The Impact of Green Finance on Green Innovation Efficiency

—— Based on Financing Constraints as an Mediator

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Abstract. Climate change and ecological degradation pose systemic global challenges, with green innovation crucial for low-carbon transition. Yet, its long R&D cycles, high costs, and environmental spillovers intensify firms' financing constraints. Green finance, through loans, bonds, and carbon finance, integrates environmental values into decision-making and reduces financing costs for green projects. Using the resource-based view and data from Chinese A-share firms (2014-2023), This study focuses on how green finance enhances green innovation efficiency and explores the mediating role of financing constraints. The empirical results confirm that green finance indeed provides a powerful impetus for improving innovation efficiency, while financing constraints partially mediate this effect, accounting for 7.37% of the total. Firm size, revenue growth, and independent director ratio enhance innovation, whereas concentrated ownership hinders it. This study establishes a "resource input to constraint alleviation to innovation improvement" framework, offering micro-level evidence and policy insights for optimizing green finance and promoting sustainable innovation.

Keywords: Green Finance, Green Innovation, Financing Restriction.

1 Introduction

Climate change and ecological degradation have become global systemic challenges, with green innovation as the core path to address environmental pressures and advance low-carbon economic transformation—its development directly impacts global sustainable goals[1]. However, green innovation's long R&D cycles, high capital demands, and environmental benefit spillovers expose enterprises to more severe financial constraints than traditional innovation[2].

Green finance bridges financial markets and green development by integrating environmental risks and values into decision-making, using green loans, bonds, and carbon finance to cut financing costs for green projects[3]. Globally, the market is expanding rapidly: IEA data shows 2023 global green bond issuance exceeded $500 billion, with more institutions incorporating ESG factors into investments[4]. Yet, research on green

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finance's impact on green innovation efficiency remains divided: some highlight its role in boosting green patent output via reducing information asymmetry [5], while others note heterogeneous effects and limited impact on SMEs due to tool standardization and measurement issues[6].

A key research gap exists: most studies focus on green finance's direct effects, with insufficient exploration of how it indirectly influences green innovation by easing firms' internal constraints[7]. Financing constraints are particularly acute for green innovation (due to high risk and limited collateral), but empirical verification of this mediating mechanism lacks cross-national/industry evidence.

This study, rooted in the resource-based view, uses global firm samples to examine green finance's impact on green innovation efficiency and verify financing constraints' mediating role. It supplements micro-level evidence for green finance-green innovation research and provides insights for policymakers to optimize green financial tools, supporting coordinated progress toward global sustainable goals.

2 Literature Review

2.1 Definition of Core Concepts

Green Finance. Green finance, as a key financial mechanism for coordinating environmental governance and economic transformation, its concept is based on the "synergy between environmental goals and financial functions" and forms a "broad - narrow" dichotomy framework. The core connotation gradually expands with the deepening of practice.

Broadly speaking, green finance is a systematic mechanism for guiding resources to be allocated to sustainable development areas. It is based on the core principle of sustainable development and provides diversified financing channels for enterprises and industries that practice ecological protection and resource conservation. At the same time, it uses green credit and green investment as positive services to regulate polluting behaviors and prevent resource waste, incorporating environmental externalities into the entire process of financial decision-making[8][9]. It breaks through the traditional financial focus on only returns, incorporating non-financial factors such as environmental risks and ecological value into the consideration of resource allocation, covering tools like green securities and green insurance, as well as supporting systems such as policy frameworks and information disclosure, forming a closed loop of "financing support - risk prevention - value transmission" .

In a narrow sense, green finance is driven by policies and is carried out through specific tools, guiding financial institutions to fulfill environmental responsibilities through mandatory or differentiated rules. For instance,green bonds must comply with the "Green Bond Support Project Catalogue", with the funds specifically allocated for environmental improvement; carbon finance converts carbon emission rights into tradable assets through carbon quota trading, directly restricting pollution behavior [10][11]. In academic research, green finance is often quantified by a single indicator such as "loan interest rate premium for high energy-consuming industries" or "green

bond issuance scale", accurately capturing the direct intervention of policies on financial resource allocation [12][13].

Green Innovation Efficiency. Green innovation efficiency is the core indicator for measuring the resource transformation and overall effectiveness in green innovation activities. The core logic lies in incorporating environmental constraints into the "input - output" assessment framework, enabling the coordinated measurement of economic value and ecological benefits.

From the perspective of essential attributes, the key difference between green innovation efficiency and traditional innovation efficiency lies in the simultaneous consideration of "expected output" and "unexpected output". The core is to measure the effectiveness of converting innovation resource investment into green outcomes: Expected output includes direct innovation achievements such as the number of green patents granted and the sales revenue of new products, while unexpected output includes pollution emissions such as wastewater, waste gas, and solid waste; Previous studies, to avoid the deviation of a single pollutant indicator, constructed a comprehensive index of pollutants using the longitudinal and transverse scattering method, correcting the overestimation of efficiency in traditional models and making the definition more in line with the dual attributes of "economic - environmental" of green innovation [1].

2.2 Resource-Based View

The resource-based view was proposed by Barney, and its core logic lies in that an enterprise's competitive advantage stems from the integration and application of scarce, valuable, and difficult-to-imitate and substitute resources. In the context of green innovation, the financial support provided by green finance, policy guidance, and the resources obtained by enterprises through alleviating financing constraints all belong to the key resources for building competitive advantages in green innovation.

From the angle of the connection between green finance and green innovation, green finance, through targeted resource allocation, invests the funds required for green innovation into enterprises - the "scarce resources" of enterprise green innovation. When Tang and Tang studied China's green credit policies, they found that enterprises supported by green finance could leverage their financial resource advantages to promote investment in the research and development of green technologies and perform better in green patent output, which is in line with the logic of resource-driven innovation competitive advantages in the resource-based view[3].

The inhibitory effect of financing constraints on green innovation can also be explained from the perspective of resource foundation. Hadlock and Pierce pointed out that the key aspect of financing constraints lies in the fact that it hinders enterprises from obtaining the keys to innovation and expansion[6]. When enterprises face financing constraints, funds required for the research and development of green innovation and the technical cooperation resources are difficult to obtain. It is like lacking key resource input, and the output of green innovation will naturally be suppressed. The process of green finance alleviating financing constraints is actually supplementing the

scarce resources for green innovation for enterprises, re-constructing their resource advantages, and helping enterprises break through the innovation bottleneck. This transmission path is highly compatible with the theoretical framework of resource integration and advantage construction in the resource foundation view.

3 Theoretical Framework and Research Design

3.1 Theoretical Analysis and Research Hypotheses

Green Finance and Green Innovation Efficiency. Green finance enhances the efficiency of green innovation. By leveraging tools, just like green loans and green bonds, it guides funds towards the green innovation sector, breaking the constraints on enterprises' access to innovation resources. From a resource-based perspective, green finance provides enterprises with scarce resources such as funds and technological cooperation needed for green innovation, optimizing the allocation of innovation inputs; at the same time, through mechanisms such as information disclosure and policy coordination, it reduces information asymmetry and risk costs in the innovation process, encouraging enterprises to enhance the efficiency of resource utilization in the process of green research and technology transfer.

Based on the above analysis, the following hypotheses are proposed:

H1: Green finance has a significant positive impact on green innovation efficiency.

The Mediating Effect of Financing Constraints. Green finance can help enterprises overcome the difficulties caused by financing constraints. In traditional financial markets, enterprises, especially green innovation enterprises, encounter high financing barriers and costs due to issues such as information asymmetry, risk assessment difficulties, and lack of collateral. The green financial system, leveraging its unique policy guidance and market mechanisms, can effectively address this situation. On one hand, green finance is policy-oriented. The government, through the formulation of green credit policies, encourages financial institutions to provide preferential credit to green projects and enterprises, reducing loan interest rates and extending loan terms, thereby directly alleviating the pressure on enterprises' financing costs [14]. On the other hand, in the green financial market, financing methods such as green bond issuance, with their strict information disclosure mechanisms and government endorsements, enhance investors' trust in the enterprises and attract more funds to flow into green enterprises.

Based on the above analysis, the following hypotheses are proposed:

H2: Green finance has huge financing constraints negative impact.

The Mediating Effect of Financing Constraints. Financing constraints will restrain enterprises' green innovation investment and efficiency improvement. When financing constraints are alleviated, enterprises can obtain more funds for green technology research and development, equipment purchase, and talent introduction . Adequate financial support can optimize the innovation process, shorten the R&D cycle, and enhance the efficiency of green patent output.

Based on the above analysis, the following hypotheses are proposed:

H3: The alleviation of financing constraints has a huge positive impact on green innovation efficiency.

Combining hypotheses H2 and H3, the following hypotheses are proposed:

H4: Green finance, by alleviating financing constraints, has a prominent positive impact on green innovation efficiency.

3.2 Sample Selection and Data Sources

Considering the availability of green finance and enterprise-related data, the sample period was selected as 2014-2023 for Chinese A-share listed companies. Previous studies were followed to exclude financial enterprises, ST and *ST enterprises, and the main variables were rounded to 1% for truncation. Among them, enterprise green innovation data was obtained from the CNRDS database, and the remaining enterprise-level data were all sourced from the CSMAR database.

3.3 Variable Definitions

Dependent Variable. In the research on innovation efficiency, the number of patents is widely recognized as a core proxy indicator by international top journals. Aghion et al. pointed out that patents can directly reflect the efficiency of enterprise innovation input-output[5]. Dechezlepretre et al. emphasized that green patents align with the dual goals of "environmental benefits + technological innovation" of green innovation efficiency[2].

This study focuses on the total number of green patent applications and grants that measure the efficiency of green innovation. At the same time, it incorporates core explanatory and control variables such as the green finance index and the absolute value of financing constraints SA, and constructs a complete logical chain.

Independent Variables. In the study about the correlation between green finance and innovation, international top journals often use a comprehensive indicator to calculate the degree of green finance development. Tang & Tang pointed out in Energy Economics that green finance affects innovation through resource allocation and needs to cover various tools such as green loans and bonds.

This study measures it using the green finance index, integrating dimensions such as the proportion of green loans and the scale of green bonds, to reflect the resource allocation and development level of green finance, providing a basis for analyzing its effect on the efficiency of green innovation.

Mediating Variables. In the research on corporate financing and innovation, the measurement of financing constraints is a crucial step. Hadlock & Pierce proposed the SA index in the Review of Financial Studies[6]. They constructed a model based on the enterprise size and establishment years to accurately capture the degree of enterprise financing constraints, avoiding the deviation of traditional indicators due to reliance on

financial data. This study measures the absolute value of the SA index of financing constraints to reflect the intensity of financing constraints, providing a basis for analyzing its mediating role between green finance and the efficiency of green innovation.

3.4 Model Specification

Main Regression Model. The main regression model is constructed to examine the direct effect of green finance on green innovation efficiency. It follows the two-way fixed effect model design for controlling industry and year heterogeneity as proposed by Peters et al. (2019) in their research on innovation efficiency, and also refers to the empirical framework of Tang & Tang (2023) on the relationship between these two factors. The specific formula is as follows:

$$lnpatent_{i,t}=\beta_0+\beta_1 green_{i,t}+\sum_{k=2}^{n}\beta_k Control_{i,t}+\mu_{ind}+\lambda_{year}+\varepsilon_{i,t} \quad (1)$$

Mediating Effect Test Model. To verify the mediating role of financing constraints in the "green finance → green innovation efficiency" process, the model follows the measurement logic of financing constraints (SA index) proposed by Hadlock & Pierce (2010) and the mediation effect test framework in Baron & Kenny, and constructs a unified logic-based mediating test model. The core formula is set as follows:

$$\ln p\,atent_{i,t}=\delta_0+\delta_1 green_{i,t}+\delta_2 abssa_{i,t}+\sum_{k=3}^{n}\delta_k\, Control_{i,t}+\mu_{ind}+\lambda_{year}+\omega_{i,t} \quad (2)$$

Table 1 provides the names and definitions of the variables used in the empirical analysis.

Table 1. Explanation of Indicators

Name	Label
ind	Industry Code
lnpatent	Natural logarithm of (total number of green patent applications + 1)
lnpatent1	Natural logarithm of (total number of green patent authorizations + 1)
green	Green Finance Index
abssa	Absolute Value of Financing Constraints (SA Index)
lev	Asset - Liability Ratio
sgr	Total Asset Turnover Ratio A
growth	Operating Income Growth Rate
top1	Shareholding Ratio of the Largest Shareholder
roa	Return on Total Assets (ROA) A
size	Company Size = ln(Total Assets)
lnage	Natural Logarithm of Company Age
board	Board Size
indep	Independent Director Ratio
balance	Equity Balance Degree

4 Empirical Analysis

4.1 Descriptive Analysis

Table 2 presents the data statistical characteristics for all variables. The sample consists of a total of 11,790 firm-year observations, indicating high data coverage.

The descriptive statistics for the natural log of total green patent applications (lnpatent) show a mean of 0.9881 and a standard deviation of 1.1933 (Min=0, Max=4.8903). This suggests considerable variation in green innovation output across the sample, with some firms being highly active in filing green patents while others are just beginning their green innovation efforts. The mean of lnpatent1 (log of granted green patents) is 0.8753, a value below that of lnpatent (log of patent applications). This difference is consistent with the expected attrition from the application to the granting stage of the patent process.

The core explanatory variable, the Green Finance Index (green), has a mean of 0.4395(SD=0.0884), with values lie between 0.1172 to 0.6639. This shows that the overall level of green finance development experienced by the sampled firms is moderate.

The mediating variable, the value of the SA index for financing constraints (abssa), has a mean of 3.9244 and SD equal to 0.2092, with values concentrated between 3.3907 and 4.3480. This indicates that the sampled firms generally face financing constraints, and the degree of these constraints is relatively small.

The mean Debt-to-Asset Ratio (lev) is 0.3959, which falls within a reasonable range for financial leverage. The average shareholding percentage of the largest shareholder (top1) is 32.1115%, reflecting a moderate level of ownership concentration among the sample firms. The percentage of independent directors (indep) has an average of 0.3814, approaching the regulatory minimum of one-third, which suggests that the corporate governance structures are generally in compliance.

Table 2. Descriptive analysis

Variable	N	Mean	SD	Min	Max
lnpatent	11790	0.9881	1.1933	0.0000	4.8903
lnpatent1	11790	0.8753	1.0843	0.0000	4.4308
green	11790	0.4395	0.0884	0.1172	0.6639
abssa	11790	3.9244	0.2092	3.3907	4.3480
Variable	N	Mean	SD	Min	Max
lev	11790	0.3959	0.1868	0.0636	0.9032
sgr	11790	0.6154	0.3218	0.1150	1.9833
growth	11790	0.1718	0.4552	-0.6372	2.6374
top1	11790	32.1115	13.9223	8.4233	70.4236
roa	11790	0.0366	0.0718	-0.2888	0.2101
size	11790	22.1965	1.1593	20.0910	25.8904
lnage	11790	2.0929	0.8717	0.0000	3.4012
board	11790	2.0764	0.1888	1.6094	2.4849
indep	11790	0.3814	0.0544	0.3333	0.5714
balance	11790	0.8096	0.6038	0.0452	2.8180

4.2 Baseline Regression Analysis

To prevent the regression coefficient bias caused by multicollinearity, we conducted a collinearity test on the data. The results showed that there was no significant multicollinearity issue among the variables, and the core test could be carried out.

This study employed a two-way fixed effects model to investigate the direct impact of green finance on green innovation efficiency. We controlled for industries and years to reduce the interference caused by heterogeneity, and used robust standard errors to address the issue of heteroscedasticity.

The results are presented in Table 3. The first column shows the core explanatory variables and fixed effects, where the coefficient of the green finance index is 0.2237, and it is significantly positive at the 5% level. After adding all control variables in the second column, the coefficient of green increased to 0.4113, and it was significantly at the 1% level. Thus, it can be seen that after controlling for the influence of enterprise-specific characteristics, the positive driving effect of green finance is more robust. That is, for every one-unit increase in the green finance index, the natural logarithm average of green patent applications increases by 0.4113 units.

Among the control variables, the coefficients for firm size, revenue growth rate and the proportion of independent directors are all significantly positive. Conversely, the coefficient for the ownership stake of the largest shareholder is significantly negative. These findings are consistent with the established logic regarding the influence of a firm's resource endowment, growth incentives, and governance structure on green innovation.

Table 3. Baseline Regression Analysis

	(1)	(2)
	lnpatent	lnpatent
green	0.2237**	0.4113***
lev		0.2312***
sgr		-0.0002
growth		0.1507***
top1		-0.0040***
roa		-0.1108
size		0.5430***
lnage		0.0276**
board		0.2003***
indep		0.6189***
balance		-0.1052***
_cons	0.8900***	-11.8562***
ind	yes	yes
year	yes	yes
N	11790.0000	11790.0000
r2	0.1530	0.4336
F	4.4226	418.8319

4.3 Mediation Effect Test

The mediation effect test adopts a three-step method to verify the transmission role of financing constraints in the 'green finance to green innovation efficiency' pathway, tje Table 4 shows the results.

The test in the (1) column for the overall effect shows that the coefficient of the green finance index on the natural logarithm of the total number of green patent applications is 0.4113, which is significant at the 1% level. This confirms the overall positive impact of green finance on the efficiency of green innovation. The column (2) tests the influence of green finance on financing constraints. The coefficient of green is also significant, indicating that green finance can effectively alleviate the financing constraints of enterprises. In the (3) column, green finance and financing constraints are both included in the model.

The coefficient of financing constraints is -0.4297, and the green financing constraint coefficient drops to 0.3810. Both are still significant at the 1% level. This indicates that green finance not only directly promotes green innovation but also indirectly promotes green innovation by alleviating financing constraints.

Table 4. Mediation Effect Test

	(1) lnpatent	(2) abssa	(3) lnpatent
abssa			-0.4297***
green	0.4113***	-0.0704***	0.3810***
lev	0.2312***	-0.0037	0.2296***
sgr	-0.0002	0.0017	0.0005
growth	0.1507***	-0.0036	0.1491***
top1	-0.0040***	-0.0001	-0.0040***
roa	-0.1108	0.1544***	-0.0444
size	0.5430***	-0.0356***	0.5277***
lnage	0.0276**	0.1135***	0.0764***
indep	0.6189***	-0.1309***	0.5626***
balance	-0.1052***	-0.0096**	-0.1094***
board	0.2003***	0.0521***	0.2228***
indep	0.6189***	-0.1309***	0.5626***
_cons	-11.8562***	4.4551***	-9.9420***
ind	yes	yes	yes
year	yes	yes	yes
N	11790.0000	11790.0000	11790.0000
r2	0.4336	0.2699	0.4377
F	418.8319	225.9514	395.8462

4.4 Robustness Test

To ensure the reliability of our research, this study replaces the dependent variable with lnpatent1 for a robustness test, the results can be seen in Table 5.

Column (1) shows green's coefficient is 0.4682 (significant at 1%), consistent with the baseline result, confirming green finance's positive effect regardless of patent measure.Column (2) replicates green's negative effect on abssa (financing constraints). Column (3) shows abssa's coefficient is -0.3985 (1% significance), green's coefficient slightly decreases (mediation effect ~6.0%), matching the mediation logic in prior analysis.

High R-squared (0.4120), F-statistic (349.9334), and consistent control variable coefficients confirm the core conclusion—green finance boosts green innovation efficiency by alleviating financing constraints—remains robust.

Table 5. Robustness Test

	(1) lnpatent1	(2) abssa	(3) lnpatent1
abssa			-0.3985***
green	0.4682***	-0.0704***	0.4402***
lev	0.2591***	-0.0037	0.2576***
sgr	-0.0074	0.0017	-0.0068
growth	0.1135***	-0.0036	0.1121***
top1	-0.0045***	-0.0001	-0.0045***
roa	-0.1858	0.1544***	-0.1243
size	0.4749***	-0.0356***	0.4608***
lnage	0.0221**	0.1135***	0.0673***
board	0.1575***	0.0521***	0.1783***
indep	0.5424***	-0.1309***	0.4902**
balance	-0.1074***	-0.0096**	-0.1112***
_cons	-10.3326***	4.4551***	-8.5573***
	(1) lnpatent1	(2) abssa	(3) lnpatent1
ind	yes	yes	yes
year	yes	yes	yes
N	11790.0000	11790.0000	11790.0000
r2	0.4077	0.2699	0.4120
F	370.8553	225.9514	349.9334

5 Conclusion

Green finance significantly boosts green innovation efficiency in Chinese A-share companies (2014–2023), as evidenced by a positive coefficient at the 1% significance level for both green patent applications and authorizations. This effect is stable even after controlling for enterprise characteristics. A key finding is that financing constraints act as a partial mediator, accounting for a 7.37% mediating effect. This means green finance achieves green innovation by alleviating these constraint factors. The study, grounded in the resource-based view, builds a "resource input - obstacle alleviation -

innovation improvement" framework. It also confirms that factors like firm size, revenue growth, and independent director ratio positively impact green innovation, while an excessive shareholding by the largest shareholder has a negative effect.

While the study provides a robust framework, it has limitations. It only focused on A-share listed companies and didn't differentiate between various green financial tools. Future research could expand the sample to include non-listed companies, analyze the specific effects of different green financial instruments, and introduce other mediating variables like technological absorption capacity to create a more comprehensive model.

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