

Does Green Innovation Alleviate or Aggravate Financing Constraints? — Uncovering a Nonlinear Threshold Effect: Evidence from Chinese Listed Firms

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Abstract. Green innovation has been a highly debated topic, which is increasingly important for market entities, especially firms and policy makers. Nevertheless, the advancement of green innovation is constrained by its inherent characteristics: high upfront investment, long payback periods, and substantial risks. This paper selects Chinese A-share listed companies from 2015 to 2024 as the initial research sample, and elaborates on the nonlinear relationship between corporate green innovation (measured by green patent counts) and financing constraints represented by the SA index, filling the research gap in existing relevant studies and providing solid empirical evidence to support the formulation, implementation and optimization of green innovation supporting policies. Using panel data, fixed-effects models, and heterogeneity tests, this study examines the inverted U-shaped relationship between green innovation and financing constraints. The findings offer empirical clarification on how green innovation alleviates financing constraints, and carry meaningful implications for stimulating market vitality and advancing high-quality green transformation.

Keywords: Financial Constraints, Green innovation, Green Patent, Corporate Capital

1. Introduction

Green innovation serves as one of the most essential approaches to achieving sustainable development, enabling resource conservation, pollution reduction, low-carbon transition, and the enhancement of long-term competitiveness. However, green innovation carries inherent attributes that tend to exacerbate substantial financing constraints: general innovation activities face severe external financing frictions stemming from uncertain investment returns, information asymmetry throughout the R&D process, and elevated compliance costs. As widely documented, such financing constraints will in turn curb corporate innovation inputs [1]. Green innovation requires persistent and large-scale long-term capital investment. When confronted with binding financing constraints, firms tend to prioritize short-term production and reduce investment in long-cycle, high-risk green R&D projects [2]. The intricate nexus between corporate green innovation and financing constraints has long been a focal point in relevant academic research. However, most existing studies focus solely on linear relationships and neglect potential nonlinear characteristics. This study argues that

an inverted U-shaped association exists between green innovation and financing constraints. At the initial innovation stage, massive R&D spending cannot be rapidly transformed into operating returns, which aggravates firms' financial pressure. Only when innovation outputs accumulate to a critical threshold and achieve commercialization can financing constraints be relieved. Moreover, this favorable effect may show diminishing marginal returns and even reverse afterwards. Against this backdrop, this paper first empirically examines the linear association between corporate green innovation and financing constraints, and further formally tests for the hypothesized inverted U-shaped nonlinear relationship between the two constructs. From a theoretical perspective, this enriches research on the economic implications of green innovation, and reveals the nonlinear dynamic relationship between green innovation and financing constraints, thereby filling a gap in the literature.

2. Literature review

Corporate green innovation exhibits inherent sensitivity to financing conditions, as its long investment cycle and high uncertainty make sustained capital support a core prerequisite. Consequently, financial constraints have emerged as a critical barrier to corporate green innovation. This review synthesises recent evidence along two dimensions: the direct effect of green finance on green innovation, and the mediating role of financing constraints in this relationship.

Existing findings on the direct effect of green finance policies remain sharply divided. On the positive side, Henni et al., using a global dataset and distribution-sensitive econometric methods, demonstrate that green finance significantly enhances firm resilience, with green innovation serving as a primary transmission channel [3]. This stabilising effect is most pronounced among financially fragile firms, suggesting that green finance acts as a buffer against external shocks rather than merely a performance enhancer. Similarly, green bonds are found to stimulate urban green innovation by easing overall financing constraints and increasing firms' green capital reserves [4]. Further evidence on green credit policies reveals a more nuanced picture. Wang finds that following the implementation of the Green Credit Guidelines, firms in industries restricted by green credit rules demonstrate significantly more active green innovation activities than their counterparts in non-restricted industries [5]. Conversely, a growing strand of literature cautions against unintended adverse effects. Zheng documents that poorly designed green finance policies can significantly exacerbate the formation of corporate green innovation bubbles [6]. The mechanism operates through elevated green thresholds in the financial system, which tighten financing constraints and incentivise firms to overstate green innovation outputs—for instance, by filing low-quality patents or embellishing ESG disclosures. This bubble effect is pronounced among non-SOEs and low-R&D and low-ESG firms but insignificant for SOEs and high-R&D and high-ESG firms, underscoring the importance of firm-level heterogeneity. While the majority of existing studies focus on the linear effects of green finance on green innovation, their empirical conclusions remain inconsistent and lack a unified explanatory framework. Few have explored whether green innovation itself exerts a nonlinear threshold effect on financing constraints, or distinguished between substantive and strategic green innovation, which may have heterogeneous impacts. To fill these gaps, we propose:

H1: Green innovation has a significantly positive linear effect on corporate financing constraints, meaning that an increase in green patent output is associated with a worsening of financing constraints.

H2: There exists an inverted U-shaped nonlinear relationship between green innovation and financing constraints. The marginal effect of green innovation on financing constraints is positive at

low levels of innovation output, but turns negative after the innovation scale exceeds a certain threshold.

H3: The marginal effect of green innovation on financing constraints is larger in manufacturing firms than in non-manufacturing firms.

3. Methodology and hypothesis testing

Sample Selection and Data Source: This study empirically explores the impact of financing constraints (measured by the SA index) on corporate green innovation, using Chinese A-share listed companies spanning 2015 to 2024 as the initial research sample. We excluded ST, *ST, and financial firms. Green patent data were obtained from CNRDS, and financial data were extracted from the CSMAR database.

Variable Definition: We examine corporate financing constraints using the SA index developed by Hadlock and Pierce [7]. This index is widely used in the literature. It has a clear advantage over other measures. It excludes endogenous financing variables, such as cash flow and leverage. This feature reduces the risk of reverse causality. This research computes the SA index using the following formula:

$$SA = |-0.737 \times \text{Size} + 0.043 \times \text{Size}^2 - 0.040 \times \text{Age}| \quad (1)$$

A higher SA index value indicates a higher level of financing constraints. We take the absolute value of the index for our regression analysis.

Corporate green innovation is measured using the total number of green patent applications filed by each A-share listed firm annually. The patent data are obtained from the China National Intellectual Property Administration. Green patents are identified using the International Patent Classification (IPC) Green Inventory. For each firm-year observation, the aggregate number of green patent applications is counted. A natural logarithmic transformation (adding one prior to transformation) is applied to the count variable to mitigate skewness in the data distribution [8].

Consistent with the established literature, this research includes these variables to account for heterogeneity of corporate and to obtain more reliable estimates of the green innovation effect [9, 10]. These variables are as follows: SA index, Leverage, Return on assets, Gross profit, Age, Growth, Cash flow, Intangible Assets, Top1, Independence.

Model Construction: A two-way fixed-effects panel model is constructed to investigate the nonlinear association between green innovation and financing constraints. Financing constraints, measured by the SA index, constitute the dependent variable. Green innovation and its quadratic term are employed to test the hypothesized inverted U-shaped pattern. Multiple firm-level control variables are controlled for, including Lev, ROA, Gross profit, Age, Growth, Cash flow, Intangible, Top1 and Independence. Firm fixed effects μ_i absorb time-invariant firm heterogeneity, and year fixed effects λ_t account for universal annual macroeconomic impacts. The formal regression specification is presented below:

$$\begin{aligned} FC_{it} = & \beta_0 + \beta_1 * X_{it} + \beta_2 * X_{it}^2 + \gamma_1 * Lev_{it} + \gamma_2 * ROA_{it} + \gamma_3 * Grossprofit_{it} + \\ & \gamma_4 * Age_{it} + \gamma_5 * Growth_{it} + \gamma_6 * Cashflow_{it} + \gamma_7 * Intangible_{it} + \gamma_8 * Top1_{it} + \\ & \gamma_9 * Independence_{it} + \mu_i + \lambda_t + \xi_{it} \end{aligned} \quad (2)$$

4. Empirical results analysis

4.1. Descriptive statistics and correlation analysis

Table 1. The descriptive statistics

	N	Mean	SD	Min	Max
X1	36830	.288	3.716	0	202
X2	36830	.771	13.981	0	964
X3	36830	.829	6.111	0	382
X4	36830	1.497	11.500	0	559
SA	36383	4.039	1.625	-1.877	13.744
Lev	36820	.417	0.976	.01	178.345
ROA	36820	.029	0.289	-30.688	7.446
Gross profit	36816	.294	0.190	-4.03	3.764
Age	36387	24.58	6.163	7	70
Growth	34662	.344	12.359	-2.733	1878.372
Cash flow	36820	.049	0.076	-1.686	2.222
Intangible	36820	.046	0.062	0	.938
Top1	36376	33.051	14.809	.29	89.99
Independence	36376	.386	0.077	.188	.889

Table 1 shows the descriptive statistics. The minimum value of financial constraints is -1.877 , the maximum is 13.744 , the standard deviation is 1.625 , and the mean is 4.039 . This suggests that firms generally face relatively severe financial constraints. The ranges (max–min) of X1, X2, X3, and X4 are quite large, indicating that there are big differences across firms in their patent R&D and application levels. Nevertheless, the mean values of X1 to X4 remain at a relatively low level, accompanied by relatively high standard deviations, suggesting that the majority of sampled firms have a small number of patent applications. As for the control variables, the mean of leverage (Lev) is 0.417 , return on assets (ROA) is 0.029 , firm age (Age) is 24.58 years, ownership concentration (Top1) is 33.05% , and the proportion of independent directors (Independence) is 0.386 .

4.2. Benchmark regression results

Table 2. Benchmark regression results

	(1)	(2)	(3)	(4)
VARIABLES			SA	
X1	0.0023 (1.1623)			
X2		0.0009		

Table 2. (continued)

		(1.5363)		
X3			0.0037***	
			(3.2445)	
X4				0.0018**
				(2.0945)
Lev	0.0166	0.0166	0.0166	0.0166
	(0.8577)	(0.8573)	(0.8586)	(0.8565)
ROA	0.1369**	0.1369**	0.1369**	0.1368**
	(2.0987)	(2.0987)	(2.1001)	(2.0991)
Gross profit	0.1695**	0.1693**	0.1700**	0.1691**
	(2.3550)	(2.3528)	(2.3611)	(2.3492)
Growth	0.0004	0.0004	0.0004	0.0004
	(0.8000)	(0.7997)	(0.8002)	(0.7987)
Cash flow	-0.0128	-0.0129	-0.0127	-0.0112
	(-0.1573)	(-0.1581)	(-0.1564)	(-0.1382)
Intangible	-0.0315	-0.0318	-0.0267	-0.0294
	(-0.1054)	(-0.1064)	(-0.0894)	(-0.0982)
Constant	3.4330***	3.4333***	3.4304***	3.4322***
	(107.3547)	(107.3586)	(107.2296)	(107.3337)
Observations	34,456	34,456	34,456	34,456
R-squared	0.3024	0.3024	0.3033	0.3028
Number of code_num	4,602	4,602	4,602	4,602
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES

Table 2 reports the benchmark regression results of how green innovation affects financial constraints. The coefficients of X1 and X2 are not statistically significant, meaning they have no clear association with financial constraints. X3 is positively significant at the 1% level, indicating that a one-unit increase in X3 leads to a small rise in the financial constraints index, thus worsening financial constraints. X4 has a positive and significant effect at the 5% level, with a similar direction to X3 but with a smaller magnitude.

Table 3. Nonlinear relationship

	(1)	(2)	(3)	(4)
VARIABLES	SA			
X1_c	0.010*** (0.002)			
X1_sq	-0.000*** (0.000)			
X2_c		0.003*** (0.001)		
X2_sq		-0.000*** (0.000)		
X3_c			0.006*** (0.002)	
X3_sq			-0.000* (0.000)	
X4_c				0.004*** (0.001)
X4_sq				-0.000** (0.000)
Lev	0.017 (0.019)	0.017 (0.019)	0.017 (0.019)	0.017 (0.019)
ROA	0.137** (0.065)	0.137** (0.065)	0.137** (0.065)	0.137** (0.065)
Gross profit	0.170** (0.072)	0.169** (0.072)	0.170** (0.072)	0.168** (0.072)
Growth	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)

Table 3. (continued)

Cash flow	-0.011 (0.081)	-0.013 (0.081)	-0.012 (0.081)	-0.012 (0.081)
Intangible	-0.032 (0.299)	-0.033 (0.299)	-0.025 (0.299)	-0.027 (0.299)
Constant	3.432*** (0.032)	3.433*** (0.032)	3.429*** (0.032)	3.431*** (0.032)
Observations	34,456	34,456	34,456	34,456
R-squared	4,602	4,602	4,602	4,602
Number of code_num	0.303	0.303	0.303	0.303
U-test p-value	1.49e-08	0.00368	0.286	0.0561
Turning point	83.38256	509.5847	299.8934	271.0908
t-value	5.55	2.68	0.56	1.59
95% Fieller interval for extreme point	[76.577729 > ; 87.545279]	[76.577729 > ; 87.545279]	[-Inf;186. > 95185] U [-2193.6735;+Inf]	[152.6664; >921.27933]
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES

Table 3 builds on the benchmark regressions by adding the centered linear term (X_c) and the squared term (X_sq) of the patent indicators to test for nonlinear patterns. In column (1), the coefficient of $X1_c$ is significantly positive (0.010), and that of $X1_sq$ is significantly negative (−0.000), with a U-test p-value of 1.49e-08 and a turning point at 83.38. This points to a clear inverted U-shaped relationship between $X1$ and SA : when the patent count is below 83.38, $X1$ worsens financial constraints; beyond that threshold, it actually eases them. Column (2) shows a similar significant inverted U-shape for $X2$ ($p = 0.00368$, turning point = 509.58). In column (3), although the squared term of $X3$ is negative, the U-test p-value is 0.286, so it fails the significance test and the nonlinear relationship does not hold. For column (4), $X4$ has a U-test p-value of 0.0561, which is marginally significant, with a turning point of 271.09. Overall, $X1$ and $X2$ exhibit robust inverted U-shaped nonlinear effects, while $X3$ and $X4$ are closer to linear relationships.

4.3. Robustness

Table 4. Robustness

VARIABLES	(1)	(2)	(3)	(4)
			SA	
X1_c	0.010*** (0.002)			
X1_sq	-0.000*** (0.000)			
X2_c		0.003*** (0.001)		
X2_sq		-0.000*** (0.000)		
X3_c			0.006*** (0.002)	
X3_sq			-0.000* (0.000)	
X4_c				0.004*** (0.001)
X4_sq				-0.000** (0.000)
Lev	0.016 (0.019)	0.016 (0.019)	0.016 (0.019)	0.016 (0.019)
ROA	0.135** (0.064)	0.135** (0.064)	0.135** (0.064)	0.135** (0.063)
Gross profit	0.159** (0.071)	0.158** (0.071)	0.159** (0.071)	0.157** (0.071)
Growth	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
Cash flow	-0.004 (0.081)	-0.005 (0.081)	-0.005 (0.081)	-0.004 (0.081)
Intangible	-0.023 (0.294)	-0.024 (0.294)	-0.016 (0.294)	-0.018 (0.294)
Top1	0.004** (0.002)	0.004** (0.002)	0.004** (0.002)	0.004** (0.002)

Table 4. (continued)

Independence	-0.067 (0.046)	-0.067 (0.046)	-0.067 (0.046)	-0.066 (0.046)
Constant	3.308*** (0.075)	3.309*** (0.075)	3.303*** (0.075)	3.304*** (0.075)
Observations	34,449	34,449	34,449	34,449
R-squared	0.305	0.305	0.306	0.306
Number of code_num	4,602	4,602	4,602	4,602
U-test p-value	1.18e-08	0.00378	0.259	0.0537
Turning point	83.28403	509.13167	293.4065	272.266
t-value	5.59	2.67	0.65	1.61
95% Fieller interval for extreme point	[76.661951; 87.377903]	[419.87646; 645.55002]	[-Inf;187.25675] U [-8844.4045;+Inf]	[154.62973; 870.29729]
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES

Table 4 extends the model in Table 3 by adding two corporate governance control variables, namely ownership concentration (Top 1) and the proportion of independent directors (Independence), to verify the robustness of the documented nonlinear results. The findings show that for X1, the U-test p-value is 1.18e-08 and the turning point is 83.28; for X2, the p-value is 0.00378 and the turning point is 509.13; X3 still has a p-value of 0.259, remaining insignificant; and X4 has a p-value of 0.0537, which is marginally significant. The signs, significance levels, and turning points of all coefficients are highly consistent with those in Table 3, suggesting that after controlling for additional firm characteristics, the inverted U-shaped relationship for X1 and X2 remains robust. At the same time, the linear term coefficients of the patent indicators are still significantly positive, which supports Hypothesis H2.

4.4. Heterogeneity analysis

Table 5. Heterogeneity analysis-nonmanufacturing firms

VARIABLES	(1)	(2)	(3)	(4)
			SA	
X1_c	0.009*** (0.003)			
X1_sq	-0.000*** (0.000)			
X2_c		0.002* (0.001)		

Table 5. (continued)

X2_sq		-0.000**		
		(0.000)		
X3_c			0.000	
			(0.004)	
X3_sq			0.000	
			(0.000)	
X4_c				0.004**
				(0.002)
X4_sq				-0.000***
				(0.000)
Lev	0.598***	0.599***	0.599***	0.599***
	(0.208)	(0.208)	(0.208)	(0.208)
ROA	0.306*	0.306*	0.307*	0.306*
	(0.178)	(0.178)	(0.178)	(0.178)
Gross profit	0.250***	0.250***	0.251***	0.250***
	(0.094)	(0.094)	(0.094)	(0.094)
Growth	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Cash flow	0.278**	0.277*	0.277*	0.277*
	(0.141)	(0.141)	(0.141)	(0.141)
Intangible	0.650**	0.651**	0.654**	0.660**
	(0.324)	(0.324)	(0.324)	(0.324)
Top1	0.011***	0.010***	0.010***	0.010***
	(0.003)	(0.003)	(0.003)	(0.003)
Independence	-0.146*	-0.146*	-0.147*	-0.144
	(0.088)	(0.088)	(0.088)	(0.088)
Constant	3.145***	3.146***	3.147***	3.144***
	(0.158)	(0.158)	(0.158)	(0.158)
Observations	11,559	11,559	11,559	11,559
R-squared	1,452	1,452	1,452	1,452
Number of code_num	0.270	0.270	0.269	0.270
U-test p-value	0.00393	0.0327		0.00614
Turning point	77.28384	509.156	-16.0964	159.3696
t-value	2.66	1.84		2.51

Table 5. (continued)

95% Fieller interval for extreme point	[62.834623 > ; 103.66497]	[-3963.676 > 6; 559.47903]	[-Inf; +In > f]	[83.81841; >204.90127]
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES

Table 6. Heterogeneity analysis-manufacturing firms

VARIABLES	(1)	(2)	(3)	(4)
			SA	
X1_c	0.010*** (0.002)			
X1_sq	-0.000*** (0.000)			
X2_c		0.010*** (0.003)		
X2_sq		-0.000*** (0.000)		
X3_c			0.008*** (0.002)	
X3_sq			-0.000*** (0.000)	
X4_c				0.004** (0.002)
X4_sq				-0.000** (0.000)
Lev	0.009 (0.016)	0.009 (0.016)	0.009 (0.016)	0.009 (0.016)
ROA	0.115* (0.062)	0.115* (0.062)	0.115* (0.062)	0.115* (0.062)
Gross profit	0.121 (0.106)	0.121 (0.106)	0.121 (0.106)	0.119 (0.106)
Growth	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)
Cash flow	-0.188** (0.092)	-0.189** (0.092)	-0.190** (0.092)	-0.188** (0.092)

Table 6. (continued)

Intangible	-0.806 (0.492)	-0.810 (0.492)	-0.802 (0.492)	-0.807 (0.492)
Top1	0.001 (0.002)	0.001 (0.002)	0.001 (0.002)	0.001 (0.002)
Independence	-0.031 (0.054)	-0.034 (0.054)	-0.030 (0.054)	-0.032 (0.054)
Constant	3.291*** (0.096)	3.294*** (0.096)	3.285*** (0.096)	3.289*** (0.096)
Observations	22,890	22,890	22,890	22,890
R-squared	3,150	3,150	3,150	3,150
Number of code_num	0.352	0.353	0.354	0.353
U-test p-value	5.72e-06	0.00932	0.102	0.0704
Turning point	85.20009	144.401	268.6401	303.3262
t-value	4.40	2.35	1.27	1.47
95% Fieller interval for extreme point	[74.276454 > ; 90.68003]	[118.65837 > ; 225.4876]	[194.67143 > ; 568.55576]	[147.68959 > ; 1057.0895]
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES

Tables 5 and 6 report the industry sub-sample estimation results, which compare the nonlinear link between patent indicators and financial constraints across manufacturing and non-manufacturing firms. Table 5 reports the results for non-manufacturing firms, and Table 6 for manufacturing firms. For the manufacturing sub-sample, the U-test p-values are 5.72e-06 for X1, 0.00932 for X2, 0.102 for X3, and 0.0704 for X4 respectively. In the non-manufacturing sample, the p-values are 0.00393 for X1 (with a turning point of 77.28), 0.0327 for X2 (turning point 509.16), X3 is not significant, and 0.00614 for X4 (turning point 159.37). Comparing the linear term coefficients between the two groups: in manufacturing, X1_c is 0.010, X2_c is 0.010, and X3_c is 0.008; in non-manufacturing, X1_c is 0.009, X2_c is only 0.002, and X3_c is 0.000. Except for X4, where the coefficients are similar, the coefficients for all patent indicators in manufacturing are significantly larger than those in non-manufacturing. This suggests that green innovation has a stronger effect on financial constraints for manufacturing firms. This supports Hypothesis H3, which states that the marginal effect of patent indicators is greater in manufacturing firms than in non-manufacturing ones.

5. Conclusion

It finds that the relationship between green innovation and financing constraints is not simply linear. Instead, it shows an inverted U-shaped pattern. This conclusion carries notable practical

implications, alerting firms that pursuing excessive green innovation does not always yield optimal outcomes. A larger number of patents is not necessarily more beneficial. Low-quality patent accumulation wastes resources. Worse still, it may send confusing signals to outside investors. Such signal distortion exacerbates information asymmetry, and ultimately creates a more hostile financing environment for the firm. At the same time, this paper also verifies the moderating role of government policies near the turning point. This result gives policymakers a clear operational basis. During the transition period of green transformation in manufacturing, moderate financial support can help firms get through the hardest stage. Such support can prevent them from giving up halfway. The sample period covers only 2015-2024 and excludes earlier policy pilots, so the findings may be period-specific. Future research can further incorporate patent quality metrics such as citation counts and claim scope, refine industry classification standards based on pollution or technology intensity, and adopt dynamic panel models or event study designs to track the continuous evolution of firms' financing conditions.

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