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The Effect of Enterprise Digital Transformation on Green Technology Innovation: A Quantitative Study on Chinese Listed Companies

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Abstract: Promoting enterprise digital transformation is of great significance in accelerating the innovation capability of green technology and boosting green and low-carbon economic development. Therefore, based on the textual analysis of enterprise annual reports, the measurement index of enterprise digital transformation was constructed, and combined with the data of listed, A-share companies in Shanghai and Shenzhen from 2011 to 2021, a quantitative study was conducted on the relationship between enterprise digital transformation and green technology innovation. The quantitative study shows that there is a significant positive correlation between enterprise digital transformation and green technology innovation. The CEO IT background plays a positive moderating role between digital transformation and green technology innovation in enterprises. Based on the quantitative study from the perspective of fiscal incentives, it was found that different fiscal incentive policies play different roles in an enterprises' digital transformation and green technology innovation; that is, government subsidies play an intermediary role between the two, and tax preferences play a positive moderating role between the two. This research enriches the mechanism analysis between enterprise digital transformation and green technology innovation, and it provides a useful exploration for the further promotion of both enterprise digital transformation and green technology innovation.

Keywords: enterprise digital transformation; green technology innovation; CEO IT background; fiscal incentives

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1. Introduction

Industry 4.0 is a manufacturing philosophy that includes modern automation systems with a certain level of autonomy, flexible and effective data exchanges empowering the implementation of next-generation production technologies, innovation in design, a more personal and more agile production, and customized products [1]. Its core concept is to use advanced information technology, such as the Internet of Things, new generation mobile communication, and big data, to achieve the empowerment and transformation of industrial manufacturing, which is an important way to realize the fourth industrial revolution [2]. Green technological innovation, also known as ecological technological innovation, is a kind of technological innovation that modifies processes, equipment, materials, and products to reduce energy consumption, reduce environmental pollution, and improve the ecological environment [3]. From the perspective of its macro definition, technological innovation and management innovation oriented toward sustainable development and ecological civilization construction belong to green technology innovation. Therefore, with the global advocacy of sustainable development, the question of how we can rely on the intelligent service features of Industry 4.0 to improve the level of green technology development and achieve sustainable development in enterprises has received wide attention from academics [4]. Green technology innovation plays an important role in promoting high-quality, global economic development and is an important driving force in sustainable, global economic growth. Accelerating green technology innovation is an important measure in embracing Industry 4.0 and an important support for solving ecological and environmental problems. However, from a practical point of view, many enterprises still lack sustainable motivation for green transformation [5]. On one hand, the level of green production technology in some enterprises is low, the proportion of traditional resource factors being input is high, and environmental performance is still unsatisfactory [6]. On the other hand, enterprises have to spend abundant money on green technology innovation in its early stages, and increasingly strict environmental regulations are further increasing the operating costs of enterprises, some of which are limited by the pressure of financial constraints and are not yet able to actively choose a green transformation [7].

Therefore, helping enterprises explore the road of green transformation with their own characteristics has become an urgent practical problem. The traditional view is that the sustainable development of an enterprise is incompatible with business growth and profitability. However, Industry 4.0, based on advanced digital tools and advanced analytical techniques, can not only generate green technologies but also increase productivity and improve existing production models. Under the impetus of Industry 4.0, enterprises may significantly improve their ecological benefits so that productivity improvement and sustainable development "coexist harmoniously" and "blend together." The era of Industry 4.0 is the era of big data, which is characterized by intelligent, networked, and data-oriented industrial production and enterprise operation. It corresponds to the development of the fourth industry. Enterprise digital transformation is the carrier of the development of Industry 4.0. It is a process that integrates the internet, cloud computing, big data, artificial intelligence and other information technologies with the operation and management mode of an enterprise so as to realize the continuous upgrading of the enterprise's resource integration ability and business execution ability and, finally, form the market competitive advantage of the enterprise and realize its value creation [8,9]. Therefore, in the era of Industry 4.0, digital transformation has become an important engine for enterprises to improve their resource utilization efficiency and promote sustainable development [10]. As a new factor of production, digital development provides enterprises with a favorable factor supply, environmental support, and new opportunities for sustainable development. The integration and development of digital technologies and enterprises has changed the traditional innovation model of enterprises and the way innovation elements are combined [11]. Therefore, digital development has been embedded into all aspects of enterprise production, services, innovation, etc., giving rise to new business models. The new, gradually formed digital business model has become a driving force for sustainable development as well as a stabilizer to help in coping with the economic downward pressure [12]. Therefore, promoting enterprise digital transformation provides a new direction and path for enterprise sustainable development.

At a time when global digitalization is advancing rapidly, enterprises should seize the major strategic opportunities brought by this era; accelerate the deep combination of digital technology with the production, R&D, management, sales, and services of enterprises [13]; and realize the transformation of traditional production mode of enterprises. As a development paradigm shift based on technological progress, digital transformation will not only lead to improved economic benefits, but it will also generate corresponding social and ecological benefits by changing corporate behavior [14]. With the increase in global environmental requirements, the sustainable development of enterprises no longer depends on economic value. Especially in a socialist market economy system, the importance of enterprise social value and ecological value has become increasingly prominent. Therefore, the sustainable development of enterprises should not simply pursue the maximization of shareholder benefits, but it should actively seek to maximize the integrated value of economic and ecological benefits, including green innovation [15,16].

Some scholars have pointed out that digitalization has a catalytic effect on the development of green transformation in enterprises [17,18]. Digital transformation makes the enterprise green technology innovation model shift from closed to open; this helps enterprises establish a convenient information exchange platform and strengthen the two-way communication between information supply and demand [19,20]. Therefore, digital transformation facilitates all departments, customers, and other stakeholders of enterprises in participating in the R&D and design of new products through the digital platform and in reducing the information gap between demanders and designers, thereby decreasing the risk of green innovation and motivating enthusiasm for green technology innovation [21]. Digital transformation can alleviate financial constraints and provide continuous financial security for business innovation [22–24]. Under the wave of the digital economy, promoting an enterprise digitally is in line with national strategic development requirements and can lead to certain policy preferences [25]. However, through information sharing on digital platforms, not only can financial institutions quickly identify high-quality enterprises [26], making it easier to lend money, but enterprises can also obtain effective financing information in a timely manner to alleviate the problems of difficult financing [27] and enterprises reducing R&D input because of a lack of funds.

However, the effect of enterprise digital transformation on green innovation development is comprehensive, and the above analysis of the mechanism of enterprise digital transformation affecting green technology innovation is not comprehensive enough; it needs to be further expanded and deepened. Following existing research, we attempt to quantitatively study the enhancement scheme of green technology innovation from the viewpoint of digital transformation. Specifically, this paper mainly addresses the following issues: First, will enterprise digital transformation promote green innovation? Second, does a CEO IT background enhance the promoting effect between the two? Third, what role do fiscal incentives play in the relationship between the two?

The contributions of this paper are that, first, we integrated digital transformation and green technology innovation in the context of Industry 4.0 into the same analytical framework of sustainable development and quantitatively studied the contribution of digital transformation to green innovation from the perspective of constructing and enhancing enterprise digital transformation. This reveals the ecological benefits created by the digital transformation of enterprises, broadens the research ideas of the digital concept in sustainable development, and provides a new perspective on promoting green technology innovation. Second, the authors explored the influence mechanism between the two from two viewpoints: that of the CEO IT background and that of fiscal incentives. The authors provide new research ideas to explore the role that digital transformation plays in affecting enterprise green technology innovation.

The rest of the paper is structured as follows: the second section provides a theoretical analysis and research hypotheses on the issues raised in the introduction. The third section designs the empirical model and provides detailed explanations of the variables in the model. The fourth section performs the baseline regression analysis and enhances the reliability of research results from endogeneity and robustness tests. The fifth section provides the mechanism analysis from the perspectives of the CEO IT background and fiscal incentives. The sixth section discusses the test results and puts forward relevant policy recommendations. The seventh section summarizes the relevant research conclusions.

2. Theoretical Background and Research Hypothesis

2.1. Enterprise Digital Transformation and Green Technology Innovation

Green innovation is the key to coordinating the pressure of environmental protection and the economic performance of enterprises, and it is an intrinsic requirement in promoting the harmonious coexistence of human and nature [28]. Along with a new round of global technological changes, the integration and development of digital technologies and corporate business models have become the mainstream of the current efforts to improve the productivity and financial performance of enterprises [29]. Digitalization is a dynamic, new, digital business model. Because of its better accuracy, systematization, and real-time performance, it can not only promote the improvement of corporate financial performance but also help companies improve their efficiency of energy and material use, reduce their carbon emissions, and, further, improve the eco-efficiency in their environmental protection activities. As a result, enterprise digitalization has become an important driver of green innovation, and it has driven enterprises to achieve green transformation in many ways [25].

First, it improves the efficiency of information interaction. Enterprises using digital technology can fully exploit and utilize information resources to achieve rapid connections and the deep communication of both internal and external information [30]. Efficient information transmission and communication can help enterprises optimize personnel management, financial control, comprehensive operation, etc., thereby improving the diversity and scientific allocation of internal resources. At the same time, the rapid flow of information elements and the improvement of search efficiency has enabled information technology to achieve low-cost penetration so that enterprises can make trial and error innovations at a lower cost [31]. Therefore, with the efficient interaction of information, the willingness of enterprises to conduct green innovation is enhanced. This will result in more funds flowing to green innovation activities, thus ensuring the further improvement of green technology innovation capabilities.

Second, enterprise digitalization will realize green collaborative innovation among enterprises. In the age of IT, the introduction of artificial intelligence and other technologies can not only help to deeply dig and analyze business data but can transform the green innovation model and provide useful decision-making information for green innovation. Additionally, it can also help enterprises establish a convenient information exchange platform and reduce the information asymmetry between information supply and demand. The digital platform facilitates the exchange of information between organizations and enhances the intentions of investors and other companies to cooperate with a company, which in turn enhances their own green innovation capacity [32].

Third, enterprise digitalization helps to grasp the difficult issues of green innovation. Enterprises can use digital technologies to not only accelerate the internal and external exchange of information and knowledge technologies but also to form a collaborative innovation knowledge sharing network with external enterprises [33]. This can help enterprises to quickly identify any difficult problems, and then to enhance their green innovation capability. Therefore, the authors propose Hypothesis 1 here:

Hypothesis 1. *Enterprise digital transformation can facilitate green technology innovation.*

2.2. Mechanism Analysis Based on CEO IT Background

Green innovation encompasses processes that require capital investment and are full of unknown risks [25]. CEOs with differing degrees of understanding of digital technology and different risk tolerances will show different tendencies toward enterprise innovation activities. First of all, CEOs with an IT background have clearer knowledge and judgment on R&D input, technological innovation, and R&D risks, so they are more inclined to conduct green technology R&D. A previous study has shown that CEOs with an IT background tend to have the characteristics of technologists and researchers [34]. Barker and Mueller found that CEOs with an IT background can significantly increase the innovation investment of their firms [35]. According to the resource dependency theory, CEOs with a technology background are more willing to conduct green technology innovation because they have better information technology knowledge and more practical experience. Secondly, CEOs with an IT background have knowledge and understanding of green innovation projects. They deeply understand the significance of R&D input for research projects, and they place emphasis on increasing R&D input when allocating resources. Finally, Heath and Tversky pointed out that people manifest overconfidence when they have more knowledge about a decision, since they attribute good outcomes to their successful decisions and bad outcomes to external causes, such as luck [36].

Similarly, as CEOs with an IT background have a high degree of understanding and mastery of the company in its business-related technological aspects, they will be more confident in conducting green innovation projects. CEOs without an IT background focus on capital operation and investment and the financing efficiency of the enterprise, but they do not know enough about green technology innovation projects. Therefore, they do not pay enough attention to these projects, or they cannot realize the reasonable allocation of R&D funds and may even reduce the R&D input [35]. Meanwhile, R&D input, as a source of funds for green innovation in enterprises, is an important influencing factor in enterprises maintaining their sustainable development ability in an increasingly competitive market [37]. Therefore, a sufficient R&D input helps to fully exploit the value of digital transformation; this, in turn, smoothly produces green innovation results [38]. Here, the authors propose the following hypothesis:

Hypothesis 2-1. *The facilitation of digital transformation and green innovation is more obvious under the influence of a CEO IT background.*

Hypothesis 2-2. *A CEO IT background can enhance the R&D input.*

Hypothesis 2-3. *R&D input can enhance the facilitation between digital transformation and green technology innovation in an enterprise.*

2.3. Mechanism Analysis Based on Fiscal Incentives Perspective

The probability of successful green innovation is low, and it is difficult to obtain a stable capital inflow in the later period [39]. Additionally, it may lead to the formation of more severe financial constraints in the future, which in turn may cause management to avoid implementing risky green innovation projects [40]. Therefore, the rapid enhancement of an enterprises' green innovation cannot simply rely on market power—it also needs government incentives. As an important external driving force, the government can facilitate this change through fiscal incentives. Fiscal incentives are a kind of policy implemented by the government to help enterprises [41], aiming to help them alleviate the pressure of financial constraints in a complex but crucial process to influence management's innovation decisions and, thus, help enterprises achieve green innovation and get out of the green transformation dilemma. Therefore, in order to explore what role fiscal incentives play between the two, in this paper, government subsidy and tax preference have been selected as proxy variables for fiscal incentives with reference to the research of related scholars [42–45].

A government's financial support to enterprises can effectively alleviate the shortage of funds and the operational burdens that arise from R&D input, and that support can correct the functional distortion of the market mechanism on the optimal allocation of resources, thus correcting the market failure of the mechanism behind green innovation. Studies have pointed out that government policy incentives can significantly accelerate the pace of corporate green transformation, and the two exhibit a strong positive correlation [46,47]. Government grants, as an important form of policy incentives, have a strong signaling effect. Therefore, digital enterprises can alleviate the problem of corporate financial constraints by obtaining government subsidies, which in turn can enhance their green innovation capacity [48].

There are two specific reasons for this: first of all, in recent years, the pressure on ecology and environmental protection has been increasing in all regions, and regional governments, in order to encourage enterprises to save energy, reduce consumption, and carry out green innovation activities, will give certain government subsidies directly to enterprises that carry out digital transformation [49]. Meanwhile, digital companies, based on their better digital information channels, can quickly access consumers' thoughts and ideas regarding green products. To cater to consumer preferences, companies will target green R&D. As the leader of the innovation system, governments, in order to guide technological innovation and progress, prefer to provide government subsidies to digital enterprises with high innovation capacities and to set up special funds for development, thus accelerating the green transformation of economic development.

Secondly, the information among society is incomplete. Enterprises carrying out green technology innovation who seek external investment and support hope to convert invisible and better green technology innovation abilities into information that can be seen by the outside world, and let the partners receive it through government subsidies [50]. Therefore, government subsidies can reflect the support of government departments for enterprises' green innovation capabilities. If an enterprise can receive a government subsidy, investors and other companies may come to believe that the green innovation ability of the enterprise has been recognized by the government department; this would improve the cooperation intentions of investors and other companies toward the enterprise and, thus, improve the green technology innovation ability of the enterprise itself. Here, the authors propose Hypothesis 3:

Hypothesis 3. *Enterprise digital transformation can promote green technology innovation by obtaining government subsidies.*

Tax preference is a post-reward policy, referring to government departments reducing part of the state tax receivable or the implementation of the first levy and then refunding it as a way to subsidize. Because of the post-event nature of tax preference, coupled with the fact that government departments generally only publish the list of companies that obtain innovation tax credits and do not vigorously report the events of tax preference obtained by companies [25], it is more difficult for companies to convey their better green technology innovation capabilities to the outside world through tax preference. However, a tax preference refunded to firms indirectly increases their future funds for green technology innovation, leading more scholars to place emphasis on the innovative properties of tax preferences for firms [51].

On one hand, tax preference has a greater financial subsidy effect; this is conducive to enhancing the green innovation of enterprises [45]. On the other hand, tax preference reduces the tax burden of enterprises. It is equivalent to an indirect approach for increasing the supply of funds, easing the real situation of tight research funds of enterprises and enhancing the willingness of enterprises to invest in high-cost and high-risk green innovation projects [52]. At the same time, for the expected income post-reward, tax preference has greater autonomy in its actual use. The government subsidy is a special grant awarded by the ministry for certain items of an enterprise. Its subsidy method is very simple, and the subsidy target is very clear. In contrast, tax preference is different from a government subsidy.

Tax preference is the corresponding preferential policy formulated by a government department; the beneficiary group does not refer to a specific, special company. Therefore, the beneficiary group of the tax preference is relative. According to the above analysis, tax preference can not only solve the problem of tight research funds for enterprises but it can also enhance the willingness of enterprises to invest in high-cost and high-risk green technology innovation projects [53]. This is beneficial toward enhancing green innovation. In addition, it can also make up for limitations of the application of government subsidies, and it is the substitution and supplement of government subsidies that helps it to play the role of an enterprise in resource allocation and, thus, mobilize the enthusiasm of enterprises in green technology innovation. Therefore, the authors propose Hypothesis 4 here:

Hypothesis 4. *Tax preference can significantly enhance the facilitation between enterprise digital transformation and green technology innovation.*

Through the above analysis, in order to more intuitively reflect the research ideas of this paper and the relationship between variables, the authors constructed a diagram of the empirical analysis framework for this paper, as shown in Figure 1.

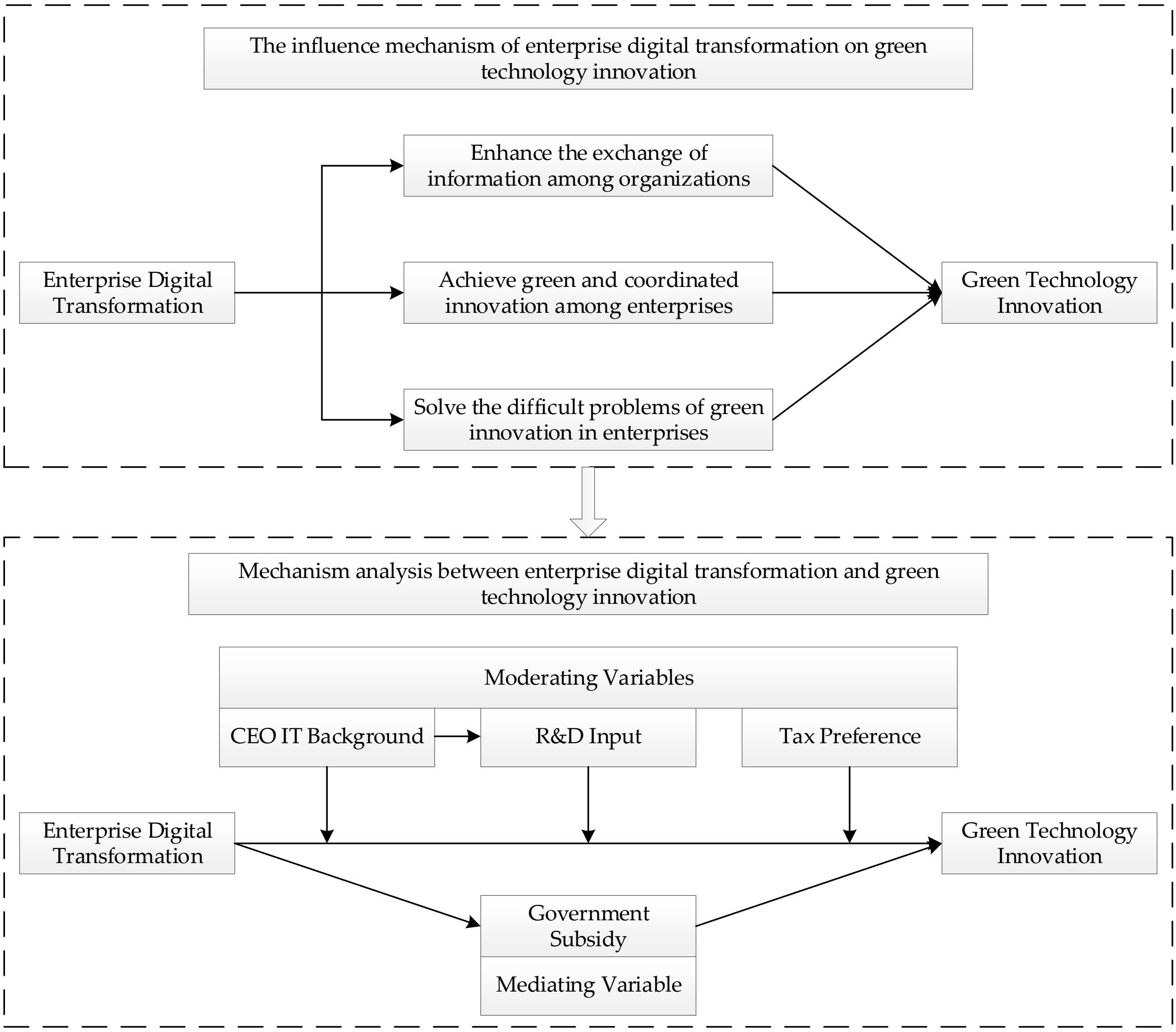

Figure 1. Empirical analysis framework for the impact of enterprise digital transformation on green technology innovation.

3. Research Design

3.1. Sample Selection and Data Source

The research sample of this paper is listed, A-share companies in China's Shanghai and Shenzhen stock markets from 2011 to 2021. In the process of sample selection, industries such as finance and insurance were excluded, and ST, ST*, PT, and samples with serious missing key data were excluded. Additionally, all continuous variables were minorized at the upper and lower 1%, finally leading to 18,655 observations containing 3285 listed companies. Except for enterprise digital transformation and CEO IT background, all other data in this paper are from the CSMAR and Wind databases.

3.2. Variable Definition

3.2.1. Green Technology Innovation

According to existing research, green technology innovation is commonly measured by the number of patents and the R&D expenditure in an environmental field. Since the green technology innovation ability of enterprises is the main objective of this paper, the number of patent applications was selected as the proxy variable. The data come from the State Intellectual Property Office and are identified by the classification number of each patent, combined with the IPC Green List. The types of patents include invention, utility model, and design patents. Because design patents do not use IPC classification, invention patents have more creative and technical content while utility model patents have a lower degree of innovation and only protect the shape and structure of the product. Therefore, in order to ensure the robustness of the research, the authors selected the total number of green patent applications and the total number of green invention patent applications to measure the green technology innovation ability of enterprises by referring to the research experience of relevant scholars [54–56].

3.2.2. Enterprise Digital Transformation

Considering that the annual report of an enterprise can truly reflect changes in the enterprise's decision-making and business behaviors, the authors downloaded the annual reports of listed companies from 2011 to 2021 from the official websites of the Shanghai and Shenzhen Stock Exchanges, and used Python to calculate the length of the full text of the annual reports. Secondly, the authors collected planning schemes, important news, conferences, and recent government work reports related to the development of the digital economy and built a relatively complete digital transformation vocabulary using Python word separation processing and manual recognition. Finally, expanding the vocabulary to Python's Jieba library, the authors counted the number of occurrences of digital keywords in the full-text annual report and then calculated these occurrences as the word frequency of the digital transformation of enterprises. To overcome the right-skewed distribution problem of such counting statistics, the frequencies were processed by adding 1 and taken as the natural logarithm.

3.2.3. CEO IT Background

In this paper, by manually collating the educational background and work experience of the CEOs of listed companies, we determined that when a CEO has educational or practical experience related to enterprise information technology management and information technology, the CEO is considered to have an IT background and is called a CEO with IT background. The specific manual collation process referred to the research of Enns et al. [57].

3.2.4. R&D Input

In this paper, the total R&D input of enterprises in each year was chosen as the measurement index of the R&D input.

3.2.5. Tax Preference

In this paper, the sum of each tax rebate received was divided by the sum of each tax rebate received and each tax paid as the measurement index of tax preference.

3.2.6. Government Subsidy

In this paper, the total amount of government subsidy obtained by companies in each year was selected as the government subsidy measurement index.

3.2.7. Control Variables

With reference to several related studies [17,25,58], this paper selected ownership, enterprise size, management's rights, Tobin Q values, financial leverage, profitability, enterprise growth, equity concentration, and management shareholding ratios as control variables. The specific definitions of the key and control variables in this paper are listed in Table 1.

Table 1. Variable Definition Table.

Variable Type	Variable Name	Code	Variable Definition and Description
Dependent variables	Green technology innovation	GIT1	The total number of green patent applications plus 1 is taken as the natural logarithm.
		GIT2	The total number of green invention patent applications plus 1 is taken as the natural logarithm.
Independent variable	Enterprise digital transformation	Edi	The sum of digitized word frequencies plus 1 is taken as the natural logarithm.
Moderating variables	CEO IT background	CEO	When the CEO has education or practice experience related to enterprise information technology management and information technology, the value is 1, otherwise it is 0.
	R&D input	RDI	The total amount of R&D expenses invested by the enterprise plus 1 is taken as the natural logarithm.
	Tax preference	Tax	Refund of various taxes received/(refund of various taxes received and various taxes paid).
Mediating variable	Government subsidy	Gov	Total government subsidy for the year plus 1 is taken as the natural logarithm.
Control variables	Ownership	soe	State-controlled enterprises take the value of 1, otherwise it is 0.
	Enterprise size	size	Natural logarithm of total assets at the end of the year.
	Management's rights	dual	Chairman and general manager position unity take 1, otherwise 0.
	Tobin Q value	tq	Natural logarithm of enterprise's Tobin Q value.
	Financial leverage	lev	Total liabilities at end of period/total assets at end of period.
	Profitability	roa	Net income/total assets average balance.
	Enterprise growth	growth	Operating income growth rate.
	Equity concentration	top10	Total shareholding of top ten shareholders/total share capital.
	Management shareholding ratio	mshare	Total management shareholding/total share capital.

3.3. Model Construction

Digital transformation provides a new direction and path for enterprise green technology innovation. Therefore, in order to test whether enterprise digital transformation can promote green technology innovation, the authors constructed model (1).

$$\begin{aligned} \text{GIT} = {} & \alpha_0 + \alpha_1\text{Edi} + \alpha_2\text{soe} + \alpha_3\text{size} + \alpha_4\text{dual} + \alpha_5\text{tq} + \alpha_6\text{lev} + \alpha_7\text{roa} \\ & + \alpha_8\text{growth} + \alpha_9\text{top10} + \alpha_{10}\text{mshare} + \sum\text{Year} + \sum\text{Ind} + \varepsilon \end{aligned} \quad (1)$$

To test the moderating role of a CEO IT background in digital transformation affecting green technology innovation, the authors constructed model (2).

$$\begin{aligned} \text{GIT} = \alpha_0 + \alpha_1\text{Edi} + +\alpha_2\text{CEO} + \alpha_3\text{Edi} \times \text{CEO} + \alpha_4\text{soe} + \alpha_5\text{size} + \alpha_6\text{dual} + \alpha_7\text{tq} \\ +\alpha_8\text{lev} + \alpha_9\text{roa} + \alpha_{10}\text{growth} + \alpha_{11}\text{top10} + \alpha_{12}\text{mshare} + \sum\text{Year} + \sum\text{Ind} + \varepsilon \end{aligned} \quad (2)$$

To further test that a CEO IT background can increase corporate R&D input, the authors constructed model (3). Meanwhile, to test that corporate R&D input can enhance the facilitation effect of digital transformation on green technology innovation, the authors constructed model (4).

$$\begin{aligned} \text{RDI} = \alpha_0 + \alpha_1\text{CEO} + \alpha_2\text{soe} + \alpha_3\text{size} + \alpha_4\text{dual} + \alpha_5\text{tq} + \alpha_6\text{lev} + \alpha_7\text{roa} \\ +\alpha_8\text{growth} + \alpha_9\text{top10} + \alpha_{10}\text{mshare} + \sum\text{Year} + \sum\text{Ind} + \varepsilon \end{aligned} \quad (3)$$

$$\begin{aligned} \text{GIT} = \alpha_0 + \alpha_1\text{Edi} + +\alpha_2\text{RDI} + \alpha_3\text{Edi} \times \text{RDI} + \alpha_4\text{soe} + \alpha_5\text{size} + \alpha_6\text{dual} + \alpha_7\text{tq} \\ +\alpha_8\text{lev} + \alpha_9\text{roa} + \alpha_{10}\text{growth} + \alpha_{11}\text{top10} + \alpha_{12}\text{mshare} + \sum\text{Year} + \sum\text{Ind} + \varepsilon \end{aligned} \quad (4)$$

To identify the influencing role of government fiscal incentives between digital transformation and green technology innovation, the authors constructed model (5) based on model (1) to test the moderating role of tax preference between the two and models (6) and (7) to test the mediating role of a government subsidy between the two.

$$\begin{aligned} \text{Gov} = \alpha_0 + \alpha_1\text{Edi} + \alpha_2\text{soe} + \alpha_3\text{size} + \alpha_4\text{dual} + \alpha_5\text{tq} + \alpha_6\text{lev} + \alpha_7\text{roa} \\ +\alpha_8\text{growth} + \alpha_9\text{top10} + \alpha_{10}\text{mshare} + \sum\text{Year} + \sum\text{Ind} + \varepsilon \end{aligned} \quad (5)$$

$$\begin{aligned} \text{GIT} = \alpha_0 + \alpha_1\text{Edi} + \alpha_2\text{Gov} + \alpha_3\text{soe} + \alpha_4\text{size} + \alpha_5\text{dual} + \alpha_6\text{tq} + \alpha_7\text{lev} \\ +\alpha_8\text{roa} + \alpha_9\text{growth} + \alpha_{10}\text{top10} + \alpha_{11}\text{mshare} + \sum\text{Year} + \sum\text{Ind} + \varepsilon \end{aligned} \quad (6)$$

$$\begin{aligned} \text{GIT} = \alpha_0 + \alpha_1\text{Edi} + +\alpha_2\text{Tax} + \alpha_3\text{Edi} \times \text{Tax} + \alpha_4\text{soe} + \alpha_5\text{size} + \alpha_6\text{dual} + \alpha_7\text{tq} \\ +\alpha_8\text{lev} + \alpha_9\text{roa} + \alpha_{10}\text{growth} + \alpha_{11}\text{top10} + \alpha_{12}\text{mshare} + \sum\text{Year} + \sum\text{Ind} + \varepsilon \end{aligned} \quad (7)$$

4. Empirical Analysis

4.1. Descriptive Statistics

In Table 2, the medians of the dependent variables (GIT1 and GIT2) are both 0.000 and the value ranges are large, which indicates that the level of green technology innovation in enterprises is low and that there are large differences between the sample enterprises. The independent variable (Edi) has a mean value of 1.294, a standard deviation of 1.387, a minimum value of 0.000, and a maximum value of 5.050, indicating that there is a large difference between the degree of digitization of companies and that there is a significant proportion of companies that have not yet carried out digital transformation. In addition, the mean and median values of CEO IT background (CEO) are small, indicating that fewer companies have CEOs with IT background. The maximum value of R&D input (RDI) is 24.091 and the minimum value is 14.082, which indicates that companies have a large gap in their R&D input, and some of them need to continue to increase the relevant input. The median and mean values of government subsidy (Gov) are significantly larger than the minimum values; this indicates that the Chinese government provides more financial subsidy to enterprises, which can better relieve the pressure of the financial constraints and, thus, help them have more funds for green technology R&D. The value range of tax preference (Tax) is large, and the median and mean values are significantly smaller than the maximum values, which indicates that there are distinct discrepancies in the tax preferences received by the enterprises.

Table 2. Descriptive statistical analysis.

Variable	N	Mean	Standard Deviation	Min.	P50	Max.
GIT1	18,655	0.376	0.787	0.000	0.000	3.644
GIT2	18,655	0.254	0.619	0.000	0.000	3.135
Edi	18,655	1.294	1.387	0.000	1.099	5.050
CEO	18,655	0.074	0.262	0.000	0.000	1.000
RDI	18,655	14.082	7.233	0.000	17.217	24.091
Gov	18,655	15.415	2.279	3.491	15.687	23.121
Tax	18,655	0.139	0.196	0.000	0.042	0.811
Soe	18,655	0.377	0.485	0.000	0.000	1.000
Size	18,655	22.255	1.292	20.008	22.062	26.277
Dual	18,655	0.265	0.441	0.000	0.000	1.000
Tq	18,655	2.040	1.274	0.870	1.617	8.171
Lev	18,655	0.428	0.207	0.052	0.421	0.888
Roa	18,655	0.041	0.058	−0.200	0.038	0.205
Growth	18,655	0.172	0.388	−0.508	0.109	2.428
Top10	18,655	0.584	0.152	0.233	0.592	0.906
Mshare	18,655	0.129	0.194	0.000	0.004	0.678

4.2. Baseline Model Regression Analysis

The regression results are shown in Table 3. The regression results (1) and (3) show that there is a positive relationship between enterprise digital transformation and green technology innovation. The regression results (2) and (4) show that, after adding the control variables, the regression coefficients of Edi are still positive at 0.066 and 0.057 for GIT1 and GIT2, respectively, which are past the significance test at the level of 1%, indicating that the higher the degree of enterprise digital transformation, the better the level and quality of enterprise green technology innovation. Therefore, Hypothesis 1 is supported by the empirical results.

Table 3. Baseline regression test results.

Variable	GIT1		GIT2	
	(1)	**(2)**	**(3)**	**(4)**
Edi	0.080 *** (14.67)	0.066 *** (12.34)	0.069 *** (15.23)	0.057 *** (13.05)
Controls	No	Yes	No	Yes
cons	0.080 ** (2.39)	−3.147 *** (−18.65)	0.045 * (1.87)	−2.663 *** (−19.10)
Year	Yes	Yes	Yes	Yes
Ind	Yes	Yes	Yes	Yes
R^2	0.1021	0.1527	0.0831	0.1383
N	18,655	18,655	18,655	18,655

Note: * represents $p < 0.1$, ** represents $p < 0.05$, *** represents $p < 0.001$, where Controls represent all control variables selected for this paper.

4.3. Endogeneity Tests

4.3.1. Instrumental Variable Method

There may have been endogeneity problems caused by mutual causality in the process of empirical testing. Therefore, two methods were adopted to deal with any possible reverse causality problems.

First, the instrumental variables for enterprise digital transformation were constructed by drawing on Lewbel's research idea of using the cube of the difference between the mean value of the digital transformation of firms and the digital transformation by industry and province as an instrumental variable [59]. The results of the test are shown in (1)–(3) of

Table 4. Results (1)–(3) report the regression results using a two-stage least squares analysis with instrumental variables. The first stage regression result (1) shows that the instrumental variable L_ Edi's coefficient is significant and meaningful; that is, the selected instrumental variable meets the correlation conditions. The regression results of the second stage, seen in (2) and (3), show that Edi's coefficient remains largely consistent with the results expressed above; that is, the core conclusion is still robust and reliable.

Table 4. Results of endogeneity tests.

Variable	**Edi**	**GIT2**	**GIT1**	**GIT1**	**GIT2**	**GIT1**	**GIT2**	**GIT1**	**GIT2**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
L_Edi	0.125 *** (125.32)								
Edi		0.065 *** (8.87)	0.064 *** (11.02)						
L_1Edi				0.085 *** (11.93)	0.080 *** (13.05)				
L_2Edi						0.098 *** (10.71)	0.093 *** (11.69)		
L_3Edi								0.102 *** (8.91)	0.100 *** (9.90)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
cons	−2.007 *** (−13.45)	−3.149 *** (−22.65)	−2.639 *** (−23.90)	−3.365 *** (−20.62)	−3.399 *** (−24.18)	−3.515 *** (−18.76)	−3.600 *** (−22.04)	−3.573 *** (−16.77)	−3.741 *** (−19.89)
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	-	0.147	0.159	0.156	0.147	0.159	0.151	0.162	0.155
N	18,655	18,655	18,655	14,129	14,129	11,624	11,624	9497	9497

Note: *** represents $p < 0.001$, where Controls represent all control variables selected for this paper.

4.3.2. Lagging Core Explanatory Variable

Second, given that the process of green innovation is time-consuming, digital transformation has a long window of impact on its effects. This paper introduces the core explanatory variable with a lag of one to three periods into the model for regression [13]. Table 4 regression results (4) to (9) show that the coefficients of the core explanatory variables are consistent with the results of the previous tests; that is, the core conclusions are robust and credible.

4.4. Robustness Tests

4.4.1. Sample Screening

Since this paper portrays the Edi through a textual analysis of enterprise annual reports, the calculation results may have been affected by strategic information disclosure behavior. Therefore, the method of screening samples was used for robustness test. First, samples with a word frequency of 0 in enterprise digital transformation during the sample period were eliminated, and then regression was performed again. The results are shown in (1) and (2) of Table 5. At the same time, the fact that some samples had not applied for green patents may affect the results of this paper. To eliminate the interference of samples with 0 application numbers on the regression results, the authors removed the samples with 0 application numbers. The results are shown in (3) and (4) of Table 5. The results show that the Edi's coefficients still have a significant positive effect; this is consistent with the previous conclusions and indicates the high robustness of the results in this paper.

Table 5. Results of robustness tests.

Variable	GIT1	GIT2	GIT1	GIT2	GIT3	GIT1	GIT2	GIT1	GIT2
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Edi	0.071 ***	0.069 ***	0.059 ***	0.080 ***	0.044 ***			0.052 ***	0.053 ***
	(9.05)	(10.64)	(5.82)	(7.85)	(10.46)			(12.41)	(15.96)
Edi1						0.066 ***	0.052 ***		
						(11.95)	(11.68)		
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
cons	−3.461 ***	−3.068 ***	−4.327 ***	−4.327 ***	−2.675 ***	−3.266 ***	−2.778 ***	−2.500 ***	−2.148 ***
	(−15.25)	(−16.20)	(−13.60)	(−13.60)	(−22.70)	(−23.82)	(−25.49)	(−19.36)	(−21.22)
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Ind	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
R^2	0.172	0.159	0.196	0.195	0.146	0.151	0.135	0.050	0.057
N	11,347	11,347	4573	3510	18,655	18,655	18,655	18,655	18,655

Note: *** represents $p < 0.001$, where Controls represent all control variables selected for this paper.

4.4.2. Replacing the Dependent Variable

The number of patents obtained represents the innovation results and performance of the company and the patents that were actually available to the company. Therefore, in order to further investigate the robustness of the study findings, the total number of green patents obtained by enterprises plus 1 was taken as the natural logarithm and the dependent variable (GIT3). The results are shown in (5) of Table 5. The results show that the coefficients of Edi are significantly positive; this further strengthens the credibility of the results of this paper.

4.4.3. Replacing the Independent Variable

This paper portrays the degree of digital transformation of enterprises by means of a textual analysis of keywords in their annual reports in order to avoid the subjectivity of keyword selection. Therefore, this paper reselected the keywords of digital transformation to calculate a new word frequency of enterprise digital transformation, and then added 1 to the new enterprise digital transformation word frequencies and took the natural logarithm as the independent variable (Edi1). The results are shown in (6) and (7) of Table 5. The results show that the regression coefficients of Edi1 are still significantly positive, and the credibility of the results of this paper is further enhanced.

4.4.4. Changing the Model Estimation Method

This paper used OLS regression instead of fixed effect regression for the robustness test. The results are shown in (8) and (9) of Table 5. The results show that the coefficients of the core explanatory variables are generally consistent with the results above; that is, the core findings are robust and plausible.

5. Mechanism Analysis

5.1. Mechanism Test Based on the CEO IT Background Perspective

The test results of models (2)–(4) are shown in Table 6. The regression results (1) and (2) show that the coefficients of Edi × CEO are significantly positive at the 10% and 1% level, indicating that enterprises with a CEO IT background add a more significant contribution of digital transformation to their green technology innovation. In regression results (3), the coefficient of CEO is significantly positive at the 1% level, indicating that CEO IT background can improve increased corporate R&D input. The results (4) and (5) show that the coefficients of Edi × RDI are both significantly positive at the 1% level, indicating that the higher the R&D input of enterprises, the more significant the promotion effect of digital transformation on their green technology innovation. Therefore, Hypotheses 2-1, 2-2, and 2-3 were verified.

Table 6. Results of mechanism test based on the perspective of CEO IT background.

Variable	**GIT1**	**GIT2**	**RDI**	**GIT1**	**GIT2**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Edi	0.060 *** (12.02)	0.052 *** (13.18)		0.055 *** (11.00)	0.049 *** (12.19)
CEO	0.111 *** (4.21)	0.079 *** (3.78)	0.806 *** (5.08)		
Edi × CEO	0.024 * (1.80)	0.036 *** (3.39)			
RDI				0.013 *** (13.30)	0.010 *** (11.89)
Edi × RDI				0.003 *** (5.65)	0.004 *** (6.90)
Controls	Yes	Yes	Yes	Yes	Yes
cons	−3.133 *** (−22.76)	−2.651 *** (−24.26)	−14.547 *** (−14.30)	−2.990 *** (−21.70)	−2.558 *** (−23.36)
Year	Yes	Yes	Yes	Yes	Yes
Ind	Yes	Yes	Yes	Yes	Yes
R^2	0.155	0.141	0.446	0.161	0.146
N	18,655	18,655	18,655	18,655	18,655

Note: * represents $p < 0.1$, *** represents $p < 0.001$, where Controls represent all control variables selected for this paper.

5.2. Testing the Influence Mechanism Based on the Fiscal Incentives Perspective

To test Hypotheses 3 and 4, first, following the test method for the mediating effect, the sequential test method for the mediating effect was adopted to test the mediating mechanism based on the baseline regression. The regression results (1) in Table 7 show that the impact coefficient of Edi on Gov is 0.069, which passes the significance test at the level of 1%, indicating that enterprise digital transformation helps to strengthen government subsidies. After the further inclusion of mediating variables, the regression results (2) and (3) in Table 7 show that the impact coefficients of Edi on GIT1 and GIT2 are 0.064 and 0.056, respectively. The impact coefficients are lower than the impact coefficient in the benchmark regression, and the significance is still met, indicating that government subsidy has a partial mediating effect. This shows that the digital transformation of enterprises can strengthen a government's financial subsidy to enterprises, alleviating the problem of insufficient investment in R&D funds and, thus, promoting the green technology innovation of enterprises. The results (4) and (5) in Table 7 show that the coefficients of Edi × Tax are 0.157 and 0.144, and both pass the 1% significance, indicating that tax preference has a positive moderating effect. This shows that tax preference can enhance the positive relationship between enterprise digital transformation and green innovation. Therefore, Hypotheses 3 and 4 were verified.

Table 7. Test results of the influence mechanism based on the fiscal incentives perspective.

Variable	**Gov**	**GIT1**	**GIT2**	**GIT1**	**GIT2**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Edi	0.069 *** (5.80)	0.064 *** (12.06)	0.056 *** (12.75)	0.060 *** (12.00)	0.052 *** (13.16)
Gov		0.022 *** (7.12)	0.019 *** (7.99)		
Tax				0.236 *** (8.22)	0.209 *** (9.18)
Edi × Tax				0.157 *** (7.50)	0.144 *** (8.65)

Table 7. *Cont.*

Variable	Gov	GIT1	GIT2	GIT1	GIT2
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Controls	Yes	Yes	Yes	Yes	Yes
cons	−1.426 *** (−4.27)	−3.116 (−18.53)	−2.636 *** (−19.99)	−3.184 *** (−23.14)	−2.696 (−24.69)
Year	Yes	Yes	Yes	Yes	Yes
Ind	Yes	Yes	Yes	Yes	Yes
R^2	0.407	0.155	0.141	0.158	0.145
N	18,655	18,655	18,655	18,655	18,655

Note: *** represents $p < 0.001$, where Controls represent all control variables selected for this paper.

6. Discussion

Through an empirical analysis, it was found that digital transformation can significantly promote an enterprises' green technology innovation. This is in agreement with the findings of Zhang et al. and Xue et al. [18,25]. Digital enterprises can use digital technology to strengthen inter-organizational communication; reorganize innovative factors such as product manufacturing, design and development, and technical processes; improve enterprise production efficiency; and, thus, promote the improvement of enterprise green technology innovation ability.

Previous studies have mainly focused on the influence mechanism between corporate internal governance [60] and government environmental regulation [61,62] but have paid relatively little attention to the backgrounds of executives and government incentive policies. Therefore, relevant research needs to be further deepened. This paper analyzed this mechanism from the perspective of an internal CEO technical background and external government incentive in order to enrich the relevant research on the relationship between them. It has been found that the CEO IT background can enhance the contribution of digital transformation to green technology innovation. This suggests that CEOs with technology backgrounds are able to identify promising green innovation opportunities in their industries as a result of their relatively good knowledge and experience in technology innovation, are willing to take on green innovation challenges, and can increase their green R&D input. Therefore, in enterprises with CEO's having an information technology background, digital transformation has a better promotion effect on green technology innovation abilities.

Different government incentive policies have different mechanisms behind digital transformation and green technology innovation. Government subsidies play an intermediary role between the two, and tax preference plays a moderating role between the two. This is mainly because a government subsidy is a special fund given by the government to support certain matters of an enterprise. Its subsidy method is simple, the subsidy target is clear, and the autonomy of its fund use is poor. Tax preference is broad and not specific to a single company. Therefore, the signaling effect of tax preference is weak. However, for the expected income of an enterprise post incentives, the autonomy and breadth of use of tax preference funds are significantly better than those of government subsidies, and they can compensate for the problem of application limitations for government subsidy funds. Therefore, the two incentive policies complement each other and play different incentive roles in digital transformation and enterprise green innovation.

7. Conclusions and Insights

7.1. Conclusions

The authors used the frequency of digital transformation keywords in annual reports of sample enterprises to describe their digital transformation status, and then the authors empirically tested the impact of digital transformation on their green technology innovation. The analysis results show that the digital transformation of enterprises has significantly improved their green technology innovation; this is valid for both the endogenous test and the robustness test. Through a mechanism analysis, it was found that a CEO IT background plays a positive moderating role between the two and can also promote corporate R&D input. The increase in R&D input can also promote the positive relationship between the two. Additionally, fiscal incentive policies play different roles between the two. Enterprise digital transformation can improve green innovation through obtaining government subsidies; the government can enhance the positive promotion between the two through the incentive of tax preference.

7.2. Research Limitations and Perspectives

This paper has the following deficiencies, which deserve further study in the future. First, the paper did not specifically divide the industries to which the sample companies belong; however, digital transformation and green innovation may be heterogeneous across industries. In the future, the relationship between digital transformation and green innovation should be studied and compared in different industries to enrich research in related fields.

Second, the development of enterprise digitalization and green innovation is influenced by factors such as regional economic development and industrial structure; however, this paper did not analyze the influence of the external macro environment on the relationship between the two. In the future, the influence of the external macro environment on related research should be considered.

Finally, this paper analyzed the relationship between enterprise digitization and green technology innovation from the perspective of theoretical and empirical analysis and, further, explored the influencing mechanisms behind the two from different perspectives; however, the influence relationship between the two may be multidimensional and complex. In the future, relevant studies should be further discussed from the perspective of configuration analysis.

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