The Impact of Digital Transformation on Green Technology Innovation in Manufacturing Enterprises in China

Yili Zhang [1]*, Miao Shi[2]

[1]Lyceum of the Philippines University, Manila City, 0900, Philippines, zhangyl1236@163.com

[2]Pass College Chongqing Technol & Business University, Chongqing, 400000, China, 172818141@qq.com

Abstract. This study aims to contribute to research by providing a new perspective on the influencing factors of enterprise green technology innovation and explain how the research contributes to the current trend of digitalization and greening of Chinese manufacturing companies. This article examines the impact of digital transformation on green technology innovation in Chinese manufacturing enterprises. At the same time, this study examines the mediating effect of knowledge sharing in the relationship. This study uses data on A-share markets from 2011 to 2021 and performs a series of regression analyses. The findings show the significant and positive effect of digital transformation on manufacturing enterprise' green technology innovation. Practical implications are discussed.

Keywords: Green Technology Innovation, Digital Transformation, Knowledge Sharing, Manufacturing Enterprises

1 Introduction

As China continues to advance in the new wave of digital revolution, it continuously deepens its digital reform, providing crucial impetus for manufacturing enterprises to undertake digital transformation and construct a digitally centered green ecological system, further realizing sustainable development in the manufacturing sector [1]. On one hand, green construction has become a focal point of social attention. On the other hand, the digital economy is gaining momentum and has gradually become a significant driving force for global economic and social development. From this perspective, manufacturing enterprises must focus on digitization and greenization to achieve sustainable development. Therefore, in the current environment where manufacturing enterprises are moving towards digitalization and greenization, exploring whether digital transformation can enhance green investment in areas such as green enterprises and green industries holds significant practical significance [2].

The proportion of the core industry value of China's digital economy in the GDP continues to grow, and China's total digital economy scale ranks second in the world [2]. From the perspective of micro-enterprises, digital transformation injects new development momentum into enterprises. This trend is gradually reflected in the specific production practices of enterprises [3]. Digital transformation not only helps enterprises overcome innovation obstacles and enhance innovation capabilities but has also become an important means to transform and upgrade

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traditional driving forces, cultivate new driving forces, and is a new source for achieving sustainable development and enhancing core competitiveness for enterprises [4].

Promoting the deep integration of the digital economy and the real economy, digital transformation aims to comprehensively integrate industry and digital technology to drive optimized resource allocation and restructure business processes, thus enhancing economic operational efficiency [2]. Enterprise digital transformation leverages emerging technologies to empower the transformation and upgrading of traditional industries. This process involves the comprehensive integration of enterprises with digital technology, leading to changes in business models, processes, and organizational structures [5]. Additionally, it reshapes the vision, strategy, and corporate culture, helping enterprises enter new markets. It features cross-disciplinary integration, structural reshaping, innovation-driven, and extensive connectivity. Enterprise digital transformation, premised on a new round of industrial upgrading, catalyzed by government policies, and based on technological innovation, signifies not only the deep integration of digital technology and production efficiency but also the establishment of an innovative system for enterprises to transition from traditional manufacturing to the digital economy [6].

This study aims to contribute to research by providing a new perspective on the influencing factors of enterprise green technology innovation, enriching relevant theoretical achievements. Existing studies on the mechanism of enterprise green technology innovation mainly focus on the macro-policy level. This article takes the enterprise digital transformation as a starting point and reveals the influencing factors of enterprise green development transformation and green technology progress from a micro-level by collecting unique data on enterprise green technology innovation. In addition, this study aims to expand the research on the practical paths of enterprise digital transformation. This article, starting from enterprise green technology innovation, deeply analyzes the economic driving forces of digital transformation, clarifies the multidimensional effects, influence pathways, and heterogeneity analysis of enterprise digital transformation on enterprise green technology innovation, and reveals the compatible path between enterprise digital transformation and green sustainable development. It can provide decision-making basis for many enterprise entities to implement digital transformation and green innovation practices, and also provide reference suggestions for the policy formulation of government departments.

2 Literature Review

2.1 Digital Transformation and Green Technology Innovation

In the digital era, enterprises have no secrets to stakeholders. Relying solely on their own resources and capabilities to conduct production and operations is difficult to maintain a competitive advantage [4]. Internal and external resources can play different advantages in promoting enterprise development. On the one hand, the richness of internal redundant resources will directly determine the level of enterprise development, which is conducive to alleviating contradictions and conflicts in enterprise development, and enhancing cohesion, thereby better coping with the impact and challenges brought by changes in the external environment [7]. At the same time, due to the flexibility and development potential of redundant resources, manufacturing enterprises with more redundant resources have more energy to carry

out long-term strategic investments [5]. When the market environment is conducive to enterprises carrying out environmental protection reforms, redundant resources can be quickly invested in green production and operations, enabling enterprises to comply with national development requirements and obtain government subsidies. On the other hand, when government subsidies act on enterprises as external resources, the support signals they bring will be quickly transmitted to external investors and the public, enabling them to obtain more resources and increase resource redundancy [8].

The Natural Resource-Based View (NRBV) is a theoretical framework in strategic management that emphasizes the role of firm-specific resources and capabilities in achieving competitive advantage and superior performance. It posits that a firm's unique bundle of resources, such as physical, human, and organizational capital, along with its relationships with external stakeholders, can enable it to create value and sustain its competitive position over time. NRBV suggests that firms should focus on developing and leveraging their internal resources, rather than solely relying on market dynamics, to achieve sustained success in dynamic and competitive environments. NRBV suggests that the future sustainable competitive advantage of enterprises will inevitably depend on the effectiveness of the enterprise itself in promoting environmental sustainability and the utilization of capital. This covers all aspects of green innovative management, research and development, production, and marketing. The heterogeneity of resources that enterprises possess determines the differential advantage of innovation [3]. The effectiveness of resources in different dimensions of green innovation will have varying degrees of fluctuating effects on the level of green technology innovation within enterprises, including but not limited to human resources, financial resources, physical resources, knowledge resources, and technological resources [2][6]. Among these, technological resources are the core elements of the development of green innovation for enterprises, mainly referring to the ability of enterprises to purchase green technology, upgrade existing technology, and independently achieve technological innovation [9]. Therefore, based on the literature review, this study proposes the first hypothesis.

H1: Digital transformation is positively related to green technology innovation

2.2 The Mediating Effect of Knowledge Sharing

Digital technology enhances the availability of information, improves the ability of enterprises to process and explore data. The digital transformation of enterprises directly increases the quantity and quality of information disclosure, enhances the efficiency of internal and external information transmission, thereby alleviating information asymmetry. Enterprise digitization accelerates the transmission and feedback of various information within organizational structures, promotes greater transparency in business processes, and fosters the integration and complementary innovation of internal resources [2]. Simultaneously, enterprise digitization facilitates the exchange and sharing of information related to the environment and resources both internally and externally [3], enhances the quantity and quality of information available to investors, mitigates the degree of internal and external information asymmetry, conveys confidence in digital transformation to the outside world, attracts more high-quality external resources, optimizes green innovative technological resources, and thereby incentivizes enterprises to engage in green technology innovation activities [7]. Therefore, based on the literature review, this study proposes the second hypothesis.

H2: Knowledge sharing mediates the relationship between digital transformation and green technology innovation.

3 Research Methods

3.1 Data Collection

This study uses information on manufacturing companies listed on the Shanghai and Shenzhen A-share markets from 2011 to 2021. This study excluds ST and *ST companies and comapnies that were delisted or faced severe data deficiency during the sample period.

3.2 Measurement

Digital Transformation. Following prior studies [4], this study uses text analysis techniques to locate and identify keywords related to digital transformation, the frequency of their occurrence is used as an index to construct indicators for enterprise digitization transformation. Through Python web scraping technology, annual reports of A-share listed companies were collected and organized from financial websites such as Netease Finance and Sina Finance.

Green Technology Innovation. This article adopts the application volume of green patents (including green utility model patents and green invention patents) to measure the level of enterprise green technology innovation. Following prior studies [5], to eliminate the problem of right-skewed distribution of green patent application data, the natural logarithm of the sum of enterprise green patent applications plus 1 is taken, resulting in lnGreen.

Knowledge Sharing. This study utilizes text analysis techniques and employs Python web scraping technology to collect and organize annual reports of A-share listed companies from financial websites such as Netease Finance and Sina Finance [7]. The frequency of words related to effective information sharing is used to construct indicators for enterprise effective information sharing.

Control Variables. This study controlled for variables such as company size (Size), growth (Growth), Tobin Q value (TobinQ), leverage (Lev), return on assets (ROA), as well as board size (Bsize), and ownership concentration (Inp) as corporate governance variables in the model.

3.3 Data Analysis

Selecting appropriate estimation methods based on the characteristics of the data is crucial for improving the reliability of hypothesis testing. This article conducted a serial correlation test, and the results significantly rejected the null hypothesis of no first-order serial correlation in the model, indicating the possibility of autocorrelation issues in the regression model. All variables in the model were subjected to variance inflation factor (VIF) tests, and the results showed that the VIF values for each variable were below the threshold of 10, indicating no significant multicollinearity issues in the regression model. Considering the potential issues in the model mentioned above, this study ultimately chose to use the feasible generalized least squares method (FGLS) in the baseline regression [3].

4 Results

4.1 Descriptive Analysis

From Table 1, it can be seen that the mean of enterprise green technology innovation is 0.923, with standard deviation of 1.003. The enterprise digital transformation index is 6.512, with a standard deviation of 10.902, indicating a large degree of dispersion and significant differences in digital transformation levels among different enterprises. The mean of knowledge sharing is 3.023, with a satndard deviation of 2.302. Other control variables are generally consistent with existing research conclusions and will not be elaborated further. The VIFs of the regression model are lower than 4, indicating that there is no serious multicollinearity problem among variables.

Table 1. Descriptive Analysis.

Variable	N	Mean	SD
Digital Transformation	13389	6.512	10.902
Green Technology Innovation	13389	0.923	1.003
Knowledge Sharing	13389	3.023	2.302
Digital Transformation	13389	6.512	10.902

4.2 Inferential Analysis

For table 2, we can see that the results reveal a substantial positive influence of both digital transformation and knowledge sharing on green technology innovation in manufacturing enterprises. For the model predicting green technology innovation, the coefficient of digital transformation is 0.009, coupled with a t-value of 6.131, indicates that a one-unit increase in digital transformation corresponds to a 0.009 unit increase in green technology innovation. This statistically significant relationship is evident at the 1% confidence level. Similarly, the coefficient of knowledge sharing is 0.511, with a t-value of 3.912, suggests that a one-unit increase in knowledge sharing leads to a 0.511 unit increase in green technology innovation. Once again, the significant t-value underscores the statistical significance of this relationship at the 1% confidence level. At the same time, growth, Tobing, Lev and Inp are significantly associated with green technology innovation of the company.

In the model predicting knowledge sharing, the coefficient of digital transformation is 0.007, coupled with a t-value of 5.071, indicates that a one-unit increase in digital transformation corresponds to a 0.007 unit increase in green technology innovation. This coefficient is significant at the 1% confidence level. Size, growth, Tobing, and Lev are significantly associated with knowledge sharing in the listed manufacturing enterprises in our sample.

Table 2. Regression Analysis.

Independent Variable	Knowledge Sharing		Green Technology Innovation	
	Coeff	t-value	Coeff	t-value
Digital Transformation	0.007***	5.071	0.009***	6.131
Knowledge Sharing			0.511***	3.912
Size	0.365***	3.041	0.424***	4.201
Growth	0.072***	3.142	0.092***	3.090

ROA	0.197	1.574	0.220	1.049
Tobing	-0.041***	-4.992	-0.039***	-9.832
Lev	0.122***	2.598	0.149***	2.604
Bsize	0.093	0.301	0.070	0.460
Inp	-0.002	-0.750	-0.008*	-1.750

Note: *, **, *** represent significance at the 10%, 5%, 1% confidence levels respectively.

4.3 Heckman Two-Stage Model

The self-selection issue may influence the results. In order to mitigate this potential endogeneity effect, this study employs the Heckman two-stage model. In the first stage of the Heckman Probit regression model, variables for enterprise digital transformation are first set. If the degree of digital transformation of the enterprise is higher than the median, the value is set to 1; otherwise, it is 0. At the same time, the proportion of digital transformation of other enterprises in the same industry is added as an exogenous instrumental variable. The inverse Mills ratio (IMR) is estimated using the regression results of this stage, and then the IMR calculated in the first stage is inserted into the second-stage model for regression analysis. In the regression results, the coefficient of IMR in Heckman's second stage is significantly positive, but at the same time, the coefficient of digital transformation remains significantly positive at the 1% level.

5 Conclusion

This study uses data from A-share listed companies in the Shanghai and Shenzhen stock markets from 2011 to 2021 to thoroughly verify the impact path between the degree of enterprise digital transformation and the level of green technology innovation. The research findings indicate a positive correlation between enterprise digital transformation and green technology innovation, meaning that enterprise digital transformation significantly enhances the level of green technology innovation. Mechanism tests show that knowledge sharing, as a mechanism for the positive relationship between digital transformation and green technology innovation, generates a certain mediating effect. Digital transformation can promote green technology innovation by facilitating information sharing within enterprises. Enterprise digital transformation can drive green technology innovation, thereby promoting the transformation and upgrading of manufacturing enterprises [2][3][7].

The results of this study suggested that the standard deviation of the enterprise digital transformation index is large, indicating that the degree of dispersion in the digital transformation levels of different enterprises is large. This maybe due to the fact that we collected on manufacturing enterprises. For enterprises in fields such as communication and entertainment, most of the enterprises would embrace the development of new media and spend resources on digital transformation in management and marketing. There are some manufacturing enterprises may not be very interested in digital transformation. Therefore, the degree of dispersion in the digital transformation levels of different enterprises is large.

Although digital transformation significantly promotes green investment in manufacturing enterprises, inter-group difference tests show that its promotion effect on green investment in manufacturing enterprises in regions with high levels of digital infrastructure is greater [1]. This may be because compared to regions with low levels of digital infrastructure, regions with high

levels of digital infrastructure can better assist local enterprises in developing energy-saving, emission-reducing technologies, improving regional green total factor productivity, meeting green development requirements, and directing various resources from financial institutions and stakeholders to manufacturing enterprises with low energy consumption and low pollution, thereby driving green investment [2][8]. The examination results of the pathways under different levels of digital infrastructure in regions indicate that the impact of digital transformation on internal and external resource coordination is more effective in manufacturing enterprises located in regions with high levels of digital infrastructure [7]. This may be because regional digital infrastructure construction promotes the digital transformation of manufacturing enterprises, and in the early stages of digital economic development, digital infrastructure generates more carbon emissions [5][8]. At this time, the resource consumption generated by digital economic development may offset the effects of digital empowerment, but manufacturing enterprises in high-level regions can more fully apply digital technologies such as big data and the Internet of Things to daily production and operations, promote the accumulation of internal resources, facilitate the inflow of government resources, and further enhance their development momentum. At the same time, the ability of manufacturing enterprises to coordinate internal and external resources depends on the level of digital technology development. The higher the level of regional digital infrastructure, the more vibrant the digital economic development, thereby promoting manufacturing enterprises to conduct green investment activities more efficiently.

This study offers intricate micro-level evidence to dissect how enterprise digital transformation drives innovation in green technologies. The adoption of digital technologies by enterprises has become increasingly prevalent, with profound implications for various sectors, including environmental sustainability. Embracing digital transformation, enterprises can not only enhance their efficiency and competitiveness but also contribute to environmental conservation through the development and adoption of green technologies.

The research findings support the positive driving effect of enterprise digital transformation on green technology innovation, providing a basis for judgment for the decision-making of numerous enterprise subjects' green innovation practices and also offering certain suggestions for government departments' policy-making. First, the government should deeply understand how enterprises interact with resources and the environment. This understanding should inform the creation of robust supervision systems to ensure responsible resource management [2][7]. Moreover, governments should offer timely support to enterprises, facilitating their access to external resources necessary for sustainable operations. This support could include incentives for environmentally friendly practices or subsidies for research and development aimed at resource efficiency. Fostering collaboration between government and enterprises, the government can advocate for a regulatory environment that encourages responsible resource utilization while promoting economic growth.

Second, it is necessary to promote enterprises to accelerate digital transformation and upgrade, strengthen the synergy and complementarity between digital technology and the original business models of enterprises, form resource redundancy, and thereby promote the utilization of internal resources of enterprises and the coordination of internal and external resources to achieve green development. This entails leveraging digital technologies to enhance operational efficiency, reduce resource consumption, and minimize environmental impact. Integrating digital solutions such as Internet of Things (IoT), artificial intelligence (AI), and big data

analytics, enterprises can optimize resource utilization and streamline processes, thus achieving greater sustainability. Additionally, strengthening the synergy and complementarity between digital technology and the original business models of enterprises is crucial [4]. This involves aligning digital initiatives with existing business strategies to maximize their impact on resource efficiency and environmental sustainability. For example, manufacturing firms can adopt smart manufacturing techniques to minimize waste and energy consumption, while service-oriented businesses can implement digital platforms for remote operations to reduce the need for physical infrastructure [6]. Moreover, fostering resource redundancy through digital transformation can enhance resilience and flexibility in resource management.

Third, the government needs to fully consider the differences in enterprise attributes and formulate differentiated strategies to achieve precise support. Regions should continuously strengthen the construction of digital infrastructure, support industry enterprises in the region to carry out digital technology innovation to further consolidate the development of the digital economy.

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