strategy helps companies establish positive interactions with stakeholders, making it easier to obtain key external resources such as necessary capital, advanced technology, and skilled talent (Lei, Deng, & Chin, 2025; Taliento, Favino, & Netti, 2019). The effective implementation of open innovation depends on external resources such as policies, funding, and supply chains (Phonthanukitithaworn, Srisathan, Ketkaew, & Naruetharadhol, 2023). Therefore, ESG has the potential to be positioned as a significant driver of open innovation.

Existing studies have validated the connection between ESG and innovation through the lens of green innovation (Yang, Yang, Zhou, & Liu, 2024), technological innovation (Zhang, Li, Ji, & Xie, 2024), or aggregate innovation (Li & Li, 2024). They also point out from a theoretical perspective that ESG concepts can promote social openness, optimize the allocation of social capital, and thereby drive open innovation (Song & Sun, 2024). However, there is a lack of empirical studies that integrate open innovation into research models examining the relationship between ESG and corporate innovation (Zou et al., 2025). Most studies have focused on corporate social responsibility (CSR), a single dimension of ESG, rather than adopting a comprehensive ESG framework (Cai, Gu, & Wu, 2025). Furthermore, existing research on the role of CSR (as part of ESG) in open innovation generally ignores the possible mediating mechanism of financing constraints (Zou et al., 2025). Therefore, this study introduces open innovation into the ESG-corporate innovation analytical framework and develops a "resource-channel model" with financing constraints as the core mediator.

Drawing on panel data from Chinese listed companies (2018-2023), the empirical model specification tests the relationship between overall ESG performance and open innovation, incorporating financing constraints as a mediator. The model is subsequently extended to disentangle the separate influences of the environmental, social, and governance pillars. Compared with previous studies, this research offers a number of contributions to existing literature.

First, this study focuses on a new perspective by incorporating ESG performance into the modeling of open innovation, which is an area that has been neglected in existing ESG-innovation literature. This not only enriches the driving factors of open innovation from the perspective of green governance effectiveness but also strengthens the foundations for economic modeling of open innovation dynamics.

Second, the study uses financing constraints as a key intermediate variable to reveal underlying mechanisms, enriching the modeling of the interaction between ESG, financial frictions, and firms' innovation outcomes, offering greater explanatory power for the green–innovation linkage.

Third, a disaggregated assessment of the E, S, and G factors is undertaken, revealing the non-uniform influence each dimension exerts on open innovation processes, which enhances the precision of the empirical model and supplies an empirical foundation for calibrating parameters in future theoretical models.

The rest of this study is organized as follows. Section 2 reviews the relevant literature and develops the research hypotheses. Section 3 outlines the research design. Section 4 presents the main empirical findings. Section 5 discusses the results of heterogeneity analysis. Finally, Section 6 concludes with a summary of key insights and their implications.

2. LITERATURE REVIEW AND HYPOTHESIS CONSTRUCTION

2.1. Overview of Research Linking ESG and Innovation

A growing body of research has explored the connections between ESG performance and different types of innovation, including green innovation (Wang, Ma, Dong, & Zhang, 2023; Yang et al., 2024) overall innovation (Li & Li, 2024) and technological innovation (Chen, Khurram, Gao, Abedin, & Lucey, 2023; Zhang et al., 2024). ESG practices have been shown to enhance green innovation outcomes by alleviating financing constraints, reducing information asymmetry, and improving access to key resources (Wang et al., 2023; Yang et al., 2024). While some

studies report nonlinear effects, such as a U-shaped pattern linking ESG ratings and green innovation (Yang et al., 2024). Regarding overall innovation, existing research shows that proactive ESG signaling enables firms to secure policy support (Wan, Fu, & Zhong, 2024), reduces financing constraints and agency costs (Tang, 2022), and enhances human capital, thus collectively driving innovation efficiency (Wan et al., 2024). As for technological innovation, good ESG performance helps enhance organizational legitimacy and convey positive social signals, secure key resources for technological innovation, reduce information asymmetry with stakeholders, lessen financing constraints, and thereby facilitate technological innovation (Yang et al., 2024; Zhang et al., 2024). In a timely investigation, Hao et al. (2025) demonstrated that ESG performance can remarkably enhance digital technology innovation.

Against this backdrop of open innovation emerging as a key catalyst for sustainable management, a growing scholarly effort is dedicated to theorizing its relationship with ESG. Song and Sun (2024) theoretically explore how the ESG concept empowers social openness, promotes rational allocation of social capital, and encourages open innovation. However, a review of relevant literature reveals that there are few empirical studies investigating ESG's influence on open innovation. Existing limited work has primarily focused on an isolated dimension, such as CSR, without thoroughly examining the comprehensive effect of the full ESG framework (Cai et al., 2025).

2.2. Corporate ESG Performance and Open Innovation

Successful open innovation relies on policy support, financial investment, and key external resources such as supply chains (Phonthanukitithaworn et al., 2023). In view of the social capital theory, valuable, scarce, and difficult to imitate and replace information and resources can often be obtained from stakeholder networks, and such resources embedded in inter-company relationship networks are called corporate social capital (Wacquant & Bourdieu, 1992). The core of open innovation lies in establishing close ties with diverse stakeholders and building an efficient resource flow mechanism (Ozdemir, de Arroyabe, Sena, & Gupta, 2023), which coincides with ESG philosophy. Under the dual support of stakeholder theory and social capital theory, actively implementing ESG initiatives can enhance social acceptance by meeting stakeholder expectations and integrating diverse resources (Taliento et al., 2019), thereby effectively driving the process of open innovation.

In environmental performance (E), the company's environmental protection efforts are not only a catalyst for expanding external innovation cooperation opportunities but also a key factor in fostering open innovation outcomes (Sarango-Lalangui, Castillo-Vergara, Carrasco-Carvajal, & Durendez, 2023). Companies actively fulfilling their environmental responsibilities can help them obtain various external support from other stakeholders. These forms of support provide firms with greater opportunities to establish collaborative links with universities, research institutes, and state-owned enterprises. These external knowledge acquisition platforms serve as critical, though often intangible, drivers for enhancing a corporate open innovation capability (Zou et al., 2025).

In social performance (S), proactive social responsibility fulfillment strengthens corporate reputation and cultivates stakeholder relationships (Yang et al., 2024). These ties directly facilitate access to innovation resources and increase key stakeholder participation in open innovation (OI), thereby advancing OI processes (Cai et al., 2025). Social responsibility practices enhance investor confidence (Abdel Magid, Hussainey, De Andrés, & Lorca, 2023) and reduce information risk premiums and financing costs (Ge, Cheng, Niu, & Yang, 2024), thereby accumulating the necessary funds for open innovation. It can also cultivate customer trust (Han & Lee, 2021) and promote deep customer involvement in product and service co-creation (Zhou, Wang, & Zhao, 2020), thereby promoting open innovation. Social responsibility practices can help strengthen supply chain collaboration, helping organizations gain access to external insights offered by stakeholders, which not only enriches their internal knowledge base but also fosters broader knowledge sharing and dissemination (Zhang & Liu, 2023) and promotes open innovation. In addition, social responsibility practices can attract high-quality scientific and technological talent, expand exchanges with knowledge-intensive institutions, and reshape corporate knowledge systems and

innovative thinking (Zhang & Liu, 2023). This will ultimately lead to the effective gathering of all kinds of diverse social capital needed to drive open innovation.

In governance performance (G), governance-oriented firms not only demonstrate a stronger commitment to environmental and social responsibilities but also actively cultivate stakeholder trust. Such alignment increases the likelihood of harmonizing managerial and stakeholder interests and enhances their capacity to secure critical resources (Zhang, Loh, & Wu, 2020), which is instrumental to open innovation. Companies with good corporate governance will adopt appropriate reward and control mechanisms, which could mitigate open innovation risks arising from misaligned management motives and stakeholder interest asymmetries, institutionalize open innovation, and thereby promote open innovation (Shaikh & Randhawa, 2022). Therefore, this reasoning leads to the proposition of the following hypothesis.

H_1: ESG performance is significantly and positively correlated with open innovation.

2.3. The Intermediary Function of Financing Constraints in the ESG–Innovation Link

As a high-risk, long-term professional R&D activity, open innovation by enterprises is highly dependent on continuous capital investment, and strong financing capabilities are key to ensuring its success. Empirical research shows that financing constraints directly curtail the innovation level of enterprises (Milani & Neumann, 2022). Actively fulfilling ESG responsibilities can help firms better seek financial support from external stakeholders and is an important way to alleviate the financial constraints of open innovation.

Firstly, the company's active fulfillment of environmental responsibility is highly compatible with the policy guidelines of ecological civilization construction and the new development concept, which is conducive to getting along with the government and enhancing its political legitimacy, and is expected to win government subsidies for the company, which eases the financing constraints (Liu, Li, Hao, & Liu, 2021). As a signaling mechanism, the company's commitment to environmental responsibility enhances its commercial legitimacy, which helps foster trust with key stakeholders (e.g., creditors, suppliers), thus reducing capital acquisition costs (Zhang et al., 2020), alleviates financing constraints, and promoting open innovation (Liu et al., 2021).

Secondly, proactive social responsibility fulfillment strengthens corporate reputation and fosters stakeholder alignment (Cai et al., 2025). Superior ESG performance facilitates stakeholder financial support, expands financing channels, and alleviates constraints, thereby promoting open innovation (Zhang et al., 2024). Furthermore, financing constraints have their fundamental roots in the information asymmetry that exists between a firm and its potential providers of capital. The CSR performance of a company can mitigate the information gap with the market, help ease financing constraints, and ultimately have a favorable influence on open innovation (Zhang & Liu, 2023).

Thirdly, the agency problem in corporate governance is a critical determinant of the financing capacity of enterprises (Lee & Tulcanaza-Prieto, 2024). Effective governance mechanisms serve as a deterrent to opportunistic conduct by a firm's executives, reduce agency costs resulting from damage to the interests of enterprises due to the private interests of managers, thereby reducing financing constraints (Li, Dong, Liu, Huang, & Wang, 2016). Furthermore, firms that value governance place greater emphasis on gaining the trust of stakeholders, further aligning stakeholder interests (Zhang et al., 2020).

This will create structural advantages for broadening financing channels and enhance the corporate open innovation ability. Therefore, this reasoning leads to the proposition of the following hypotheses:

H_2: ESG performance is significantly and negatively correlated with corporate financing constraints.

H_3: Financing constraints function as a mediator linking ESG performance to open innovation.

3. RESEARCH DESIGN

3.1. Sample Construction and Data Collection

The sample for this study includes Chinese companies publicly listed on the A-share market from 2018 to 2023. Data on open innovation was obtained from the China Research Data Service Platform (CNRDS), while ESG ratings (Wind and Huazheng) and other financial data were sourced from the WIND and CSMAR databases, respectively. The data purification process excluded: (1) ST and *ST companies; (2) financial institutions; (3) companies with missing data; (4) firms listed for less than one year. Additionally, this study applied 1%-99% winsorization to all continuous variables to address extreme values. After screening, the final dataset comprises an unbalanced panel of 17,250 firm-year observations.

3.2. Variables Measures

3.2.1. Dependent Variable: Open Innovation

Open innovation in this study is the dependent variable. Following Brockman, Khurana, and Zhong (2018), open innovation is quantified using the natural logarithm of one plus the annual count of a firm's joint patent applications. To address the heterogeneity in technical content and value among patent types, robustness tests employ separate measures for joint invention, utility model, and design patents.

3.2.2. Independent Variable: ESG Performance

ESG performance employs the Wind ESG score (Wen & Huang, 2025). Building on established international ESG rating frameworks, the Wind ESG indicator system integrates China's distinctive ESG investment practices and contextual realities. This methodology incorporates over 300 quantitatively measurable indicators with localized relevance. The system thereby generates comprehensive assessments of corporate ESG performance through standardized scoring and rating protocols. The Wind ESG score range is 0-10 points. For robustness, the Huazheng ESG rating score substitutes this measure to verify baseline regression results. Furthermore, to examine the heterogeneous effects of each ESG dimension, a disaggregated analysis is conducted using the environmental, social, and governance management practice scores (each scaled 0-10).

3.2.3. Mediating Variable: Financing Constraints (WW)

Common metrics for assessing financing constraints encompass sensitivity coefficients (cash-flow or investment-based), text analysis indicators, and multi-factor models including KZ, SA, and WW (Ge et al., 2024; Zhang & Liu, 2023). The SA index is limited in scope, the FC index is constrained by substantial data omissions, and Tobin's Q, which underlies the KZ index, is frequently affected by estimation bias (Liu & Du, 2025). Following Liu and Du (2025), Whited and Wu (2006), and Zhang and Lucey (2022), this study employs the Whited-Wu (WW) index, derived from the CSMAR database, to gauge corporate financing constraints. Specifically, a higher WW index score reflects greater difficulty in accessing external financing.

3.2.4. Control Variables

Consistent with established literature (Liu et al., 2025; Tan, 2025; Yang et al., 2024; Zou et al., 2025) this study controls for potential omitted variable bias by including the following control variables: asset-liability ratio (LEV), firm size (SIZE), fixed asset ratio (FIX), revenue growth rate (GROW), firm listing age (AGE), intangible asset ratio (INTAN), and ownership (SOE). Furthermore, to avoid the influence of time trends and industry characteristics on the research results, this analysis accounts for both year and industry fixed effects. A detailed list of all variables is provided in Table 1.

Table 1. Variable definition table.

Dependent variable		Code	Measurement
Open Innovation		OI	=ln (1+ the annual count of joint patent applications within the current year) (Brockman et al., 2018).
Independent variable			
ESG Performance	ESG Overall Score	ESG	The Wind ESG overall score (Wen & Huang, 2025).
	Environmental Score	ES	The Wind Environmental score (Wen & Huang, 2025).
	Social Score	SS	The Wind Social score (Wen & Huang, 2025).
	Governance Score	GS	The Wind Governance score (Wen & Huang, 2025).
Mediating variable			
Financing constraints		WW	WW=-0.091 × CF + 0.062 × DivPos + 0.021 × Lev− 0.044 × Size + 0.102 × ISG − 0.035 × SG where: CF = Net operating cash flow divided by total assets; Lev = ratio of long-term debt to total assets; DivPos is equal to 1 if the firm pays cash dividends in the current period and 0 otherwise; Size = ln (total assets); SG = sales revenue growth rate; ISG = industry average sales growth rate (Zhang & Lucey, 2022).
Control variable			
	Firm leverage	LEV	=Ending liabilities / ending assets (Tan, 2025).
	Firm size	SIZE	= Natural logarithm of the total number of employees (Liu et al., 2025).
	Firm growth	GROW	= the change in operating income from the previous year to the current year, scaled by the operating income of the previous year (Yang et al., 2024).
	Firm listed age	AGE	The number of years since its initial public offering (IPO) in China (Jung & Kim, 2019; Zou et al., 2025).
	Fixed asset ratio	FIX	=Fixed assets / total assets (Yang et al., 2024).
	Intangible asset ratio	INTAN	=Intangible assets / total assets (Zou et al., 2025).
	Ownership	SOE	Dummy variable, which takes the value 1 for state-owned firms and 0 otherwise (Tan, 2025).
	Industry	IND	Dummy variable, which has a value of 1 if it belongs to the industry, and 0 otherwise (Tan, 2025).
	Time	YEAR	Dummy variable, take 1 when the year is t, otherwise take 0 (Tan, 2025).

3.3. Model Design

To accurately identify the influence of ESG performance on open innovation in enterprises, this study constructed the following regression equation to be tested.

$$OI_{it} = \alpha_0 + \alpha_1 ESG_{it} + \beta_1 SIZE_{it} + \beta_2 LEV_{it} + \beta_3 GROW_{it} + \beta_4 AGE_{it} + \beta_5 FIX_{it} + \beta_6 INTAN_{it} + \beta_7 SOE_{it} + \beta_8 \Sigma IND + \beta_9 \Sigma YEAR + \varepsilon_{it} \quad (1)$$

Where i denotes firms, t denotes years, and OI_{it} represents the natural logarithm of one plus firm i's joint patent applications in year t. ESG_{it} represents the overall ESG score in period t. The control variables include firm size (SIZE), firm listing age (AGE), proportion of fixed assets (FIX), asset-liability ratio (LEV), ownership (SOE), proportion of intangible assets (INTAN), and revenue growth rate (GROW). ΣIND and ΣYear are industry control variables and year control variables, respectively, and ε_{it} are residual terms.

This study follows the method of Baron and Kenny (1986) to verify the mediating role of financing constraints, based on Model (1), the following regression models for mediating effects are constructed to be tested.

$$WW_{it} = \alpha_2 + \alpha_3 ESG_{it} + \beta_1 SIZE_{it} + \beta_2 LEV_{it} + \beta_3 GROW_{it} + \beta_4 AGE_{it} + \beta_5 FIX_{it} + \beta_6 INTAN_{it} + \beta_7 SOE_{it} + \beta_8 \Sigma IND + \beta_9 \Sigma YEAR + \varepsilon_{it} \quad (2)$$

Where WW_{it} represents financing constraints. When the regression coefficient $\alpha_3 < 0$ and significant, it implies that stronger ESG performance effectively mitigates financing constraints, and Hypothesis 2 (H2) holds true.

$$OI_{it} = \alpha_4 + \alpha_5 ESG_{it} + \alpha_6 WW_{it} + \beta_1 SIZE_{it} + \beta_2 LEV_{it} + \beta_3 GROW_{it} + \beta_4 AGE_{it} + \beta_5 FIX_{it} + \beta_6 INTAN_{it} + \beta_7 SOE_{it} + \beta_8 \Sigma IND + \beta_9 \Sigma YEAR + \varepsilon_{it} \quad (3)$$

If both Hypothesis 1 and Hypothesis 2 hold true, then based on Model (1), Model (3) incorporates financing constraints (WW) to formally test mediation effects, following the Baron-Kenny framework. If the regression coefficients $\alpha_5>0$ and $\alpha_6<0$ are both significant, and the ESG regression coefficient $\alpha_1>\alpha_5$, it implies that ESG-open innovation link is partially mediated by financing constraints. Then Hypothesis 3 holds.

4. EMPIRICAL RESULTS

4.1. Descriptive Analysis

Table 2 reports summary statistics for all variables. Notably, for open innovation (OI), the mean value is 0.705, with a standard deviation of 1.231, indicating a generally low and heterogeneous level of open innovation among Chinese publicly listed firms. The WindESG rating score (ESG) ranges from a minimum of 4.480 to a maximum of 8.380, with an average value of 6.051, suggesting that ESG performance is at a medium to lower level. The standard deviation of 0.794 reflects moderate overall ESG performance and small differences. Additionally, compared with corporate governance (G), environmental (E), and social (S) responsibilities are relatively weak. The average environmental score (ES) is 1.970, and the social score (SS) is 3.943, both significantly lower than the governance score (GS) at 6.522. The standard deviation of the environmental score (ES) is 2.134, which is relatively high and exceeds the mean, indicating substantial heterogeneity in environmental metrics across A-share listed firms. The standard deviations of the social score (SS) and governance score (GS) are 1.812 and 0.859, respectively, both lower than their means, indicating relatively low data dispersion. The financing constraints measure (WW index) has a mean of -1.033, with a median-aligned value, and a standard deviation of 0.072, suggesting limited cross-sectional dispersion and relative homogeneity in external financing challenges across the sample period.

Table 2. Descriptive statistics of variables (n=17,250).

Variable	Mean	Median	Std. dev.	Min.	Max.
OI	0.705	0	1.231	0	5.242
ESG	6.051	5.960	0.794	4.480	8.380
ES	1.970	1.400	2.134	0	8.830
SS	3.943	3.830	1.812	0.440	8.640
GS	6.522	6.530	0.859	4.260	8.870
WW	-1.033	-1.028	0.072	-1.241	-0.883
SIZE	7.824	7.722	1.224	5.198	11.304
LEV	0.445	0.441	0.191	0.071	0.893
FIX	0.205	0.174	0.153	0.002	0.669
INTAN	0.047	0.032	0.056	0	0.369
GROW	0.128	0.083	0.332	-0.537	1.807
AGE	12.180	10.407	8.525	1.101	30
SOE	0.340	0	0.474	0	1

Note: Variables are defined as follows: Open innovation (OI), ESG overall score (ESG), Environmental score (ES), Social score (SS), Governance score (GS), Financing constraints (WW), Firm size (SIZE), Firm leverage (LEV), Firm growth (GROW), Fixed asset ratio (FIX), Intangible asset ratio (INTAN), Firm age (AGE), Ownership (SOE. The same notation applies to the subsequent tables.

4.2. Correlation Analysis

The Pearson correlation coefficient results of all variables are shown in Table 3. It can be known from Table 3 that the ESG overall score (ESG) is significantly positively correlated with open innovation (OI). Meanwhile, financing constraints (WW) are significantly negatively correlated with both the ESG overall score (ESG) and open innovation (OI), which aligns with expectations. Most control variables also show statistically significant associations with the dependent variable. ESG composite scores are derived from environmental (ES), social (SS),

and governance (GS) sub-components, and they are not included in the same model. Although the coefficients of ESG and SS exceed 0.8, there is no issue of multicollinearity. This further confirms that the sample and model design are reasonable, and the impact of multicollinearity is relatively low.

Meanwhile, the mean variance inflation factor (VIF) values for Models 1 and 3 (Table 4) are well below the critical threshold of 10. Given identical, independent, and control variables in Models 1 and 2, only Model 1 results are presented. These findings indicate negligible multicollinearity, supporting reliable coefficient estimates.

Table 3. Correlation coefficient analysis.

Variable	OI	ESG	ES	SS	GS	WW	SIZE
OI	1						
ESG	0.195***	1					
ES	0.189***	0.648***	1				
SS	0.204***	0.832***	0.390***	1			
GS	0.103***	0.525***	0.232***	0.230***	1		
WW	-0.275***	-0.206***	-0.284***	-0.106***	-0.202***	1	
SIZE	0.287***	0.208***	0.310***	0.108***	0.169***	-0.682***	1
LEV	0.092***	-0.102***	0.033***	-0.098***	0.004	-0.277***	0.354***
FIX	0.045***	0.021***	0.126***	0.039***	-0.017**	-0.100***	0.189***
INTAN	0.006	0.0001	0.041***	0.027***	0.016**	-0.063***	0.072***
GROW	0.0004	0.025***	-0.023***	0.053***	0.028***	-0.266***	0.044***
AGE	0.046***	-0.058***	0.121***	-0.156***	0.042***	-0.318***	0.309***
SOE	0.095***	0.018**	0.114***	-0.032***	0.033***	-0.306***	0.237***
	LEV	FIX	INTAN	GROW	AGE	SOE	
LEV	1						
FIX	0.068***	1					
INTAN	0.049***	0.057***	1				
GROW	0.046***	0.001	-0.002	1			
AGE	0.292***	0.100***	0.083***	-0.073***	1		
SOE	0.235***	0.143***	0.091***	-0.034***	0.521***	1	

Note: **, *** denote significance at 5%, and 1% levels, respectively.

Table 4. Results of VIF.

Variable	M1				M3			
	VIF	VIF	VIF	VIF	VIF	VIF	VIF	VIF
ESG	1.10				1.11			
ES		1.13				1.14		
SS			1.07				1.08	
GS				1.04				1.05
WW					2.26	2.27	2.24	2.27
SIZE	1.35	1.36	1.29	1.29	2.17	2.17	2.14	2.13
LEV	1.24	1.22	1.22	1.21	1.24	1.22	1.22	1.21
FIX	1.05	1.05	1.05	1.05	1.05	1.06	1.05	1.06
INTAN	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
GROW	1.01	1.01	1.01	1.01	1.15	1.16	1.15	1.15
AGE	1.51	1.49	1.54	1.49	1.52	1.50	1.56	1.50
SOE	1.41	1.41	1.41	1.41	1.45	1.45	1.45	1.45
Mean VIF	1.21	1.21	1.20	1.19	1.44	1.44	1.43	1.43

4.3. Selection of Fixed or Random Effects

The decision to use either fixed or random effects models is based on the outcome of the Hausman test. Consequently, this study conducted Hausman tests prior to regression analysis for all specifications. In all models, the results indicated that fixed effects estimation was appropriate. Table 5 summarizes the model selection outcomes based on the Hausman test results.

Table 5. Results of Hausman's test of the main regression model.

Model	χ^2	*p-value*	FE/RE**
M1	404.87	0.0000	FE
M2	600.14	0.0000	FE
M3	388.88	0.0000	FE

Note: **FE/RE: fixed or random effect: χ^2 (k)>χ^2 (Hausman) RE; χ^2 (k)<χ^2 (Hausman) FE.

4.4. Heteroscedasticity and Serial Correlation Test

Table 6 presents the results of the White test for heteroskedasticity, which confirms the existence of heteroskedasticity in all models ($p < 0.01$). Furthermore, time-series dependence tests identify serial correlation in the residuals, as shown in Table 7. To address these concerns, all regression analyses utilize cluster-robust standard errors, clustered by firm.

Table 6. Results of the Heteroscedasticity test of the main regression model.

Model	χ^2	p-value
M1	2376.54	0.0000
M2	2832.85	0.0000
M3	2513.99	0.0000

Table 7. Results of the serial correlation test of the main regression model.

Model	F	p-value
M1	198.665	0.0000
M2	156.052	0.0000
M3	198.512	0.0000

4.5. Results and Analysis of Benchmark Regression and Mediating Effect Regression

Table 8 presents the benchmark regression and mediation analyses of corporate ESG performance on open innovation. The baseline regression result, presented in Column (1), indicates a statistically significant positive coefficient for ESG (0.181) at the 1% significance level, supporting Hypothesis 1 that strong ESG performance fosters open innovation. Actively implementing ESG initiatives can enhance social acceptance by meeting stakeholder expectations and integrating diverse resources (Taliento et al., 2019). This is consistent with external resources required for open innovation (Phonthanukitithaworn et al., 2023). From a policy perspective, this evidence justifies using public procurement, R&D funding allocations, and other policy tools to channel resources toward high-ESG performers, effectively leveraging ESG as a market-based mechanism to stimulate open innovation.

The regression results for the control variables indicate that both firm size (SIZE) and financial leverage (LEV) show statistically significant positive correlations with open innovation. This finding provides empirical support for policy approaches aimed at nurturing leading enterprises and enhancing credit support for innovation. In contrast, the ratios of fixed assets (FIX) and intangible assets (INTAN) exhibit significant negative effects on open innovation, suggesting that an overly heavy asset structure may constrain resource flexibility and weaken firms' willingness to engage in external collaboration. Accordingly, policymakers should encourage a shift toward asset-light and highly agile business models, while actively fostering a market for intellectual property transactions to improve the allocation efficiency of intangible assets. The negative association of revenue growth rate (GROW) implies that short-term performance pressures may curb long-term innovation investment. Furthermore, the significantly positive coefficient for the state-owned enterprise (SOE) variable indicates that SOEs demonstrate a higher level of open innovation, reflecting the role of state capital as a "stabilizer" and "pioneer" in major original and long-cycle innovation projects. Policy measures should continue to support SOEs in leading industry-university-research collaboration, while refining incentive mechanisms to enhance innovation efficiency.

Columns (2) to (3) in Table 8 establish financing constraints (WW) as a significant mediator. Column (2) demonstrates that enhanced ESG performance notably alleviates financing constraints (coefficient = -0.010, p < 1%), confirming H2's proposition of ESG-driven financial alleviation. Column (3) shows that financing constraints (WW) significantly constrain open innovation (coefficient = -4.126, p < 1%). Meanwhile, the ESG coefficient remains positive (coefficient = 0.140, p < 1%) but decreases compared to the baseline (0.181 in Column 1), suggesting that ESG performance fosters open innovation, in part by alleviating financing constraints. These findings verify the partial mediating role of financing constraints, consistent with Hypothesis 3. Financing constraints function as a mediating role linking ESG performance to open innovation. For economic policymakers, this mediating effect underscores the importance of crafting financial policies that explicitly recognize and reward strong ESG performance. By creating ESG-linked financing channels or reducing capital costs for high-ESG firms, policymakers can directly alleviate the financial bottlenecks that hinder open innovation, thereby amplifying the innovation dividends of ESG practices.

Table 8. The benchmark regression and mediation analysis results on how corporate ESG performance affects open innovation.

Variable	(1)	(2)	(3)
	OI	WW	OI
ESG	0.181***	-0.010***	0.140***
	(8.453)	(-13.593)	(6.744)
WW			-4.126***
			(-11.566)
SIZE	0.249***	-0.038***	0.091***
	(14.174)	(-53.298)	(4.777)
LEV	0.285***	0.026***	0.391***
	(3.214)	(6.689)	(4.437)
FIX	-0.382***	0.023***	-0.286**
	(-2.806)	(4.188)	(-2.133)
INTAN	-0.578**	0.010	-0.538*
	(-2.016)	(0.746)	(-1.901)
GROW	-0.062**	-0.061***	-0.313***
	(-2.442)	(-46.980)	(-9.439)
AGE	-0.003	-0.0004***	-0.005**
	(-1.385)	(-3.729)	(-2.026)
SOE	0.201***	-0.012***	0.152***
	(4.274)	(-7.100)	(3.286)
_cons	-2.375***	-0.675***	-5.158***
	(-13.535)	(-125.304)	(-15.613)
IND	Yes	Yes	Yes
YEAR	Yes	Yes	Yes
N	17250	17250	17250
adj. R2	0.141	0.653	0.161
F	44.928	1101.439	46.165
p	0.000	0.000	0.000

Note: *, **, *** denote significance at 10%, 5%, and 1% levels, respectively, and Values in parentheses represent t-statistics.

4.6. Robustness and Endogeneity Tests

4.6.1. Robustness Test

4.6.1.1. Replacing The Independent Variable

There are already many third-party rating agencies that regularly release ESG rating data of firms every year. To avoid the influence of the data characteristics of a single rating agency on the research results, robustness tests

employ Huazheng ESG ratings to retest H1-H3. Table 9 presents results that are statistically robust and consistent with the baseline, confirming that the key findings hold true regardless of the specific independent variables chosen.

Table 9. Robust test results: Huazheng ESG score and open innovation.

Variable	(1)	(2)	(3)
	OI	WW	OI
ESG	0.191***	-0.011***	0.145***
	(10.350)	(-17.167)	(8.092)
WW			-4.046***
			(-11.308)
Controls	Yes	Yes	Yes
N	17248	17248	17248
adj. R^2	0.142	0.657	0.162
F	48.564	1159.220	48.201
p	0.000	0.000	0.000

Note: *** denote significance at 1% levels, and Values in parentheses represent t-statistics. To save space, the results of the control variables are not listed one by one. The same notation applies to the subsequent tables.

4.6.1.2. Replacing the Dependent Variable

Recognizing that invention, utility model, and design patents capture distinct aspects of corporate open innovation, the study employs the annual application counts of each patent type to represent open innovation separately. Table 10 confirms significantly positive effects of ESG performance across all joint patent categories. Moreover, financing constraints (WW) also play a mediating role in joint invention patents, joint utility model patents, and joint design patents, respectively, with robust results consistent across specifications.

Table 10. Robust test results: ESG score and different types of open innovation.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	OI(Invention)	WW	OI(Invention)	OI (Practical)	WW	OI (Practical)	OI(Design)	WW	OI(Design)
ESG	0.165***	-0.010***	0.130***	0.088***	-0.010***	0.061***	0.024***	-0.010***	0.020***
	(9.090)	(-13.593)	(7.445)	(5.402)	(-13.593)	(3.866)	(3.708)	(-13.593)	(3.326)
WW			-3.479***			-2.680***			-0.316***
			(-11.589)			(-10.174)			(-3.174)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	17250	17250	17250	17250	17250	17250	17250	17250	17250
adj. R2	0.138	0.653	0.159	0.110	0.653	0.126	0.041	0.653	0.042
F	41.472	1101.439	42.625	29.134	1101.439	29.185	11.826	1101.439	10.716
p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: *** denotes significance at 1% levels, and values in parentheses represent t-statistics.

4.6.2. Endogeneity Test

The possibility that superior ESG performance may be driven by a firm's open innovation capabilities necessitates considering reverse causality as an issue that cannot be ruled out. Therefore, to ensure robustness, this study introduces a one-period lag for both the independent and control variables. The findings presented in Table 11 (columns 1-3) offer robust confirmation of H1 to H3 across multiple specifications.

Table 11. Robust test results: ESG score lagging behind by one period and open innovation.

Variable	(1)	(2)	(3)
	OI	WW	OI
ESG	0.170***	-0.009***	0.138***
	(7.300)	(-10.411)	(6.109)
WW			-3.643***
			(-11.710)
Controls	Yes	Yes	Yes
N	14460	14460	14460
adj. R^2	0.143	0.551	0.163
F	44.544	604.599	46.135
p	0.000	0.000	0.000

Note: *** denotes significance at 1% levels, and values in parentheses represent t-statistics.

5. HETEROGENEITY ANALYSIS THE MULTI-DIMENSIONAL ANALYSIS ON ENVIRONMENT (E), SOCIETY (S), AND CORPORATE GOVERNANCE (G) FACTORS

To disentangle the effects, the three ESG components, environmental (ES), social (SS), and governance (GS) scores, are examined separately. The analyses, detailed in columns (1), (4), and (7) of Table 12, yield significantly positive coefficients (0.042, 0.097, and 0.094, all at the 1% level) for their respective relationships with OI, indicating that each ESG component positively contributes to open innovation. Environmental performance (E) is a key factor in open innovation outcomes by attracting stakeholder support and enhancing collaboration opportunities (Sarango-Lalangui et al., 2023; Zou et al., 2025). Social performance (S) enhances reputation and deepens stakeholder relationships (Yang et al., 2024), helping to secure innovation resources and drive open innovation (Cai et al., 2025). A sound governance mechanism (G) reflects a company's dedication to environmental and social responsibility, coordinates stakeholder interests, enables access to critical resources, and mitigates risks associated with open innovation, thereby promoting open innovation (Shaikh & Randhawa, 2022; Zhang et al., 2020).

The results of mediation analyses employ the WW index to indicate a partial mediating effect of financing constraints in the relationship between individual ESG dimensions and open innovation. Specifically, in Columns (2) and (3), environmental performance significantly reduces financing constraints (coefficient = -0.003, $p < 0.01$). Column (3) shows that the WW index negatively affects open innovation (coefficient = -4.350, $p < 0.01$), while the effect of the environmental score remains positive (coefficient = 0.028, $p < 0.01$) but weaker than in Column (1). This suggests that the positive influence of environmental performance on open innovation is partially channeled through the mitigation of financing constraints. This mediating role is consistent across social score (SS) and governance score (GS), although coefficient magnitudes vary. Columns (5) and (6) demonstrate that social performance lowers financing constraints (coefficient = -0.003, $p < 0.01$), and the WW index negatively impacts open innovation (coefficient = -4.098, $p < 0.01$). The effect of social score remains positive (coefficient = 0.082, $p < 0.01$) but weaker than in Column (4), indicating that social performance promotes open innovation partly by easing financing constraints. Columns (8) and (9) show that governance performance lowers financing constraints (coefficient = -0.008, $p < 0.01$), and the WW index negatively impacts open innovation (coefficient = -4.367, $p < 0.01$). The effect of governance score remains positive (coefficient = 0.061, $p < 0.01$) but weaker than in Column (7),

suggesting that the positive effect of governance performance on innovation is partly underpinned by a reduction in financing constraints.

Table 12. Model 1-3-the effect of E/S/G sub-score and Open innovation (OI), and the mediating effect of Financing constraints (WW) on the above relationship.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	OI	WW	OI	OI	WW	OI	OI	WW	OI
ES	0.042***	-0.003***	0.028***						
	(5.192)	(-11.555)	(3.609)						
SS				0.097***	-0.003***	0.082***			
				(10.399)	(-10.983)	(9.120)			
GS							0.094***	-0.008***	0.061***
							(5.688)	(-12.495)	(3.837)
WW			-4.350***			-4.098***			-4.367***
			(-12.100)			(-11.596)			(-12.232)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	17250	17250	17250	17250	17250	17250	17250	17250	17250
adj. R^2	0.134	0.650	0.156	0.147	0.650	0.167	0.133	0.651	0.156
F	41.255	1058.691	44.119	48.876	1038.951	49.585	41.336	1092.392	44.125
p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: *** denotes significance at 1% levels, and Values in parentheses represent t-statistics.

6. CONCLUSIONS AND IMPLICATIONS

6.1. Main Research Conclusions

Utilizing 2018-2023 panel data from A-share listed companies in China, this study conducts an empirical investigation into how corporate ESG performance affects open innovation, while also examining the underlying mechanisms. The following research conclusions are mainly obtained: First, empirical evidence demonstrates that corporate ESG performance fosters firms' open innovation activities, as well as a significantly negative influence on financing constraints, which is consistently supported by robustness checks. Second, the mechanism analysis indicates that ESG engagement facilitates open innovation primarily by mitigating financing constraints. The robustness of the mediating effect of financial constraint relief in the ESG-open innovation relationship is confirmed by a series of supplementary tests. Third, a further investigation reveals that each of the three ESG sub-dimensions, environmental, social, and governance, independently contributes to bolstering open innovation capacity through the reduction of financing frictions.

6.2. Theoretical Implications

This study provides several theoretical insights. First, it formalizes ESG performance as a signaling mechanism within a resource-based model of open innovation, providing theoretical micro-foundations for how non-financial signaling impacts cross-organizational knowledge flows. Second, it develops a mediation model that explicitly parameterizes financing constraints as the channel through which ESG signals translate into innovation resource acquisition, advancing beyond simple direct-effect specifications. Third, by demonstrating parameter heterogeneity across environmental, social, and governance dimensions, it establishes the empirical necessity of modeling ESG as a multidimensional construct rather than a composite index in innovation production functions.

6.3. Policy Implications

The validated theoretical model, which captures both the direct effect of ESG on open innovation and its indirect effect through alleviating financing constraints, offers a structured framework for evidence-based policy design.

To leverage the direct promoting effect of ESG on open innovation, policymakers should integrate ESG criteria as a key dimension in national innovation evaluation and support systems. Specifically, eligibility for public

R&D funding, innovation awards, and government-led innovation partnerships could be linked to corporate ESG performance. This direct channeling of public support rewards high-ESG firms for their inherent strengths in stakeholder engagement and resource coordination, which the model identifies as foundational to open innovation.

To amplify the indirect effect via mitigating financing constraints, policy should be tailored to transform ESG performance into tangible financial advantages. The significant mediating role of financing constraints justifies creating ESG-linked financial instruments, such as preferential loans or credit guarantees tied to corporate ESG ratings. Furthermore, guiding financial institutions to incorporate ESG metrics into their credit risk models can systematically lower financing barriers for high-ESG firms, thereby activating the model-predicted pathway where improved ESG performance decreases capital costs and fuels innovation.

To enhance the overall policy ecosystem, building a mandatory, high-quality ESG disclosure framework is essential. Standardized and reliable ESG data are prerequisites for both direct and indirect policy instruments to function effectively. Such transparency ensures that resources are allocated to genuine performers, strengthening the entire causal chain from ESG commitment to enhanced open innovation.

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