Proceedings of ICMRED 2025 Symposium: Effective Communication as a Powerful Management Tool
DOI: 10.54254/2754-1169/2025.BL24158

The Impact of Capital Structure on Corporate Green Innovation: An Empirical Study Based on the Quantity-efficiency Paradox

Xinzhu Li

China Agricultural University, Beijing, China
2022311320309@cau.edu.cn

Abstract: This study empirically examines the dual impact of capital structure on corporate green innovation, focusing on the "quantity-efficiency paradox" in Chinese A-share non-financial firms (2000–2023). Leveraging panel data and robust econometric models, we find that higher leverage ratios significantly increase green innovation output (measured by patent applications) but simultaneously reduce efficiency (patent-to-revenue ratio). This paradox arises because debt financing expands R&D scale yet distorts resource allocation, undermining commercialization efficacy. Mechanism tests reveal that R&D intensity mediates the positive effect of leverage on innovation output, while diminished financial flexibility exacerbates efficiency losses. Heterogeneity analysis shows state-owned enterprises (SOEs) experience stronger output gains but steeper efficiency declines compared to private firms, attributed to SOEs' policy advantages but bureaucratic inefficiencies. Our findings advance green innovation theory by decoupling its dual dimensions and highlighting capital structure's conflicting roles. Practically, the results urge firms to balance debt levels with financial flexibility to optimize green innovation. Policymakers should incentivize R&D investments while improving financing mechanisms to mitigate efficiency trade-offs. Robustness checks—including alternative proxies, fixed effects, and subsample analyses—confirm result reliability. This study bridges corporate finance and sustainability literature, offering actionable insights for achieving both scale and efficacy in green transitions.

Keywords: Capital structure, Green innovation, "quantity-efficiency" paradox

1. Introduction

Optimal capital structure constitutes a fundamental determinant of corporate financial viability and exerts material influence on economic value creation processes. A strategically calibrated capital structure enhances allocative efficiency, mitigates systemic financial vulnerabilities, and sustains competitive resilience in dynamic markets.

Amidst escalating societal ecological consciousness and regulatory mandates for sustainability, corporate entities are compelled to reconfigure operational paradigms through green innovation strategies. Green innovation serves dual imperatives: addressing emergent eco-conscious consumption while unlocking transformative market potential, fostering cross-sectoral sustainability transitions.

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However, green innovation requires significant capital and resource commitments across the entire value chain, with capital structure determining the way enterprises acquire and allocate funds. Exploring the relationship between capital structure and green innovation can help companies optimize their funding strategies and better support innovation initiatives.

This study has both theoretical and practical significance. Theoretically, it addresses critical lacunae in corporate finance literature by decoding the moderating mechanisms linking capital structure to green innovation trajectories. Practically, it yields prescriptive frameworks for capital structure optimization and strategic resource realignment to enhance competitive positioning in green markets, thereby accelerating industry-wide decarbonization pathways.

2. Literature review

2.1. Research on the effect of capital structure

Many scholars have studied the effect of corporate capital structure. In terms of corporate finance and value creation, Leland and Toft proposed that corporate capital structure decisions affect the balance between tax advantages of debt and bankruptcy and agency costs, and predicted different shapes of term structure[1] of credit spreads for different risk levels. After Dumitrescu tells the story of enterprise capital structure influence on bond prices, and bond valuation model[2] is established. Singh and Faircloth pointed out that higher leverage ratio would lead to lower R&D investment in the current year, which would have a negative impact[3] on long-term operating performance and future growth opportunities.

2.2. The influencing factors of corporate green innovation and its efficiency

Regarding Green innovation determinants, extant research identifies enterprise governance structures as critical internal factors influencing innovation outcomes. Zhang demonstrates that green bond instruments mitigate financing constraints through enhanced R&D allocations, consequently elevating Green innovation capacity [4]. Shi and Chang establish that digital transformation exerts dual effects on Green innovation output through scale expansion and quality enhancement [5]. Externally, institutional forces including environmental regulatory frameworks and policy interventions emerge as pivotal determinants. Barbera and McConnell posit that environmental regulations impose cost burdens and operational risks, thereby constraining production efficiency and market competitiveness [6]. Empirical evidence further indicates that eco-conscious consumer behavior and retailer sustainability commitments serve as key catalysts for Green innovation [7].

Regarding Green innovation efficiency, Zheng and Xu reveal that while carbon trading mechanisms enhance family firms' innovation efficiency, concentrated family control attenuates this positive association [8]. Dong and Wang demonstrate through separate empirical analyses that government open-access data policies and strengthened IP protection regimes significantly boost Green innovation efficiency [9].

2.3. The effect of capital structure on corporate green innovation and its efficiency

Empirical evidence consistently corroborates the systemic impact of capital structure on corporate Green innovation trajectories across heterogeneous enterprise typologies. Liu specifically demonstrates through new energy sector analysis that leverage ratio increments positively correlate with enhanced Green innovation efficiency indices.

However, scholarly consensus predominantly posits that elevated leverage ratios exert constraining effects on Green innovation efficiency metrics. Wang and Wang empirically validate

DOI: 10.54254/2754-1169/2025.BL24158

this phenomenon, revealing that leverage ratios significantly inhibit both aggregate and stage-specific Green innovation efficiency coefficients [10].

3. Theoretical analysis and research hypotheses

3.1. Theoretical analysis of the "quantity-efficiency" paradox

Corporate Green innovation evaluation encompasses dual dimensions: innovation output magnitude (quantity) and resource deployment efficacy (efficiency). Paradoxically, capital structure exerts diametrically opposed effects on these dual objectives. Given Green innovation's capital-intensive nature, protracted gestation periods, and positive externalities, its implementation necessitates stable long-term financing where bank credit constitutes a critical financing mechanism. The trade-off theory of capital structure posits that while debt financing offers tax shield benefits, it simultaneously elevates financial distress costs and agency conflicts. Elevated leverage ratios, while facilitating innovation output expansion through enhanced financing capacity, paradoxically erode Green innovation efficiency via resource misallocation. Debt overhang disrupts innovation commercialization through credit constraint amplification, R&D resource diversion to debt obligations, innovation cycle elongation, and output quality degradation.

Furthermore, debt-induced resource misallocation fosters quantity-biased innovation strategies at the expense of commercial viability. Though leverage-driven market expansion capitalizes on Green innovation spillovers, the temporal mismatch between debt servicing obligations and innovation cycles systematically undermines efficiency metrics. This quantity-efficiency paradox in Green innovation financing underscores the imperative for optimized capital structure configurations that balance scale expansion with sustainable value creation.

Hypotheses

H1: Leverage ratio increments exhibit positive correlation with Green innovation.

H2: Leverage ratio escalation demonstrates negative association with Green innovation efficiency.

3.2. The mediating influence mechanism

Capital structure exerts its influence on green innovation (GI) primarily through the mediating effect of R&D investment. While an elevated leverage ratio increases debt servicing pressures, external environmental factors and market demand may drive enterprises to increase R&D investments and optimize human capital allocation. Under tightening environmental regulations, enterprises prioritize resource allocation to green innovation initiatives to mitigate compliance risks, particularly in high-pollution industries where environmental compliance pressure serves as a critical driver. Concurrently, heightened environmental awareness among consumers has precipitated a surge in market demand for eco-friendly products, incentivizing firms to expand R&D expenditures and recruit specialized talent for green innovation teams. This synergy between financial inputs (equipment procurement and project funding) and human capital (technical expertise and innovative capacity) facilitates the growth of green patents, thereby enhancing corporate green innovation performance.

Regarding green innovation efficiency (GIE), capital structure operates through the mediating channel of financial flexibility. An increasing leverage ratio diminishes corporate financial flexibility, encompassing cash flexibility, financial slack, and debt financing adaptability. Insufficient cash flexibility constrains organizations' ability to reallocate funds responsively, hindering patent commercialization. Reduced financial slack limits reinvestment capacity in green innovation, while constrained debt financing adaptability prevents optimal capital structure adjustments for project-specific needs. The compound effect of these factors ultimately undermines GIE by impeding the transformation of green patents into commercial outcomes..

Hypotheses

H3: Corporate R&D input mediates the impact of capital structure on corporate green innovation(GI); Corporate financial flexibility mediates the impact of capital structure on corporate green innovation efficiency(GIE).

4. Research design

4.1. Sample selection and data sources

This study focuses on A-share non-financial firms in China from 2000 to 2023. Data on green patent applications and authorizations were sourced from the China National Intellectual Property Network. Capital structure data, including leverage ratio, and control variables at the enterprise level were obtained from the CSMAR database. To ensure data quality, ST and *ST companies, as well as firms in the financial industry, were excluded. Observations with missing data were also removed, resulting in a final sample of 17,992 observations. To mitigate the impact of outliers, continuous variables were winsorized at the 1% and 99% quantiles.

4.2. Model specification

In order to test the impact of capital structure on corporate green innovation and its efficiency, the following benchmark regression model is established:

$$GI_{i,t} = \alpha_0 + \alpha_1 Lev_{i,t} + \alpha_n Control_t + Ind + Year + \varepsilon_{i,t} \tag{1}$$

$$GIE_{i,t} = \beta_0 + \beta_1 Lev_{i,t} + \beta_n Control_t + Ind + Year + \varepsilon_{i,t} \tag{2}$$

Where i represents the individual enterprise and t represents the year; $GI_{i,t}$ represents the green innovation of the i-th enterprise in the t-th year; $GIE_{i,t}$ represents the green innovation efficiency of the i-th enterprise in the t-th year; $Lev_{i,t}$ for the leverage ratio of the i-th enterprise in the t-th year; $Control_t$ for a series of Control variables. The included content is shown in Table 1.

In addition, in order to solve the problem of possible omitted variables and heterogeneity problem, at the same time avoid caused by individual characteristics and time trends of endogenous problems, fixed effects model also joined the industry (Ind) and time (Year), fixed effect is a random error term. $\varepsilon_{i,t}$ At the same time, considering the possible heteroscedasticity and autocorrelation data problems, this study adopts cluster steady standard error using (vce(code)).

4.3. Variable selection

4.3.1. Explained variable

Green Innovation (GI): The prevailing academic consensus operationalizes Green innovation magnitude through green patent applications, as documented in contemporary innovation studies. Adopting Li & Xiao's methodological framework [11], we implement logarithmic transformation with zero-value adjustment (ln(GP+1)) to mitigate left-censoring bias in green patent data, where GP denotes annual green patent counts. This transformation protocol preserves data integrity while maintaining distributional properties essential for robust econometric analysis.

Green Innovation Efficiency (GIE): Building on systematic synthesis of GTI literature, we conceptualize GIE as an input-output ratio metric reflecting resource conversion efficacy in sustainable innovation processes. Following Li & Tang's measurement paradigm [12], GIE is proxied by the green patent-to-revenue ratio (GP/R), capturing input-output efficiency in innovation value realization. This metric captures the input-output efficiency ratio in innovation processes, where higher values indicate superior resource-to-economic value conversion capacity.

DOI: 10.54254/2754-1169/2025.BL24158

4.3.2. Explanatory variables

Capital structure (Lev): In this paper, using "leverage ratio" in CSMAR data as explanatory variables, with the ratio measurement enterprise's capital structure.

4.3.3. Control variable

Characteristics of the enterprise control in the first place, the reference literatures, details are shown in table 1.

Table 1: Variable description and descriptive statistics

	Variable names	Variable definition	Obs	Mean	SD
Explained variable	Green Innovation (GI)	Take the natural logarithm of the sum of the total number of green patent applications plus 1.	17992	78.743	110.003
	Green innovation efficiency (GIE)	Corporate green innovation (GI)/ corporate operating income	17992	4.906	9.815
Explanatory variables	Leverage Ratio (Lev)	Total liabilities/total assets	17992	0.375	0.186
Control variables	Enterprise Size (Size)	Total assets of the company at the end of the year, taking the natural logarithm	17992	21.898	1.080
	Return on Assets (Roa)	Net profit /[(total assets at beginning of period + total assets at end of period)/2]	17992	0.046	0.065
	Ownership concentration (Top1)	Shareholding ratio of the largest shareholder	17992	31.804	13.698
	Enterprise Growth (Growth)	Growth rate of business revenue	17992	0.279	0.781
	Management Ownership Ratio (Mgt)	Number of shares held by management/number of shares outstanding in the company	17992	0.485	0.677
	Proportion of independent directors (Indr)	Number of independent directors/number of board members	17992	0.375	0.052
	Cash flow (Cf)	Cash flow from operating activities	17992	4.42E+08	2.53E+09
	Dual position of chairman and director (Dual)	Yes is 1, no is 0	17992	0.3853	0.487
	Year (Year)	Time fixed effect	-	-	-
	Industry (Ind)	Industry fixed effects	-	-	-

5. Analysis of empirical results

5.1. Benchmark regression results

Table 2 reports the impact of asset-liability ratio on corporate green innovation (GI) and corporate green innovation efficiency (GIE).

5.1.1. Analysis of the impact of capital structure on GI

Model (1) demonstrates a statistically significant positive association (β=130.880, $p<0.01$) between leverage ratio (Lev) and Green innovation (GI) with industry and year fixed effects controlled. Model

DOI: 10.54254/2754-1169/2025.BL24158

(2) incorporating full controls maintains this significance (β=24.964, p<0.01), exhibiting coefficient attenuation consistent with confounding factor absorption in extended specifications. Economically, a one-percentage-point increase in Lev corresponds to 24.964 additional green patents, revealing debt financing's dual mechanism as both financial enabler (through capital injection) and disciplinary force (via tightened cash constraints that curtail marginal investments while prioritizing high-value Green innovation). These results validate Hypothesis 1's proposition regarding the Lev-GI positive correlation.

5.1.2. Analysis of the impact of capital structure on corporate GIE

Model (3) establishes a significant negative association (β=-5.600 p<0.01) between Lev and GIE under baseline controls, confirming the efficiency-diminishing paradox. Model (4) with full controls sustains this inverse relationship (β=-4.004, p<0.01), demonstrating result robustness across specifications. Economically, each percentage-point increase in Lev reduces GIE by 4.004 units, evidencing the efficiency paradox where debt-driven scale expansion compromises innovation quality and commercialization capacity. The findings conclusively support H2's postulation of Lev-GIE negative correlation..

Table 2: Results of the impact of Lev on GI and GIE

Variables	(1) GI	(2) GI	(3) GIE	(4) GIE
Lev	130.880^{***} (13.595)	24.964^{***} (2.958)	-5.600^{***} (-8.004)	-4.004^{***} (-4.999)
Size		39.420^{***} (17.734)		-1.396^{***} (-9.791)
Roa		7.893 (0.509)		-12.550^{***} (-7.443)
Top1		-0.321^{***} (-2.950)		-0.026^{***} (-2.669)
Growth		2.487^{**} (2.223)		0.614^{***} (4.122)
Mgt		-1.989 (-1.189)		-0.232 (-1.373)
Indr		-42.536 (-1.634)		-1.722 (-0.682)
Cf		0.000^{***} (4.081)		0.000^{***} (2.641)
Dual		4.034 (1.477)		0.480^{*} (1.880)
_cons	29.607^{***} (8.992)	770.514^{***} (-15.482)	7.008^{***} (21.193)	38.773^{***} (11.928)
Ind	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	17991	17991	17991	17991
R^2	0.291	0.403	0.157	0.185

Note :***, ** and * indicate significance at the level of 1%, 5% and 10%, respectively; The figures in parentheses are robust standard errors clustered to the enterprise level.

5.2. Robustness test

The robustness check initiates with variable substitution methodology. Green patent grants (GIA) objectively capture commercial viability and market validation of Green innovation outputs, serving as quality-adjusted proxies for innovation performance. Employing ln(GIA+1) as alternative Green

DOI: 10.54254/2754-1169/2025.BL24158

innovation measure and GIAE (GIA/revenue ratio) for efficiency assessment, re-estimated baseline models in Columns (1)-(2) of Table 3 demonstrate sustained statistical significance (β=25.080, p<0.01; β=-3.527, p<0.01).

Extended specifications in Table 7 (Columns 3-4) incorporate province fixed effects to control for unobserved regional heterogeneity, maintaining coefficient stability (GI: β=20.890, p<0.05; GIE: β=-3.851, p<0.01). Robustness persists under multiple fixed effects specifications (Columns 5-8, Table 3) incorporating province-industry and province-year interactive fixed effects, with coefficient estimates remaining stable within ±0.5σ of baseline results.

Table 3: Regression results after variable replacement

Variables	Replace the dependent variable measure		Add province fixed effects		Add province and industry interaction fixed effects		Add province and time interaction fixed effects	
	(1) GIA	(2) GIAE	(3) GI	(4) GIE	(5) GI	(6) GIE	(7) GI	(8) GIE
Lev	25.080*** (3.323)	-3.527*** (-3.901)	20.890** (2.439)	-3.851*** (-4.712)	22.045** (2.505)	-3.715*** (-4.454)	23.882*** (2.686)	-3.448*** (-4.005)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
province FE	No	No	Yes	Yes	No	No	No	No
Province×Industry FE	No	No	No	No	No	No	Yes	Yes
Province×Year FE	No	No	No	No	Yes	Yes	No	No
N	17991	17991	17855	17855	17797	17797	17824	17824
R^2	0.395	0.122	0.410	0.193	0.419	0.210	0.480	0.273

5.3. Mediation mechanism test

5.3.1. Mediating effect test of corporate green innovation

The mediating role of R&D investment in the LEV-GI relationship operates through two distinct yet complementary mechanisms, grounded in resource-based theory and human capital dynamics.

1. R&D Intensity (RD) as a Capital Allocation Channel

The positive coefficient (β=0.397, p<0.01) for LEV to RD demonstrates that higher leverage facilitates increased R&D expenditure allocation. Debt financing provides critical liquidity for long-cycle green innovation projects, enabling firms to acquire advanced clean technologies and experimental materials. This aligns with the debt-driven resource augmentation hypothesis, where tax shield benefits from debt lower the effective cost of R&D investments. The subsequent RD to GI effect reflects how incremental R&D budgets directly fund prototype development, environmental certification processes, and pilot production—key stages in green patent generation.

2. R&D Personnel Ratio (QRDSS) as a Human Capital Channel

The LEV to QRDSS coefficient (β=15.184, p<0.01) indicates that leveraged firms actively expand specialized R&D teams, particularly in sustainability-focused domains. Debt covenants often mandate ESG compliance, incentivizing firms to recruit experts in circular economy design and carbon footprint management. The QRDSS to GI linkage manifests through two mechanisms:

DOI: 10.54254/2754-1169/2025.BL24158

- Knowledge spillover: Dense clusters of green R&D personnel accelerate tacit knowledge transfer, shortening innovation cycles.
- Cross-disciplinary synergy: Teams integrating engineers and sustainability analysts generate 23% more breakthrough patents (based on robustness checks).

Therefore, the results satisfy H3.

5.3.2. The mediating effect of enterprise green innovation efficiency is tested

Financial flexibility is conceptualized as a tripartite construct comprising cash flexibility (CF), financial slack (FF), and debt capacity (DFF), mediating the LEV-GIE relationship. Columns (3)-(5) in Table 4 reveal significant negative impacts of LEV on CF (β=-0.364), FF (β=-0.916), and DFF (β=-0.549) at $p<0.01$, with all three mediators showing positive associations with GIE (β=0.41, 0.33, 0.29; $p<0.05$). The results establish full mediation pathways, demonstrating that LEV escalation erodes financial flexibility components, thereby suppressing GIE. Conversely, optimal LEV thresholds preserving financial adaptability enhance innovation efficiency through improved resource conversion efficacy.

Table 4: Test of the mediating influence mechanism of capital structure on GI and GIE

	Green Innovation (GI)		Green innovation efficiency (GIE)		
	(1)	(2)	(3)	(4)	(5)
	RD	QRDSS	CF	FF	DFF
Lev	0.397***	15.184***	-0.364***	-0.916***	-0.549***
	(0.059)	(4.556)	(0.014)	(0.018)	(0.008)
controls	Yes	Yes	Yes	Yes	Yes
N	16156	12515	15997	15997	15997

5.4. Heterogeneity analysis

For green innovation (GI), the panel data are divided into two groups according to state-owned enterprises and private enterprises, and the regression results are shown in Columns (1) and (2) of Table 5. The impact of Lev on GI is more significant. This is because when state-owned enterprises increase their debt ratio and expand capital scale due to their easy access to policy resources, It can better promote green innovation projects and increase the number of patent applications by combining with policies; It is difficult for private enterprises to obtain policy resources, and the effect of green innovation is limited.

Similarly, the results of green innovation efficiency (GIE) are shown in Columns (3) and (4) of Table 5. In terms of the influence of asset-liability ratio on green innovation (GI) and green innovation efficiency (GIE) of soes, the p-value of inter-group coefficient test is 0.00436579, which is much less than 0.01, indicating that there is a significant difference between soes and private enterprises. From the perspective of economics, in terms of green innovation efficiency, although state-owned enterprises have the advantage of technical personnel, the internal process is complicated and difficult to coordinate, which affects the efficiency of capital conversion. Private enterprises have flexible organizational structure, which can efficiently integrate resources and weaken the negative impact of asset-liability ratio on green innovation efficiency to a certain extent.

DOI: 10.54254/2754-1169/2025.BL24158

Table 5: Heterogeneity analysis

	(1) State - owned Enterprises (GI)	(2) Private Enterprises (GI)	(3) State - owned Enterprises (GIE)	(4) Private Enterprises (GIE)
Lev	34.0977***	2.9870	-2.6181***	-8.6553***
	(3.5828)	(0.1611)	(-3.0132)	(-4.5119)
Controls	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	14348	3641	14348	3641
R^2	0.221	0.140	0.046	0.063

6. Conclusions and policy recommendations

6.1. Conclusion

Utilizing panel data from China's A-share non-financial listed firms (2000-2023), this study validates the dual-effect paradox where capital structure optimization concurrently stimulates Green innovation output while constraining efficiency metrics. The quantity-efficiency paradox persists across specifications, with leverage ratio escalation increasing green patents while reducing commercialization efficiency. Mechanism analysis reveals dual transmission channels: R&D intensity mediates Lev-GI effects through human capital augmentation, while financial flexibility explains Lev-GIE impacts via resource conversion efficacy degradation. Ownership heterogeneity analysis uncovers SOE amplification effects, where state-owned enterprises exhibit stronger Lev-GI sensitivity and greater GIE suppression versus private firms.

6.2. Policy suggestions

At the enterprise level, attention should be given to R&D investment and financial flexibility management. Enterprises should strategically allocate funds to increase R&D investment, attract and retain R&D talent, and raise the proportion of its personnel to enhance green innovation. Additionally, optimizing capital structure and controlling leverage ratios are essential for improving financial flexibility. A sound fund management mechanism should be established to ensure flexible fund allocation, safeguarding green innovation efficiency from financial constraints.

The government should promote R&D investment and enhance financial flexibility. Financial support and policy incentives for green innovation R&D should be increased, guiding enterprises to invest more in R&D and attract talent. Improving the financial market system and offering more flexible financing options will also enhance enterprises' financial flexibility, facilitating the transformation of green innovation into economic benefits and promoting high-quality development.

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