Digital Economy Facilitates Low-Carbon Transformation of Enterprises: A Study on the Mediating Mechanism Based on Green Technological Innovation

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Abstract. Against the backdrop of the dual carbon goals, digitalization and low-carbon transformation have become core issues for enterprises. Based on panel data of China's A-share listed companies from 2014 to 2023, this paper employs benchmark regression models and mediation effect models to empirically examine the relationship between the digital economy, green technological innovation, and corporate low-carbon transformation. The study finds that the digital economy can actively promote corporate low-carbon transformation and effectively drive green technological innovation. Green technological innovation plays a partial mediating role between the two, meaning that the digital economy can promote corporate low-carbon transformation by fostering green technological innovation.

Keywords: Digital Economy; Green Technology Innovation; Low-carbon Transformation Of Enterprises.

1 Introduction

Digital technology can accelerate the sharing and circulation of high-quality resources, breaking through the spatial and temporal limitations of traditional production models. Academia has achieved three main research results in this field: First, in research related to the digital economy, scholars generally believe that the digital economy can effectively improve the green innovation output of cities by optimizing regional financial services[1], promoting market competition, and optimizing the innovation ecosystem[2]. This effect is more significant in regions with a higher degree of marketization[3]. Second, regarding the impact of the digital economy on enterprise transformation, the academic community emphasizes that digital technology innovation can reduce internal management costs and improve asset operation efficiency through efficient production information management[4] and optimization of human capital structure[5]. Finally, in the field of corporate green transformation, academic research mainly focuses on green technology innovation[6] and industrial structure upgrading[7] as important pathways to green and low-carbon transformation, aiming to achieve a balance between ecological and economic benefits. This

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paper conduct an empirical study on the relationship between the digital economy, green technology innovation, and corporate low-carbon development.

2 Research Hypothesis

2.1 Digital Economy and Low-Carbon Development of Enterprises

The digital economy is transforming operating models across industries, significantly improving productivity in technology. First, the application of digital technologies breaks down information barriers in the production process, reducing waste through real-time monitoring and precise control, thereby lowering carbon intensity at the source. Second, the digital economy promotes inter-industry collaboration, fostering communication and low-carbon cooperation between upstream and downstream enterprises, forming a complete energy-saving and emission-reduction chain from raw material procurement and production to end-consumer consumption. Third, digital infrastructure provides technological support for enterprises to apply clean energy, and intelligent energy management systems can optimize energy consumption structures and increase the proportion of renewable energy in production. The following hypothesis is proposed:

H1: The digital economy has a significant impact on the low-carbon development of enterprises.

2.2 Digital Economy and Green Technology Innovation

The digital economy promotes the efficient allocation of resources and production factors, achieves the synergistic integration of innovation elements, and provides important support for green technology innovation. First, the digital economy breaks down physical boundaries and information asymmetry between different innovation entities, enabling enterprises to easily integrate cross-domain knowledge and capital elements, broadening their channels for acquiring green technology resources. Second, the digital economy can accurately capture market green demands through big data analysis, guiding innovation resources towards high-value green technology fields. Third, the application of digital technology accelerates the research and development of green technologies, reduces trial-and-error costs, shortens the technology iteration cycle:

H2: The digital economy has a significant impact on green technology innovation.

2.3 The Mediating Effect of Green Technological Innovation

Green technological innovation is the core mechanism through which the digital economy promotes enterprises' low-carbon development. The digital economy provides sufficient factor supply and an efficient collaborative environment for green technological innovation. The green technological innovation achievements brought about by the digital economy can not only reduce the resource consumption and car-

bon emissions per unit output through improving production processes, but also reduce reliance on high-carbon technologies by developing low-carbon alternative technologies. During this process, the digital economy provides impetus and support for green technological innovation, and green technological innovation becomes the carrier for the digital economy to empower low-carbon development. The following hypothesis can be proposed:

H3: The digital economy can significantly influence enterprises' low-carbon transformation by promoting green technological innovation.

3 Research Design

3.1 Explanatory Variables: Digital Economy

Academic measurement of the digital economy primarily focuses on the micro-enterprise level, resulting in three commonly used indicators: First, based on detailed corporate intangible assets, the proportion of assets such as software, data systems, and intelligent platforms is selected to measure the level of digitalization investment; second, text analysis methods are used to statistically analyze the frequency of digitalization-related keywords; finally, single or comprehensive indicators are used to directly or indirectly reflect the degree of digitalization development. Data assets directly reflect the resource reserves of enterprises during digital transformation, possessing both rationality and feasibility. This paper draws on the method used by Qi Huaijin et al.[8], namely, using detailed corporate intangible asset data to measure the level of digitalization, and using the logarithm of corporate data assets as an indicator to measure the degree of digital economy development.

3.2 Dependent Variable: Enterprise Low-Carbon Transformation

Academic indicators for measuring corporate low-carbon transformation mainly include: first, carbon emission-related indicators; and third, environmental, social, and governance (ESG) related indicators. These indicators comprehensively reflect the effectiveness of corporate low-carbon transformation through the environmental dimension scores in ESG ratings published by third-party rating agencies. Given that Huazheng's environmental dimension in its ESG rating covers key information such as corporate carbon emission management, green operations, and environmental protection investment, this paper uses Huazheng's average annual ESG score as the main indicator to reflect the long-term effectiveness of the company's low-carbon transformation.

3.3 Mediating Variable: Green Technology

In academia, mainly including the following three categories: First, the number of green patent applications, which directly reflects the company's output of green technology innovation; second, the number of granted green patents and their proportion

in the total patents, reflecting the concentration of green technology innovation; and finally, green technology R&D investment indicators, such as the proportion of green R&D expenditure and the number of green R&D personnel, reflecting the intensity of investment in green technology innovation. In addition, some studies have supplemented related indicators. The total number of green patent applications directly reflects the scale of a company's green technology innovation output and its capabilities in green technology innovation. Therefore, this paper adopts the method of Song Deyong et al.[9], that is, measuring the level of green technology innovation through the total number of green patent applications.

3.4 Control Variables

The following control variables were selected based on the existing studies: the years since company listing, which refers to the period from the company's listing to the observation year; the number of board members; the percentage of independent directors; the return on total assets, that is, the ratio of the company's net profit to the average total assets; the asset growth rate, that is, the ratio of the total asset growth in the current period to that in the previous period.

4 Empirical Analysis

This study uses companies listed on the A-share market in China from 2014 to 2023 as the initial research subjects and constructs a balanced panel data at the enterprise level. In the process of sample screening and cleaning, this study first constructs an initial sample based on all A-share listed companies from 2014 to 2023, obtaining approximately 40,000 company-year observations. (1) Considering the time continuity requirement of the research variables, companies that were delisted, suspended from listing, or had been listed for less than ten years during the sample period were excluded. (2) To ensure the reliability of the regression results, company samples with more than 10% missing values for key variables were further removed, and company-year observations with missing records were also deleted. (3) To reduce the interference of extreme values on the estimation results, box plots were used to identify outliers in continuous variables, and identified extreme observations were deleted. After the above step-by-step screening and cleaning steps, 26,463 valid samples were finally obtained, constituting balanced panel data of Chinese A-share listed companies from 2014 to 2023, which were used for subsequent empirical analysis. The descriptive statistics are shown in Table 1:

Table 1. Descriptive Statistics.

Variables	Symbols	Sample Size	Minimum	Maximum	Mean	Standard Deviation
Logarithm of Enterprise Data Assets	DIG	26463	0	30	23.01	1.371
Total Green Patent Applica-	GTI	26463	0	1888	11.	58.759

tions					43	
Huazheng ESG Score - Annual Average	ESG	26463	1	8	4.08	0.935
Years Since Company Listing	AGE	26463	1	34	13.86	7.807
Number of Board Members	BODSIZE	26463	3	19	8.54	1.797
Percentage of Independent Directors	INDRATIO	26463	15	80	37.85	5.71
Return on Total Assets	ROA	26463	-192	86	2.42	8.714
Asset Growth Rate	ASGROW	26463	-1	48	0.15	0.678

4.1 Mediation Effect Analysis

The relevant results are shown in Table 2. Model 1 aims to explore the direct impact of the digital economy on corporate low-carbon transformation. Through regression analysis, corporate low-carbon transformation level (ESG) is used as the dependent variable, and digital economy (DIG) is used as the core independent variable. The results show that the digital economy has a significant positive impact on corporate low-carbon transformation (β=0.265, t=42.707, p<0.01). This indicates that the development of the digital economy can directly promote the improvement of enterprises' comprehensive performance in environmental, social, and governance aspects, thereby driving low-carbon transformation, and hypothesis H1 is supported. Model 2 aims to explore the impact of the digital economy on green technology innovation to verify the necessary conditions for the mediating variable path. Regression analysis is used, with green technology innovation (GTI) as the dependent variable. The results show that the regression coefficient of the digital economy is significantly positive (β=0.299, t=47.296, p<0.01), indicating that the digital economy can effectively promote the improvement of enterprises' green technology innovation level. These results confirm the necessary conditions for testing the mediation effect and support hypothesis H2. Model 3 combines the digital economy with green technology innovation to test the mediating effect of green technology innovation. In the regression model with enterprise low-carbon transformation (ESG) as the dependent variable, the digital economy (DIG) and green technology innovation (GTI) are introduced. The results show that green technology innovation has a significant positive impact on enterprise low-carbon transformation (β=0.053, t=8.817, p<0.01), while the regression coefficient of the digital economy is still significantly positive, but lower than that in Model 1 (β=0.249, t=38.606, p<0.01). Thus verifying hypothesis H3.

Table 2. Mediation Effect Results.

	Model 1	Model 2	Model 3
Dependent Variable	ESG	GTI	ESG
	Mediator Variable		
GTI			0.053 (8.817)
	Independent Variable		
DIG	0.265 (42.707)	0.299 (47.296)	0.249 (38.606)
	Control Variable		
AGE	-0.088 (-14.943)	0.007 (1.208)	-0.088 (-15.03)
BODSIZE	0.089 (12.68)	0.026 (3.703)	0.087 (12.494)
INDRATIO	0.093 (13.951)	0.046 (6.714)	0.091 (13.596)
ROA	0.165 (28.132)	-0.021 (-3.429)	0.166 (28.352)
ASGROW	-0.021 (-3.656)	-0.02 (-3.432)	-0.02 (-3.475)
Sample Size	26463	26463	26463
R^2	0.132	0.096	0.135
Adjusted R^2	0.132	0.095	0.135

4.2 Robustness Tests

To ensure the reliability of the core conclusions, this paper employs two robustness tests, the results of which are shown in Table 3: **Sample Size Reduction Test.** After removing some observations, 13,127 sample data points are ultimately retained. The results show that green technology innovation has a significant positive impact on enterprises' low-carbon transformation (β=0.064, t=7.41, p<0.01), while the regression coefficient of the digital economy is still significantly positive, but lower than that of Model 1 (β=0.228, t=25.142, p<0.01); **Replacing the Measurement Indicator of Independent Variables.** The results of Model 3 show that green technology innovation has a significant positive impact on enterprises' low-carbon transformation (β=0.054, t=7.241, p<0.01), while the coefficient of the digital economy patent indicator decreased slightly compared to Model 1, but still maintained a significant positive correlation (β=0.102, t=13.678, p<0.01).

Table 3. Robustness Test Results.

	(1)DIG			(2)DIG-PAT		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Dependent Variable	ESG	GTI	ESG	ESG	GTI	ESG
		Mediator Variable				
GTI			0.064 (7.41)			0.054 (7.241)

	Independent Variable					
DIG	0.248 (28.5)	0.308 (35.04)	0.228 (25.142)			
DIG-PAT				0.136 (23.036)	0.615 (127.54)	0.102 (13.678)
	Control Variable					
AGE	-0.053 (-6.312)	0.030 (3.5)	-0.055 (-6.548)	-0.062 (-10.33)	0.015 (2.998)	-0.063 (-10.47)
BODSIZE	0.052 (5.111)	-0.002 (-0.221)	0.052 (5.135)	0.167 (24.56)	0.066 (11.92)	0.164 (23.989)
INDRATIO	0.085 (8.614)	0.014 (1.421)	0.084 (8.539)	0.139 (20.665)	0.065 (11.844)	0.135 (20.105)
ROA	0.172 (20.317)	-0.015 (-1.78)	0.173 (20.471)	0.199 (33.515)	0.008 (1.718)	0.199 (33.469)
ASGROW	-0.022 (-2.582)	-0.025 (-3.023)	-0.020 (-2.391)	-0.005 (-0.818)	-0.005 (-1.103)	-0.005 (-0.769)
Sample Size	13127	13127	13127	26463	26463	26463
R^2	0.115	0.096	0.118	0.091	0.393	0.093
Adjusted R^2	0.114	0.096	0.118	0.091	0.392	0.092

5 Conclusions

First, the digital economy has a significant positive impact on corporate low-carbon transformation. In the daily production and operation activities of enterprises, the digital economy transforms emissions management from post-event statistics to real-time recording and tracking of production, logistics, and energy use. Second, the digital economy can significantly promote corporate green technology innovation. Through the widespread application of digital tools in corporate R&D management, investment and financing, and industry-academia-research cooperation, the digital economy makes the progress, capital flow, and division of labor in the green technology R&D process more intuitive. Third, green technology innovation plays a crucial mediating role between the digital economy and corporate low-carbon transformation. In the digital age, enterprises can more easily apply green technologies to their actual production processes and gradually reduce carbon emission intensity through technological application.

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