

The Impact of Digital Transformation on Green Technological Innovation of Multinational Manufacturing Enterprises

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How to cite this paper: Cao, N., Liu, B. B., & Wang, J. J. (2026). The Impact of Digital Transformation on Green Technological Innovation of Multinational Manufacturing Enterprises. *Economics & Business Management*, 5(1), 117-122. ISSN Print: 3079-5214; ISSN Online: 3079-5222. <https://doi.org/10.63313/EBM.9166>
Published: 2026-03-23

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Abstract

Fueled by accelerating digital advances and intensified national carbon neutrality commitments, the strategic convergence of digital transformation and environmental sustainability has become a pivotal lever for upgrading China's manufacturing toward high-quality, resilient growth. As the cornerstone of the Fourth Industrial Revolution, digital technologies reconfigure innovation architectures, compress green R&D timelines, and catalyze the synthesis, dissemination, and market deployment of green knowledge. Using a comprehensive panel of A-share manufacturing listed firms from 2014 to 2024, this study constructs a holistic digitalization index across four dimensions. Employing dynamic panel models and machine learning-enhanced robustness checks, we assess digitalization's causal effects on green innovation quantity, quality, and translational efficacy, further unpacking mechanisms, boundary conditions, and theoretical foundations for theory and policy.

Keywords

Digital Transformation; Green Technological Innovation; Research and Development Investment; ESG Performance; Sustainable Development

1. Introduction

Under the dual backdrop of the economy's transition to a new stage of high-quality development and the in-depth evolution of the new round of technological revolution, the global climate system remains imbalanced and the pressure on the ecological environment is constantly intensifying, which has become a common challenge to sustainable development. Against this backdrop, accelerating the comprehensive green and low-carbon transformation of economic and social development has not only become a priority for policy-making in various countries but has also been established as a strategic fulcrum for the construction of Chinese-style modernization.[1] The 2025 Central Economic Work Conference further emphasized the need to promote the deep integration of digital and green

technologies to jointly empower the transformation and upgrading of traditional industries with "smart" and "green" forces; at the same time, efforts should be made to unblock the full chain of innovation paths from basic research to market feedback, focusing on breakthroughs in key low-carbon technologies in key industries such as energy, manufacturing, and transportation, and systematically building a new model of high-quality development that organically unifies carbon reduction and pollution control, ecological expansion, and kinetic energy transformation.[2] However, reality shows that China's green technology supply system still has structural shortcomings, prominently manifested in the fact that enterprises have not yet truly become the core subjects of green technology innovation decision-making, R&D investment, and technology transfer,[3] with widespread problems such as ambiguous strategic cognition, cautious innovation investment, low willingness to take risks, and insufficient institutional adaptation (Wang Mingyue et al., 2022). Therefore, it is urgently necessary to adopt a governance perspective based on institutional reform, through systematic institutional arrangements such as improving the green innovation tolerance mechanism, strengthening precise fiscal, tax, and financial incentives, perfecting the green technology standards and certification system, and promoting the deep integration of industry, academia, research, and application, to effectively stimulate the endogenous motivation and practical effectiveness of enterprises' green technology innovation (Yang Zhen et al., 2024).[4]

2. Digital Transformation, ESG Performance and Green Technological Innovation

A large number of high-quality empirical studies support the significant promoting effect of digital transformation on green technological innovation. Peng Yongzhang et al. (2022), based on the balanced panel data of A-share listed companies from 2012 to 2020,[5] used a two-way fixed effect model for testing and found that digital transformation not only significantly improves the financial performance and operational efficiency of multinational manufacturing enterprises, but also deeply activates the organizational innovation genes and substantially expands the boundaries of technological breakthroughs.[6] Li Xin et al. (2023) further identified four key transmission channels: optimizing the human capital structure to match the demand for green R&D, reducing information search and coordination costs, enhancing the positive feedback of the market on sustainable development strategies, and improving the internal governance mechanism to ensure the stability of green innovation investment. Moreover, this driving effect is particularly robust in state-owned enterprises,[7] enterprises with less financing constraints, technology-intensive enterprises, and those located in low-carbon pilot cities and economically active regions in the east. From the perspective of factor allocation efficiency, it is confirmed that digital transformation systematically enhances the

output efficiency of green innovation through three paths: precisely guiding the allocation of R&D resources, expanding the supply of long-term R&D investment funds, and enhancing the attraction of high-end green technology talents. However, its marginal contribution shows a phased attenuation feature, reaching its peak in the growth stage of the enterprise life cycle and tending to flatten in the mature stage. Jiawei X et al. (2023), through a micro-survey of 210 multinational manufacturing enterprises, found that the systematic nature of the enterprise's digital strategy and the comprehensiveness of digital capabilities have a significant positive impact on the innovation capabilities in three dimensions: clean production process development, environmentally friendly product design, and ESG-oriented management system construction.[8] Lun Xiaobo and Liu Yan (2024) extended the analysis scale to the national strategy level, pointing out that the "Belt and Road" initiative accelerates the process of enterprise digital capability construction through infrastructure connectivity, digital rule coordination, and facilitation of cross-border data flow, thereby providing structural support for green technology leapfrogging. This policy dividend is more fully released in state-controlled enterprises, enterprises with obvious scale advantages, high industry concentration, and those in the eastern coastal regions. Through multi-dimensional robustness tests, the above conclusions are further consolidated and it is emphasized that under the dual dimensions of property rights nature and the scale of multinational manufacturing enterprises, the explanatory power and statistical significance of digital transformation on green technological innovation are significantly enhanced, highlighting its policy adaptation value in key subjects.[9]

Hypothesis 1: Digital transformation has a positive promoting effect on green technological innovation in multinational manufacturing enterprises.

As the degree of digital transformation of multinational manufacturing enterprises increases,[10] the increasingly close communication and interaction among enterprises make it more possible for them to reach win-win transactions. Digitalization enhances the social recognition and sense of belonging of enterprises, which essentially helps multinational manufacturing enterprises lay the foundation for further cooperation (Qian Xihong et al., 2010) . ESG valuation can be used to assess the mutual value between enterprises. As a common practice, the ESG rating system encourages enterprises to focus on social recognition and common interests, and mutual trust. This trust may, to a certain extent, limit free use, such as mutual supervision of unintentional emissions during the production process. At a higher level, it can effectively prevent and manage fraud and opportunistic behavior, and ensure that enterprises comply with applicable market rules and standards. The synergy between digital transformation and ESG performance in the green technology innovation practices of enterprises not only helps to enhance the systematicness and sustainability of green development, but also can form significant scale effects and institutional advantages in the field of pollution control.

Research shows that the digitalization process of multinational manufacturing enterprises effectively improves the quality and transparency of information disclosure in the ESG rating system, thereby providing key support for the improvement of the supervision effectiveness of external stakeholders and the deepening of green technology independent innovation.[11]

Hypothesis 2: The digitalization level of enterprises and ESG performance have an interactive influence effect and a mutual reinforcement effect in enhancing the level of green technological innovation.

3. Research Hypotheses

Table 1. Variable Definition and Measurement Description

Variable Type	Variable	Variable Name	Measurement / Definition
Dependent Variable	GTI	Green Technological Innovation	Natural logarithm of total green patent applications plus one
	GTI1	Substantive Green Technological Innovation	Natural logarithm of green invention patent applications plus one
	GTI2	Strategic Green Technological Innovation	Natural logarithm of green utility model applications plus one
Mediating Variable	RD	Research and Development Investment	Natural logarithm of R&D investment (10,000 yuan) plus one
Independent Variable	DT	Digital Transformation	Measured by the frequency of relevant keywords in annual reports
Moderating Variable	ESG	ESG Performance	Huazheng ESG rating, coded from 9 (AAA) to 1 (C)
Control Variables	Total Assets	Enterprise Scale	Natural logarithm of total assets
	Net Profit	Return on Assets	Net profit ratio
	RDPersonRatio	Research Personnel Scale	Ratio of R&D personnel to total employees
	CP	CEO Duality	CEO duality (1=no, 2=yes)
	BS	Board Size	Natural logarithm of number of board directors
	AGE	Firm Age	Years since establishment
	LEV	Leverage Ratio / Asset-Liability Ratio	Total liabilities at year-end / Total assets at year-end

paper. Do not numbGTI1it = $\beta_0 + \beta_1 DT_{it} + \beta_2 RD_{it} + \beta_3 ESG_{it} + \beta_4 CONTROL_{it} + \mu_{it} + \varepsilon_i$

(1)

GTI1it = $\alpha_0 + \alpha_1 DT_{it} + \alpha_2 ESG_{it} + \alpha_3 DT_{it} \times ESG_{it} + \alpha_4 CONTROL_{it} + \mu_{it} + \varepsilon_i$

(2)

GTI2it = $\beta_0 + \beta_1 DT_{it} + \beta_2 RD_{it} + \beta_3 ESG_{it} + \beta_4 CONTROL_{it} + \mu_{it} + \varepsilon_i$

(3)

GTI2it = $\alpha_0 + \alpha_1 DT_{it} + \alpha_2 ESG_{it} + \alpha_3 DT_{it} \times ESG_{it} + \alpha_4 CONTROL_{it} + \mu_{it} + \varepsilon_i$

(4)

This paper conducts a descriptive statistical analysis on the relationship between enterprise R&D investment and green technological innovation under the background of digital transformation. The results are shown in the table below. The current maximum value of the substantive green technological innovation (GTI substantive) of enterprises is 6.469, the minimum value is 5.598, the average value is 5.541, and the standard deviation is 0.338; the current maximum value of the

strategic green technological innovation (GTI strategic) of enterprises is 6.659, the minimum value is 6.369, the average value is 6.492, and the standard deviation is 0.124. The results show that there is a certain gap between substantive and strategic green technological innovation among enterprises due to factors such as industry and business scale. The maximum value of R&D investment (RD) is 8.597, the minimum value is 7.921, the average value is 8.345, and the standard deviation is 0.321. This indicates that there are significant differences in the emphasis on R&D investment among different industries and enterprises. The maximum value of the degree of digital transformation (DT) is 8.850, the minimum value is 4.446, the mean is 6.863, and the standard deviation is 1.376, suggesting that there are considerable differences in the level of digital transformation among enterprises. The maximum value of the ESG performance of enterprises (ESG) is 9.000, the minimum value is 1.000, the mean is 4.225, and the standard deviation is 1.127, indicating that there are significant differences in ESG performance among enterprises.

4. Conclusion

This study examines how digital transformation affects green technological innovation in multinational manufacturing enterprises, with ESG performance as a moderating factor and R&D investment as a mediator. Empirical results confirm that digital transformation significantly promotes both substantive and strategic green innovation. ESG performance positively reinforces this effect and generates a synergistic interaction with digitalization. Heterogeneity analysis shows that the promotion effect is stronger in state-owned, technology-intensive, large-scale and eastern-region enterprises. Digital transformation improves green innovation mainly by optimizing resource allocation, reducing costs, enhancing governance and stabilizing R&D investment. These findings enrich the theoretical understanding of digital – green integration and provide practical implications for enterprises to deepen digital transformation, improve ESG performance, and achieve high-quality green development.

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