Role of AI in Advancing Firm's Green Innovation : Analysing Mechanisms and Impact

Asif Razzaq
Senior Research Specialist
Research Division, CAREC Institute

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Background

Green innovation is a critical strategy to enhance corporate competitiveness in pursuing the United Nations' 2030 Agenda for Sustainable Development.

Green innovation consists of innovative activities in products, processes, technologies, and management that aim to reduce resource consumption and environmental pollution while providing economic benefits. Given this win-win situation, enhancing green innovations and exploring their influencing factors is imperative.

Artificial intelligence is a driving force in promoting corporate green innovation through data analysis, decision support, and automated production, which enhance the firm's operational and production efficiency and offer new innovative solutions and means for green innovation.

Therefore, AI is a significant driving force in promoting corporate green innovation.

Background

However, there is a lack of systematic intrinsic mechanisms through which AI promote corporate green innovations, while capabilities of green innovations and AI are heterogeneous across enterprises.

Addressing how AI development can better promote corporate green innovation remains a pressing research question

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Background: Objectives

What is the development status of artificial intelligence and firms' green innovation?

Can artificial intelligence improve firms' green innovation?

How can artificial intelligence influence firms' green innovation through managerial myopia, management cost, greenwashing behavior and R&D efficiency?

Are there heterogeneous characteristics of the role of the artificial intelligence on firms' green innovation?

Mechanisms and Hypotheses

Hypothesis 1

AI can promote green innovation.

- Reduces uncertainty in the innovation process through risk and predictive assessment
- Enhances team collaboration
- Improves information sharing
- Embed and diffuse green innovation culture
- Create an environment for green innovation through spillover effects across enterprises

Hypothesis 2

AI promotes green innovation by reducing managerial myopia

- Provide data-driven insights to reduce inherent biases
- Monitor market and technology dynamics that prevent short-sightedness decisions
- Help managers identify cognitive biases through decision-support systems
- Offer decision outcomes under different scenarios

Hypothesis 3

AI promotes green innovation by reducing management costs

- AI can automate many repetitive tasks, which increases efficiency and reduces labor costs, i.e., Robot Process Automation
- Automated decision-making support reduces costs caused by decision-making errors
- Firms allocate resources optimally and promote R&D and green innovation

Mechanisms and Hypotheses

Hypothesis 4

AI promotes green innovation by reducing greenwashing

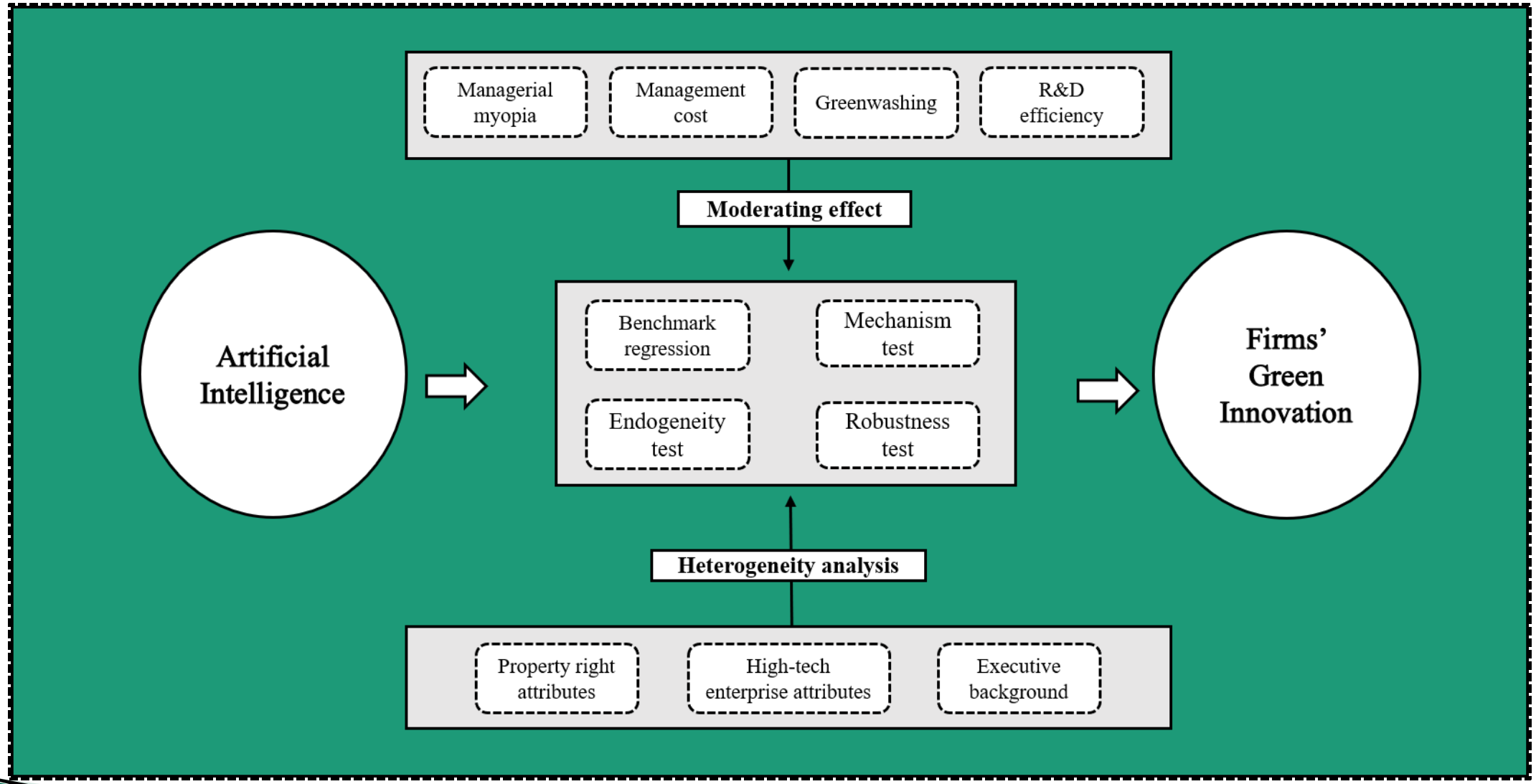
- Enable regulatory bodies to track firms' environmental data (CO2 emissions, industrial waste, and energy consumption)
- Identify potential greenwashing risks and issue timely warnings to correct taken actions
- Assess the firm's environmental practices that must be genuine and regulatory-compliant and reduce greenwashing behavior

Hypothesis 5

AI promotes green innovation by enhancing R&D efficiency

- Contributes to industrial development and progress
- AI expedites R&D such as product design, performance testing, and iterative optimization processes
- All these shorten the innovation cycle and accelerate green innovations.

Analytical Framework



Research Design: Sample

Employ panel data from **Chinese A-share listed companies** from 2012 to 2022

Financial industry companies are excluded to avoid industry-biases on results

Companies that are not listed or listed in the same year are excluded

The total number of firms are 4100 with 25190 observations after data processing

Research Design: Model

Model construction

This study set green innovation as the explanatory variable and the level of AI development as the explanatory variable, and constructed a multidimensional fixed effects model by adding individual fixed effects, industry fixed effects and year fixed effects. The specific setup form is as follows:

$$GINV_{i,t} = \beta_0 + \beta_1 AI_{i,t} + \beta_2 Control_{i,t} + \gamma\_i + \theta\_t + \mu\_j + \varepsilon\_(i,t,j) \quad (1)$$

Where i and t represent the location and year, respectively. $GINV$ denotes the dependent variable, green innovation. AI is the independent variable representing the level of AI development within the enterprise. $Control$ encompasses control variables, including firm size (Size), firm age (ListAge), firm growth (Growth), leverage (Lev), ownership concentration (Top1), CEO duality (Dual), proportion of independent directors (Indep), and board size (Board). γ represents firm fixed effects, μ denotes industry fixed effects, and θ indicates year fixed effects. Finally, ε is the random error term.

Research Design: Variables

Dependent variable

Green innovation (GERD) is expressed in the number of green patent applications as the measure of corporate green innovation. Green patent data for new energy companies are extracted based on the World Intellectual Property Organization's (WIPO) "International Patent Classification Green Inventory.“

Independent variable

The **artificial intelligence (AI) index** calculates the proportion of intelligent investment in the total annual assets based on keywords in fixed and intangible assets, such as "intelligent," "software," and "systems. "This paper measures keyword frequency in annual report texts to evaluate the efficiency of a company's AI technology application. First, using Python software, we obtain annual reports of manufacturing companies and convert them into readable text. We then extract and count keywords related to intelligent technology and its applications, such as "artificial intelligence," "robots," "Industry 4.0," and "smart manufacturing." Finally, the entropy weight method assigns weights to secondary indicators and calculates the company's intelligent transformation index. The entropy weight method provides objective weighting, avoiding subjective bias and information loss, thereby ensuring the accuracy and reliability of the measurement results.

Research Design: Variables

Control variables

The selected control variables include:

- **Firm size (Size):** Represented by the natural logarithm of total assets.
- **Firm age (Age):** Represented by the natural logarithm of the current year minus the listing year plus one.
- **Revenue growth rate (Growth):** Represented by the ratio of the increase in operating revenue to the previous year's operating revenue.
- **Leverage (Lev):** Represented by the ratio of total liabilities to total assets.
- **Proportion of independent directors (Indep):** Represented by the number of independent directors ratio to the total number of directors.
- **CEO duality (Dual):** Assigned a value of 1 if the same person holds the chairman and CEO positions; otherwise, 0. Ownership concentration (Top1): Represented by the shareholding ratio of the largest shareholder.
- **Board size (Board):** Represented by the natural logarithm of the number of board members.

Research Design: Variables

Mechanism Variables

These include managerial myopia (Myopia), management cost (Mfee), "greenwashing" behavior (Gws), and R&D efficiency (Eff).

- **Managerial myopia** is measured by developing a Chinese word set reflecting short-termism, based on Brochet's (2015) English "short-term vision" word set, characteristics of MD&A Chinese corpus, and Word2Vec machine learning. The short-termism index is then constructed using the dictionary method.
- **Management cost** is measured by the ratio of management expenses to operating revenue.
- **Greenwashing behavior** is measured using Bloomberg ESG and Huazheng ESG data to calculate "greenwashing data" for listed companies, following the methodology of Hu et al. (2023).
- **R&D efficiency** is measured by the ratio of invention patent applications to R&D investment.

Empirical Results

Table 2 Descriptive statistical results

Variable	N	Mean	SD	Min	p50	Max
GINV	25200	0.382	2.228	0	0	150
AI	25190	0.116	0.127	0	0.0741	0.815
Size	25190	22.30	1.244	19.60	22.12	26.48
ListAge	25190	2.188	0.842	0	2.398	3.401
Growth	25190	0.155	0.423	-0.672	0.0935	4.728
Lev	25190	0.430	0.203	0.0500	0.422	0.908
Top1	25190	34.25	14.60	8.413	32.15	76.68
Dual	25190	0.281	0.450	0	0	1
Indep	25190	37.62	5.314	30	36.36	60
Board	25190	2.121	0.195	1.609	2.197	2.708

Empirical Results- Benchmark Regression

Table 4 Benchmark regression results

VARIABLES	(1) GINV	(2) GINV	(3) GINV	(4) GINV
AI	0.8210***	0.9543***	1.2684***	1.2808***
	(4.4317)	(5.1643)	(6.7301)	(6.6582)
Size			0.2604***	0.2633***
			(8.7312)	(8.6193)
ListAge			-0.0252	-0.0255
			(-0.4798)	(-0.4827)
Growth			0.0272	0.0205
			(1.0729)	(0.8060)
Lev			-0.1008	-0.0960
			(-0.8797)	(-0.8312)
Top1			-0.0029	-0.0032
			(-1.4803)	(-1.6433)
Dual			-0.0145	-0.0152
			(-0.3967)	(-0.4146)
Indep			0.0011	0.0008
			(0.2920)	(0.2210)
Board			-0.0333	-0.0320
			(-0.2618)	(-0.2514)
Constant	0.2869***	-0.0947**	-5.5388***	-5.4996***
	(12.2450)	(-2.1305)	(-7.8498)	(-6.5118)
ID	Y	Y	Y	Y
Year	N	Y	Y	Y
Industry	N	N	N	Y
Observations	25,190	25,190	25,190	25,190
R-squared	0.0009	0.0165	0.0205	0.0225
Number of id	3,936	3,936	3,936	3,936

Note: t-statistics in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.01. Same table below.

The positive role of AI development in enhancing corporate green innovation capabilities.

Empirical Results-Mechanism Tests

Table 4 Mechanism test results

	(1)	(2)	(3)	(4)	(5)
VARIABLES	GINV	Myopia	Mfee	Gws	Eff
AI	1.2808***	-0.0205**	-0.0296***	-0.8854***	0.0193***
	(6.6582)	(-2.5501)	(-2.7987)	(-3.3243)	(2.9820)
Size	0.2633***	-0.0044***	-0.0228***	0.0661	0.0244***
	(8.6193)	(-3.4698)	(-13.5713)	(1.4958)	(22.4289)
ListAge	-0.0255	0.0077***	-0.0010	-0.3234***	0.0016
	(-0.4827)	(3.4759)	(-0.3351)	(-3.5294)	(0.8918)
Growth	0.0205	-0.0074***	-0.0323***	0.0659*	-0.0004
	(0.8060)	(-6.9413)	(-23.0727)	(1.9596)	(-0.4370)
Lev	-0.0960	0.0392***	0.0309***	0.0211	-0.0093**
	(-0.8312)	(8.1398)	(4.8729)	(0.1284)	(-2.3180)
Top1	-0.0032	-0.0001	-0.0004***	0.0011	-0.0001
	(-1.6433)	(-0.8809)	(-3.9057)	(0.4193)	(-0.7831)
Dual	-0.0152	-0.0036**	-0.0003	-0.0239	0.0024**
	(-0.4146)	(-2.3272)	(-0.1298)	(-0.4998)	(2.0051)
Indep	0.0008	0.0000	-0.0000	-0.0047	-0.0001
	(0.2210)	(0.0926)	(-0.0179)	(-1.1188)	(-0.6799)
Board	-0.0320	-0.0061	0.0056	0.3298**	-0.0022
	(-0.2514)	(-1.1545)	(0.8026)	(2.2374)	(-0.5085)
Constant	-5.4996***	0.1983***	0.6703***	-0.2984	-0.3652***
	(-6.5118)	(5.6313)	(14.4442)	(-0.2565)	(-12.1201)
ID	Y	Y	Y	Y	Y
Year	Y	Y	Y	Y	Y
Industry	Y	Y	Y	Y	Y
Observations	25,190	25,190	25,190	6,680	21,745
R-squared	0.0225	0.0989	0.0719	0.0244	0.1552
Number of id	3,936	3,936	3,936	1,119	3,732

The findings indicate that AI significantly enhances corporate green innovation

AI reduces managerial short-sightedness, enabling firms to engage in more effective long-term planning and decision-making, increasing investment in green innovation

AI optimizes management processes and improves efficiency, lowering management costs and freeing up more resources for green innovation projects

AI enhances the transparency of corporate environmental governance, reducing false environmental claims and ensuring resources are genuinely directed towards green innovation.

AI significantly boosts R&D efficiency, allowing firms to develop green technologies and products more effectively.

Empirical Results-Endogeneity Test

Table 5 Endogeneity test results

Variables	(1) First Stage	(2) Second Stage	(1) First Stage	(2) Second Stage
IV1	0.8784*** (309.28)			
IV2			0.6055*** (69.46)	
AI		1.1547*** (9.13)		1.5401*** (5.69)
Weak instrumental variables	96000		4825	
Underidentification tests	19000***		4050***	

Empirical Results-Robustness test

Table 6 Robustness test results

Variables	(1)	(2)
AI		**1.2808*** **
		(6.6582)
AI2	**0.0719*** **	
	(3.9334)	
Constant	-4.2430***	-5.4996***
	(-5.0547)	(-6.5118)
ID	Y	Y
Year	Y	Y
Industry	Y	Y
Observations	25,190	25,190
R-squared	0.0212	0.0225
Number of id	3,936	3,936

The **robustness test** shows that regardless of the AI indicators used or the exclusion of outliers, AI technology significantly enhances corporate green innovation capabilities.

Empirical Results-Heterogeneity Results

Table 7 Heterogeneity test results

	(1) SOEs	(2) Non- SOEs
AI	**0.7168****	**1.6404*****
	(2.1046)	**(6.7230)**
Constant	-7.5354***	-6.3362***
	(-4.1966)	(-5.8388)
ID	Y	Y
Year	Y	Y
Industry	Y	Y
Observations	8,922	15,795
R-squared	0.0452	0.0184
Number of id	1,207	2,903

Non-state-owned enterprises drive more market forces and exhibit greater innovation flexibility, making AI technology more effective in promoting green innovation.

Empirical Results-Heterogeneity Results

Table 8 Heterogeneity test results

	(1) High-tech	(2) Non-high-tech
AI	**1.6884*** **	**0.6439*** **
	(5.6554)	**(2.9381)**
Constant	-8.9408***	-3.0746***
	(-4.4990)	(-3.8777)
ID	Y	Y
Year	Y	Y
Industry	Y	Y
Observations	14,006	11,184
R-squared	0.0236	0.0236
Number of id	2,471	1,632

High-tech enterprises with inherent advantages in technology and innovation can leverage AI more effectively for green innovation

Empirical Results-Heterogeneity Results

Table 9 Heterogeneity test results

	(1) With overseas executives	(2) Without overseas executives
AI	**1.0678*** **	**0.5125** **
	(3.1920)	**(2.4128)**
Constant	-5.5693***	-4.4835***
	(-3.7035)	(-4.5302)
ID	Y	Y
Year	Y	Y
Industry	Y	Y
Observations	12,466	12,724
R-squared	0.0263	0.0253
Number of id	2,625	3,816

Enterprises with overseas executive backgrounds possessing international perspectives and diverse experiences can adopt and apply AI technology more rapidly, achieving greater progress in green innovation

Conclusion

Overall results

- The findings indicate that **AI significantly enhances corporate green innovation**.

Mechanism Analysis

- AI significantly **reduces managerial myopia, management costs and green washing, while increasing R&D efficiency.**

Heterogeneity tests

- AI has a more pronounced effect on green innovation **in non-state-owned enterprises, high-tech enterprises, and enterprises with overseas executive backgrounds.**

Recommendations

1. • **Establish special funds and incentives** include tax reductions, research and development subsidies, and financial rewards for enterprises that excel in AI application.
2. • **Implement strict environmental protection and social responsibility regulations** to guide enterprises about environmental sustainability during technology advancements.
3. • **Increase AI investments and develop comprehensive information disclosure** and evaluation systems to increase the transparency and comparability of AI applications and green innovations
4. • **Enhance executives' training on AI technology and green innovation** to improve their understanding and ability to promote relevant technologies and practices.
5. • **Collaborate with research institutions and universities** to leverage external forces in driving innovation. During the technology transfer process, enterprises should **emphasize the market application of products** to ensure that green technology can quickly reach the market, meeting consumer demand