

How does Digital Transformation Affect the Conversion of R&D Investment into Green Technological Innovation in Enterprises ?

Ning Cao¹, Beibei Liu^{1*} and Jianjun Wang²

¹School of Business, Shanghai Dianji University, Shanghai 201316, China

²School of Economics and Management, Shanghai Ocean University, Shanghai 201306, China

Email: 1452777634@qq.com

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Abstract

Against the backdrop of global climate change and intensified resource constraints, green technological innovation has become the core driving force for enterprises to achieve sustainable development. Although research and development(R&D) investment is widely recognized as a key element in promoting green technological innovation in enterprises and has received considerable attention, the moderating role of digital transformation, an emerging technological environment factor, in the process of converting R&D investment into green technological innovation in enterprises has rarely been explored. Based on the resource-based theory and the innovation process theory, this paper aims to deeply investigate the impact of R&D investment on green technological innovation in enterprises and further analyze how digital transformation plays a moderating role in this process. Through an empirical study of sample data from manufacturing enterprises listed on the A-share market from 2013 to 2024, the following findings were discovered: (1) R&D investment has a significant positive impact on green technological innovation in enterprises, meaning that R&D investment is conducive to promoting both substantive and strategic green technological innovation in enterprises;(2) Digital transformation has a significant positive impact on green technological innovation in enterprises, indicating that digital transformation is beneficial for enterprises to carry out both strategic and substantive green technological innovation;(3)Digital transformation positively moderates the relationship between R&D investment and green technological innovation, meaning that enterprises with a high degree of digital transformation can more effectively convert R&D investment into substantive and strategic green technological innovation. This research finding reveals the crucial role of digital transformation in facilitating the conversion of R&D investment into green technological innovation, providing practical guidance for enterprises in formulating R&D strategies and digital transformation strategies to accelerate the pace of green technological innovation.

Keywords

R&D investment; Enterprise green technological innovation; Digital transfor-

mation; Sustainable development

1. Introduction

In the face of intensifying global competition and strengthening resource and environmental constraints, green technology innovation has become a key driving force to promote sustainable development and green change of enterprises. As global attention to climate change continues to deepen, governments have begun to launch relevant policies aimed at incentivizing enterprises to increase investment in green technology research and development. According to a report by the International Energy Agency, by 2024, the total global investment in renewable energy and energy efficiency has exceeded \$3 trillion, which signifies that green technology innovation has become a new hotspot for global investment. In the Outline of the 14th Five-Year Plan, China explicitly states that “it is necessary to comprehensively promote the green transformation of the economy and society, strengthen the key industries, and promote the green transformation of the economy and society. In the Outline of the 14th Five-Year Plan, China clearly states that “we must comprehensively promote the green transformation of the economy and society, and strengthen the green upgrading of key industries”, and at the same time, “we will build a green innovation system with enterprises as the core and the market as the driving force”. Motivated by both policy and market demand, a large number of enterprises are striving to increase their investment in green technology research and development, aiming to promote green technological innovation in enterprises. However, enterprises are facing the problems of big challenges and high input costs in green technology innovation[1]. Although the investment in green technology innovation by enterprises is increasing, its expected results are not ideally matched. Many enterprises have invested a lot of green R&D funds, but failed to realize the effectiveness of green innovation or achieve green competitive advantage. This phenomenon has aroused widespread concern in both academic and practical circles, and therefore it has become a valuable topic to explore the key factors affecting the input and output process of enterprises' green technological innovation.

Focusing on the relationship between enterprise R&D investment and green technology innovation, scholars generally agree that R&D investment is an important indicator to enhance the competitiveness of enterprise green innovation. By analyzing the patent situation of green technology in China, Xu Xiaoyan[2] clarified that there exists a kind of significant positive influence between enterprise R&D expenditure and the level of green technology innovation. Wang Hui[3] concluded that increased capital investment in R&D by medium and large enterprises can effectively promote their green technology innovation by using panel threshold analysis. The results of Zhang Xu[4] also show that increasing the proportion of enterprise R&D capital investment will be conducive to improving the performance of the enterprise in green

technology innovation. In summary, most of the current research focuses on direct causality, arguing that the resources invested and knowledge accumulated by enterprises in green products, technologies, processes, etc., have a positive facilitating effect on green technology innovation. However, the existing literature neglects the moderating role of other potential variables [5], especially in the wave of global digital transformation, does the digital transformation of enterprises have an important impact on green technology innovation?

In the wave of the information age, digital technology has been widely used in many industries and become a “new driving force” for economic development. Enterprises have not only become the core force to promote high-quality development through the integration and application of digital technologies in various aspects, but have also given rise to the emergence of many new technologies, new methods and new business models[6].With the increased global emphasis on sustainable development, green innovation activities of enterprises have gradually become a key way to enhance their competitive advantages.A study by El-Kassar and Singh[7] showed that through empirical analysis of micro research data from 504 companies, the use of big data applications by enterprises significantly impacted their green innovation activities, a finding that provides new insights into how enterprises can utilize digital technology to enhance green competitiveness.Meanwhile, the study of Mubarak [8] pointed out that Industry 4.0 technology promotes open innovation through efficient information transfer and knowledge accumulation, which promotes its wider participation in green technology innovation. Based on panel data of listed companies, Kou Dongxue[9] explored how digital transformation promotes the specific path of enterprises' shift to green mode from both financial and business perspectives, verified the positive impact of digital empowerment on green transformation, and demonstrated the potential of digitization in promoting sustainable development of enterprises. The research results of Hu Yuhui and other scholars [10] reveal that digital carbon reduction measures significantly reduce the carbon emission intensity of manufacturing enterprises, thus highlighting the important role of digital technology in the field of environmental governance. Despite the results of existing studies, there is a lack of in-depth discussion on the moderating role of digital transformation in the process of transforming R&D investment into green technological innovation. Therefore, future research should focus on how digital transformation can contribute more effectively to corporate practices in the field of green innovation in order to realize both economic and environmental benefits.

In view of this, this study takes the digital transformation of enterprises as a moderating variable and constructs a comprehensive analytical framework to reveal the moderating effect of digital transformation in the transformation process of R&D investment and green technology innovation. Based on the large sample data of Chinese A-share listed companies from 2013 to 2024, we empirically analyze the intrinsic mechanism of the role of R&D investment on green technology innovation

under digital transformation in enterprises of different industries and sizes. Through the study of the above issues, we hope to enrich and expand the theoretical framework of the driving factors of enterprises' green technological innovation from the theoretical level, reveal the facilitating role of R&D investment in it, and provide new perspectives and ideas for the research in the related fields, and at the same time provide the decision-making basis for the optimization of the green investment structure of the enterprises from the practical level to better promote the transformation of R&D investment into green technological innovation.

2. Literature Review

2.1. R&D investment and enterprises' green technology innovation

Increasing R&D investment by enterprises is conducive to enhancing innovation performance. From the perspective of the resource-based theory, increasing R&D investment and establishing R&D centers can help expand the scope of resource acquisition by enterprises, especially when investing in regions with different market advantages, which enables enterprises to obtain scarce resources[12]. Through R&D activities, enterprises can mobilize specific resources to create new technologies and improve their dynamic response capabilities, maintaining their competitive advantages[13]. Chen Hongwei[14] found that R&D investment has a promoting effect on innovation performance in the research and development stage.

R&D investment is the primary factor promoting substantive green technological innovation. China's technological progress and productivity improvement have significantly benefited from the increase in the intensity of enterprises' R&D investment, and have driven the growth of substantive green technological innovation. Enterprises can stabilize their market position and build core competitiveness through substantive innovation[11]. Xu Xiaoyan[2] clearly identified a significant positive impact between enterprise R&D expenditures and the level of green technological innovation. Wang Hui[3] through panel threshold analysis method concluded that medium-sized and large enterprises can effectively promote their green technological innovation by increasing R&D investment. The research results of Zhang Xu[4] also showed that increasing the proportion of R&D funds investment is conducive to improving the green technological innovation performance of enterprises.

Enterprise R&D investment is also beneficial to strategic green technological innovation. When R&D investment is low, enterprises may abandon the pursuit of difficult substantive green innovation due to a lack of resource support and financial guarantee, and instead pursue the "quantity" and "speed" of innovation. Compared with strategic green technological innovation, substantive green technological innovation has higher risks, longer cycles, and greater uncertainty, posing a great challenge to enterprises' short-term operation and development. Strategic green innovation can precisely compensate for the risks brought by substantive green

technological innovation to enterprises[15]. This is because the generation and transformation speed of strategic green innovation results is faster, which can make up for the deficiencies of substantive innovation and enable enterprises to obtain more resource support. Therefore, enterprises will consider conducting strategic green technological innovation when making R&D investment. Li Yuguang[16] found that R&D significantly affects enterprise specialization operation, and specialization operation is conducive to strategic green technological innovation. Yang Min[17] found that enterprise R&D has a significant positive effect on enterprise value creation. Wang Zhige[18] based on the data of listed companies found that enterprise R&D directly affects its innovation strategy and affects strategic green technological innovation. Therefore, this paper proposes the following hypotheses:

H1: Enterprise R&D investment has a positive and significant impact on green technology innovation

H1a: Enterprise R&D investment has a positive and significant impact on substantive green innovation

H1b: Enterprise R&D investment has a positive and significant impact on strategic green innovation.

2.2. Digital Transformation and Green Technology Innovation in Enterprises

Digital transformation provides support for enterprises' green technological innovation by integrating information technology and optimizing resource allocation. Liu Zhiming[19] believe that digital transformation significantly promotes the implementation of active and passive green innovation strategies of enterprises, thereby enhancing the quality and quantity of enterprise green technological innovation, that is, improving the substantive and strategic green technological innovation of enterprises. Substantive green technological innovation emphasizes the frontier, uniqueness and high quality of technology, while strategic technological innovation focuses on increasing the number of innovations through innovation strategies, and improving the short-term benefits of enterprises. The effect paths of digital transformation on both have differences.

Digital transformation can promote substantive green technological innovation of enterprises. With the advancement of Internet and big data technologies, Industry 4.0 is developing at an exponential rate[20]. Digital transformation provides tool support for reducing information asymmetry. Through the digestion and absorption of massive information, knowledge resources and other innovative elements, enterprises can form high-level innovation capabilities that are difficult to imitate and replace[21], form unique competitive advantages[22], and promote substantive green technological innovation[23]. Substantive green technological innovation emphasizes the concentration, optimization and allocation of innovation resources. Digital transformation optimizes the structure of human capital in innovation resources.

Guo Feng [24] studied that human capital is the core input factor of green technological innovation, and digital transformation improves the composition of enterprise human resources, enhances the multiplier effect of talents and knowledge assets[25], and reserves high-end innovation resources support for substantive green technological innovation [26].

Digital transformation also promotes strategic green technological innovation of enterprises. Strategic technological innovation focuses on short-term benefits. Given the essence of enterprise profitability, some enterprises tend to choose those more cost-effective strategic green technologies that are beneficial to their development when promoting green technological innovation. Xiao Renqiao[27] further pointed out that digital transformation reduces information opacity and resource consumption, enabling enterprises to obtain innovation resources more conveniently through value networks, promoting strategic green technological innovation. Jin Yu[28] pointed out that enterprise digital transformation can alleviate financing restrictions, alleviate agency conflicts, and enhance development capabilities, thereby improving the strategic green innovation capabilities of enterprises.

In conclusion, digital transformation significantly improves the substantive and strategic green technological innovation performance of enterprises through technology empowerment, resource optimization and innovation resource allocation, providing support for enterprises to occupy an advantageous position in global green competition. Based on the above analysis, this paper proposes the following research hypotheses:

H2: Enterprise digital transformation can positively promote the role of green technology innovation.

H2a: Enterprise digital transformation can positively promote substantive green technological innovation.

H2b: Enterprise digital transformation can positively promote strategic green technology innovation.

2.3. The moderating role of enterprise digital transformation

Data, as a new innovative element, not only enriches the types of innovation resources but also improves the utilization efficiency of existing resources, forming a "multiplier effect" of innovation[29]. Green technological innovation is an important way for enterprises to achieve sustainable development. With the advancement of digital transformation, the boundaries between enterprise R&D and production processes, as well as between manufacturers and consumers, have gradually become blurred, and the innovation process is gradually integrating into a unified whole [30]. The demand data of consumers can be more easily transmitted to the R&D department, stimulating the vitality of enterprises' green technological innovation.

When enterprises have a higher degree of digital transformation, they can more effi-

ciently coordinate and utilize a large amount of digital resources [31]. Including talents, technologies, and market information. Through the integration and analysis of information, enterprises can optimize the allocation of R&D investment and the decision-making process, thereby enhancing the promoting effect of R&D investment on green technological innovation performance. The combination of digital transformation and R&D investment generates a synergy effect, increasing the return on R&D investment, and thereby improving innovation performance. On the other hand, from the perspective of transaction cost theory, digital transformation improves operational efficiency and innovation capabilities [32], reduces traditional transaction costs such as transaction asymmetry, contract negotiation, and regulation [33], provides an efficient platform for information exchange and cooperation, reduces barriers to resource acquisition and integration, and thus enhances the positive impact of R&D investment on green technological innovation, especially in strategic green technological innovation [34].

Therefore, digital transformation significantly enhances the ability of green technological innovation through optimizing resource allocation and reducing transaction costs. Thus, under the promotion of digital transformation, enterprises are more motivated to increase R&D investment to improve substantive and strategic green technological innovation. Therefore, this paper proposes the following hypotheses:

H3: Enterprise digital transformation positively regulates the impact of R&D investment on green technology innovation

H3a: Enterprise digital transformation positively regulates the impact of R&D investment on empirical green technology innovation.

H3b: Enterprise digital transformation positively regulates the impact of R&D investment on strategic green technology innovation.

3. Research design

3.1. Data sources

During the sample selection stage, 504 manufacturing enterprises with representative characteristics were selected from the A-share listed companies in the Guotai National Database from 2013 to 2024, excluding those with ST status, financial-related industries, complex equity nature (not a single type of equity), and missing data. The total sample consisted of 6,048 observations. The focus was on enterprises with high R&D investment, green innovation potential, and those that have implemented a digital transformation strategy, to ensure the representativeness of the sample and the diversity of the industry background. In the data collection process, the data mainly came from the annual reports, quarterly reports, social responsibility reports of enterprises, as well as professional databases such as Guotai National (CSMAR) and Wind. Information on enterprise financial data, corporate governance data, and R&D investment was obtained from these sources. Stata 19 software was used to organize, calculate, and con-

duct regression analysis on the data, and all data were truncated by 1% and 99% to accurately reveal the impact of digital transformation on R&D investment and green innovation.

3.2. Definition and Measurement of Variables

(1) Explained variables

Referring to the research results of Wang Jiating [35], the level of green technology innovation adopts the number of green patent applications as a proxy variable. In view of the differences in the motivation of green technological innovation, green technological innovation can be subdivided into substantive green innovation and strategic green innovation, which are measured by the total number of green invention-type patent applications and the total number of green utility model patent applications respectively, and considering that there is a zero value in the number of green patent applications, both of them are processed by taking the natural logarithm of the number of green patent applications with “1”. The natural logarithm of the number of green patent applications is added with “1”.

(2) Explanatory Variables

Referring to the practice of Tse [36], the ratio of R&D expenditure to operating revenue is chosen to measure R&D investment. The R&D expenditure indicator reflects the expenditure of the enterprise in R&D activities, i.e., the expenditure of the enterprise in the research and development of new products and technologies.

(3) Moderating Variables

Digital Transformation (DATE). Drawing on the research method of Yun Zhang and Peiwen Bai [37], specific digital industries are classified, while the logarithm of the number of patents granted plus one in the AI industry, 5G industry, blockchain industry, and big data industry are selected as samples for analysis.

(4) Control variables

Drawing on the research of Song Deyong[38], this paper selects the following control variables: enterprise size (Total Assets), expressed in logarithmic terms by the total assets of the enterprise (Total Liability); R&D personnel size (RDPersonRatio), expressed in logarithmic terms by the number of R&D personnel; and the two positions in one (CP), whether the chairman of the board of directors and the general manager are the same person; Net Profit, measured as the percentage of net profit of the enterprise; Board Size (BS), expressed as the logarithm of the number of board members; descriptive statistics of specific variables are shown in Table 1.

4. Empirical Analysis

4.1. Model Construction

Following the approach of Tse(2021), a regression model is constructed to empirically examine the relationship between the degree of corporate digital transfor-

mation, R&D investment, and green technology innovation. The model is as follows:

$$GTI1_{it} = \beta_0 + \beta_1 Dt_{it} + \beta_2 RD_{it} + \beta_3 CONTROL_{Sit} + \mu_{it} + \varepsilon_i \quad (1)$$

$$GTI1_{it} = \alpha_0 + \alpha_1 Dt_{it} + \alpha_2 RD_{it} + \alpha_3 Dt_{it} \times Rd_{it} + \alpha_4 CONTROL_{Sit} + \mu_{it} + \varepsilon_i \quad (2)$$

$$GTI2_{it} = \beta_0 + \beta_1 Dt_{it} + \beta_2 RD_{it} + \beta_3 CONTROL_{Sit} + \mu_{it} + \varepsilon_i \quad (3)$$

$$GTI2_{it} = \alpha_0 + \alpha_1 Dt_{it} + \alpha_2 RD_{it} + \alpha_3 Dt_{it} \times Rd_{it} + \alpha_4 CONTROL_{Sit} + \mu_{it} + \varepsilon_i \quad (4)$$

Among them, $i=1,2,3,\dots,504$ represents the enterprise sample; $t=1,2,3,\dots,10,11,12$ represents the sample period from 2013 to 2024. $GTI1_{it}$ denotes the substantive green technology innovation capability of the i enterprise in t year, $GTI2_{it}$ indicates the strategic green technology innovation capability of the i enterprise in t year, Dt_{it} and RD_{it} represent the R&D investment and digital transformation level of the i -th enterprise in year t respectively, $CONTROL_{Sit}$ stands for the control variables, $Dt_{it} \times RD_{it}$ is the interaction term between multinational enterprises' R&D investment and digital transformation, while μ_{it} and ε_i are the random error terms.

4.2. Descriptive statistical analysis

In this paper, the relationship between enterprise R&D investment and green technology innovation in the context of digital transformation is analyzed by descriptive statistics, and the results are shown in Table 2.

The current maximum value of enterprises' substantive green technology innovation (GTI1) is 0.986, the minimum value is 0.281, the mean value is 0.625, and the standard deviation is 0.156; the current maximum value of enterprises' strategic green technology innovation (GTI2) is 0.999, the minimum value is 0.267, and the mean value is 0.597, and the standard deviation is 0.177. The results show that, influenced by factors such as industry and operation scale, the relationship between enterprises' R&D investment and green technology innovation among enterprises is not as strong as that between enterprises. industry and business scale and other factors, there is a certain gap between substantive and strategic green technology innovation. Research and development (RD) investment is measured by the ratio of R&D expenditure to operating revenue, with the maximum value of 24.41%, the minimum value of 9.79%, the mean value of 18.85%, and the standard deviation of 1.598, which shows that there is a big difference in the degree of importance attached to R&D investment among different industries and enterprises. The degree of digital transformation (DT) is measured. The maximum value is 5.964, the minimum value is 0.693, the mean value is 2.484, and the standard deviation is 1.076, indicating that there is a large gap in the level of digital transformation among enterprises.

Table 1. Descriptive statistical analysis results

Variable name	Observed value	Mean value	Standard deviation	Standard deviation	Standard deviation
GTI1	6048	0.625	0.156	0.281	0.986
GTI2	6048	0.597	0.177	0.267	0.999
RD	6048	18.849	1.598	9.795	24.410
DT	6048	2.484	1.076	0.693	5.964

Total Assets	6048	22.353	1.464	16.757	29.535
Net Profit	6048	19.109	1.676	12.977	25.077
RDPersonRatio	6048	0.180	0.167	0	0.937
CP	6048	1.624	0.537	0	2.000
BS	6048	2.193	0.259	2.386	3.219

4.3. Correlation analysis

According to the results of correlation analysis in Table 2, the correlation coefficients between the variables do not exceed the critical value of 0.7, and the test values of variance inflation factor (VIF) are lower than 10, indicating that there is no problem of multicollinearity between the variables.

From the analysis results in Table 3, it can be seen that enterprise R&D investment (RD) shows a significant positive correlation with current green technological innovation, which preliminarily verifies the research hypothesis 1. Specifically, the correlation coefficients between R&D investment (RD) and substantive green technological innovation (GTI1) are 0.464, and the correlation coefficients between R&D investment (RD) and strategic green technological innovation (GTI2) are 0.360, which are significantly positively correlated at 1% level, suggesting that there is no multicollinearity problem between the variables. significant positive correlation, which indicates that increasing R&D investment helps to improve the level of green technology innovation of enterprises. In addition, the degree of enterprise digital transformation (DATE) shows a significant positive correlation with both substantive green technological innovation (GTI1) and strategic green technological innovation (GTI2), with correlation coefficients of 0.440 and 0.328, respectively, and both are significant at the 1% level. This result preliminarily verifies Hypothesis 2, indicating that the higher the degree of enterprise digital transformation, the more conducive to promoting enterprise green technology innovation.

Table 2. Correlation Analysis

	1	2	3	4	5	6	7	8	9
1.GTI1	1.000								
2.GTI2	0.470* **	1.000							
3.RD	0.464* **	0.360* **	1.000						
4.DT	0.440* **	0.328* **	0.148* **	1.000					
5.TotalAssets	0.015	-0.025*	-0.012	-0.070* **	1.000				
6.Net Profit	0.053* **	0.070* **	0.029* *	-0.014	0.768* **	1.000			
7.RDPersonRatio	0.180* **	0.179* **	0.082* **	0.382* **	-0.244* **	-0.145* **	1.000		
8. CP	-0.043* **	-0.057* **	-0.028 **	-0.066* **	0.159* **	0.110* **	-0.110* **	1.000	
9. BS	-0.007	-0.036* *	-0.006	-0.062* **	0.264* **	0.190* **	-0.137* **	0.147* **	1.000

(Note: The values in parentheses are t-values; *, **, and *** indicate significance levels of 10%, 5%, and 1%, respectively. The same applies below.)

At the same time, enterprise net profit (Net Profit) and RDPersonRatio are also positively correlated with enterprise green technology innovation (GIT). The correlation coefficients between the two and substantive green technology innovation are 0.053 and 0.180, respectively, and the correlation coefficients with strategic green technology innovation are 0.070 and 0.179, respectively, indicating that the increase of corporate profitability or the expansion of R&D personnel scale may have a positive impact on corporate green technology innovation.

4.4. Analysis of regression results

After testing, Table 3 corresponds to $F(7, 6048) = 70.70$, $P = 0.000 < 0.05$, indicating that research and development investment (RD) has a significant effect on substantive green technology innovation capacity (GTI1) under the moderating effect of digital transformation (DT); Table 4 corresponds to $F(7, 6048) = 88.00$, $P = 0.000 < 0.05$, indicating that research and development (RD) investment has a significant effect on strategic green technology innovation capability (GTI2) under the moderating effect of digital transformation (DT). This result supports the research hypothesis that digital transformation plays a significant moderating role between RD investment and green technology innovation. According to the results of Hausman test in Tables 3 and 4, the test statistic rejected the original hypothesis at 1% significance level ($P < 0.01$), which indicated that the fixed effect model was better than the random effect model, so this study used the fixed effect model for regression analysis, and the results are shown in Table 3. The regression results of the fixed effect model further verified the linear relationship between the variables and indicated that the set regression model was statistically significant.

Table 3. Hausman test

GTI1	(b) Fixed ef- fects model FE	(B) Random Effects Model RE	(b_B) Difference	Sqrt(diag(V_b_V_B)) Std.err.
RD	0.020	0.026	-0.006	0.001
DT	0.063	0.026	0.017	0.005
CP	-0.002	-0.013	0.011	0.006
BS	-0.027	-0.017	-0.010	0.013
TotalAssets	0.016	-0.005	0.021	0.004
Net Profit	0.014	0.007	0.007	0.003
RDPersonRatio	0.031	0.080	-0.048	0.028

Table 4. Hausman test

GTI2	(b) Fixed ef- fects model FE	(B) Random Effects Model RE	(b_B) Difference	Sqrt(diag(V_b_V_B)) Std.err.
RD	0.028	0.030	-0.002	0.001
DT	0.054	0.039	0.015	0.004
CP	-0.008	-0.006	-0.002	0.005
BS	0.009	0.003	0.006	0.011
TotalAssets	0.013	-0.004	0.017	0.004
Net Profit	0.005	0.004	0.001	0.002
RDPersonRatio	0.023	0.062	0.001	0.024

5. Conclusion and Outlook

Based on 6,048 observations of A-share listed companies from 2013 to 2024, this study empirically explores the effects of the degree of digital transformation of enterprises, R&D investment on green technology innovation, and investigates the effects of moderating variables on R&D investment and green technology innovation. The study mainly draws the following conclusions.

- (1) Enterprises' R&D investment significantly enhances their green technology innovation performance. Regarding the relationship between R&D investment and green innovation, there are two different views in the academic world. One viewpoint is that increasing R&D investment helps to enhance the green innovation performance of enterprises. The other viewpoint is that there may be a negative correlation between an enterprise's R&D investment and green innovation performance. This study shows that increasing R&D investment can significantly enhance enterprises' green innovation performance. By broadening the access to R&D resources, combining company-specific R&D resources with market demand, and increasing the degree of marketization of R&D, companies are able to enhance their green technology innovation capability.
- (2) Digital transformation has a significant positive effect on enterprise green technology innovation. Although enterprise digital transformation has a “double-edged sword” effect, this study finds that in the practice of Chinese enterprises, digital transformation has a significant positive effect on green technology innovation by promoting the optimal allocation of enterprise resources, improving the information processing capability, and accelerating the innovation process. Digital transformation reduces transaction costs and improves the operational efficiency of enterprises by efficiently fusing massive amounts of data and creating powerful synergies. Combined with the advantages of massive data resources and the aggregation of high-quality innovative talents brought about by the digital transformation of enterprises, enterprises are able to improve their operating environment and business performance, continue to innovate, and explore new markets and develop new business models.
- (3) When the degree of enterprise digital transformation is high, the positive impact of R&D investment on the enterprise's green technology innovation capability is more significant. Empirical studies reveal that digital transformation positively moderates the relationship between R&D investment and green technology innovation capability. As the level of enterprise digitization increases, enterprises are able to coordinate and utilize abundant digital resources and capabilities more efficiently, improve operational efficiency and innovation capability, and then reduce transaction costs and management burdens, which strengthens the positive driving effect of R&D investment on enterprises' green technology innovation. This finding provides a new perspective for understanding the impact of digital transformation on green innovation performance of Chinese firms.

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