

Study on the Effect of Digital Transformation on Green Technology Innovation

-- Empirical Evidence from Chinese A-Share Listed Companies

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Abstract. In the context of the growing digital economy and China's push to build a market-oriented green technology innovation system, it is crucial to study whether digital transformation can promote enterprise green technology innovation for China's economic transformation and high-quality development. This paper empirically examines the impact of digital transformation on corporate green technology innovation using data from A-share listed companies in China from 2007-2019 as a research sample. The study finds that digital transformation can significantly promote corporate green technology innovation and the findings still hold after a series of robustness tests. The mechanism analysis shows that digital transformation promotes green technology innovation by reducing information asymmetry and improving the quality of internal controls. Further analysis reveals that digital transformation promotes green substantive innovation more than green strategic innovation based on the quality of innovation. Moreover, digital transformation has a stronger incentive effect on high-tech enterprises to conduct green technology innovation. This paper reveals the microscopic mechanism of digital transformation to promote green technology innovation and expands the research on digital transformation and green technology innovation, which can provide useful reference for promoting green economic growth and achieving carbon peaking and carbon neutrality goals in China.

Keywords: Digital Transformation; Green Technology Innovation; Information asymmetry; Quality of internal control.

1. Introduction

Since the reform and opening up, China's GDP has been growing at a medium to high speed every year, and economic development has made world-renowned achievements. However, the crude economic development model of high input, high energy consumption and high pollution has led to serious environmental pollution problems. The report to the 19th National Congress of the Communist Party of China proposed to "accelerate the reform of ecological civilization system and build a beautiful China", and explicitly requested to "build a market-oriented green technology innovation system". Green technology innovation is an important driving force for green development and an important means to promote the construction of ecological civilization, and enterprises, as the main body of innovation, should take the responsibility of accelerating green technology innovation and promoting the coordinated development of economy and environment to promote the sustainable development of China. However, the proportion of green patents in China is only 2%~3% of all patents over the years. There is a phenomenon of "favoring one over the other" in the relationship between non-green and green technology innovation, and enterprises emphasize non-green technology over green technology. On the one hand, this is because non-green technology innovation is often directly related to products and can bring direct economic benefits to enterprises, while green technology innovation brings more social benefits and has strong positive externalities. On the other hand, green technology innovation, due to its complexity, novelty and riskiness, makes enterprises lacking technological reserves and forward-looking vision still choose the original technology innovation route. Therefore, it is urgent to promote corporate change and thus green technology innovation.

At the same time, with the rapid development of new digital technologies represented by cloud computing, big data, Internet of Things, mobile Internet, artificial intelligence, etc., the deep integration of digital technology and traditional industries has released tremendous energy. China's 14th Five-Year Plan and the outline of 2035 Visionary Goals propose to "accelerate digital development and build a digital China". Therefore, in order to respond to the wave of digital development to seek new development models and economic growth points, more and more companies are integrating new digital technologies into their production, sales and even R&D and other important businesses, opening their own digital transformation road. Generally speaking, digital transformation can not only bring enterprises information technology improvement and reduce internal and external information asymmetry, but also further promote the change of enterprise organization and operation mode and strengthen the internal control of enterprises. However, at this stage, enterprises do not know enough about the importance and connection between digital transformation and green technology innovation, and the supporting role of digital transformation to enterprise green technology innovation has not been fully developed, and there are still many serious problems of enterprise green technology innovation that need to be solved.

In the context of synergistic development of the digital economy and green sustainability goals, the impact of digital transformation on corporate green technology innovation has attracted initial attention from academics. After literature combing, we found that the existing literature mainly studied the impact of digital transformation on corporate governance, corporate innovation, productivity, social responsibility and capital market performance, while there are still many gaps and deficiencies in the research on how digital transformation affects corporate green technology innovation activities. Based on this, this paper investigated the mechanism of digital transformation on corporate green technology innovation using data related to A-share listed companies in China from 2007-2019, and conducted a heterogeneity analysis based on substantive and strategic innovation and whether they belong to high-tech enterprises. The marginal contribution of this paper is reflected in the following aspects.

First, this paper reveals the micro mechanisms and impact effects of digital transformation on corporate green technology innovation using micro-level data of enterprises, showing that digital transformation can significantly promote corporate green technology innovation by reducing information asymmetry and improving the quality of internal control, which fills the gap of existing studies.

Secondly, this paper considers the analysis of green innovation quality and explores the heterogeneity of the impact of digital transformation on corporate green technology innovation based on substantive and strategic innovation. In addition, the influence of individual characteristics of enterprises is considered, and the samples are tested in groups based on whether they belong to high-tech enterprises, which enriches the relevant theoretical studies.

Third, most of the existing literature studying green technology innovation is based on a specific industry and lacks an overview description of the enterprise as a whole. In this paper, the research sample is selected more comprehensively to avoid the research bias that may be brought by selecting enterprises in a specific industry as the research sample.

Fourth, from a practical perspective, this paper analyzes the relationship between digital transformation and enterprise sustainable development from the perspective of green technology innovation, and reveals the synergistic development path between digital transformation and green sustainable development, which can provide useful reference for promoting China's green economic growth and the realization of the carbon peaking and carbon neutrality goals.

2. Literature Review

2.1 Digital transformation

The existing literature has studied the economic consequences of digital transformation mainly in terms of corporate governance, corporate innovation, productivity, social responsibility, and capital

market performance. In terms of corporate governance, Wei et al. found that digitalization improves governance by reducing the degree of information asymmetry in governance, and the lower the information asymmetry, the more beneficial it is for firms to strengthen their governance. Qi et al. found that digital transformation improves corporate governance by reducing the degree of information asymmetry and the irrationality of managers' decision-making behavior. In terms of corporate innovation, Zhang and Du found that digitalization only promoted "incremental" but not "qualitative" technological innovation in manufacturing listed companies. And Cong and Zhang also found that digital technology promoted high quality innovation by increasing the quantity of innovation output and improving human capital of enterprises using data from listed manufacturing enterprises. And Xiao et al. found, based on a full sample of A-share listed companies in China, that the increase in the degree of digital transformation still significantly promoted corporate innovation input, innovation output and innovation efficiency. In terms of productivity, Wang et al. found an inverted U-shaped relationship between digital transformation and firms' total factor productivity. Tu and Yan found that digital transformation had a significant enhancement effect on their total factor productivity, and the effect was more pronounced over time. In terms of CSR, Shen et al. argue that digitalization can enhance the willingness and ability of enterprises to fulfill their social responsibility, and enhance their social responsibility fulfillment through the path of improving management mechanisms, improving production methods, and improving external relationships. Xiao et al. found that digital transformation has a significant empowering effect on CSR and can significantly improve CSR performance. In terms of capital market performance, Wu et al. found that digital transformation significantly improved stock liquidity and showed certain structural heterogeneity characteristics. Zhang et al. found that digital transformation can contribute to capital allocation efficiency through two paths: enhancing corporate information transparency and reducing corporate financing constraints.

2.2 Green technology innovation

There have been many previous studies on green technology innovation, especially on the influencing factors of green technology innovation, mainly in terms of firm management, corporate governance, environmental regulation, environmental information disclosure, and financial policies. From the perspective of company management, Shen et al. found that returnee directors focused on corporate reputation management would increase the proportion of green technology innovation to the overall corporate technology innovation, improve the quantity and quality of green technology innovation output, and thus promote corporate green technology innovation activities. Zhang and Shi, on the other hand, found that CEO academic experience can promote corporate green technology innovation to a certain extent. From the perspective of corporate governance, Geng argue that a good and stable corporate internal control environment makes the corporate monitoring system work effectively and prevents executives from making self-interested decisions and takes more social responsibility for the long-term development of the company, thus promoting the investment in green innovation. From the perspective of environmental regulation, Tao et al. found that while the implementation of the environmental protection target responsibility system promoted the expansion of the number of green patent applications, it also led to a decline in the quality of related innovation activities. From the perspective of heterogeneity of environmental regulation tools, Li and Xiao found that emission charges "pushed" enterprises' green innovation capacity, while environmental subsidies "squeezed" enterprises' green innovation capacity. From the perspective of environmental information disclosure, Wang, Xin, and Wang, Ying find that after the implementation of the Ambient Air Quality Standard, the incentive for green innovation in high-environmental-risk industries, especially state-owned enterprises and non-patent-intensive enterprises, increases significantly. From the financial policy perspective, Xin Wang and Ying Wang find that after the implementation of the Green Credit Guidelines, green innovation performance in green credit-restricted industries is more active compared to non-green credit-restricted industries, but the quality of green innovation is not significantly improved. In contrast, Wu and You find that while the quantity of green technology

innovations of the underlying firms increases significantly after the implementation of the financing and financing trading system, the quality of green innovations of the underlying firms likewise does not change significantly .

And there are fewer studies on digital transformation and green technology innovation in the existing literature, and there are still many gaps and deficiencies on how digitalization affects enterprise green technology innovation. First, although some scholars have studied the impact of digital transformation on enterprise green technology innovation, most of them choose heavy polluting enterprises or resource-based enterprises as research samples, while digital transformation is the current trend of enterprise development, and its impact on enterprise green technology innovation is bound to produce biased conclusions if it is limited to specific types of enterprises for research. Secondly, there is a lack of micro data use, and some of the studies only use industry or regional panel data, which cannot study the promotion mechanism of digitalization on green technology innovation from enterprises as the main body of digitalization and green technology innovation. Third, there is a lack of in-depth research on the influence of heterogeneity factors on digital transformation to promote green technology innovation. Most of the literature only studies whether digital transformation promotes green technology innovation in enterprises, and there is little heterogeneity analysis involving the quality of green innovation and individual characteristics of enterprises.

3. Theoretical Analysis and Research Hypothesis

3.1 Path analysis based on the reduction of information asymmetry

The specialized nature of innovation activities and the uncertainty of its output often make the innovation process imply high information asymmetry . Internal information asymmetry will make enterprises' investment efficiency decrease, and external information asymmetry will lead to investors' misjudgment of enterprises, overestimate the value of enterprises engaged in a large number of innovation activities, and induce adverse selection problems, thus increasing the difficulty of enterprises' financing, which is not conducive to enterprises' green technology innovation activities.

Digital transformation can help alleviate the information asymmetry problem faced by enterprises and promote their green technology innovation. From the perspective of internal information asymmetry, enterprises will produce a large amount of data information in their long-term internal production and operation, but due to the lagging data and information processing ability of traditional enterprises, it will lead to the accumulation and precipitation of this information without being effectively mined, which will eventually lead to the loss of information . Digital transformation, on the other hand, can make its data mining and processing capabilities significantly improve, transforming the accumulated information into standardized and structured data and increasing the degree of information availability . Therefore, with the enhanced data processing capability brought about by digital transformation, enterprises can analyze their business status data more comprehensively and systematically, reasonably assess the risks of their innovation projects and identify high-value innovation projects, thus improving their investment efficiency and fundamentally improving the quantity and quality of their innovation investment . From the perspective of information asymmetry outside the enterprise, digital transformation can "push" information to market players by better processing and outputting effective information, and market investors outside the enterprise have a better grasp of the enterprise's information, which strengthens positive market expectations. In addition, digital transformation has become a social consensus, and enterprises that implement digital transformation strategies tend to have higher expectation levels from market investors because they follow the new trend of digital economy development, which further strengthens positive market expectations, thus the risk premium required by external institutions to inject capital into enterprises will be reduced, and the financing cost of enterprises will decrease, which motivates enterprises to increase their investment in green technology innovation . In summary, digital transformation increases the transparency of internal and external information of

enterprises, improves their investment efficiency and alleviates financing constraints, which in turn promotes green technology innovation.

3.2 Path analysis based on improving the quality of internal control

In the context of the rapid development of the digital economy, the digital transformation and accelerated growth of industry has become an important supporting force for national economic development, and the transformation from enterprise informatization to enterprise digitalization has become an inevitable trend for future development. Compared with traditional enterprise informatization, digital transformation is more focused on strategic transformation, performance growth and value creation, and its objectives are basically consistent with those of internal control, and digital transformation will bring about improvement in the quality of internal control. On the one hand, digitalization as an organizational management tool has the advantages of information supervision and auditing, and the management processes of production management, procurement management, sales management, quality management, and financial management of enterprises are more transparent, which can effectively reduce organizational agency costs and improve the quality of internal control. On the other hand, the application of digital technologies such as big data and cloud computing can improve the management capabilities of managers, help enterprises improve their internal control systems, and improve the quality of internal control.

And high quality internal control can have an effect on technological innovation activities in many ways and promote green technological innovation in enterprises. Firstly, a high-quality internal control system can improve the efficiency of information exchange and communication within the enterprise and improve the quality of information, which in turn helps the enterprise to effectively face and deal with the business risks arising from innovation activities. Secondly, high-quality internal control can improve the integrity of corporate accounting information reporting, enable external organizations to accurately judge the future profitability of enterprises, alleviate corporate financing constraints and reduce financing costs, thus alleviating financial risks such as shortage of funds that may arise from high investment in green technology innovation and promoting enterprises to increase investment in green technology innovation. Again, the COSO report emphasizes that internal control should be integrated with the business management process to monitor the formulation and execution of corporate decisions, including the direction of the use of corporate funds. The effective supervision brought by high-quality internal control can ensure that corporate funds are continuously invested in innovation activities, reduce the possibility of illegal misappropriation of funds, and prevent executives from making self-interested decisions while taking more social responsibility for long-term corporate development and promoting corporate investment in green innovation. In addition, high-quality internal control can improve corporate governance, improve incentive mechanisms, help cultivate executive risk-taking spirit, make executives take risks for innovation and increase green innovation investment. And it can create a better innovation environment for companies, which helps to attract innovative technical talents and promote the level of green innovation. Finally, high-quality internal control helps innovation information to be effectively transmitted between management and various departments of the enterprise, makes the creation and approval of innovation projects more standardized, helps management to understand and analyze innovation activities in a timely manner, reasonably invest in technological innovation based on innovation information, and avoid inefficient investment behaviors of under-investment or over-investment in innovation. In summary, digital transformation can improve the quality of internal control and thus improve the level of green technology innovation in enterprises.

Based on this, this paper proposes:

Hypothesis 2 (H2). Other things being equal, digital transformation can significantly contribute to corporate green technology innovation

Hypothesis 2 (H2). Other things being equal, digital transformation promotes corporate green technology innovation by reducing information asymmetry and improving the quality of internal controls.

4. Study Design

4.1 Data sources and sample selection

In this paper, we select the data of Chinese A-share listed companies from 2007-2019 as the initial sample, and screen the data as follows: (1) exclude the samples of ST and *ST companies; (2) exclude the samples of financial companies; (3) remove the samples with missing observations of variables; (4) control the effect of extreme values, and perform the upper and lower 1% tailing process (Winsorise) for all continuous variables. After the above screening, a total of 28,772 samples were obtained in this paper. The main data in this paper are obtained from the Cathayan database (CSMAR) and Incopat database.

4.2 Variable definition and descriptive statistics

4.2.1 Enterprise green technology innovation level.

This paper uses the total number of green invention and utility model patent applications (Greentot) of listed companies in the current year as a proxy variable for the number of green technology innovation indicators, and takes the natural logarithm of this variable to solve the problem of skewed distribution, drawing on the study of Wu Gezhi et al. (2022). Compared with the number of patents granted, the use of patent application data is more reliable and timely, and fits better with the problem studied in this paper.

4.2.2 Degree of digital transformation

In this paper, based on the study by Fei Wu et al., the annual reports of listed companies were collected and organized by Python crawler function, and used as a data pool. Based on this data pool, we search, match, and count the word frequencies based on four categories of characteristic words: artificial intelligence technology, big data technology, cloud computing technology, and blockchain technology, and then categorize the word frequencies of key technology directions and form the final summed word frequencies to build an index system of enterprise digital transformation. Finally, the indexes are logarithmically processed to eliminate the "right bias" feature, and the digital transformation degree measurement index (Digital) is obtained.

4.2.3 Control variables

Table 1. Descriptive statistics values of main variables

Variables	Average value	Standard deviation	Median	Minimum value	Maximum value
<i>Greentot</i>	0.416	0.829	0.000	0.000	3.784
<i>Digital</i>	1.032	1.302	0.693	0.000	4.844
<i>Size</i>	22.020	1.300	21.839	19.541	26.048
<i>Age</i>	2.768	0.382	2.833	1.386	3.434
<i>Roa</i>	0.041	0.057	0.039	-0.216	0.200
<i>Lev</i>	0.428	0.211	0.419	0.049	0.929
<i>Growth</i>	0.179	0.458	0.105	-0.591	3.073
<i>Tobinq</i>	1.995	0.916	2.197	0.000	3.258
<i>Board</i>	2.143	0.200	2.197	1.609	2.708
<i>Indep</i>	0.373	0.053	0.333	0.313	0.571

To control for other indicators of economic characteristics that affect the green technology innovation of enterprises, a series of control variables are introduced in this paper. (1) Enterprise size (Size): natural logarithm of total enterprise assets; (2) Enterprise age (Age): logarithm of the length of time the enterprise has been listed; (3) Return on assets (Roa): pre-tax profit over total assets; (4) Capital structure (Lev): total liabilities/total assets; (5) Enterprise growth (Growth): (current period operating revenue - previous period operating revenue)/ (6) Tobin's Q(Tobinq): the natural logarithm of Tobin's Q; (7) Board size(Board): the natural logarithm of the number of board members; (8) Board independence(Indep): the proportion of the number of independent directors to the total number of

board members; (9) Dual chairman and CEO (Dual): control whether the CEO and the chairman of the board both control CEO power, 1 if yes, 0 otherwise. descriptive statistics are shown in Table 1.

4.3 Model Setting

$$Greentot_{it} = \beta_0 + \beta_1 Digital_{it} + \rho X + \delta_t + \gamma_j + \varepsilon_{it} \quad (1)$$

In the model, i , j , and t denote listed companies, industries, and time, respectively. The explanatory variable is *Greentot*, which indicates the level of green technology innovation of enterprises based on the number of green patents. The core explanatory variable is *Digital*, which indicates the degree of digitalization of enterprises based on word frequency data measures, and the coefficient β_1 reflects the impact of digital transformation on enterprises' green technology innovation. In order to absorb the effects of unobservable factors at industry and time levels on the technological innovation capability of enterprises, this paper adds 2 fixed effects at year (δ_t) and annual industry (γ_j) levels, and ε_{it} it is the residual term.

5. Analysis of empirical results

5.1 Digital transformation and enterprise green technology innovation

Table 2 reports the regression results of digital transformation on firms' green technology innovation. Column (1) shows the regression results with only the core explanatory variables included, and the *Digital* regression coefficient is significantly positive at the 1% level. Column (2) includes the control variables, and the *Digital* regression coefficient is still significantly positive at the 1% level. With the inclusion of industry-year fixed effects in column (3), the *Digital* regression coefficient is still significantly positive at the 1% level. The above results indicate that digital transformation significantly improves the green technology innovation capability of firms in both economic and statistical sense.

Table 2. Digital Transformation and Enterprise Green Technology Innovation

	(1) <i>Greentot</i>	(2) <i>Greentot</i>	(3) <i>Greentot</i>
<i>Digital</i>	0.103*** (24.580)	0.087*** (20.578)	0.052*** (10.194)
<i>Roa</i>		0.122 (1.472)	0.582*** (7.177)
<i>Size</i>		0.169*** (30.545)	0.174*** (31.270)
<i>Age</i>		-0.001 (-0.040)	-0.016 (-1.008)
<i>Growth</i>		0.008 (0.997)	0.015* (1.941)
<i>Board</i>		-0.008 (-0.263)	0.104*** (3.476)
<i>Indep</i>		-0.032 (-0.280)	0.063 (0.609)
<i>Lev</i>		0.046* (1.823)	0.107*** (4.025)
<i>Tobinq</i>		-0.133*** (-19.865)	-0.049*** (-7.446)
<i>Dual</i>		-0.025** (-2.211)	-0.004 (-0.413)
<i>Controls</i>	No	Yes	Yes
<i>Ind & year</i>	No	No	Yes
<i>_cons</i>	0.309*** (55.794)	-3.080*** (-21.778)	-3.956*** (-27.464)
<i>N</i>	28772	28772	28772
<i>adj. R²</i>	0.026	0.089	0.228

Note: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Same as the table below.

5.2 Robustness test

First, endogeneity test. Considering the possible endogeneity between digital transformation and corporate green technology innovation. In this paper, we use one period lag of digitalization (L.Digital) as the instrumental variable and two-stage least squares (2SLS) method for regression test, and the results are shown in Table 3. from the regression results of the first stage, it can be seen that the coefficient of L.Digital is 0.805 and significant at 1% level, which is consistent with the expected results. From the regression results of the second stage, it can be seen that the coefficient of Digital is 0.069 and is significant at the 1% level, indicating that digital transformation can still significantly contribute to corporate green technology innovation after considering the endogeneity issue.

Table 3. Robustness test

	Digital	Greentot
	(1)	(2)
	Phase I	Phase II
Digital		0.069*** (11.038)
L.Digital	0.805*** (197.895)	
Controls	Yes	Yes
Ind & year	Yes	Yes
_cons	-0.381** (-3.288)	-3.871*** (-26.824)
N	25827	25827

Second, the relative indicator of green patent data is considered to remove the influence of other unobservable factors, thus alleviating the possible endogeneity problem in the empirical evidence. In this paper, the relative indicator of the number of green patent applications to total patent applications (Greenratio) is used for robustness testing. The corresponding regression results are reported in column (1) of Table 4. It can be seen that the findings are consistent with Table 2 after replacing the explanatory variables.

Third, considering the possible omitted variable problem, this paper introduces the proportion of R&D investment (Rd) and the shareholding ratio of the top shareholder (Top1) in model (1). The corresponding regression results are reported in column (2) of Table 4. As can be seen, the findings are consistent with Table 2 after the omitted variables are introduced.

Fourth, considering that the State Intellectual Property Office (SIPO) has modified the method of counting patent application data, starting from 2017, the scope of SIPO statistics only includes patent applications for which filing fees have been paid; before that, the scope of SIPO statistics covered all patent applications received. This may affect the robustness of the above regression results, and a re-regression is conducted in this paper after excluding the observations in 2017. The corresponding regression results are reported in column (3) of Table 4. It can be seen that the findings are consistent with Table 2 after excluding the 2017 sample.

Combined with the above analysis, the hypothesis H1 of this paper holds.

Table 4. Other robustness tests

	Replacing the explanatory variable	Introduction of omitted variables	Excluding the 2017 sample
	(1)	(2)	(3)
	Greenratio	Greentot	Greentot
Digital	0.059** (2.518)	0.048*** (6.983)	0.051*** (9.353)
Controls	Yes	Yes	Yes
Ind & year	Yes	Yes	Yes
_cons	0.186** (2.049)	-5.723*** (-23.022)	-3.924*** (-26.232)
N	3818	15437	25681
adj.R ²	0.074	0.222	0.229

6. Mechanism Analysis

According to the previous analysis, digitization may promote firms to engage in green innovation activities by improving information asymmetry and enhancing the quality of internal controls. In this paper, a mediation model is used to test this. The specific model is as follows:

$$Greentot_{it} = \beta_0 + \beta_1 Digital_{it} + \rho X + \delta_t + \gamma_j + \varepsilon_{it} \quad (2)$$

$$Mechanism_{it} = \beta_0 + \beta_1 Digital_{it} + \rho X + \delta_t + \gamma_j + \varepsilon_{it} \quad (3)$$

$$Greentot_{it} = \sigma_0 + \sigma_1 Digital_{it} + \sigma_2 Mechanism_{it} + \rho X + \delta_t + \gamma_j + \varepsilon_{it} \quad (4)$$

Among them, $Mechanism_{it}$ denotes the mediating variable, which specifically contains two mechanism variables: Asy and Ic , Asy is the variable that tests the mechanism of information asymmetry mediation, and Ic is the variable that tests the mechanism of internal control quality. All other variables are defined in line with model (1).

6.1 Information asymmetry mechanism test

The digital transformation of enterprises draws on cutting-edge digital technologies to process information and can largely improve the information asymmetry of enterprises. In this paper, drawing on the study of Luxia Yi et al. , the intensity of analyst attention is used to reflect the degree of information asymmetry (Asy) of the firm. Table 5 reports the information asymmetry mechanism test. From column (1) of Table 5, it can be seen that digitization can significantly improve the degree of information optimization and reduce information asymmetry in firms. From column (2) of Table 5, it can be seen that there is a partial mediation effect as the coefficient of $Digital$ is significantly positive and the absolute value of the coefficient of $Digital$ decreases. This empirical result is consistent with the previous theoretical analysis, which indicates that digitalization improves the information asymmetry problem faced by enterprises by increasing the degree of information optimization, and thus significantly improves the level of green technology innovation of enterprises.

6.2 Internal control quality mechanism test

Drawing on the study of Zhou Weihua et al. , this paper measures the quality of internal control (Ic) based on the internal control index published by Shenzhen Dibo Big Data Research Center, which can reflect the level of internal control and risk management capability of listed companies. Table 5 reports the mechanism test of internal control quality. From column (3) of Table 5, it can be seen that digitization can significantly improve the quality of internal control of companies. From column (4) of Table 5, it can be seen that there is a partial mediation effect as the coefficient of $Digital$ is significantly positive and the absolute value of the coefficient of $Digital$ decreases. This empirical result is consistent with the previous theoretical analysis, indicating that digitalization significantly improves the level of green technology innovation of enterprises by improving the quality of their internal control.

Combining the above analysis, hypothesis H2 of this paper holds.

Table 5. Mechanism test results

	Information asymmetry mechanism test		Internal control quality mechanism test	
	(1) <i>Asy</i>	(2) <i>Greentot</i>	(3) <i>Ic</i>	(4) <i>Greentot</i>
<i>Digital</i>	0.076*** (13.589)	0.048*** (9.420)	0.033*** (4.309)	0.047*** (8.842)
<i>Asy</i>		0.050*** (9.806)		
<i>Ic</i>				0.012*** (3.676)
<i>Controls</i>	Yes	Yes	Yes	Yes
<i>Ind & year</i>	Yes	Yes	Yes	Yes
<i>_cons</i>	-9.172*** (-60.562)	-3.496*** (-23.068)	-0.791*** (-3.031)	-3.965*** (-26.609)
<i>N</i>	28772	28772	26535	26535
<i>adj. R²</i>	0.443	0.231	0.235	0.235

7. Further Analysis

7.1 Heterogeneity based on substantive and strategic innovation

It has been found that Chinese listed companies simply pursue "quantity" and neglect "quality" in green innovation, while the quality of green innovation is of strategic importance to the development of green innovation and the achievement of China's "carbon neutrality" goal. The quality of green innovation is of strategic importance to the development of green innovation and the realization of China's "carbon neutral" goal. Drawing on the metric of Jinko Liu et al., this paper divides green innovation into substantive innovation and strategic innovation according to the type of patents, with invention patents as substantive innovation and utility patents as strategic innovation. The ratio of the number of green invention patents to the total number of patents is used to measure the level of green substantive innovation, and the ratio of the number of green utility patents to the total number of patents is used to measure the level of green strategic innovation. Based on this regression analysis, the regression results are shown in Table 6. column (1) shows the estimation results of green substantive innovation level, and the coefficient of Digital is 0.049 and significant at the 1% level, indicating that digital transformation can significantly promote green substantive innovation. The coefficient of Digital is 0.015, which is significant at the 1% level, indicating that digital transformation can significantly promote green strategy innovation, but the enhancement effect is weaker compared to green substantive innovation. The possible reason is that, compared with invention patents, utility model patents have a lower degree of embedded innovation, and most of their innovation points revolve around the shape and structure of products, thus companies face fewer difficulties in the process of utility model patent development compared with invention patents. The digital transformation has enhanced the availability of advanced technologies and data, shortened the spatial distance between enterprises and external technologies and knowledge, and provided better conditions and foundation for enterprises to overcome difficulties in substantive innovation. Therefore, digital transformation has a stronger role in promoting green substantive innovation in enterprises compared to green strategic innovation.

Table 6. Heterogeneity based on substantive and strategic innovation

	(1) <i>Greenino</i>	(2) <i>Greenfm</i>
<i>Digital</i>	0.049*** (11.565)	0.015*** (4.031)
<i>Controls</i>	Yes	Yes
<i>Ind & year</i>	Yes	Yes
<i>_cons</i>	-3.218*** (-26.420)	-2.626*** (-24.354)
<i>N</i>	28772	28772
<i>adj.R²</i>	0.201	0.200

7.2 Heterogeneity based on whether it is a high-tech enterprise

The enhancement effect of digital transformation on the level of green technological innovation of enterprises is influenced by the level of technological innovation of the enterprises themselves. In this paper, the dummy variable of whether it belongs to high-tech enterprises is used to divide listed companies into two groups, and the impact of digitalization on green technological innovation of enterprises with different technological innovation levels is compared by means of group regression, and the regression results are shown in Table 7. columns (1)-(2) are the group estimation results according to whether it is a high-tech enterprise sample, and the regression coefficients of Digital are 0.061 and 0.030, respectively. Both are positively significant at the 1% level, and the comparison of the absolute magnitude of the coefficients reveals that the incentive effect of digital transformation on corporate green innovation is more significant in high-tech enterprises. Column (3) shows the estimation results after introducing the Th×Digital cross product term, and it can be seen that the coefficient of Th×Digital is significantly positive at the 1% level, which indicates that the effect of

digital transformation on green technology innovation is stronger in high-tech enterprises compared to non-high-tech enterprises. The possible reason is that, compared with non-high-tech enterprises, high-tech enterprises have faster technological update iteration and higher competitive pressure in the industry, and their willingness to promote technological innovation through digital transformation is stronger, so the promotion effect of digitalization on high-tech enterprises' green technological innovation is stronger compared with non-high-tech enterprises .

Table 7. Heterogeneity based on whether it is a high-tech enterprise

	(1) <i>Greentot</i>	(2) <i>Greentot</i>	(3) <i>Greentot</i>
<i>Digital</i>	0.061*** (8.313)	0.030*** (4.885)	0.024*** (3.918)
<i>Th</i>			0.172*** (14.237)
<i>Th</i> × <i>Digital</i>			0.042*** (5.327)
<i>Controls</i>	Yes	Yes	Yes
<i>Ind & year</i>	Yes	Yes	Yes
<i>_cons</i>	-6.265*** (-24.971)	-2.452*** (-15.559)	-4.092*** (-28.609)
<i>N</i>	15703	13069	28772
<i>adj. R²</i>	0.231	0.238	0.239

8. Conclusions and Recommendations

In the context of the digital economy wave and China's vigorous promotion of green development, it is important to study the relationship between digital transformation and enterprise green technology innovation to achieve a "win-win" situation between digital economy and green development in China. This paper empirically examines the impact of digital transformation on corporate green technology innovation using data of Chinese A-share listed companies from 2007 to 2019. It is found that: (1) digital transformation can significantly promote corporate green technology innovation, and this finding still holds after a series of robustness tests such as endogeneity test, adding omitted variables and changing estimation methods. (2) Mechanism analysis shows that digital transformation promotes corporate green technology innovation by reducing information asymmetry and improving the quality of internal control. (3) Further analysis shows that, based on the quality of innovation perspective, digital transformation promotes green substantive innovation in firms more strongly than green strategic innovation. And digital transformation has a stronger incentive effect on high-tech enterprises to conduct green technology innovation. Based on the above research findings, this paper puts forward the following suggestions.

(1) Government departments should improve the digital transformation governance system, encourage and guide enterprises to carry out digital transformation plans, and implement the application of digital technology in the process of enterprise R&D innovation and energy saving and emission reduction management. Enterprises should strengthen the awareness of digital transformation, formulate scientific and reasonable digital development plans, promote the deep integration of advanced artificial intelligence technology, blockchain technology, cloud computing technology, big data technology and other technologies with the company's business, thus improving the level of green technology innovation and empowering the sustainable development of enterprises with digitalization.

(2) Enterprises should make full use of digital technology to implement digital transformation into all aspects of their production and operation, thus strengthening their ability to mine and process data and information, reducing information asymmetry, strengthening positive market expectations, and thus reducing the cost of financing green technology innovation. In addition, enterprises should

further optimize the quality of internal control operations and open up the intermediary channel for digital development to promote green technology innovation.

(3) Government departments need to fully consider the heterogeneous characteristics of enterprises when implementing and supervising relevant policies. Policy support should be given to the green technology innovation characteristics and needs of different types of enterprises to encourage high-quality green substantive innovation. And for high-tech industries whose core competitiveness is technological innovation, the government should increase policy support and strengthen green credit support to stimulate enterprises to carry out green technological innovation activities.

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