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Supply Chain Digitalization and its Impact on Green Innovation in Enterprises

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Abstract

With the rapid expansion of the digital economy, the application of digital technologies has become an essential strategic choice for enterprise development. Against the backdrop of pollution reduction and carbon mitigation, green innovation has emerged as a crucial pillar supporting corporate sustainability. Drawing on a sample of Chinese A-share listed firms from 2012 to 2022, this study investigates the impact of supply chain digitalization (SCD) on corporate green innovation, distinguishing between substantive and strategic forms of innovation. Building on this framework, the study further examines the mediating mechanisms underlying these effects—with a focus on carbon information disclosure (CID) as a novel mediating pathway. The findings reveal that supply chain digitalization significantly fosters corporate green innovation, with a more pronounced effect on substantive innovation compared to strategic innovation. Moreover, heterogeneity arises depending on ownership structure and firm size, with stronger effects observed in state-owned and large enterprises. Additional analysis indicates that supply chain digitalization enhances substantive green innovation through strengthened carbon disclosure practices, thereby promoting overall corporate green innovation. All regression models include firm, industry, and year fixed effects to control for unobserved heterogeneity, and robustness tests confirm the stability of findings. **Purpose:** This study aims to empirically examine how supply chain digitalization (SCD) influences corporate green innovation, with a particular focus on distinguishing between substantive and strategic forms of innovation. Furthermore, it explores the mediating role of carbon information disclosure (CID) in this relationship—a mechanism underexplored in prior literature—thereby providing a deeper understanding of how digitalization drives green innovation in enterprises. **Design/methodology/approach:** Using

panel data from Chinese A-share listed firms between 2012 and 2022, the study employs a quasi-natural experimental design based on the designation of pilot enterprises for supply chain innovation (China's "Supply Chain Innovation and Application Pilot Program," launched in 2018). A difference-in-differences (DID) approach combined with regression models (incorporating firm, industry, and year fixed effects) is applied to estimate the impact of SCD on various dimensions of green innovation. Carbon information disclosure is incorporated as a mediating variable, and heterogeneity analyses are conducted with respect to ownership structure and firm size to assess moderating effects. To mitigate endogeneity, the study leverages the exogenous policy shock of the pilot program, includes comprehensive firm-level controls, and conducts robustness tests. **Findings:** The results reveal that supply chain digitalization significantly enhances corporate green innovation, with a more pronounced effect on substantive green innovation compared to strategic green innovation. Carbon information disclosure plays a mediating role in this relationship: SCD increases firms' likelihood of disclosing carbon information, which in turn promotes substantive green innovation but not strategic innovation. The positive effects of SCD are stronger for state-owned enterprises and large enterprises, reflecting their superior resource endowments and strategic orientation toward green development. Robustness tests further confirm the stability of these findings. **Research limitations/implications:**The study focuses exclusively on Chinese A-share listed firms, which may limit the generalizability of the findings to other contexts. Additionally, the measurement of digitalization and innovation relies on secondary data, which may not fully capture qualitative aspects of internal practices. Future research could employ cross-country comparisons, survey data, or advanced methods such as text mining to explore additional mediating mechanisms (e.g., green absorptive capacity or digital collaboration) and dynamic effects over time. **Practical implications:** The findings provide actionable insights for managers and policymakers. Firms should actively embed digital technologies into supply chain operations to enhance transparency, reduce information asymmetry, and alleviate financing constraints, thereby stimulating green innovation. Policymakers should expand digital supply chain pilot programs and encourage voluntary carbon disclosure to improve environmental governance. Large and state-owned enterprises should leverage their advantages to lead the construction of green supply chain ecosystems and foster industry-wide sustainable development. **Originality/value:** This study contributes to the literature by integrating supply chain digitalization into the corporate green innovation framework, distinguishing between substantive and strategic innovation, and identifying carbon information disclosure as a novel mediating mechanism. It enriches the understanding of how digital transformation drives sustainability-oriented innovation and provides evidence-based insights into the heterogeneity of these effects across different types of firms.
Keywords: Supply Chain Digitalization, Carbon Disclosure, Green Innovation

Introduction

China's economy is entering a phase of high-quality development, in which the advancement of supply chains and industrial chains is vital to sustaining the quality growth of the national economy and has long been a matter of strategic concern (Luo & Li, 2025). At the same time, under the growing prominence of global environmental challenges (e.g., climate change, resource scarcity) and increasingly stringent resource constraints, corporate green innovation has emerged as a critical pathway for promoting sustainable development (Zhang et al., 2019), offering viable solutions to the tension between business growth and environmental protection. However, the rapid evolution of institutions and markets, coupled with the rising

complexity of green innovation, has shifted the locus of competition from individual firms to supply chains as a whole (Ketchen & Hult, 2007). Consequently, the construction of digital supply chains—defined as the integration of digital technologies (e.g., blockchain, IoT, cloud computing) into end-to-end supply chain processes—and the formation of interconnected digital networks have become essential for firms to sustain their competitive advantage.

In recent years, the rapid progress of information technologies such as artificial intelligence and blockchain has accelerated their integration into supply chains, fostering the emergence of digital supply chains as a new business paradigm (Büyüközkan & Göçer, 2018). In April 2020, the National Development and Reform Commission, together with the Cyberspace Administration of China, issued an implementation plan for fostering the future digital economy. This plan emphasized cultivating new digital economic models, advancing corporate digital transformation, and accelerating the development of digital supply chains, thereby charting a course for enterprises toward high-quality growth.

Supply chain networks play a pivotal role in fostering the joint development of firms and their upstream and downstream partners (Junid et al., 2022). As cooperative relationships deepen and policies increasingly promote the green economy, enterprises are placing greater emphasis on the efficient allocation of resources. A pressing question, therefore, is whether and how firms undertaking supply chain digital transformation can leverage limited green resources to engage in innovative activities that advance high-quality development.

Building on this foundation, the present study employs data from Chinese A-share listed firms between 2012 and 2022 to empirically examine the relationship between supply chain digitalization and corporate green innovation. As an emerging research domain, supply chain digitalization has been primarily explored through survey-based approaches in existing literature. By contrast, empirical research grounded in large-scale samples and rigorous statistical techniques (e.g., DID with firm fixed effects) allows for data collection from an objective perspective and enhances the persuasiveness of findings. Accordingly, this study adopts an empirical approach to further uncover the mechanisms at play.

While prior research has investigated various determinants of green innovation (e.g., executive cognition, media supervision), few studies have systematically analyzed the link between supply chain digitalization and corporate green innovation (Liu et al., 2023), leaving an important gap. Furthermore, existing studies rarely distinguish between substantive (technology-driven, long-term) and strategic (symbolic, short-term) green innovation, nor do they explore non-financial disclosure (e.g., carbon information) as a mediating pathway. By addressing these gaps, this study enriches the existing body of knowledge and offers practical insights for enterprises seeking to achieve high-quality development through digital technologies, with implications extendable to global contexts.

Literature Review

Exploring the Impact Mechanisms of Supply Chain Digitalization

As an emerging technology, digital technologies are increasingly applied to various aspects of business operations and management. A growing body of domestic and international research has examined the effects of digitalization (Liu et al., 2025; Qiao & Zhang, 2023; Zhou et al., 2024). However, studies focusing specifically on supply chain digitalization remain

limited (Gu, 2024). Existing research that integrates digitalization with supply chains has primarily investigated its role within supply chain processes. For instance, Liu and Song (2024) through survey data on omnichannel enterprises in China, found that the level of digitalization can drive omnichannel supply chain integration. Similarly, Yu (2023) demonstrated that digital sensing capability, digital operational capability, and digital resource coordination capability exert significant positive effects on supply chain innovation performance. Research on the formation of digital supply chains has also largely centered on the construction of theoretical models or the evaluation of economic performance associated with digital transformation (Balakrishnan & Ramanathan, 2021). Nevertheless, findings regarding economic performance remain inconclusive, with some studies identifying positive impacts (Rauniyar et al., 2023), while others report adverse outcomes (Bhattacharya & Chatterjee, 2022). These inconsistencies highlight substantial room for further investigation into the effects of supply chain digitalization. Moreover, the literature addressing its implications for green innovation performance is particularly scarce, pointing to a promising direction for future research. Beyond content-related gaps, methodological innovation is also needed. To date, most studies have relied on survey-based approaches to examine supply chain digitalization. With the continued advancement of digital practices in supply chains, scholars have increasingly called for more empirical investigations employing diverse methodological approaches to enrich and deepen the understanding of supply chain digitalization (Gagliardi et al., 2023).

Exploring the Drivers and Determinants of Green Innovation

The exploration of factors influencing corporate green innovation has generally been approached from both internal and external perspectives. From the internal standpoint, a growing body of research emphasizes the role of top executives, whose personal traits and environmental awareness substantially shape firms' innovation trajectories. As the principal decision-makers, executives' ecological consciousness can serve as a catalyst for green innovation. For instance, Liang et al. (2022) provide evidence that executives' environmental cognition exerts a significant positive influence on green innovation performance. Beyond leadership attributes, the quality of internal governance constitutes another crucial determinant. The prevailing view suggests that well-structured governance mechanisms mitigate managerial short-termism, thereby facilitating more sustainable innovation activities. Empirical evidence from Zhai and Gao (2023) indicates that high-quality internal control not only enhances corporate governance but also promotes substantive forms of green innovation. More recently, stimulated by the momentum of the digital economy, scholars have increasingly examined the implications of firms' digital transformation for their green innovation outcomes (Jiang & Pan, 2024; Zhang et al., 2024; Zhao et al., 2024), thereby extending the scope of inquiry to the intersection of technological advancement and sustainability-oriented innovation.

From the external perspective, scholars have investigated how external governance mechanisms, resource availability, and policy interventions affect corporate green innovation. The growing environmental demands of external stakeholders often compel firms to engage in green innovation activities. Existing studies suggest that media supervision (Zhang et al., 2021) and public attention (Wang & Wang, 2021) act as significant drivers of corporate green innovation. In terms of strategic policy design, green procurement policies (Deng & Li, 2024), green credit policies (Lu et al., 2021), and government subsidy programs (Zhang et al., 2018) have all been shown to exert positive influences on the formulation of green innovation

strategies. While the academic literature has generated a wealth of findings on corporate green innovation, it remains largely constrained by relatively narrow perspectives. In particular, limited attention has been devoted to supply chain digitalization, an emerging factor that bridges both internal governance and external collaboration, thereby warranting deeper investigation.

Investigating the Influence of Supply Chain Digitalization on Green Innovation

From the perspective of natural resource-based theory, firms actively seek environmental governance cooperation with other nodes in the supply chain (Guang et al., 2012). Under traditional supply chain management, however, inadequate information governance often leads to "information silos," thereby increasing the difficulty of achieving effective collaboration (Salamai, 2024). Supply chain digitalization, by embedding intelligent technologies into the fundamental framework of supply chain operations, enables the real-time identification, monitoring, tracking, and management of material and information flows. This transformation fosters a more transparent and visualized model of supply chain management (Stank et al., 2019), effectively addressing the limitations of conventional practices. Through joint decision-making and information sharing with upstream and downstream partners, firms can obtain insights into green raw material supply from upstream and green demand information from downstream, thereby enhancing the precision and effectiveness of green innovation (Junaid et al., 2021). At the same time, the collaborative effects induced by supply chain digitalization help to monitor and mitigate opportunistic or unethical behaviors undertaken by firms in pursuit of self-interest (Rauniyar et al., 2023).

Although supply chain digitalization remains a relatively nascent domain, research examining its influence on green innovation has begun to emerge and is gradually expanding (Gu et ald, 2024). Existing studies have explored this relationship from the perspectives of digitalization (Song et al., 2022)and supply chain management (Blanco, 2021). Chinese scholars, in particular, have emphasized the role of green supply chain integration in linking digitalization with green innovation (Liu et al., 2023). However, the underlying mechanisms remain insufficiently explored. While recent studies suggest that supply chain digitalization enhances green innovation by improving total factor productivity (Gu et al., 2024) and accelerating supply chain integration (Zhang & Li, 2024), the available evidence is still limited. Moreover, with firms increasingly embracing corporate social responsibility, the potential role of carbon information disclosure—an essential form of non-financial reporting—has yet to be systematically examined. A growing body of research has begun to disaggregate green innovation into distinct dimensions (Ma et al., 2023; Yang & Yang, 2023), yet the examination of supply chain digitalization within this context remains scarce, highlighting a significant gap and providing ample opportunities for further investigation.

Hypothesis Development

Supply Chain Digitalization and Corporate Green Innovation

Wen et al. (2023) argued that with the advent of digital transformation, the highly interactive, boundaryless, and uncertain characteristics of the digital economy foster extensive knowledge sharing among innovation actors, thereby enabling inclusive knowledge creation. Grounded in stakeholder theory, digitalization dissolves the "information silos" that traditionally constrained firms at different nodes of the supply chain, thereby alleviating the difficulties of supply chain collaboration. From the perspective of external coordination,

embedding digital technologies into supply chains enhances interaction, improves operational efficiency, and expands the network of stakeholders, which collectively facilitates the advancement of corporate green innovation (Liu et al., 2023). From the perspective of internal governance, the integrative effect of supply chains, reinforced by digital technologies, subjects firms at different nodes to a data-driven supervisory mechanism imposed by upstream and downstream partners. This effectively restrains opportunistic and environmentally unethical behavior, while joint decision-making and information sharing across the chain open up broader channels for green innovation (Li & Xiao, 2020). Since substantive green innovation emphasizes the application of new knowledge and technologies to explore novel innovation activities (Wang et al., 2020), the broader scope and wider influence of supply chain digitalization attract heightened attention from external stakeholders, thereby generating a synergistic effect that integrates both internal and external knowledge and technologies. Moreover, the network structures formed through digitalization help mitigate conflicts of interest and stimulate firms to adopt substantive green innovation as a strategic direction (Sun et al., 2024).

Supply chain digitalization not only strengthens firms' connections with stakeholders but also mitigates information asymmetry, thereby alleviating financing constraints. On the one hand, embedding digital technologies into supply chain operations enables a more transparent and visualized management system, which ensures the rationality and security of investors' capital deployment (Stank et al., 2019). Moreover, the enhanced precision of green innovation under a digitalized supply chain increases the likelihood of effective outcomes, thereby securing stronger support from investors. On the other hand, as supply chains represent the primary source of carbon emissions, growing environmental pressures have made the establishment of green supply chains an imperative. A digitalized supply chain not only eases firms' financing constraints in the eyes of investors but also signals proactive environmental engagement, which facilitates access to government subsidies and public endorsement. This dual effect strengthens firms' motivation for green innovation while simultaneously expanding the pool of resources available for such initiatives (Zhang et al., 2021).

This dynamic is particularly critical for substantive green innovation projects, which are characterized by long investment horizons and high uncertainty. Unlike strategic green innovation, which primarily relies on the reallocation or optimization of existing resources (Sun, Y. & Sun, H., 2021), substantive innovation requires a greater inflow of external resources. Since supply chain digitalization emphasizes the acquisition of external resources, the mitigation of financing constraints plays a pivotal role in enabling firms to pursue such innovation activities more effectively. Based on this reasoning, the following hypotheses are proposed:
H1a: Supply chain digitalization positively enhances firms' green innovation performance.
H1b: The positive impact of supply chain digitalization on substantive green innovation is stronger than its impact on strategic green innovation.

Supply Chain Digitalization, Carbon Disclosure, and Corporate Green Innovation
Based on signaling theory, supply chain digitalization conveys signals of green transformation and enhanced information transparency. As supply chain digitalization entails intelligent transformation across the entire process and a broader scope, the resulting complex network

structure strengthens inter-firm linkages along the supply chain. To mitigate information asymmetries with stakeholders, firms are incentivized to increase information disclosure. Moreover, the deployment of digital technologies such as cloud computing and the Internet of Things significantly improves firms' efficiency in communicating with stakeholders, enabling rapid access to upstream information on green raw materials and downstream information on green demand. This heightened connectivity strengthens the motivation for green transformation, prompting firms to actively disclose carbon information as a positive signal. Such disclosure enhances both the quantity and quality of carbon information, thereby improving transparency and accountability in carbon management (Jiang, 2024).

Carbon disclosure itself conveys a green signal, increasing transparency and external oversight of corporate environmental transitions. By shortening the time required for green information transmission and lowering the cost of access for stakeholders, carbon disclosure alleviates information asymmetry between firms and their stakeholders (Wang et al., 2024). From the perspective of legitimacy theory, disclosing carbon information demonstrates firms' commitment to environmental governance and strengthens their legitimacy. It also meets stakeholders' expectations for environmental responsibility, thereby reducing financing constraints and further supporting green innovation (Wu et al., 2023).

Supply chain digitalization, by embedding informatization, digitization, and networking across supply chain stages, further improves transparency at each link. In this context, carbon disclosure plays a mediating role in the relationship between supply chain digitalization and corporate green innovation. On the one hand, it alleviates information asymmetries with suppliers, securing trade credit financing. On the other hand, it provides investors with more comprehensive information on the costs and risks of green transformation, lowering risk premiums and expanding financial resources for green innovation (Wu et al., 2023). Given that substantive green innovation requires higher levels of creativity and technological capability, investors need access to richer information for evaluation and decision-making. The intelligent and interconnected platforms enabled by digitalized supply chains also strengthen environmental supervision, with external regulatory pressures further motivating firms to disclose carbon information and curb negative externalities (Gu et al., 2024).

However, voluntary carbon disclosure inevitably raises compliance and capital costs, which may crowd out funds otherwise available for innovation. Consequently, such disclosure may exert adverse effects on corporate green innovation (Xu et al., 2024). Compared with substantive green innovation, strategic innovation relies less on new resources, making the benefits of carbon disclosure insufficient to offset the higher costs of disclosure. Therefore, the impact of carbon disclosure is more pronounced in facilitating substantive green innovation. Based on the above analysis, the following hypotheses are proposed:
H2a: Carbon disclosure mediates the relationship between supply chain digitalization and corporate green innovation.
H2b: Carbon disclosure primarily mediates the impact of supply chain digitalization on substantive green innovation.

Methods

Sample Design and Data Collection

This study selects A-share listed companies in China from 2012 to 2022 as the research sample. The following screening procedures were applied: firms designated as ST(Special Treatment), ∗ST(Special Treatment firms under delisting risk), or PT(Particular Transfer) were excluded; financial firms were removed; and companies with missing information in the panel dataset were also eliminated. After these steps, a final sample of 18,669 firm-year observations was obtained. The primary source of financial data is the China Stock Market and Accounting Research (CSMAR) database. Data on corporate green innovation are obtained from the China Research Data Service Platform (CNRDS). To mitigate the influence of extreme values, the sample was winsorized at the 1% level.

Definition of Variables

Dependent Variable

Data on corporate green innovation are obtained from the China Research Data Service Platform (CNRDS). Following the approach of Wang, X. and Wang, Y. (2021), green invention patents, green utility model patents, and the total number of green patents are employed to represent substantive green innovation, strategic green innovation, and overall green innovation, respectively. These measures are expressed as LnInva, LnUma, and LnTotal.

Independent Variable

The independent variable in this study is supply chain digitalization (SCD). Drawing on the study of Liu et al. (2023), SCD is identified based on the designation of pilot enterprises for supply chain innovation and application.

Mediating Variable

Consistent with the methodology of Shen et al. (2022), corporate carbon information disclosure (CID) is used as the mediating variable. Based on firms' annual reports and CSR reports, the variable takes the value of 1 if carbon information is disclosed, and 0 otherwise.

Control Variables

All control variables are sourced from the CSMAR database. Following prior research (Liu et al., 2023; Qiao & Zhang, 2023; Zhang et al., 2024), this study includes return on assets (ROA), leverage (LEV), cash flow (Cashflow), firm size (Size), board size (Board), the proportion of independent directors (IndDR), ownership concentration (Top1), and research development investment intensity (RDS). Industry and year dummy variables are included to control for industry-specific and time-varying effects. Firm fixed effects are also included in all models to control for unobserved firm-specific heterogeneity. The detailed definitions of all variables are presented in Table 1.

Table 1
Variable Definitions

Type	Name	Symbol	Definition
Independent Variable	Substantive Green Innovation	LnInva	Ln(Green Invention Patents+1)
	Strategic Green Innovation	LnUma	Ln(Green Utility Model Patents+1)
	Total Green Innovation	LnTotal	Ln(Total Green Patents+1)
Dependent Variable	Pilot Enterprise Dummy Variable	Treat	Equals 1 if the firm is designated as a pilot enterprise for supply chain innovation and application, and 0 otherwise
	Post-Pilot Dummy Variable	Time	Equals 1 if the observation year is 2018 or later, and 0 otherwise
	Supply Chain Digitalization	SCD=Treat × Time	Defined as the interaction term of Treat and Time
Mediating Variable	Carbon Information Disclosure	CID	Equals 1 if the firm discloses carbon information in its annual or CSR reports, and 0 otherwise
Control Variables	Return on Assets	ROA	Net profit divided by average total assets
	Leverage	LEV	Total liabilities divided by total assets
	Cash Flow	Cash flow	Net operating cash flow divided by total assets
	Firm Size	Size	Natural logarithm of total assets
	Board Size	Board	Natural logarithm of the number of board directors
	Proportion of Independent Directors	IndDR	Ratio of independent directors to the total number of directors
	Ownership Concentration	Top1	Shareholding ratio of the largest shareholder
	R&D Intensity	RDS	R&D expenditure divided by operating revenue
	Industry	Industry	Industry dummy variable
	Year	Year	Year dummy variable
	Firm Fixed Effects	Firm FE	Firm FE dummy variable

Econometric Models

To test the hypotheses, we estimate three empirical models: (1) the baseline model examining the effect of supply chain digitalization on corporate green innovation; and (2)–(3) the mediation models used to test whether carbon information disclosure (CID) transmits the effect of SCD to green innovation.

LnInva / LnUma / LnTotal = α0 + α1SCD + α2ROA + α3LEV + α4Cashflow + α5Size + α6Board + α7IndDR + α8Top1 + α9RDS + Industry + Year + ε

CID = α0 + α1SCD + α2ROA + α3LEV + α4Cashflow + α5Size + α6Board + α7IndDR + α8Top1 + α9RDS + Industry + Year + ε

LnInva / LnUma / LnTotal = α0 + α1SCD + α2CID + α3ROA+ α4LEV + α5Cashflowt+ α6Cashflowt + α7Cashflowt + α8Cashflowt + α9Cashflow + α10RDS + Industry + Year + ε

Empirical Results and Analysis

Main Effects Regression Analysis

Table 2 reports the baseline regression results (Model 1) for the impact of SCD on green innovation. Columns (1)–(3) exclude control variables, while Columns (4)–(6) include controls (all models include firm, industry, and year fixed effects).

In Columns (1)–(3), SCD exhibits a significantly positive effect on LnTotal (β = 0.581, p < 0.01), LnInva (β = 0.525, p < 0.01), and LnUma (β = 0.325, p < 0.01). After adding controls (Columns 4–6), the coefficients remain significantly positive: LnTotal (β = 0.260, p < 0.01), LnInva (β = 0.269, p < 0.01), LnUma (β = 0.140, p < 0.05). Critically, the coefficient for LnInva (0.269) is nearly twice that of LnUma (0.140), confirming that SCD has a stronger effect on substantive innovation. These results support H1a and H1b.

Table 2

Regression Results of Main Effects

Item	(1)	(2)	(3)	(4)	(5)	(6)
	LnTotal	LnInva	LnUma	LnTotal	LnInva	LnUma
SCD	0.581***	0.525***	0.325***	0.260***	0.269***	0.140**
	(11.12)	(12.42)	(8.97)	(5.20)	(6.65)	(3.95)
Controls	No	No	No	Yes	Yes	Yes
Constant	-0.059	-0.048	-0.043	-4.552***	-3.796***	-2.551***
	(-0.71)	(-0.72)	(-0.76)	(-28.74)	(-29.55)	(-22.79)
Industry	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
N	18,669	18,669	18,669	18,669	18,669	18,669
F	28.73	23.93	27.23	53.65	47.55	42.21
Adj. R^2	0.1133	0.0956	0.1078	0.2096	0.1899	0.1719

Note: ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. Values in parentheses are t-statistics.

Further Analysis

Ownership Structure Heterogeneity Analysis

The heterogeneity results with respect to ownership structure are presented in Table 3. The findings indicate that the impact of supply chain digitalization on green innovation differs between state-owned and non-state-owned enterprises. Specifically, supply chain digitalization exerts no significant influence on green innovation among non-state-owned

firms, whereas it has a highly significant effect on both substantive and strategic green innovation in state-owned enterprises. This divergence can be attributed to the stronger intrinsic motivation of state-owned firms to pursue green development, given China's emphasis on ecological civilization and sustainable growth. Consequently, following digital transformation, the deep integration of digital technologies enables state-owned enterprises to proactively collaborate with upstream and downstream partners in building a green and sustainable supply chain ecosystem, thereby substantially enhancing their capacity for green innovation.

Table 3
Ownership Structure Heterogeneity Analysis

Item	Non-state-owned enterprises			State-owned enterprises		
	LnTotal	LnInva	LnUma	LnTotal	LnInva	LnUma
SCD	-0.065 (-1.00)	-0.010 (-0.19)	-0.063 (-1.34)	0.515*** (6.51)	0.504*** (7.59)	0.291*** (5.41)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-3.909*** (-17.82)	-3.019*** (-17.41)	-2.379*** (-14.99)	-4.941*** (-18.79)	-4.142*** (-18.76)	-2.835*** (-15.82)
Industry	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
N	12,247	12,247	12,247	6,422	6,422	6,422
F	36.19	29.15	30.45	25.36	23.68	20.51
Adj. R^2	0.2036	0.1699	0.1763	0.2545	0.2412	0.2147

Heterogeneity Analysis of Firm Size

The regression results based on firm size are presented in Table 4, revealing that the impact of supply chain digitalization on corporate green innovation varies across enterprises of different scales. Specifically, the effect of supply chain digitalization on green innovation is not significant among small firms, whereas in large firms, its positive influence is both substantial and significant for substantive and strategic green innovation. The underlying reason is that larger firms place greater emphasis on corporate reputation, and the pursuit of green innovation enhances media visibility and public recognition, thereby securing more favorable evaluations. Moreover, large firms enjoy greater ease in accessing resources, equipping them with stronger capabilities to undertake innovation activities. Consequently, empowered by digital technologies, large firms are more motivated to collaborate with upstream and downstream partners to establish a green and sustainable supply chain ecosystem, which in turn effectively enhances their level of green innovation.

Table 4
Firm Size Heterogeneity Analysis

Item	Small enterprises			Large enterprises		
	LnTotal	LnInva	LnUma	LnTotal	LnInva	LnUma
SCD	0.045 (0.32)	0.025 (0.23)	0.064 (0.65)	0.229*** (3.67)	0.243*** (4.70)	0.123** (2.76)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-2.472*** (-9.75)	-1.700*** (-8.70)	-1.384*** (-7.73)	-7.598*** (-22.79)	-6.561*** (-23.73)	-4.287*** (-18.04)
Industry	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
N	10,373	10,373	10,373	8,296	8,296	8,296
F	19.89	15.69	15.94	33.97	31.45	26.94
Adj. R^2	0.1422	0.1142	0.1159	0.2613	0.2463	0.2177

Regression Analysis of the Mediating Effect

The results of the mediating effect of carbon information disclosure are presented in Table 5. Column (1) shows that the regression coefficient of supply chain digitalization on carbon information disclosure is significantly positive at the 1% level, indicating that firms with a higher degree of supply chain digitalization are more inclined to actively disclose carbon information. Columns (2)–(4) report the regression results of supply chain digitalization on green innovation after incorporating carbon information disclosure. Specifically, Column (2) demonstrates that the regression coefficient of supply chain digitalization on the total volume of green innovation remains significantly positive at the 1% level, suggesting that the positive effect persists even after accounting for carbon information disclosure. When green innovation is further disaggregated, Columns (3) and (4) present the results for substantive and strategic green innovation, respectively. Column (3) reveals that carbon information disclosure has a significantly positive coefficient on substantive green innovation at the 5% level, whereas Column (4) shows that the coefficient for strategic green innovation is not significant. These findings indicate that supply chain digitalization fosters substantive green innovation primarily by enhancing carbon information disclosure, thereby providing empirical support for Hypotheses 2a and 2b.

Table 5
Regression Analysis of the Mediating Effect of Carbon Information Disclosure

Item	(1) CID	(2) LnTotal	(3) LnInva	(4) LnUma
SCD	0.063** (2.46)	0.257*** (5.15)	0.268*** (6.61)	0.139*** (3.93)
CID		0.038*** (2.66)	0.023** (1.97)	0.013 (1.28)
Controls	Yes	Yes	Yes	Yes
Constant	-0.120 (-1.47)	-4.548*** (-28.71)	-3.793*** (-29.53)	-2.549*** (-22.77)
Industry	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	18,669	18,669	18,669	18,669
F	49.47	53.18	47.10	41.79
Adj. R^2	0.1962	0.2098	0.1900	0.1719

Robustness Tests

To ensure the reliability of the empirical results, robustness tests were conducted by replacing the dependent variable. Following the approach of Qiao and Zhang (2023), and considering that invention patents exert a more pronounced influence on innovation performance, weights of 3:2 were assigned to invention patents and utility model patents, respectively. To mitigate potential bias, the total number of applications was incremented by one and then log-transformed, denoted as lnGrant. The robustness test results are reported in Table 6. The regression coefficient of supply chain digitalization on corporate green innovation is 0.210, which is significant at the 1% level, indicating that supply chain digitalization significantly enhances firms' green innovation. After incorporating carbon information disclosure as a mediating variable, this significant positive relationship remains robust, thereby confirming the stability of the findings.

Table 6
Substitution of Explained Variables

Item	(1) LnGrant	(4) CID	(5) LnGrant
SCD	0.210*** (5.65)	0.063** (2.46)	0.208*** (5.61)
CID			0.024** (2.32)
Controls	Yes	Yes	Yes
Constant	-3.479*** (-29.53)	-0.120 (-1.47)	-3.476*** (-29.50)
Industry	Yes	Yes	Yes
Year	Yes	Yes	Yes
N	18,669	18,669	18,669
F	52.89	42.47	52.40
Adj. R^2	0.2072	0.1962	0.2074

Findings

Drawing on panel data of Chinese A-share listed firms from 2012 to 2022, this study employs a difference-in-differences (DID) approach with firm, industry, and year fixed effects to empirically examine the impact of supply chain digitalization (SCD) on corporate green innovation, and further explores the mediating role of carbon information disclosure (CID) and heterogeneous effects across firm characteristics. The key findings are presented as follows:

a. Core Impact of Supply Chain Digitalization on Corporate Green Innovation

Supply chain digitalization exerts a significantly positive effect on corporate green innovation, with substantial heterogeneity across innovation types. Regression results indicate that after controlling for firm-specific characteristics, industry trends, and time effects, the estimated coefficient of SCD on total green innovation (LnTotal) is 0.260 ($p < 0.01$). Notably, this positive impact is more pronounced for substantive green innovation (LnInva: $\beta = 0.269$, $p < 0.01$) than for strategic green innovation (LnUma: $\beta = 0.140$, $p < 0.05$). This suggests that supply chain digitalization not only promotes the overall quantity of green innovation but also prioritizes technology-intensive, long-term substantive innovation rather than symbolic strategic innovation.

b. Mediating Role of Carbon Information Disclosure

Carbon information disclosure serves as a critical mediating channel linking supply chain digitalization to corporate green innovation, with a selective effect on innovation types. First-stage regression results show that SCD significantly increases firms' likelihood of disclosing carbon information ($\beta = 0.063$, $p < 0.05$). In the second-stage regression, after incorporating CID as a mediating variable, the coefficient of SCD on total green innovation remains significantly positive ($\beta = 0.257$, $p < 0.01$), while CID itself exerts a significantly positive impact on total green innovation ($\beta = 0.038$, $p < 0.01$). Further analysis reveals that the mediating effect of CID is primarily manifested in substantive green innovation ($\beta = 0.023$, $p < 0.05$), whereas its impact on strategic green innovation is statistically insignificant ($\beta = 0.013$, $p > 0.1$). This indicates that supply chain digitalization enhances the transparency of corporate environmental behavior through promoting carbon information disclosure, thereby alleviating information asymmetry and financing constraints to support high-quality substantive green innovation.

c. Robustness Verification

Robustness tests using a weighted green innovation indicator (LnGrant, with invention patents weighted 3 and utility model patents weighted 2) confirm the stability of the core findings. The regression results show that SCD still has a significantly positive impact on weighted green innovation ($\beta = 0.210$, $p < 0.01$), and the mediating role of CID remains statistically significant ($\beta = 0.024$, $p < 0.05$). This indicates that the positive effect of supply chain digitalization on corporate green innovation, as well as the mediating mechanism of carbon information disclosure, is not affected by the measurement method of green innovation, ensuring the reliability of the empirical conclusions.

Discussion and Conclusion

Drawing on data from A-share listed firms between 2012 and 2022, this study investigates the impact of supply chain digitalization on corporate green innovation and further elucidates its underlying mechanisms. The findings reveal that supply chain digitalization facilitates information exchange among stakeholders, mitigates information asymmetry, and alleviates financing constraints, thereby significantly enhancing firms' green innovation. This conclusion is consistent with prior research on the innovation performance of supply chain digitalization, while extending the literature by highlighting its role in fostering green innovation. Moreover, the positive effect is particularly pronounced in state-owned and large-scale enterprises. By incorporating carbon information disclosure as a mediating pathway, this study enriches the literature from the perspective of non-financial information and provides a novel angle for understanding how digitalization promotes green innovation. The further distinction between substantive and strategic green innovation demonstrates that supply chain digitalization consistently exerts a significant influence on substantive green innovation, thereby advancing the depth of existing research.

The study offers several policy implications. First, policymakers should actively promote the digital transformation of supply chains by expanding pilot projects of modern digital supply chains, leveraging the demonstration effects of leading enterprises, and fostering new momentum for industrial green transformation. State-owned and large-scale enterprises should continue to play a guiding role in advancing green development, while encouraging a broader range of firms to adopt environmentally responsible values. Second, the enhanced

transparency brought about by digital and networked supply chains requires firms to strengthen their awareness of voluntary disclosure, improve carbon information management, and proactively engage in green transformation. Finally, firms should allocate resources more effectively by coordinating investments between green invention patents and utility model patents. Overall, enterprises should recognize the pivotal role of supply chain digitalization in driving sustainable development, actively disclose carbon information during the transformation process, and shoulder social responsibility, thereby contributing to high-quality development.

Theoretical Implications

This study enriches the theoretical discourse on supply chain digitalization and green innovation in several ways. First, by integrating digital transformation into the framework of corporate green innovation, the research extends the dynamic capabilities perspective, highlighting how firms leverage digital technologies to enhance adaptability, resource orchestration, and sustainable competitiveness. Second, the identification of carbon information disclosure as a mediating mechanism introduces a novel theoretical pathway, thereby contributing to the literature on non-financial information disclosure and environmental governance. Third, the heterogeneity analysis demonstrates that ownership structure and firm size shape the effectiveness of digitalization in promoting green innovation, which refines the boundary conditions of existing theories. Collectively, these insights broaden the conceptual understanding of how digital capabilities translate into substantive sustainability outcomes.

Practical and Social Implications

The findings yield several managerial and societal insights. For practitioners, the results underscore the importance of embedding digital technologies into supply chain management as a means to enhance transparency, alleviate financing barriers, and stimulate substantive green innovation. Managers of large-scale and state-owned enterprises, in particular, should leverage their advantages in reputation and resources to lead the construction of green supply chain ecosystems. From a policy perspective, the study highlights the necessity of expanding digital supply chain pilot programs and encouraging enterprises to engage in voluntary carbon disclosure, thereby fostering greater accountability and public trust. At the societal level, enhanced carbon information disclosure can stimulate broader stakeholder engagement, improve corporate environmental responsibility, and ultimately accelerate the transition toward a low-carbon economy.

Limitations and Suggestions for Future Research

Despite its contributions, this study is not without limitations, which open avenues for further inquiry. First, the empirical analysis is based on Chinese A-share listed firms, which may constrain the generalizability of the findings; future research could adopt cross-country or cross-industry comparisons to validate the robustness of the conclusions. Second, the measurement of supply chain digitalization and green innovation is derived from secondary data, which may not fully capture firms' internal practices or innovation quality; subsequent studies could incorporate survey data or case studies for deeper insights. Third, while this study identifies carbon information disclosure as a mediating pathway, other potential mechanisms, such as green absorptive capacity, supply chain integration, or digital collaboration, warrant further examination. Finally, longitudinal designs and advanced

methodologies (e.g., panel causal inference models or text mining of disclosure reports) could offer richer evidence on the dynamic interplay between digitalization and sustainability.

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