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Does green innovation promote the status of supply chain? Evidence from listed Chinese companies

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Abstract. At the enterprise level, green innovation capability plays a crucial role in enhancing competitiveness within the supply chain. Enterprises leverage their green innovation resources to gain a stronger foothold in production competition. Drawing on data from listed enterprises in China, the findings support the notion that green innovation ability can enhance supply chain positioning, while also highlighting heterogeneity among different green innovation resources. Furthermore, we elucidate the mechanism through which value co-creation contributes to supply chain performance and how collaborative green innovation within the supply chain promotes its competitiveness. Additionally, our research reveals a lag effect associated with green innovation capability and demonstrates that the positive impact of green innovation capability is significantly regulated by asset-liability ratios. Consequently, this study suggests that enterprises should allocate more resources towards cultivating talent for driving both establishing partnerships within the supply chain and improving their position within the supply chain.

Keywords: Green innovation, Green value co-creation, Green supply chain management, Corporate sustainability.

1. Introduction

In the current globalized economic landscape, recognition of the significance of supply chain status increasing. Supply chain status refers to how a firm to integrate resources and impact other enterprises within the supply chain (Falcone et al., 2021). Enterprises situated at the core of the supply chain are typically better equipped to govern and steer various activities within it.

Green innovation ability is reflected in the adoption of new technologies and products, as well as innovative management methods to expand the market and progress the organization (Chen et al., 2018). According to a report by World Economic Forum (2019), enterprises demonstrating exceptional performance in green innovation tend to occupy more favorable positions within the supply chain. A prime example is a small to medium-sized US company with disruptive green innovation packaging materials has garnered attention from major enterprises such as IKEA and Dell.

However, the current theoretical research on the impact of green innovation capability on supply chain status is insufficiently comprehensive. While existing studies primarily focus on how green innovation capability affects internal enterprise performance, such as enhancing green product development (Frempong et al., 2021), improving environmental performance and achieving sustainability performance (Xie et al., 2019), they fail to delve into whether green innovation capability significantly enhances its influence on supply chain partners. Some literature has focused on the interplay between green innovation and the supply chain.For instance, Sun and Sun (2021) investigated the relationship between dual strategy for green innovation and integration with a greener supply chain. Nevertheless, these studies predominantly concentrate on collaboration and management aspects of the green supply chain, there are still deficiencies in theoretical research: firstly, regarding whether heterogeneous levels of green innovation capability yield different impacts on overall supply chain status; secondly, concerning understanding their underlying internal correlation mechanisms. This paper aims to comprehensively uncover these theoretical principles.

De Marchi (2012) discovered that green innovation companies exhibit a greater emphasis on supply chain collaboration. Through the overall optimization of the supply chain, all parties gain resource advantages in competitive markets to enhance organizational competitiveness ultimately. Consequently, we introduce supply chain value co-creation as a mediating variable. Two or more enterprises within the supply chain exchanging resources related to environmental management ,

while integrating them into the supply chain (Ramanathan et al., 2014). Supply chain value co-creation promotes the influence of green innovation capability on supply chain status indirectly.

In summary, this study employs resource dependence theory and considers supply chain value co-creation as a mediating variable to investigate the impact of green innovation capability on supply chain status. Firstly, existing research primarily focuses on green innovation as an antecedent for enhancing internal performance, while this study expands upon this conclusion. Simultaneously, this study further explores how heterogeneous green innovation capabilities affect supply chain status—an endeavor that deepens theoretical understanding regarding the impact of green innovation. Secondly, this paper investigates the mediating role of supply chain value co-creation and elucidates the internal mechanism. Finally, this study employs entropy methods to quantify green innovation capability by integrating enterprises' investments in human resources, financial resources, and technical resources. This approach provides a reference framework for future research endeavors in similar domains.

2. Theoretical basis and research hypothesis

2.1 Theoretical Basis

The core point of view of resource dependence theory emphasizes that possessing resources can confer dominance (Barney, 1991). The direct link between power and resource dependence implies that an enterprise's autonomy is influenced by its degree of reliance on external resources (Pfeffer & Salancik, 2015). Having access to green innovation resources serves as the foundation for enterprises to engage in green innovation activities and plays a pivotal role in enhancing the green innovation capabilities of supply chains (Chesbrough, 2003).Not only do partners lacking critical resources rely on enterprises possessing key resources but also those with key resources require partner participation in resource-sharing activities to sustain their competitive advantage in green innovation.

2.2 Impact of green innovation capability on supply chain status

The capability of green innovation is demonstrated through effective control and management of resources, including human resources, financial resources, and technical resources. The former two are production-side resources, while the latter refers to output-side resources. Enterprises with strong green innovation capabilities can acquire and manage these key resources, which in turn leads to the formation of a robust negotiation ability. Firstly, a robust green innovation team can compensate for the lack of human resources among supply partners by forming joint research teams to develop projects (Pierce et al., 2001). Secondly, as material guarantees for innovative activities, sufficient green financial resources facilitate the establishment and strengthening of partnerships within the supply chain (Sadorsky, 2010). Lastly, firms with advanced green innovation techniques possess exclusive technical advantages in industry for a certain period of time. They can influence industry standards or set access conditions for supply chain partners that necessitate reliance on their expertise.

Therefore, this paper proposes the following hypothesis:

H1: Green innovation capability enhances status.

H1a. Increased input of human resources in green innovation will enhance the status of the supply chain.

H1b. Increased input of financial resources in green innovation will enhance the status of the supply chain.

H1c. Increased input of technical resources in green innovation will enhance the status of the supply chain.

2.3 Mediating role of supply-chain value co-creation

Green innovation capability realizes value co-creation in supply chain through collaborative resource allocation optimization. Firstly, individuals with expertise in green innovation can establish cooperative networks with other firms by participating in various industry conferences, seminars, and

other activities that promote value co-creation within supply chains. Secondly, sufficient financial resources allows firms to invest more heavily into these projects while sharing economic burdens among participants thereby lowering entry barriers for others who wish to innovate jointly.Thirdly, an enterprise's ability to identify, acquire and utilize technological resources such as knowledge or patents related to green innovations increases its capacity for allocating heterogeneous external resources (Kogut & Zander, 1992). These technological assets can be transferred between entities involved in a given supply chain, so as to improve efficiency when collaborating on innovative initiatives.

Therefore, this paper proposes the following hypothesis:

H2: Green innovation capability has a positive impact on the co-creation of supply chain value.

H2a: Increased input of green innovation human resources promotes the co-creation of supply chain value.

H2b: Increased investment in green innovation financial resources promotes the co-creation of supply chain value.

H2c: Increased investment in green innovation technology resources promotes the co-creation of supply chain value.

During the process of supply chain value co-creation, enterprises with green innovation capabilities allocate significant human and financial resources towards research and development of green products as well as process innovations, thereby demonstrating their commitment to sustainable development and showcasing their strength. This enhances trust among partners, fosters cooperation (Zhu et al., 2008), and ultimately meets strategic needs within the context of supply chain collaboration.

Consequently, this paper proposes the following hypothesis:

H3: Supply chain value co-creation mediates between green innovation capability and supply chain status.

H3a: Supply chain value co-creation mediates between human resource input in green innovation and supply chain status.

H3b:Supply chain value co-creation mediates between financial resource input in green innovation and supply chain status.

H3c:Supply chain value co-creation mediates between technology resource input in green innovation and supply chain status.

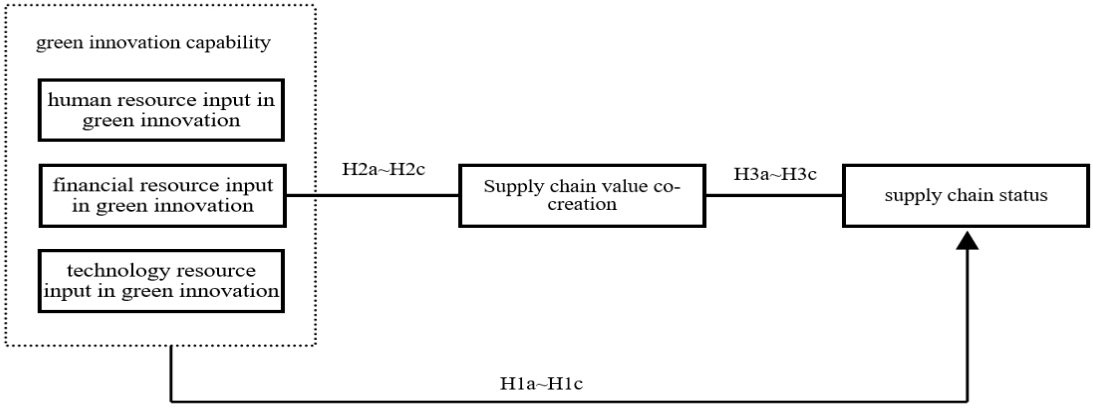

Figure 1 Theoretical model

3. Research methods

3.1 Data Sources

The research data were obtained from the panel data of China's A-share listed companies between 2012 and 2022. Abnormal status samples such as ST and *ST were excluded from the research sample. Data reflecting green innovation of enterprises were selected from the China Research Data Service

(CNRDS) database. Data related to enterprise innovation collaborative development and supply chain status were collected from CSMAR database (Yang Yang et al., 2019).

Table 1 shows the heterogeneity observed in the standard deviation of green innovation capability, supply chain value co-creation, and supply chain status. Different green innovation capabilities influence supply chain status.

Table 1 Descriptive statistics

	(1)	(2)	(3)	(4)	(5)
VARIABLES	N	mean	sd	min	max
SD	4,382	1.571	1.195	0	5
SCVC	4,382	0.539	0.499	0	1
RDPI	4,382	0.107	0.135	0	0.847
RDEI	4,382	0.0189	0.243	0	12.62
PAV	4,382	0.00895	0.0426	0	1
GIA	4,382	0.115	0.143	0	1.444
REV	4,382	21.08	1.453	12.33	27.02
UR	4,382	11.70	2.288	7.854	18.65
Scale	4,382	0.191	0.0850	0	1.379
Mfee	4,382	2.276	0.961	-1.468	9.600
CI	4,382	0.194	0.157	2.99e-05	0.863

3.2 Variable Definition

This study selects supply chain status as an explanatory variable since enterprises with greater power within a supply chain are presumed to possess more unique and valuable resources. The number of major customers can be considered a distinctive resource that improve bargaining power with customers.

We adopt green innovation capability (GIA) as the independent variable. Following the entropy method proposed by Li et al.(2019),weights are assigned to three dimensions of green human resources(RDPI), green financial resources(RDEI), and green technology resources(PAV).

Supply chain value co-creation (SCVC) is chosen as the mediating variable. The long-term cooperative relationship formed by upstream and downstream enterprises can facilitate supply chain integration.If a customer remains a supply-chain partner for two consecutive years , long-term value is co-created between enterprises(Yang,2017).

Additionally, existing literature suggests that government expenditure scale affects economic development. Accelerated urbanization and industrial upgrading may promote capital and technology concentration among enterprises. (Kim & Wemmerlöv, 2015;Hu, Liu, et al.,2019;Cho et al.,2019;Tang & Li, 2022;Deng et al., 2023).Furthermore, companies need to acquire green resources to carry out green innovation effectively. To control for company-specific factors, this study controls enterprise asset scale (REV), management fee (Mfee), urbanization rate (UR), capital intensity (CI), and government expenditure scale (Scale).

These variables are presented in Table 2.

Table 2 Measurement index and basis

Variable	Variable measurement	Sources
SD	The number of major customers contributing more than 10% to a firm's revenue	Cho et al.（2019）
RDPI	R&D personnel input/Total number of employees	Li(2017) Li et al.（2019） Zhang & Rong, (2019)
RDEI	R&D expenditure/total operating income of listed companies	
PAV	The number of green patents obtained independently in the year/number of R&D personnel	

GIA	Through the entropy weight method, the three green innovation resources are synthesized according to the weight	
SCVC	If the customer has been a major customer of the supplier company for two consecutive years, SCVC has a value of 1; otherwise, it is 0.	Yang (2017)
REV	Natural logarithm of Client Operating Income	Kim & Wemmerlöv. (2015)
UR	Proportion of urban population in each province	Tang and Li (2022)
Scale	Proportion of fiscal expenditure to GDP of each province	Hu, Liu, et al. (2019)
Mfee	The natural logarithm of the overhead/revenue ratio	Deng et al.(2023)
CI	Ratio of fixed assets to total assets	Cho et al.（2019）

3.3 Research model

This paper employs a dual-fixed model to examine the relationship between green innovation capability and supply chain status as well as the mediator and regulatory mechanisms. Finally, test the robustness with PSM.

4. Regression analysis and interpretation

4.1 Correlation analysis

The results in Table 3 indicate a significant positive correlation (P<0.01) between green innovation capability and supply chain value co-creation with supply chain status. The variance inflation factor reveals an average VIF of each variable as 1.04, indicating no multicollinearity issue.

Table 3 Correlation analyses among variables

	SD	GIA	RDPI	RDEI2	PAV	SCVC	REV	UR	Scale	Mfee	CI
SD	1										
GIA	0.086***	1									
RDPI	0.085***	0.985***	1								
RDEI	0.011	0.153***	-0.019	1							
PAV	0.002	0.025*	0.024	0.006	1						
SCVC	0.749***	0.060***	0.058***	0.016	0.003	1					
REV	-0.218***	-0.072***	-0.075***	0.013	-0.040***	-0.177***	1				
UR	-0.007	0.106***	0.109***	-0.008	0.072***	-0.011	0.026*	1			
Scale	0.024	-0.036**	-0.035**	-0.011	-0.025*	-0.004	-0.004	-0.127***	1		
Mfee	0.043***	0.091***	0.095***	-0.018	0.057***	0.01	-0.072***	-0.016	0.004	1	
CI	0.013	-0.201***	-0.219***	0.085***	0.02	0.036**	0.025	-0.002	0.057***	-0.084***	1
t statistics in parentheses * p < 0.1, ** p < 0.05, *** p < 0.01											

4.2 Empirical results and analysis

The benchmark regression results under double fixed effects presented in Table 4. By controlling for time and individual effects, Model (2) reveals a significant positive effect (p<0.01) with a standardized estimate of 0.893 in support of hypothesis H1.

The findings demonstrate that increasing capability to produce green products or services, firms can be trusted by stakeholders thereby improving the position. Models (3)-(5) introduce three different types of green innovation resources and the positive impact of green innovation human resources on supply chain status (H1a) is supported by a significant standardized estimate of 0.961 (p<0.01), while the other two resources are insignificant. These results indicate that R&D personnel's

knowledge in green innovation enables supply chain partners to realize complementary capabilities in sustainability practices and ultimately enhancing bargaining positions over time.

However, current investments in green innovation are characterized by high risk and long cycles; thus transforming financial resources into tangible outputs remains challenging (Berrone et al., 2013). Simultaneously, enterprises' inadequate attention towards leveraging technological advantages to strengthen their discourse power in the enterprise supply chain are evident.

Table 4 Baseline regression results

	(1)	(2)	(3)	(4)	(5)
REV	-0.217***	-0.211***	-0.211***	-0.217***	-0.218***
UR	-0.00208	0.00361	0.00433	-0.00240	-0.00103
Scale	-0.114	-0.0459	-0.0469	-0.113	-0.115
Mfee	0.0357*	0.0282	0.0278	0.0358*	0.0364**
CI	0.303***	0.426***	0.442***	0.296**	0.308***
GIA		0.893***			
RDPI			0.961***		
RDEI				0.0504	
PAV					-0.424
_cons	6.066***	5.760***	5.743***	6.071***	6.067***
R2	0.205	0.214	0.214	0.205	0.205
t statistics in parentheses * p < 0.1, ** p < 0.05, *** p < 0.01					

4.3 Mediating mechanism test

Table 5 presents the results of the mediating mechanism. In Model (1), there is a significant positive correlation (coefficient = 0.893, $p < 0.01$) between green innovation capability and supply chain status.In Model (3), upon introducing mediating variables, supply chain value co-creation partially mediates the relationship between green innovation capability and supply chain status, thereby validating H3. Green innovation capability influences supply chain status directly as well as through supply chain value co-creation indirectly. By leveraging lower costs and more abundant resources, firms securing a higher position via supply chain co-creation.

Model (4) reveals a significant positive correlation (coefficient=0.955, $p < 0.01$) between green innovation human resources and supply chain status; however, while the other two resources are insignificant. This shows that more supply chain collaboration makes the resources of green innovative talents more concentrated. Once an enterprise improves its position, other players may engage in green co-creation to gain short-term benefits, which can impact its supply chain status.

Table 5 Test results of mediating mechanism

	(1)	(2)	(3)	(4)	(5)	(6)
	SD	SCVC	SD	SD	SCVC	SD
GIA	0.893***	0.306***	0.392***			
REV	-0.211***	-0.0644***	-0.106***	-0.212***	-0.0646***	-0.106***
UR	0.00361	-0.0141	0.0267	0.00478	-0.0138	0.0274
Scale	-0.0459	-0.223*	0.319*	-0.0469	-0.223*	0.319*
Mfee	0.0282	-0.00540	0.0371***	0.0285	-0.00526	0.0371***
CI	0.426***	0.238***	0.0361	0.439***	0.240***	0.0461
SCVC			1.638***			1.638***
RDPI				0.955***	0.322***	0.427***
RDEI				0.0454	0.0272	0.000921
PAV				-0.311	-0.0895	-0.164
_cons	5.760***	2.041***	2.417***	5.750***	2.040***	2.408***
R2	0.214	0.183	0.595	0.214	0.183	0.595

t statistics in parentheses * p < 0.1, ** p < 0.05, *** p < 0.01

4.4 Endogeneity treatment

Green R&D personnel resource requires a certain R&D cycle and substantial investment resource to be transformed. Similarly, green innovation patents involves stages such as R&D design, application, and approval. Lag effects may exist.

Table 6 Results of lag effect test

	(1) SD	(2) SCVC	(3) SD	(4) SD	(5) SCVC	(6) SD
L2.GIA	0.372***	0.0647*	0.343**			
L2.REV	-0.0418***	-0.0173***	-0.0266*	-0.0412***	-0.0173***	-0.0259*
L2.UR	0.0365	-0.0391***	0.117***	0.0380	-0.0390***	0.122***
L2.Scale	0.222	-0.166***	0.513*	0.239	-0.163***	0.524*
L2.Mfee	0.0245	-0.0104**	0.0355	0.0233	-0.0105**	0.0351
L2.CI	-0.130	0.0199	-0.434***	-0.135	0.0145	-0.429***
L.SCVC			0.130*			0.129*
L2.RDPI				0.433***	0.0626*	0.434***
L2.RDEI				-0.00815	0.0205	-0.0121
L2.PAV				0.828**	0.0896	1.690***
_cons	0.805*	1.760***	-0.614	0.763*	1.760***	-0.701
R2	0.112	0.090	0.171	0.113	0.090	0.175

t statistics in parentheses * p < 0.1, ** p < 0.05, *** p < 0.01

The endogeneity test reveals both two-period-lagged green innovation capability and one-period-lagged supply chain value co-creation shows a positive correlation with supply chain status. Additionally, both two-period-lagged human resources and technical resources for green innovation indicate their continuous role in promoting it. One possible explanation is that joint green innovations leading to talent aggregation while also reorganizing heterogeneous external resources.

4.5 Analysis of regulation

Debt financing provides sufficient cash flow and exerts leverage to improve competitiveness (Zhang & Jin, 2022) . This study incorporates asset-liability ratio as moderating variables to further investigate the influence mechanism.

Table 7 Test results of the moderation effect of asset-liability ratio

	(1) model1	(2) model2	(3) model3
GIA	0.6772***	0.2311	0.7322***
Lev	-0.0729	-0.2046**	-0.0761
REV	-0.1775***	-0.1780***	-0.1780***
UR	-0.0043	-0.0043	-0.0043
Scale	0.0279	0.0485	0.0485
Mfee	0.0211	0.0200	0.0200
CI	0.3329***	0.3300***	0.3300***
GIA*Lev		1.1219**	
c_ GIA* c_ Lev			1.1219**
_cons	5.2132***	5.2811***	5.2237***
adj. R2	0.0572	0.0581	0.0581

Standard errors in parentheses * p < 0.1, ** p < 0.05, *** p < 0.01

The coefficient of the interaction term between asset-liability ratio and green innovation capability is significantly positive (p<0.05), indicating asset-liability ratio exerts a significant positive moderating effect. Firms with a high asset-liability ratio can amplify the competitive impact of green innovation capability on the supply chain.

4.6 Robustness test

In order to address the issue of selection bias, this study employs PSM method for testing. The balance test reveals that the ATT estimate is 0.09 ($p<0.01$).Utilizing the K-nearest neighbor matching method, we find most of the matched observations satisfying the common support hypothesis test. Table 8 establish robust conclusions.

Table 8 Test results of mediating mechanism of successfully matched samples

	(1) SD	(2) SCVC	(3) SD	(4) SD	(5) SCVC	(6) SD
GIA	0.862***	0.282**	0.384**			
SCVC			1.690***			1.690***
RDPI				0.950***	0.302**	0.441**
RDEI				0.0150	0.0201	-0.0190
REV	-0.205***	-0.0611***	-0.102***	-0.205***	-0.0612***	-0.101***
UR	-0.0122	-0.0274	0.0342	-0.0109	-0.0271	0.0349
Scale	0.0604	-0.227	0.444	0.0623	-0.227	0.446
Mfee	0.0222	-0.00903	0.0375*	0.0215	-0.00908	0.0369*
CI	0.496**	0.222*	0.120	0.510**	0.225*	0.130
_cons	5.771***	2.128***	2.176***	5.748***	2.125***	2.157***
R2	0.213	0.180	0.613	0.214	0.180	0.613

t statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5. Conclusion and discussion

The objective of this study aims to enhance theoretical understanding regarding heterogeneous green innovation capabilities while exploring how enhancements in such capabilities impact competitiveness within supply chains among enterprises. Firms with stronger green innovation capabilities are more likely to possess mastery over green resources to secure higher bargaining positions within supply chains. Secondly, enterprises and their partners engage in coordinated green innovation, thereby maximizing the efficient interaction between the innovation chain and value chain. Furthermore, the human resources, financial resources, and technical resources utilized by enterprises for green innovation collectively constitute heterogeneous innovation capabilities. Amplifying the leverage effect of green finance, firms fully harnesse employees' green creativity and technological advantages to enhance the core competitiveness and their influence in the global supply chain.

This study makes a significant contribution to literatures. Numerous scholars have identified that green innovation can stimulate market demand and green productivity to enhance corporate and environmental performance. However, there remains a theoretical gap regarding the impact of green innovation as a competitive capability on a firm's position in the supply chain. Similar to previous studies, we acknowledge the positive role played by green innovation capability. From a business operator's perspective, we find that fully allocating resources towards green innovation can effectively enhance enterprises' capabilities. During the process of co-creating a greener supply chain with their partners, enterprises form community of interests where external drivers for green innovation ultimately improving status.

The findings underscore the practical significance: firstly, enterprises can acquire external knowledge and resources related to green practices and enhance their capacity for green innovation; secondly, to gain a stronger position in the supply chain, enterprises need to master green competitive advantages in the product market; thirdly, establishing collaborative partnerships within the supply chain is crucial for building a robust green supply chain.

Although this study has contributed towards understanding how enterprises can lead in sustainable economic development within the supply chain, there are still limitations. Future research could explore how international contexts impact firms' green innovation capabilities.

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