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IMPACT OF FINANCIAL TECHNOLOGY ON ENTERPRISES' GREEN INNOVATION PERFORMANCE--BASED ON CHINESE A-SHARE LISTED COMPANIES

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Abstract: Based on the microdata of Chinese A-share listed companies from 2009 to 2023, this paper explores the impact of FinTech on the green innovation performance of enterprises and its mechanism of action. It is found that FinTech significantly enhances firms' green innovation performance, as evidenced by the increase in the number of green patent applications and patent citations, indicating that FinTech has a positive role in promoting both the quantity and quality of green innovation. Further analysis shows that the enhancement of financing constraints will weaken the positive impact of FinTech on green innovation performance. In contrast, enterprise green concern mediates between FinTech and green innovation performance. In addition, the promotional effect of FinTech on green innovation performance is more significant in SOEs, manufacturing industries, and the eastern region. The research in this paper provides empirical evidence for FinTech to promote green innovation and provides a reference for policymakers to optimize the institutional environment for FinTech to support green innovation.
Keywords: FinTech; Green innovation performance; Financing constraints; Green concern

1 INTRODUCTION

The rapid emergence and evolution of financial technology has become a vital factor in helping companies achieve sustainable development. Its impact on the innovation and performance of green businesses has been acknowledged by the public. At present, China's corporate green innovation is in the process of rapid development and significant change, from the traditional high energy consumption, high pollution production model to the green innovation-driven path of sustainable development, not only to deal with the external environmental regulations tightening and social pressure but also enterprises in the fierce market competition to achieve differentiated advantages, the inherent need to open new market space.

Achieving eco-friendly innovation faces numerous challenges, as the inherent features of elevated expenses and substantial uncertainties often discourage businesses from voluntarily engaging in sustainable development practices[1]. This is reflected in the long green investment research and development cycle and information asymmetry. The flourishing development of the new financial technology industry under the wave of digitalization, such as big data, AI and blockchain technology, provides an effective solution to break the multiple shackles of green innovation financing limitations, transformation pressure and risk loss[2].

The outcomes of corporate green innovation encompass the holistic results attained in terms of financial gains, ecological impact, and societal contributions through sustainable innovation initiatives[3]. Existing research indicates that assessing green innovation effectiveness requires a dual approach, incorporating both measurable metrics (such as the volume of eco-friendly patents filed and granted) and qualitative indicators (like the frequency of citations for green patents and related references). This combined framework provides a thorough representation of a company's achievements in sustainable innovation efforts[4].

The impact of FinTech on firms' green innovation performance is a complex and multidimensional research area. Existing literature has explored the facilitating effect of FinTech on green innovation and its potential constraints from both positive and negative aspects. FinTech can significantly contribute to the development of green finance by enhancing the efficiency of financial services, alleviating information asymmetry[5] and financing constraints[6], optimizing risk allocation, increasing the intensity of R&D investment and improving corporate ESG performance[7]. At the same time, existing research has also found that FinTech can increase operational costs and liquidity risks for firms, as well as using FinTech to "Greenwashing" the environment and neglect actual green innovation initiatives[8].

This study examines the influence of financial technology on green innovation outcomes by categorizing it into qualitative and quantitative dimensions, filling gaps in current research. It analyzes the mediating effect of funding limitations and the role of corporate environmental awareness, uncovering detailed mechanisms through which FinTech drives sustainable innovation. Additionally, analyzing heterogeneity across property rights, regions, and industries refines the differentiated impacts of FinTech, offering policy insights for FinTech development, "dual-carbon" goal implementation, and green business cultivation.

2 RESEARCH HYPOTHESES

Enterprise green innovation activities usually require long-term investment, face high risks and are irreversible. These characteristics make green innovation activities particularly vulnerable to changes in enterprises' internal management capacity and the external environment[9,10]. FinTech promotes green innovation through various mechanisms, including reducing information asymmetries, easing financing constraints and increasing willingness to invest in innovation[11]. FinTech utilizes big data and artificial intelligence to accurately identify and assess the value and risk of green projects, helping financial institutions understand corporate environmental performance while making it less challenging to finance green innovations. In addition, FinTech enhances environmental management capabilities through digital monitoring and real-time data analysis, optimizing production processes to reduce waste and emissions[12]. It also stimulates green innovation by raising awareness of environmental responsibility and enables efficient access to external knowledge resources[13], promoting interdisciplinary exchange and collaborative innovation[6]. Consequently, this study puts forward the following hypothesis:

H1: Financial technology significantly enhances the green innovation outcomes of businesses.

Financing constraints significantly inhibit green innovation, especially in highly polluting industries. Green credit policies may exacerbate these constraints by increasing the cost of finance and credit thresholds, leading firms to prioritize traditional business over green innovation[14,15]. High financing constraints can undermine the effectiveness of FinTech in mitigating information asymmetries and reducing financing costs[16-18]. As a result, this study proposes the following hypothesis:

H2: The enhancement of financing constraints weakens the positive effect of firms' FinTech level on green innovation performance.

By increasing enterprises' green focus, FinTech promotes incorporating environmental responsibility into their strategic decision-making, thereby contributing to improving green innovation performance. The growing emphasis on environmental sustainability drives companies to allocate more resources toward eco-friendly technology R&D and sustainable operations, enhancing resource efficiency and fostering the creation of greener products with stronger market appeal[19]. At the same time, the increase in green concern helps enterprises obtain policy support, market opportunities, and brand image advantages, forming a positive cycle and ultimately realizing a win-win situation for both economic and environmental benefits[20]. Therefore, this paper proposes the following hypothesis:

H3: FinTech enhances green innovation performance by increasing firms' green focus.

3 RESEARCH DESIGN

3.1 Sample Selection and Data Sources

This study utilizes A-share listed firms from the Shanghai and Shenzhen stock exchanges as the sample, covering the period from 2009 to 2023. Due to the different listing times of each company, the panel data used is an unbalanced panel. The data on green invention patents of listed companies and citations are from the China Intellectual Property Website; the data on FinTech development are from the annual reports of each company's enterprise; and the data on enterprise-level control variables are from the data collated from CSMAR and Wind. According to the existing studies, this paper deals with the sample data as follows: firstly, the data of listed companies that have been delisted before listing are excluded; secondly, companies labeled as ST, ST*, or PT are removed from the sample; thirdly, firms with significant missing data for key variables are also excluded; and fourthly, logarithmic treatment and shrinking treatment are adopted for some indicators.

3.2 Variable Setting

Here, this study discusses the rationale behind the selection and construction of the explained variable, explanatory variable, and control variables. Firstly, this study uses green innovation performance (GreenInnovation) as an explained variable and measures it from both quantitative and qualitative dimensions. In the quantitative dimension, the number of green patent applications (PatentApply) is used as a proxy variable for green innovation performance, and this metric effectively captures the level of innovative output achieved by companies in their eco-friendly technology research and development efforts. In terms of quality dimension, it is measured by the logarithmic value of patent citations (Cite), which can reflect the technological influence and knowledge diffusion effect of green innovation achievements.

Secondly, the financial technology development level (FinTech) is used as an explanatory variable. This research adopts the machine learning approach proposed by Huang, Huang and Yang [21] to analyze the frequency of 124 FinTech-related terms in listed companies' annual reports, encompassing six areas such as artificial intelligence, blockchain, cloud computing, big data, and online/mobile technologies. The extracted data is then log-transformed to determine the annual FinTech development level of these firms.

The following variables were selected as the control variables: firm size, firm age, return on assets, Herfindahl index, gearing ratio, cash holdings, and percentage of independent directors based on other corporate green innovation performance studies.

3.3 Model Setting

In order to empirically test the effect of financial technology on the green innovation performance of enterprises, the following fixed effect model is specifically constructed, as shown in equation (1):

$$GreenInnovation = \alpha_0 + \alpha_1 F\,\text{int}\,ech + \alpha_2 Control_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

Where $Control_{i,t}$ is a control variable, μ_i is an individual fixed effect, λ_t is a time-fixed effect, and $\varepsilon_{i,t}$ is a random perturbation term incorporating the remaining unobservables in the model.

4 Empirical Analysis

4.1 Benchmark Regression

Table 1 displays the baseline regression outcomes examining FinTech's influence on corporate green innovation performance, incorporating firm and time-fixed effects with clustered standard errors. Columns (1) and (2) reveal that FinTech notably boosts the volume of green innovation (PatentApply) at the 1% significance level, with findings remaining consistent even after adding firm-level controls. Columns (3) and (4) substitute the dependent variable with green patent citations (Cite), demonstrating that FinTech also significantly improves the quality of green innovation at the 1% level, irrespective of control variables. These outcomes indicate that FinTech fosters green investment and R&D incentives by optimizing resource allocation and providing technical assistance, enhancing both the volume and quality of green innovation. In summary, the results support the conclusion that FinTech significantly enhances green innovation performance, confirming Hypothesis 1.

Table 1 Benchmark Regression

	(1) PatentApply	(2) PatentApply	(3) Cite	(4) Cite
FinTech	0.892***	0.437***	0.183***	0.030***
	(0.059)	(0.067)	(0.003)	(0.004)
Age		0.060***		0.028***
		(0.017)		(0.001)
HHI		-0.990*		-0.107***
		(0.406)		(0.025)
Debt		0.042		0.014***
		(0.047)		(0.003)
ROA		-0.057		-0.018***
		(0.056)		(0.004)
Cash		1.375**		-0.324***
		(0.428)		(0.027)
Size		0.453***		0.138***
		(0.090)		(0.006)
Indep		2.250**		1.042***
		(0.723)		(0.045)
_cons	-0.938***	-11.502***	-0.113***	-3.359***
	(0.183)	(1.803)	(0.008)	(0.113)
N	58336	46988	58330	46986

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

4.2 Endogeneity Analysis

Although the benchmark regression shows that FinTech significantly promotes corporate green innovation, endogeneity issues such as omitted variables or reverse causality may exist. The Durbin-Wu-Hausman test results (p = 0.0183) reject the exogeneity hypothesis, confirming the need for an instrumental variable (IV) approach. To address this, Internet penetration (Internet) is used as an IV for FinTech development, following Ding, Jin and Tian [22]. As Table 2 shows that the first-stage regression shows a significantly positive correlation between Internet penetration and FinTech ($p < 0.01$), with an F-statistic of 10406.73, ruling out weak instrument concerns. The second-stage results indicate that FinTech remains significantly positive ($p < 0.01$) for both green patent applications (PatentApply) and citations (Cite) after controlling for endogeneity. Overall, the IV approach robustly validates FinTech's positive impact on corporate green innovation.

Table 2 Endogeneity Analysis

	(1) FinTech	(2) PatentApply	(3) Cite

Internet	5.144***		
	(0.050)		
FinTech		0.579***	0.105***
		(0.140)	(0.007)
_cons	1.744***	0.181	3.810***
	(0.017)	(0.480)	(0.025)
Controls	Yes	Yes	Yes
N	44329	44329	42881

4.3 Robustness Analysis

(1) Replacement of explained variables. For the quantity dimension, the number of green patents obtained (PatentGet) replaces green patent applications (PatentApply); for the quality dimension, the number of patents cited by others (OtherCite) replaces the number of citations (Cite). Table 3 shows that FinTech's regression coefficients remain significantly positive ($p < 0.01$) for both PatentGet (columns 1-2) and OtherCite (columns 3-4), confirming FinTech's significant contribution to both the quantity and quality of green innovation. These results robustly support the benchmark findings.

(2) Replacement of explanatory variables. This paper replaces the FinTech measure with the Peking University Digital Financial Inclusion Index of China (PKU_DFIIC, Digitalization), which reflects regional FinTech development at the municipal level. Columns (5)-(8) of Table 3 show that Digitalization's regression coefficients are significantly positive ($p < 0.01$ or $p < 0.05$) for both green patent applications (PatentApply, columns 5-6) and citations (Cite, columns 7-8), confirming that regional FinTech development significantly enhances both the quantity and quality of green innovation. These findings further reinforce the reliability of FinTech's beneficial influence on green innovation outcomes.

Table 3 Robustness Analysis

	(1) PatentGet	(2) PatentGet	(3) OtherCite	(4) OtherCite	(5) PatentApply	(6) PatentApply	(7) Cite	(8) Cite
FinTech	0.484***	0.182***	0.184***	0.036***				
	(0.025)	(0.043)	(0.003)	(0.004)				
Digitalization					0.011***	0.004*	0.002***	0.004***
					(0.001)	(0.002)	(0.000)	(0.000)
_cons	-0.449***	-7.863***	-0.146***	-3.119***	-0.516	-12.559***	0.113***	-2.312***
	(0.078)	(1.159)	(0.008)	(0.110)	(0.264)	(2.791)	(0.010)	(0.159)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	58336	46988	58330	46986	40187	33593	40184	33592

(3) Principal Component Analysis. To further test robustness, this study employs principal component analysis (PCA) to create a composite green innovation performance metric (PC1) based on four variables: PatentApply, PatentGet, Cite and OtherCite. Table 4 shows that FinTech's regression coefficient is significantly positive ($p < 0.01$) for PC1, both with and without firm-level controls, confirming FinTech's significant contribution to green innovation performance. The PCA results further validate the robustness of the findings.

Table 4 Principal Component Analysis

	(1) PC1	(2) PC1
FinTech	0.195***	0.048***
	(0.005)	(0.007)
_cons	-0.640***	-5.517***
	(0.017)	(0.212)
Controls	No	Yes
N	46105	38884

5 FURTHER ANALYSIS

5.1 Moderating Effect

In this study, we aim to investigate the moderating effect of financing constraints (SA) between the level of FinTech development (FinTech) and the number of green patent applications (PatentApply), and the model is set up as shown in equation (2):

$$GreenInnovation = \alpha_0 + \alpha_1 F\text{int}ech + \alpha_2 F\text{int}ech \times SA + \alpha_3 SA + \alpha_4 Control_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (2)$$

Variables are centered to simplify interaction effects and reduce multicollinearity. Table 5 shows that the interaction term Fin_SA_center is significantly negative at the 5% level in column (2) and the 10% level in column (4), indicating that FinTech's positive impact on green patent applications and citations weakens under high financing constraints. This suggests that while FinTech enhances green innovation, its effect is dampened when firms face significant financial limitations, as constrained access to finance hinders their ability to translate FinTech advantages into actual innovations. H2 is supported.

Table 5 Moderating Effect

	(1) PatentApply	(2) PatentApply	(3) Cite	(4) Cite
FinTech	0.437***		0.030***	
	(0.067)		(0.004)	
FinTech_center		0.468***		0.030***
		(0.068)		(0.004)
SA_center		-12.247***		-0.668***
		(0.552)		(0.032)
Fin_SA_center		-0.450**		-0.015
		(0.143)		(0.008)
_cons	-11.502***	-18.856***	-3.359***	-3.951***
	(1.803)	(1.889)	(0.113)	(0.106)
Controls	Yes	Yes	Yes	Yes
N	46988	47027	46986	53530

5.2 Mediating Effect

Based on the analysis of the theoretical mechanism in the previous section, enterprises' green concerns are chosen as the mediating variable. The mediation effect model clarifies the role of financial technology development on enterprises' green innovation performance. Equations (3) and (4) show the specific model setting.

$$GreenAttention = \alpha_0 + \alpha_1 F\text{int}ech + \alpha_2 Control_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (3)$$

$$GreenInnovation = \alpha_0 + \alpha_1 F\text{int}ech + \alpha_2 GreenAttention + \alpha_3 Control_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (4)$$

Table 6 shows that corporate GreenAttention significantly mediates the relationship between FinTech development and green patent applications. Columns (2) and (5) reveal a strong positive correlation between FinTech development and GreenAttention. Columns (3) and (6) indicate that when both variables are included, FinTech's direct impact weakens, while GreenAttention plays a partial mediating role, suggesting FinTech indirectly promotes green innovation by increasing corporate green concern. A 500-time bootstrap test confirms the mediating effect's significance at the 5% level, supporting the hypotheses and highlighting the key role of GreenAttention in this process.

Table 6 Mediating Effect

	(1) PatentApply	(2) GreenAttention	(3) PatentApply	(4) Cite	(5) GreenAttention	(6) Cite
FinTech	0.437***	25.498***	0.380***	0.030***	25.498***	0.024***
	(0.067)	(0.656)	(0.068)	(0.004)	(0.656)	(0.004)
GreenAttention			0.002***			0.000***
			(0.000)			(0.000)
_cons	-11.502***	-623.083***	-10.108***	-3.359***	-623.083***	-3.204***
	(1.803)	(17.680)	(1.829)	(0.113)	(17.680)	(0.115)
Controls	Yes	Yes	Yes	Yes	Yes	Yes

N	46988	46988	46988	46986	46988	46986

5.3 Heterogeneity Analysis

To examine the heterogeneous impact of FinTech on green innovation performance, this paper analyzes differences by property rights, industry, and region.

(1) Property Rights Heterogeneity: In Table 7, columns (1) and (3) are non-state-owned enterprises, and columns (2) and (4) are state-owned enterprises. FinTech significantly promotes green innovation in both state-owned enterprises (SOEs) and non-SOEs, with SOEs showing a more substantial effect. This is attributed to SOEs' richer resources, stable financial support, and greater focus on long-term development and social responsibility, often backed by government policies.

(2) Industry Heterogeneity: In Table 7, columns (5) and (7) are non-manufacturing industries, and columns (6) and (8) are manufacturing industries. FinTech positively impacts green innovation in both manufacturing and non-manufacturing industries, with a more pronounced effect in manufacturing. Manufacturing firms face more tremendous environmental pressures and have more mature technological foundations, enabling them to integrate FinTech more effectively for green innovation, often supported by government policies.

Table 7 Property Rights and Industry Heterogeneity

	(1) PatentApply	(2) PatentApply	(3) Cite	(4) Cite	(5) PatentApply	(6) PatentApply	(7) Cite	(8) Cite
FinTech	0.403***	0.688***	0.099***	0.160***	0.335***	0.632***	0.076***	0.126***
	(0.027)	(0.085)	(0.004)	(0.007)	(0.054)	(0.041)	(0.005)	(0.004)
_cons	-30.935***	-34.958***	-4.389***	-5.220***	-15.084***	-57.454***	-3.262***	-6.966***
	(3.825)	(3.603)	(0.126)	(0.147)	(2.486)	(5.144)	(0.130)	(0.127)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	27059	17979	27058	17978	16454	30534	16454	30532

(4) Regional Heterogeneity: In Table 8, columns (1) and (4) are the central region, columns (2) and (5) are the western region and columns (3) and (6) are the eastern region. FinTech significantly enhances green innovation in eastern, central, and western regions, with the most potent effect in the eastern region. The eastern region benefits from more developed financial markets, better FinTech infrastructure, higher environmental standards, and incredible policy support and financial investment.

Table 8 Regional Heterogeneity

	(1) PatentApply	(2) PatentApply	(3) PatentApply	(4) Cite	(5) Cite	(6) Cite
FinTech	0.336***	0.433***	0.631***	0.101***	0.119***	0.113***
	(0.058)	(0.072)	(0.047)	(0.008)	(0.009)	(0.004)
_cons	-19.387***	-16.837***	-41.459***	-4.233***	-3.645***	-5.132***
	(2.460)	(2.655)	(3.876)	(0.192)	(0.215)	(0.114)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
N	7840	6177	32742	7840	6177	32740

6 CONCLUSION AND DISCUSSION

FinTech significantly enhances green innovation by improving financing efficiency, risk management, and resource allocation. Due to its resource advantages, technological maturity, and policy support, its impact is more pronounced in state-owned enterprises, manufacturing industries, and the eastern region.

To promote green innovation through FinTech, it is essential to increase investment in technologies like big data, AI, and blockchain to enhance financing efficiency and risk management for green projects, while encouraging financial institutions to develop tailored products. Additionally, optimizing the institutional environment by strengthening legal frameworks and fostering collaboration among financial institutions, tech firms, and green enterprises is crucial. Finally, creating a supportive policy environment through targeted FinTech policies for different enterprises, industries, and regions, and promoting industry-university-research collaboration, will further advance FinTech applications in green innovation.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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