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Ownership Type and Corporate Green Innovation

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Abstract

Corporate green innovation supports the transition to a low-carbon economy, but it remains unclear how green innovation differs across ownership types and what accounts for those differences. Using data on Chinese A-share listed firms from 2010 to 2024, we apply the entropy weighting method to construct a composite index covering green innovation inputs, green innovation outputs, sustainability performance, and environmental performance. We examine the association between ownership type and green innovation, the role of financing constraints, and variation across regions and industries. State-owned enterprises score significantly higher on the composite index than non-state-owned enterprises. They also face significantly weaker financing constraints, which may help explain their green innovation advantage. The estimated advantage is statistically significant in eastern China and in manufacturing, while the estimates for central and western China and for non-manufacturing are statistically insignificant. These findings provide evidence for allocating green finance resources and tailoring policies to support green innovation.

Keywords

Ownership Type; Corporate Green Innovation; Financing Constraints; Entropy Weighting Method.

1. Introduction

Industrialization accelerated economic growth but also increased resource depletion, pollution, and greenhouse gas emissions. As climate change intensifies and environmental and resource constraints tighten, countries face a common challenge in decarbonizing industry while sustaining economic growth and protecting the environment [1]. China has long prioritized sustainable development and ecological conservation. In 2012, the 18th National Congress of the Communist Party of China incorporated ecological conservation into the country's Five-Sphere Integrated Plan. In 2020, China announced its goals of peaking carbon emissions before 2030 and achieving carbon neutrality before 2060. The 2025 Government Work Report called for developing new quality productive forces in line with local conditions and integrating technological and industrial innovation. In this context, technological innovation can help shift development away from reliance on high inputs, intensive resource use, and high emissions [2].

Firms play a central role in research and development (R&D), commercialization, and resource allocation. Their green innovation spans green products, cleaner production processes, energy-saving and emission-reduction technologies, and operational management [3]. Green innovation can help firms comply with environmental regulations, improve their reputation, and enter green markets. By improving resource efficiency, it can also lower long-term production costs, support industrial upgrading, and contribute to China's carbon peaking and neutrality goals [4][5][6]. However, green innovation often requires substantial investment and long development cycles, entails technological risk, and generates environmental benefits that extend beyond the firm. A firm's resource base and access to finance therefore shape its capacity to innovate. Ownership type is an institutional characteristic that influences business objectives, resource access, and decision-making [7]. State-owned enterprises (SOEs) typically

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have larger asset bases and better access to finance and are expected to implement national strategies and lead the green transition. They may also face administrative intervention, multiple layers of delegation, and weak incentives. Non-state-owned enterprises generally have more flexible operations and respond more quickly to market signals, but they often face greater difficulty raising capital, higher financing costs, and a more limited capacity to bear risk [8]. These differences raise two questions: how does green innovation vary by ownership type, and can financing conditions help explain that variation?

Prior research has examined environmental regulation [9], government subsidies [10], green finance [11], and corporate governance [12] as determinants of corporate green innovation. Many studies measure green innovation by green patent counts, which capture output but give less attention to other dimensions. Studies also disagree on the relationship between ownership type and green innovation [13][14]. Firms with different ownership types differ in their resource access, objectives, and governance, which may be reflected in different dimensions of green innovation. Using data on Chinese A-share listed firms from 2010 to 2024, we construct a composite measure spanning green innovation inputs, green innovation outputs, sustainability performance, and environmental performance. The study contributes a broader measure of corporate green innovation, examines financing constraints as a possible explanation for the ownership gap, and assesses where the association varies across regions and industries. This evidence can inform the allocation of green finance and the design of targeted green innovation policies.

2. Literature Review and Hypotheses

2.1. Literature Review

2.1.1. Determinants of Corporate Green Innovation

Corporate green innovation integrates goals such as energy and resource conservation, pollution prevention, and recycling into R&D, production processes, and product development. It can generate both private returns and social benefits through environmental improvements and resource savings [3]. Firms often capture only part of these social benefits, which may weaken their incentives to sustain green R&D. Substantial investment, long development cycles, and technological and market risks also make green projects difficult to pursue. Jaffe et al. [15] argue that pollution generates negative externalities and that environmental technology development and diffusion are themselves subject to market failures. Together, these failures can lead to investment in environmental technology below the socially optimal level. Research has therefore examined both external conditions and firm-level characteristics as determinants of green innovation.

Research on external conditions has focused on environmental regulation, government subsidies, and green finance. Porter and van der Linde [5] argue that well-designed regulation can induce innovation that partly offsets compliance costs. The effects vary across instruments. Pollution charges may pressure firms to innovate, whereas environmental subsidies may crowd out existing green innovation spending [9]. Emissions trading can create market incentives for green innovation [16]. Government subsidies can close R&D funding gaps and signal project quality to outside investors, encouraging private investment [10][17]. With limited oversight, however, firms may respond strategically by pursuing patent counts to meet policy targets [18]. Green finance addresses a different constraint. Long development cycles, uncertain returns, and information asymmetry make it difficult for firms to fund R&D [19]. Green credit redirects lending toward green industries and tightens access to finance for heavily polluting firms. It can reduce debt financing and increase financing costs for those firms [20]. Although it can encourage green innovation, the evidence for improvements in innovation quality is limited [11]. The effects of these policies depend on their design and on firm characteristics.

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Corporate governance [12], digital capabilities [21], managerial characteristics, and organizational culture [22] also shape green innovation. Amore and Bennedsen [23] find that firms with weaker governance obtain fewer green patents, with a stronger association among firms facing greater financing constraints. Song et al. [21] find that digitalization promotes green innovation in heavily polluting firms by facilitating information sharing and knowledge integration, with a stronger effect on green invention patents. Zhang et al. [22] find that executives' overseas experience promotes green innovation by increasing their willingness to take risks and their attention to environmental issues, especially in SOEs. Bai et al. [24] find that a green corporate culture can promote green innovation by improving firms' ability to integrate resources and raising executives' environmental awareness. Li and Yi [12] find that directors appointed by non-state shareholders can promote green innovation in SOEs by reducing government intervention and improving executive incentives, although financing constraints weaken this effect. Ownership type can shape several of these conditions at once through its relationship with governance, business objectives, and access to resources.

2.1.2. Ownership Type and Corporate Green Innovation

Green innovation requires sustained R&D spending and decisions that weigh near-term returns against long-term environmental benefits. Access to funding and the capacity to bear risk vary by ownership type, which may affect both willingness to undertake green innovation and actual performance [25]. SOEs pursue commercial objectives while also carrying social responsibilities and policy mandates, which can make the green transition a priority in business decisions [26]. Non-state-owned enterprises face more direct pressure from competition and profitability targets and must consider whether green R&D will lower costs, improve product competitiveness, or generate sales. One strand of research argues that SOEs' resource and policy advantages allow them to achieve higher levels of green innovation [13]. Another suggests that administrative intervention and weak incentives may prevent SOEs from turning these resources into innovation outcomes and may even impede innovation [27].

The first view emphasizes SOEs' access to resources and environmental responsibilities. Green R&D often takes years, and firms face the risk of technical failure or changes in demand. Stable funding and a greater capacity to bear risk help firms keep projects going. SOEs often have larger asset bases and a more stable credit standing, which may improve their access to funding, talent, and technology. Environmental responsibilities and policy mandates may also encourage them to prioritize energy conservation, emissions reduction, and green technology development. Using data from Chinese listed companies, Wang and Jiang [13] find a positive association between state ownership and corporate green innovation. The association is stronger where the legal environment is more developed, the board chair has relevant functional experience, and firms have more resources. These findings suggest that favorable external conditions and internal resources help firms realize the advantages associated with state ownership. Li and Feng [25] distinguish green invention patents from green utility model patents. They find that SOEs file and obtain more green invention patents than privately owned enterprises, but file and obtain fewer green utility model patents. Ownership differences therefore also depend on the type of innovation.

The second view emphasizes governance and incentives. Resources may be used inefficiently when managers bear the costs of failed innovation but receive rewards that do not reflect successful outcomes. Administrative intervention and multiple business objectives may also limit managerial autonomy and make it harder to redirect R&D in response to technological or market changes. Liu et al. [14] find that a higher state shareholding ratio is associated with less green innovation. Digital transformation within firms and stronger regional digital innovation capabilities weaken this association. The results suggest that constraints associated with state ownership can vary with firm and regional conditions. Li and Yi [12] show that directors appointed by non-state shareholders can promote green innovation in SOEs by reducing

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government intervention and improving executive incentives, although financing constraints weaken this effect. Their findings suggest that governance arrangements shape how effectively SOEs use existing resources.

These perspectives point to competing forces. Access to finance, resources, and policy support may favor green innovation in SOEs, while administrative intervention and weak incentives may limit their ability to use these advantages. We examine the relationship at the firm level and assess financing constraints as a possible explanation for differences across ownership types.

2.1.3. Composite Measures of Green Innovation

Through green innovation, firms can reduce resource use and pollution while pursuing economic returns. Progress toward China's carbon goals has drawn attention to how this activity is measured. Reliable measures make it possible to compare the green transition across regions, industries, and firms and to study its determinants. Corporate green innovation spans R&D spending, technological outputs, production improvements, and environmental performance. A single measure such as green patent counts or R&D spending captures only part of this activity [28][29]. Researchers have therefore begun combining indicators across dimensions.

Green innovation has been measured at national, regional, industry, and firm levels. At the national level, the OECD and Eurostat's Oslo Manual [30] provides international guidance on collecting, reporting, and using innovation data. The European Innovation Scoreboard [31] compares national innovation performance across multiple indicators and provides a reference for selecting and assessing green innovation indicators. At the regional level, studies have used composite scores and efficiency measures. Bai et al. [32] apply entropy-weighted TOPSIS to assess urban green innovation capacity across input, output, and environmental dimensions. A study of the Yangtze River Delta [33] uses a super-efficiency slacks-based data envelopment analysis model (SBM-DEA) to assess urban green innovation efficiency. At the firm and industry levels, Chen et al. [28] develop an index covering innovation inputs, innovation processes, innovation performance, and environmental performance. Tian et al. [34] use green innovation inputs and outputs in an entropy weighting and catastrophe progression method to evaluate green process innovation capacity across 29 Chinese manufacturing industries. Xu et al. [29] assess manufacturing firms' capacity to support green innovation, commit inputs, and generate outputs. Although indicator choices and methods vary by level of analysis, research has moved toward multidimensional measures.

These studies provide a basis for composite evaluation using innovation inputs, innovation outputs, and environmental performance. Firm-level evidence remains relatively limited because much of the composite measurement literature focuses on regions or industries. Studies relying on a single indicator, or primarily on inputs and outputs, may underrepresent firms' strategic commitment to sustainability and their environmental performance. The literature also varies in its choice of dimensions, indicators, and aggregation methods. We construct a firm-level composite index to capture a broader range of green innovation performance and compare firms by ownership type.

2.2. Theoretical Analysis and Hypotheses

Developing and deploying green technologies requires sustained investment, while economic returns may take years to materialize. Green innovation therefore depends on firms' willingness and ability to commit resources over time. State ownership may provide support through business and policy objectives while also imposing constraints through governance and incentives [13][14]. In addition to pursuing economic returns, SOEs have social responsibilities. Goals such as resource conservation, pollution reduction, and the green transition may lead them to pursue projects with long-term environmental benefits even when

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immediate returns are limited. SOEs may also draw on existing R&D capacity and external partnerships to supply the personnel, equipment, and organizational coordination that green projects require. Administrative intervention and weak incentives may reduce the efficiency of resource use. Given the long time horizons and social benefits of green innovation, we expect SOEs' responsibilities and access to resources to partly offset these constraints.

H1. All else equal, state-owned enterprises exhibit higher levels of green innovation than non-state-owned enterprises.

Access to capital allows firms to turn green R&D plans into projects. Green R&D requires upfront spending on personnel, equipment, and trials, while returns are delayed and uncertain. Large initial costs, long development cycles, and technological and market risks can make it difficult to sustain projects from internal funds alone. Firms may seek external financing, but information asymmetry and difficulty pledging intangible assets can raise financing costs and limit access [19]. State ownership and government ties may lead lenders to view SOEs as more creditworthy, improving their access to external financing. Non-state-owned firms may face stricter terms or higher costs. Brandt and Li [35] find that discrimination by banks led private firms to rely more heavily on costlier trade credit. Weaker financing constraints can help firms maintain R&D spending despite short-term operating pressures and absorb the risks of technical failure or uncertain commercialization. We therefore expect SOEs' more favorable financing conditions to support green innovation.

H2. State ownership is associated with greater corporate green innovation through weaker financing constraints.

3. Research Design

3.1. Sample Selection and Data Sources

The initial sample covers Chinese A-share listed firms from 2010 to 2024. We exclude financial firms because their asset structures, business models, and accounting practices differ substantially from those of other firms. We also exclude firms designated for special treatment (ST), delisted firms, and observations with missing values for key variables. To reduce the influence of extreme values on the regressions, we winsorize all continuous variables at the 1st and 99th percentiles. The final sample comprises 9,368 observations.

Financial data, firm characteristics, carbon emissions intensity, and financing constraints come from the China Stock Market & Accounting Research (CSMAR) database. Green invention patent data come from the Chinese Research Data Services (CNRDS) platform, and environmental, social, and governance (ESG) scores come from Bloomberg. Industries are classified according to the China Securities Regulatory Commission's industry classification. Firms are assigned to eastern, central, or western China based on their registered location.

3.2. Measuring Corporate Green Innovation

3.2.1. Indicator Selection

Corporate green innovation encompasses technology development and patent output as well as environmental management and the environmental performance associated with innovation. Green patent counts alone capture only part of the process from innovation inputs to outcomes. Drawing on prior research, we construct a composite index across four dimensions: green innovation inputs, green innovation outputs, sustainability performance, and environmental performance. Table 1 lists the indicators, their definitions, and the direction of scoring.

We measure the input base for green innovation using R&D expenditure divided by total assets. We measure output as the natural logarithm of one plus the number of green invention patents. We use Bloomberg's ESG performance score to capture firms' environmental, social, and governance performance [36], and carbon emissions intensity to capture the environmental

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performance of their operations. R&D intensity, green invention patents, and ESG scores enter the index positively. Higher carbon emissions intensity indicates more emissions per unit of operating activity, so we reverse the scale for this indicator.

Table 1. Indicators of corporate green innovation

Dimension	Indicator	Definition	Direction
Green innovation inputs	R&D intensity	R&D expenditure divided by total assets	Positive
Green innovation outputs	Green invention patents	Number of green invention patents	Positive
Sustainability performance	ESG performance score	Bloomberg ESG score	Positive
Environmental performance	Carbon emissions intensity	Firm-level carbon emissions intensity	Negative

3.2.2. Entropy Weighting Method

We use the entropy weighting method to reduce subjectivity in assigning weights. The method derives indicator weights from their distributions across the sample and aggregates the standardized indicators into a composite score.

We first standardize the indicators to remove differences in scale. For indicators that enter positively, including R&D intensity, green invention patents, and ESG scores, we use the min–max normalization in Eq. (1).

$$Z_{ijt} = \frac{X_{ijt} - \min(X_j)}{\max(X_j) - \min(X_j)} \tag{1}$$

For carbon emissions intensity, which enters negatively, we use the reverse normalization in Eq. (2).

$$Z_{ijt} = \frac{\max(X_j) - X_{ijt}}{\max(X_j) - \min(X_j)} \tag{2}$$

In Eqs. (1) and (2), X_{ijt} and Z_{ijt} are the raw and standardized values for firm i in year t on indicator j, respectively. The terms $\max(X_j)$ and $\min(X_j)$ are the maximum and minimum values of indicator j in the sample.

We then compute the information entropy and weight for each indicator. Equation (3) gives each firm-year observation's share of the total standardized value for indicator j.

$$P_{ijt} = \frac{Z_{ijt}}{\sum_{i,t} Z_{ijt}} \tag{3}$$

Using the shares from Eq. (3), we calculate information entropy, the degree of divergence, and the indicator weight with Eqs. (4), (5), and (6), respectively.

$$e_j = -k \sum_{i,t} P_{ijt} \ln P_{ijt}, \quad k = \frac{1}{\ln N} \tag{4}$$

$$d_j = 1 - e_j \tag{5}$$

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$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{6}$$

In Eqs. (4)–(6), N is the number of firm-year observations used in the calculation and m is the number of indicators. The terms e_j, d_j, and w_j are the information entropy, degree of divergence, and weight of indicator j, respectively. When $P_{ijt} = 0$, we set $P_{ijt}\ln P_{ijt} = 0$ by continuity. The resulting weights are 5.28% for R&D intensity, 14.58% for green invention patents, 1.32% for Bloomberg's ESG score, and 78.82% for carbon emissions intensity.

Finally, we multiply the standardized indicators by their respective weights and sum the products to obtain the composite green innovation score in Eq. (7).

$$Score_{it} = \sum_{j=1}^{m} w_j \, Z_{ijt} \tag{7}$$

In Eq. (7), $Score_{it}$ is the composite green innovation score of firm i in year t. A higher score indicates stronger overall performance across the indicators used in this study.

3.3. Variables and Definitions

3.3.1. Dependent Variable

The composite green innovation score (Score) measures corporate green innovation. Section 3.2 describes how we construct the index, and Eq. (7) gives the score. The score combines green innovation inputs and outputs, sustainability performance, and environmental performance. Higher values indicate stronger corporate green innovation.

3.3.2. Explanatory Variable

The main explanatory variable is ownership type (SOE). SOE equals 1 if the firm's ultimate controller is the central government, a local government, a state-owned assets supervision and administration agency, or another state-owned entity. It equals 0 otherwise.

3.3.3. Mechanism Variable

We measure financing constraints using the WW index developed by Whited and Wu [37]. The index combines information on cash flow, dividend payments, debt, firm size, and firm and industry growth, providing a broader measure of access to external finance than a single financial indicator. We use it to capture changes in financing constraints across firm-years because green innovation typically entails substantial investment, long R&D cycles, and uncertain returns. Higher WW values generally indicate tighter financing constraints.

3.3.4. Control Variables

We include controls for firm characteristics, financial conditions, and corporate governance to reduce omitted-variable bias. Firm characteristics include size (Size) and years since listing (ListAge). Financial controls include leverage (Lev), return on assets (ROA), and operating revenue growth (Growth). Governance controls include board size (Board), chair–general manager duality (Dual), and the largest shareholder's ownership share (Top1).

Table 2 defines the variables.

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Table 2. Variable definitions

Role	Variable	Symbol	Definition
Dependent	Corporate green innovation	Score	Composite score defined in Eq. (7)
Explanatory	Ownership type	SOE	1 for state-owned firms and 0 otherwise
Mechanism	Financing constraints	WW	WW index. Higher values indicate tighter constraints.
Controls	Firm size	Size	Natural log of annual total assets
	Years since listing	ListAge	ln(current year − listing year + 1)
	Leverage	Lev	Year-end total liabilities / year-end total assets
	Return on assets	ROA	Net income / average total assets
	Operating revenue growth	Growth	Current-year operating revenue / prior-year operating revenue − 1
	Board size	Board	Natural log of the number of directors
	Chair–general manager duality	Dual	1 if the board chair and general manager are the same person, and 0 otherwise
	Largest shareholder's ownership share	Top1	Shares held by the largest shareholder / total shares

Note. The variable symbols correspond to those in Eqs. (8) and (9) and the regression tables. The symbol ln denotes the natural logarithm.

3.4. Model Specification

To examine the relationship between ownership type and corporate green innovation, we estimate the baseline model in Eq. (8).

$$Score_{i,t} = \beta_0 + \beta_1 SOE_{i,t} + \gamma Controls_{i,t} + \lambda_t + \mu_j + \varepsilon_{i,t} \quad (8)$$

In Eq. (8), i, t, and j index firms, years, and industries, respectively. Score is the composite green innovation score. The main explanatory variable, SOE, equals 1 for state-owned firms and 0 for non-state-owned firms. Controls is the vector of firm-level covariates: Size, Lev, ROA, Growth, Board, Dual, Top1, and ListAge. The corresponding coefficient vector is γ. The terms λ_t and μ_j are year and industry fixed effects, respectively, and ε_{it} is the error term.

To examine financing constraints as a possible explanation for the ownership gap in green innovation, we follow Jiang's [38] two-step approach to mechanism testing. In Eq. (9), we use the WW index as the dependent variable.

$$WW_{i,t} = \alpha_0 + \alpha_1 SOE_{i,t} + \delta Controls_{i,t} + \lambda_t + \mu_j + \varepsilon_{i,t} \quad (9)$$

In Eq. (9), a higher WW index indicates tighter financing constraints. The remaining variables are defined as in Eq. (8).

4. Empirical Results

4.1. Descriptive Statistics

Table 3 reports the number of observations, mean, standard deviation, minimum, and maximum for each main variable. The composite green innovation score (Score) has a mean of 0.020 and a standard deviation of 0.033, with values ranging from 0.001 to 0.858. The dispersion and the gap between the maximum and the mean indicate substantial variation, with a small number of firms scoring well above most of the sample. The alternative outcome used

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in the robustness analysis, green invention patents (Gpatent), has a mean of 0.517 and a standard deviation of 0.919, indicating substantial differences in output. SOE has a mean of 0.481, so SOEs account for about 48.1% of the observations and both ownership groups are well represented. Among the controls, mean Size is 23.200, mean leverage is 45.7%, and about 22.5% of observations have the same person serving as board chair and general manager. The remaining variables also show variation in financial conditions, growth, and governance.

Table 3. Descriptive statistics

Variable	Observations	Mean	Std. dev.	Minimum	Maximum
Score	9370	.02	.033	.001	.858
Gpatent	9370	.517	.919	0	6.142
SOE	9370	.481	.5	0	1
Size	9370	23.2	1.288	19.541	28.644
Lev	9370	.457	.19	.008	.996
ROA	9370	.047	.07	-.965	.644
Growth	9370	.299	5.132	-.918	429.036
Board	9370	2.177	.202	1.386	2.89
Dual	9370	.225	.417	0	1
Top1	9370	.365	.161	.031	.9
ListAge	9370	2.513	.659	.693	3.555

Note. Gpatent is the natural logarithm of one plus the number of green invention patents. See Table 2 for the other variable definitions.

4.2. Correlation and Multicollinearity

Table 4 reports Pearson correlations among the main variables. The correlation between SOE and Score is 0.052 and is significant at the 1% level, consistent with higher green innovation scores among SOEs. Size, Lev, Dual, and ListAge are positively correlated with Score at the 1% level, and Growth is positively correlated at the 10% level. ROA and Top1 are negatively correlated with Score at the 1% level. The correlation between Board and Score is statistically insignificant. The absolute pairwise correlations among the explanatory variables are all below 0.5.

Table 5 shows that all variance inflation factors are well below 10. The maximum is 1.61, indicating that severe multicollinearity is unlikely in the regression model.

Table 4. Pearson correlation matrix

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Score	1.000									
(2) SOE	0.052***	1.000								
(3) Size	0.330***	0.245***	1.000							
(4) Lev	0.140***	0.239***	0.452***	1.000						
(5) ROA	-0.053***	-0.152***	-0.043***	-0.428***	1.000					
(6) Growth	0.017*	-0.010	0.011	0.012	0.027***	1.000				
(7) Board	0.004	0.297***	0.209***	0.157***	-0.039***	0.011	1.000			
(8) Dual	0.040***	-0.311***	-0.086***	-0.097***	0.063***	0.017*	-0.186***	1.000		
(9) Top1	-0.028***	0.281***	0.212***	0.064***	0.096***	0.009	0.060***	-0.113***	1.000	
(10) ListAge	0.085***	0.367***	0.280***	0.244***	-0.198***	-0.011	0.107***	-0.207***	-0.078***	1.000
*** p<0.01, ** p<0.05, * p<0.1										

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Table 5. Multicollinearity diagnostics

Variable	VIF	1/VIF
Lev	1.61	0.620921
SOE	1.49	0.671795
Size	1.46	0.685129
ListAge	1.33	0.752262
ROA	1.32	0.759566
Top1	1.21	0.828088
Board	1.14	0.875400
Dual	1.14	0.879478
Growth	1.00	0.997982
Mean VIF	1.30	—

Note. VIF is the variance inflation factor, 1/VIF is tolerance, and Mean VIF is the mean variance inflation factor.

4.3. Baseline Regression

Table 6. Baseline regression results

	(1)	(2)
	Score	Score
SOE	0.0059***	0.0046***
	(0.0015)	(0.0015)
Size		0.0084***
		(0.0012)
Lev		-0.0047
		(0.0034)
ROA		-0.0081
		(0.0079)
Growth		0.0001***
		(0.0000)
Board		-0.0043
		(0.0042)
Dual		0.0032
		(0.0021)
Top1		-0.0091**
		(0.0043)
ListAge		-0.0011
		(0.0007)
Constant	0.0175***	-0.1582***
	(0.0007)	(0.0271)
N	9368.0000	9368.0000
R^2	0.1506	0.2217
Year fixed effects	Yes	Yes
Industry fixed effects	Yes	Yes

Note. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors appear in parentheses. N denotes the number of observations and R^2 is the coefficient of determination. Column (1) excludes firm-level controls. Column (2) includes them.

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Table 6 reports estimates from the baseline model in Eq. (8). Column (1) includes year and industry fixed effects. The coefficient on SOE is 0.0059 and is significant at the 1% level, indicating higher composite green innovation scores for SOEs. Column (2) adds Size, Lev, ROA, Growth, Board, Dual, Top1, and ListAge. The coefficient on SOE falls to 0.0046 and remains significant at the 1% level. The positive association persists after adding firm-level controls, supporting H1.

Among the controls, the coefficient on Size is 0.0084 and is significant at the 1% level. Larger firms may have greater financial, technical, and human resources to sustain green innovation. The positive and statistically significant coefficient on Growth is consistent with faster-growing firms having greater capacity or willingness to invest. The coefficient on Top1 is −0.0091 and is significant at the 5% level, suggesting that concentrated ownership may hinder green innovation.

4.4. Robustness Checks

Table 7. Robustness checks

	(1)	(2)	(3)
	Gpatent	Score	Score
SOE	0.1194***	0.0037**	0.0036**
	(0.0410)	(0.0016)	(0.0015)
Size	0.3376***	0.0076***	0.0077***
	(0.0525)	(0.0011)	(0.0015)
Lev	-0.1075	-0.0029	-0.0014
	(0.1071)	(0.0032)	(0.0024)
ROA	-0.3723	0.0003	0.0006
	(0.2746)	(0.0062)	(0.0051)
Growth	0.0034***	0.0001***	-0.0001*
	(0.0010)	(0.0000)	(0.0001)
Board	-0.0838	-0.0035	-0.0029
	(0.0930)	(0.0047)	(0.0024)
Dual	0.0333	0.0029	0.0028
	(0.0546)	(0.0021)	(0.0023)
Top1	-0.1346	-0.0098*	-0.0090**
	(0.0915)	(0.0051)	(0.0042)
ListAge	-0.0526	-0.0010	-0.0010
	(0.0373)	(0.0008)	(0.0008)
Constant	-6.9510***	-0.1439***	-0.1484***
	(1.1327)	(0.0254)	(0.0330)
N	9368.0000	7443.0000	7584.0000
R^2	0.3585	0.2075	0.2709
Year fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes

Note. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors appear in parentheses. Column (1) uses the alternative dependent variable. Column (2) excludes 2020–2022. Column (3) excludes the four centrally administered municipalities.

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We assess whether the baseline results depend on the construction of the green innovation index, disruptions during the COVID-19 pandemic, or the inclusion of firms from centrally administered municipalities. Table 7 reports the three robustness checks.

First, we replace Score with Gpatent, the natural logarithm of one plus the number of green invention patents. This measure focuses on a technologically substantive output and reduces reliance on the construction of the composite index. In column (1), the coefficient on SOE is 0.1194 and is significant at the 1% level, indicating that the baseline association also holds for green invention patent output. Second, we omit observations from 2020 to 2022, when the pandemic may have disrupted business operations, R&D spending, and project implementation. In column (2), the SOE coefficient is 0.0037 and is significant at the 5% level. Third, we exclude firms registered in Beijing, Shanghai, Tianjin, and Chongqing. These centrally administered municipalities differ from provinces in policy support, economic development, and the concentration of innovation resources. In column (3), the SOE coefficient is 0.0036 and is significant at the 5% level. The positive association persists across all three specifications.

4.5. Financing Constraints

Table 8. Financing constraints regression

	(1)
	WW
SOE	-0.0025**
	(0.0012)
Size	-0.0488***
	(0.0006)
Lev	0.0295***
	(0.0026)
ROA	-0.1789***
	(0.0091)
Growth	-0.0348***
	(0.0000)
Board	0.0007
	(0.0019)
Dual	-0.0013
	(0.0009)
Top1	-0.0033
	(0.0030)
ListAge	0.0034***
	(0.0007)
Constant	0.0617***
	(0.0100)
N	8757.0000
R^2	0.9858
Year fixed effects	Yes
Industry fixed effects	Yes

Note. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors appear in parentheses.

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Green innovation typically requires substantial and sustained funding because development cycles are long and returns are uncertain. Differences in access to finance and other resources may help explain why SOEs and non-state-owned firms differ in green innovation. Table 8 reports the estimates from Eq. (9), with the WW index as the dependent variable. The coefficient on SOE is −0.0025 and is significant at the 5% level. Conditional on firm-level controls and year and industry fixed effects, SOEs have lower WW scores and thus face weaker financing constraints.

Taken together, the baseline and financing regressions show that SOEs have higher green innovation scores and face weaker financing constraints. Larger asset bases and stronger credit standing may give SOEs better access to bank lending and other external funding. Stable funding can help firms bear the risks of long-term R&D and maintain investment as projects progress. This pattern is consistent with financing constraints being one channel linking ownership type to green innovation and provides empirical support for H2.

5. Heterogeneity Analysis

5.1. Regional Heterogeneity

Table 9. Regional heterogeneity

	(1)	(2)	(3)
	Score	Score	Score
SOE	0.0055**	-0.0004	0.0022
	(0.0021)	(0.0017)	(0.0031)
Size	0.0091***	0.0060***	0.0052***
	(0.0013)	(0.0015)	(0.0016)
Lev	-0.0049	-0.0023	-0.0026
	(0.0042)	(0.0053)	(0.0042)
ROA	-0.0110	-0.0020	-0.0017
	(0.0106)	(0.0100)	(0.0064)
Growth	0.0001***	-0.0002	0.0001
	(0.0000)	(0.0002)	(0.0001)
Board	-0.0079	0.0057	-0.0001
	(0.0066)	(0.0049)	(0.0038)
Dual	0.0047	0.0009	-0.0018
	(0.0031)	(0.0029)	(0.0018)
Top1	-0.0151*	0.0037	-0.0039
	(0.0080)	(0.0053)	(0.0028)
ListAge	-0.0007	0.0014	-0.0036***
	(0.0012)	(0.0021)	(0.0011)
Constant	-0.1648***	-0.1386***	-0.0954***
	(0.0344)	(0.0349)	(0.0340)
N	5945.0000	1771.0000	1651.0000
R^2	0.2352	0.3937	0.3860
Year fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes

Note. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors appear in parentheses. Columns (1), (2), and (3) cover eastern, central, and western China, respectively.

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Differences in economic development, financing conditions, and innovation resources across China may affect the association between ownership type and green innovation. We divide the sample into eastern, central, and western regions based on firms' registered locations and estimate separate regressions. Table 9 shows that the estimated association is positive and statistically significant in the eastern subsample. Estimates for the central and western subsamples are statistically insignificant. Eastern China has more developed green finance instruments and innovation support services, along with a greater concentration of technology, skilled workers, and information. These conditions may help SOEs translate their access to funding and other resources into green R&D and innovation outcomes. Stricter environmental governance and greater public scrutiny may also encourage SOEs in the east to meet their environmental responsibilities. In central and western China, more limited financial and innovation services may constrain firms' access to capital, technology, and skilled workers. The concentration of resource-based industries and the cost of changing established production processes may further limit the extent to which ownership-related resource differences translate into measurable green innovation.

5.2. Industry Heterogeneity

Table 10. Industry heterogeneity

	(1)	(2)
	Score	Score
SOE	0.0044***	0.0042
	(0.0016)	(0.0029)
Size	0.0085***	0.0075***
	(0.0014)	(0.0014)
Lev	-0.0004	-0.0142*
	(0.0027)	(0.0072)
ROA	-0.0047	-0.0205
	(0.0073)	(0.0166)
Growth	0.0001***	0.0002
	(0.0000)	(0.0001)
Board	-0.0042	0.0062*
	(0.0030)	(0.0032)
Dual	0.0030	0.0014
	(0.0022)	(0.0034)
Top1	-0.0100**	0.0068
	(0.0037)	(0.0092)
ListAge	-0.0021**	0.0009
	(0.0009)	(0.0020)
Constant	-0.1593***	-0.1740***
	(0.0316)	(0.0388)
N	8006.0000	1362.0000
R^2	0.2499	0.7144
Year fixed effects	Yes	Yes
Industry fixed effects	Yes	Yes

Note. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors appear in parentheses. Column (1) covers manufacturing and column (2) covers non-manufacturing.

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Production methods, technology needs, and the requirements of the green transition vary across industries. We estimate separate regressions for manufacturing and non-manufacturing firms. Table 10 shows that SOEs have significantly higher composite green innovation scores within manufacturing. The positive estimate for non-manufacturing firms is statistically insignificant. Green R&D in manufacturing often needs to be integrated with production, and adoption can require equipment upgrades and changes to production processes. Stable funding and technical resources may help SOEs sustain these projects. Non-manufacturing firms generally have less direct need for cleaner production processes and energy-saving technologies. Their environmental improvements may occur through changes in management, service delivery, and business practices that the composite index captures less directly.

6. Conclusion and Policy Implications

The theoretical analysis and firm-level evidence yield three findings on the relationship between ownership type and corporate green innovation.

First, SOEs have higher composite green innovation scores than non-state-owned firms. Their environmental responsibilities, access to innovation resources, and ability to sustain long-term R&D may help explain this advantage. The ownership gap is also visible in green invention patent output, and the positive association persists when we change the sample period and geographic coverage.

Second, SOEs face weaker financing constraints, which may contribute to their green innovation advantage. Green innovation requires sustained funding and often involves long R&D cycles, substantial risk, and uncertain returns. SOEs' asset bases, credit standing, and resource access may help them secure external finance and keep projects running. Non-state-owned firms may reduce green R&D when financing options are limited or costly.

Third, the estimated SOE advantage is statistically significant in eastern China and among manufacturing firms. The estimates for central and western China and for non-manufacturing firms are statistically insignificant.

The findings suggest three implications for green innovation policy.

First, SOEs can lead the development of major green technologies and the transition to low-carbon production. Their performance assessments should place more weight on commercialization, patent quality, actual environmental benefits, and efficient use of resources. Opening their research facilities to universities, research institutes, suppliers, and customers could support joint R&D and help spread the benefits of green innovation.

Second, improving access to finance can help non-state-owned firms sustain green R&D. Financial institutions can improve how they evaluate green technologies and projects and reduce their reliance on ownership type and short-term financial indicators. Green credit, interest subsidies, and lending secured by intellectual property can direct longer-term funding to promising projects and reduce the likelihood that funding shortages interrupt R&D.

Third, policies should reflect regional conditions. Eastern regions can help disseminate green technologies, attract and share skilled workers, and make research resources accessible to other regions. Central and western regions can strengthen green finance, intellectual property protection, recruitment, and technology commercialization so firms can turn resources into practical outcomes. Within regions, firms' emissions profiles, technological capabilities, and financing needs offer more direct criteria for targeting support than a manufacturing versus non-manufacturing classification alone.

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