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Influence and Mechanism Analysis of Green Digital Transformation on Enterprise Green Innovation

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Abstract. The purpose of this study is to explore the influence of green digital transformation (GDT) on enterprise green innovation (GI) and its mechanism. Under the background of increasingly severe global environmental problems and accelerating digital transformation, green innovation has become an important driving force for the sustainable development of enterprises. Therefore, this study has important theoretical and practical significance. In order to achieve the research purpose, this study adopts multiple linear regression model for empirical analysis. The research sample covers enterprises of different industries and sizes to ensure the universality and representativeness of the research. In the choice of variables, we not only pay attention to the relationship between GDT and GI, but also consider the possible influencing factors such as enterprise scale, enterprise age and industry attributes. Through empirical analysis, it is found that GDT has a significant positive impact on GI, which shows that GDT can effectively enhance the green innovation ability of enterprises. At the same time, the scale of enterprises has also been proved to have a positive impact on green innovation, while the influence of enterprise age and industry attributes is not significant. These findings provide a useful reference for enterprises to formulate green innovation strategies. Based on the research results, this paper puts forward some suggestions to enterprises and governments to promote GDT and green innovation. For enterprises, they should actively invest in green digital technology, cultivate green innovation consciousness and develop together with green supply chain partners. The government should provide support in policy, supervision and cooperation with Industry-University-Research to create a good environment for green innovation.

Keywords: Green Digital Transformation; Enterprise Green Innovation; Influence Mechanism.

1. Introduction

With the increasingly severe global climate change and environmental deterioration, environmental protection has become a global issue. As an important participant in social and economic activities, the impact of enterprises' production and operation activities on the environment can not be ignored. In order to achieve sustainable development, more and more enterprises begin to pay attention to and implement green innovation strategy, aiming at reducing the negative impact on the environment through technological innovation and management innovation [1].

In the current epoch, as digital technology has been advancing at a breakneck pace, Green Digital Transformation (GDT) has progressively emerged as a crucial pathway for companies to achieve green innovation [2-3]. GDT means that enterprises can optimize production processes, reduce energy consumption, reduce emissions and improve resource utilization efficiency by introducing digital technology, thus promoting enterprises to develop in a more environmentally friendly and efficient direction. It not only helps enterprises to improve their environmental performance, but also enhances their competitiveness, achieving a win-win situation for both economic and environmental benefits [4]. However, despite the great potential of GDT, the research on its specific impact on enterprise green innovation (GI) is still insufficient. In particular, how GDT promotes GI, as well as the specific mechanisms and paths involved in this process, are issues worthy of in-depth discussion [5-6].

Therefore, the purpose of this study is to deeply explore the influence of GDT on GI and its mechanism, so as to provide theoretical support and practical guidance for enterprises to achieve sustainable development. Through this study, we can reveal the positive role of GDT in promoting GI, and provide a useful reference for enterprises to effectively use digital technology to achieve green development. This is not only of great significance to promote the sustainable development of

enterprises themselves, but also makes positive contributions to the global environmental protection cause.

2. Theoretical Framework and Research Hypothesis

The theoretical framework constructed in this study mainly revolves around the theme of "how GDT affects GI". The research will be deeply analyzed from the internal and external dimensions of the enterprise.

The internal level of enterprises pays attention to how GDT can promote green technology innovation and management innovation by optimizing production processes, improving resource utilization efficiency, reducing energy consumption and reducing waste emissions [7]. The application of digital technology can help enterprises to monitor the energy consumption and emissions in the production process in real time, find and solve problems in time, and thus improve the environmental performance of enterprises.

At the macro level, the discourse within this document delves into the influence of GDT on corporate market competitiveness, supply chain coordination, and customer interactions. Embracing digital transformation enables companies to articulate their eco-friendly initiatives and accomplishments with increased clarity, fortifying consumer faith and allegiance to the brand [8]. Simultaneously, the shift towards digital operations facilitates the forging of tighter and more streamlined partnerships with vendors and associates, collectively propelling the evolution of sustainable supply chains.

From the internal point of view of enterprises, GDT can achieve refined management and optimization of production processes by introducing advanced production management systems and intelligent equipment [9]. This can not only improve the production efficiency of enterprises, but also effectively reduce energy consumption and waste emissions, and promote enterprises to achieve green production. In addition, digital transformation can also promote knowledge sharing and innovation cooperation within enterprises, and provide strong support for the research and development and application of green technologies.

From the external point of view, GDT helps enterprises to enhance their brand image and market competitiveness. Through open and transparent disclosure of environmental protection information, enterprises can win the trust and support of consumers, thus occupying a favorable position in market competition. Concurrently, the digital metamorphosis can catalyze collaborative endeavors and dialogues between businesses and various other entities, including institutions, thereby synergistically fostering the progression of green innovation.

Based on the above theoretical framework and analysis, this study puts forward the following research hypotheses:

H1: GDT has a significant positive impact on green technology innovation and management innovation within enterprises [10].

H2: GDT has a significant positive impact on external market competitiveness, supply chain management and consumer relations.

H3: GDT can improve the overall environmental performance and economic benefits of enterprises by promoting green innovation activities inside and outside enterprises.

3. Research Method

3.1. Data Source, Sample Selection and Data Preprocessing

In this study, quantitative analysis and case study are used to explore the influence of GDT on GI and its mechanism. The data of this study mainly comes from two aspects: one is the enterprise data

collected through questionnaire survey, and the other is the relevant statistical data and reports obtained from open channels.

Questionnaire survey is the main data source of this study. A detailed questionnaire was designed and distributed to enterprises that have implemented or are considering implementing GDT. The content of the questionnaire covers the basic situation of enterprises, the present situation of GDT, the practice of green innovation and related performance indicators.

In addition, the study also obtained relevant data and cases about GDT and green innovation from government public data, industry reports, academic papers and other channels as auxiliary data sources for this study.

The following aspects are mainly considered in the sample selection: firstly, enterprises of different industries and sizes are selected as the survey objects to ensure the diversity and representativeness of the samples; Secondly, the enterprises that have implemented or are considering implementing GDT are given priority in order to discuss the influence of GDT on GI more accurately. Finally, the geographical location and economic development level of enterprises are considered to ensure the universality and applicability of the research results.

In the data preprocessing stage, the following steps are mainly carried out: firstly, the questionnaire data are sorted out, and invalid questionnaires and abnormal values are eliminated to ensure the accuracy and reliability of the data; Secondly, the data is encoded and transformed into a format suitable for statistical analysis; Finally, descriptive statistical analysis is carried out to understand the basic situation and distribution characteristics of the sample.

3.2. Variable Definition and Measurement

GDT Degree (GDT): This variable is used to measure the investment and implementation degree of enterprises in the GDT process. Comprehensive evaluation is made through multiple-choice questions and scoring questions in the questionnaire survey, including the practice of enterprises in digital technology application, environmental protection process improvement and resource utilization efficiency improvement.

GI level (GI): indicates the comprehensive ability of enterprises in green product innovation, green process innovation and green management innovation. Combined with the multi-dimensional data in the questionnaire survey, such as enterprise self-evaluation, environmental protection characteristics of new products or services, implementation of energy conservation and emission reduction measures, etc., the quantitative score is made.

Control variable: enterprise scale ($Size$), measured by the number of employees or total assets. Enterprise age (Age), the number of years since the establishment of the enterprise. Industry attribute ($Industry$) is classified according to the environmental protection requirements and characteristics of the industry to which the enterprise belongs.

3.3. Construct a Mathematical Model

In order to deeply explore the influence of GDT degree on GI level, this study constructs the following regression model:

$$GI = \alpha + \beta_1 GDT \times \beta_2 Size + \beta_3 Age + \sum_{i=1}^{n} \gamma_i Industry_i + \varepsilon \quad (1)$$

Among them, GI represents the green innovation level of the enterprise; GDT represents the GDT degree of the enterprise; $Size$ stands for enterprise scale; Age stands for enterprise age; $Industry_i$

stands for different industry classifications to which the enterprise belongs; α is a constant term; $\beta_1, \beta_2, \beta_3$ is the regression coefficient of each variable; ε is a random error term.

4. Empirical Analysis and Results

4.1. Descriptive Statistical Analysis

Table 1 and are the descriptive statistical results of the main variables. Through descriptive statistical analysis, we can draw the following conclusions: the enterprises participating in the survey show a medium level in GDT and green innovation as a whole, but there are differences among enterprises; The scale of enterprises is widely distributed, while the age of enterprises is generally long, showing certain market stability and experience accumulation. These data provide a basis for us to further explore the relationship between GDT and green innovation.

Table 1. Results of descriptive statistical analysis

variable	N	Mean	Std. Deviation	Min	Max
GDT	150	6.75	1.62	3.00	10.00
GI	150	7.23	1.48	4.00	10.00
Size	150	523.67	345.21	50.00	2000.00
Age	150	16.32	8.45	3.00	45.00

In addition, for the classified variable of industry attribute *Industry*, because it is categorical data, descriptive statistics are usually not carried out directly, but frequency distribution table or percentage distribution table is used to describe the sample number or proportion of different industries. As shown in Table 2:

Table 2. Distribution of industry attributes

Industry	N	Proportion (%)
manufacturing industry	45	30.00%
service sector	35	23.33%
information technology	25	16.67%
financial industry	15	10.00%
other	30	20.00%
amount to	150	100.00%

4.2. The Influence of GDT on GI

Firstly, correlation analysis is carried out to preliminarily understand whether there is correlation between *GDT* and *GI*. By calculating Pearson correlation coefficient, it is found that there is a significant positive correlation between *GDT* and *GI*, which means that the investment of enterprises in GDT may be closely related to the improvement of their green innovation ability (Table 3).

In order to further verify this relationship and explore other possible influencing factors, a multiple linear regression model is studied and constructed. Regression analysis was conducted with *GI* as the dependent variable and *GDT*, *Size*, *Age* and *Industry* as the independent variables (Table 4).

Table 3. Correlation analysis results

variable	Mean	Std. Deviation	r	p	N
GDT	6.75	1.62	0.65	< 0.01	150
GI	7.23	1.48	-	-	150

Table 4. Multiple linear regression results

variable	Non-standardized coefficient	Standardization coefficient	T value	significant level
constant	3.45	-	2.34	0.02*
GDT	0.67	0.45	4.67	<0.001***
Size	0.23	0.28	2.78	0.006**
Age	-0.05	-0.08	-0.98	0.33
Industry	0.10	0.07	1.12	0.27

Note: *, * * and * * respectively indicate significant at 10%, 5% and 1% levels, the same below.

The results of regression analysis show that the regression coefficient of *GDT* is significantly positive, indicating that GDT has a significant positive impact on GI level. At the same time, the regression coefficient of *Size* is also significantly positive, indicating that the larger the enterprise scale, the stronger its green innovation ability. However, *Age* and industry attribute *Industry* have no significant influence on the model.

4.3. Robustness Test

In Table 5, we can see that the regression coefficients of *GDT* and *Size* are significant in the original model and the two robust test models, and the directions are the same, which shows that the influence of these two variables on *GI* is robust. However, the significance of *Age* and *Industry* in the two robustness test models has not changed, indicating that their influence on *GI* may not be significant.

Table 5. Robustness test

variable	Regression coefficient of original model	Significance of original model	Regression coefficient of model 1	Model 1 significance	Regression coefficient of model 2	Model 2 significance
GDT	0.67	<0.001***	0.65	<0.001***	0.70	<0.001***
Size	0.23	0.006**	0.25	0.004**	0.21	0.010**
Age	-0.05	0.33	-0.03	0.45	-0.06	0.30
Industry	0.10	0.27	0.08	0.35	0.12	0.23

In the original model, robustness test model 1 and robustness test model 2, the regression coefficients of *GDT* are all significantly positive, and the coefficient values are relatively stable (0.67, 0.65, 0.70). This shows that the positive influence of *GDT* on *GI* is robust and not affected by model adjustment. The regression coefficients of *Size* in the three models are also significantly positive, and the coefficient values have little change (0.23, 0.25, 0.21). This shows that the positive influence of enterprise scale on *GI* is also stable, and the model adjustment has not changed this conclusion.

In all models, the regression coefficients of *Age* and *Industry* are not significant. This shows that no matter how the model is adjusted, the influence of enterprise age and industry attributes on *GI* is not significant, and this finding is also robust.

5. Conclusion and Suggestions

The investigation presented herein examines the impact of GDT on GI, elucidating its underlying mechanisms through empirical examination. The findings reveal that GDT exerts a substantial positive effect on GI, indicating that corporate commitment to GDT substantially augments their capacity for green innovation. Furthermore, the analysis indicates that firm size contributes positively to green innovation, whereas the influence of a company's age and industrial sector did not prove to be statistically significant within the scope of this research. Enterprises should actively embrace GDT as a key strategy to enhance their green innovation capability and competitive advantage. Specifically, enterprises can take the following measures:

Increase investment in green digital technology, and use technologies such as cloud computing, big data and Internet of Things to improve the efficiency of resource use and reduce environmental pollution in the production process. Cultivate awareness of green innovation, enhance employees' awareness of environmental protection through corporate culture construction, and encourage employees to participate in green innovation activities. Develop together with green supply chain partners, select suppliers that meet environmental protection standards, and jointly promote the greening of supply chain.

The government can play an important role in promoting GDT and green innovation, and proposes the following measures:

Provide policy support, introduce tax incentives, financial support and other policies to encourage enterprises to carry out GDT and green innovation. Strengthen supervision and standard setting, formulate strict environmental regulations and standards, and guide enterprises to transform into green development. Promote cooperation in Industry-University-Research, support universities and research institutions to carry out green technology innovation research, and promote the transformation and application of technological achievements.

Although some achievements have been made in this study, there are still some limitations: the sample of this study may not be extensive enough, and the universality of the study can be improved by expanding the sample range in the future. This study mainly focuses on variables such as GDT, enterprise scale, enterprise age and industry attributes, and other factors that may affect green innovation can be further considered in the future.

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