The Impact of Digital Transformation on Green Innovation in Business

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Abstract: When it comes to global sustainability and digital growth right now, digital transformation has a huge effect on businesses. This paper is mostly based on statistics from China's publicly traded companies from 2014 to 2023. The study looks at the real-world connection between going digital and green innovation, and it talks about the role of government funding in this connection. The study clearly showed that, at its core, digital change plays a pretty big part in encouraging businesses to come up with green ideas. For the most part, government subsidies also make the link between digital transformation and green innovation less strong.

Keywords: digital transformation, green innovation, government subsidies, corporate sustainability

1. Introduction

Green development has become an important goal for promoting sustainable economic growth as global climate change and environmental problems get worse. It has also become a key road for socio-economic development. Businesses are the main drivers of economic activity, so their ability to come up with green ideas has a direct impact on reaching sustainable development goals. Similarly, digital transformation is drastically altering how businesses make and run their operations, pushing them to follow a effective path of growth. The use of digital technologies enhances business productivity while also opening up new opportunities for green innovation. Investigating how digital transformation influences corporate green innovation is valuable both theoretically and practically, offering valuable insights for real-world business applications.

Given the pressing challenges posed by global climate change and environmental concerns, China actively implements the new development concept, accelerates economic restructuring and industrial upgrading, Encourage the high-quality growth of businesses that use digital technology. The National 14th Five-Year Plan also makes it clear that it wants to strongly support the growth of the digital economy, speed up the digital transformation of businesses, and make green technology more innovative.

This study looks at how companies' digital change affects their green innovation by asking a few main questions: Does digital transformation really promote green innovation in enterprises? In what ways do digital technologies influence firms' green innovation through various channels? Is the impact moderated by government subsidy factors?

By analyzing these issues in depth, this study hopes to provide a theoretical basis for the government to formulate relevant policies and a practical guide for enterprises to develop digital and green development strategies.

2. Theoretical analysis and research hypotheses

2.1. Impact of digital transformation on green innovation in business

Digital transformation is the process through which a company undergoes significant changes in its business model, operations, products and services. By integrating big data and cloud computing to the greatest degree of detail [1]. When it comes down to it, digital transformation is mostly about using digital technology to help a business be more innovative. Operational effectiveness and market competitiveness can be greatly enhanced through digital transformation. The process of digitizing business operations significantly boosts the level of green technological innovation, with a more pronounced impact on advancing green invention patents that demonstrate a higher degree of originality [2]. In fact, digital transformation is very effective for the development of enterprises. Sustainable development is becoming more and more important to more and more people these days. This means that digital transformation is not only a new way for businesses to grow, but it also gives green innovation a boost in some ways.

Digital transformation positively impacts green innovation in companies in the following ways:

To begin with, the use of digital technologies, particularly big data, cloud computing, and the Internet of Things, can greatly improve the efficiency of research and development in enterprises [3]. The use of big data technologies enables enterprises to identify potential opportunities for green innovation through the analysis of large amounts of environmental data, production process data and market demand data.

Secondly, the application of intelligent production management system helps enterprises optimize the management of resources and reduce energy waste and raw material consumption. During digital transformation, IoT technology enables the real-time tracking and data gathering of equipment. By analyzing this data, businesses can better forecast resource needs and energy usage throughout the production process. This not only improves the efficiency of resource utilization, but also helps enterprises identify and eliminate sources of waste and environmental pollution in production, thus promoting green innovation.

Finally, digital transformation, by its nature, really provides greater support for the design and production of green product [4]. Enterprises can optimize the design process of green products through digital technology, so that they can meet market demand while being more in line with the requirements of environmental protection and resource conservation. For example, using digital technology, enterprises can significantly reduce product manufacturing costs and energy consumption and improve production efficiency through 3D printing and digital design.

H1: Digital transformation has a positive impact on corporate green innovation.

2.2. Moderating role of government subsidies on the relationship between digital transformation and green innovation

As a policy measure, government funding can help companies that are going digital by easing their financial burdens and by providing substantial support for green innovation. This is especially important in the early stages of going digital, when businesses often have to spend a lot of money on technology and change. In this context, government subsidies can effectively lower these expenses, provide financial backing, and ease the challenges businesses may face during the transition. As a result, government subsidies not only act as financial incentives for digital transformation but also foster the alignment of green innovation with sustainable development goals.

Most of the time, government subsidies are a big part of digital change and green innovation. These can help businesses grow by easing the stress they're under. First of all, enterprises often face high financial needs in the early stage of digital transformation, and need to invest a lot of resources in IT upgrading, equipment renewal and personnel training, which may be difficult to reap returns in the short term. Government subsidies can provide the necessary financial support at this stage, helping enterprises to reduce their financial burden and giving them more incentive to push forward with digitization and laying the foundation for green innovation [5]. Second, green innovation usually requires sustained R&D investment, but due to long technology development cycles and high market uncertainty, enterprises may reduce their innovation investment due to financial constraints. Government subsidies can motivate companies to boost their research and development activities by providing direct financial support or offering tax breaks. This helps drive the creation and adoption of green technologies, improve the environmental performance of their products, and speed up the commercialization and widespread use of these technologies [6]. Finally, government subsidies can also play a policy-guiding role in prompting enterprises to devote more resources to green investments, especially when green technologies are not yet mature and market demand is not yet stable, and enterprises may lack sufficient confidence to invest. By providing financial assistance, the government can lower the investment risks faced by businesses, encourage their involvement in green innovation, and foster the connection between digital transformation and sustainable development.

H2: Government subsidies play a positive moderating role between digital transformation and corporate green innovation.

3. Model construction

3.1. Research sample and data sources

The exact research objects in this study are Chinese companies that went public between 2014 and 2023. During the whole study, the following steps are taken with certain samples: (1) All insurance and financial samples were thrown out; (2) samples with mostly missing data were thrown out; and (3) To avoid data errors, continuous factors in the data were shrunk by 1% up or down. The information in this piece comes from CSMAR and cnrds.

3.2. Definition of variables

3.2.1. Explained variable: firms' green innovation (Green)

Green innovation shows how companies protect the environment during technology research and production, as well as how they contribute to long-term growth. It's a key sign of how innovative a company is when it comes to protecting the environment and saving resources.

Green Innovations1 = ln(number of green inventions independently filed in the year+ number of green utility models independently filed in the year +1)

Green innovations2 = ln(number of green inventions independently filed in the year + 1)

3.2.2. Explanatory variable: digital transformation of enterprises (Dig)

Big data, cloud computing, the Internet of Things, and other digital technologies are being used by businesses to improve their efficiency and ability to come up with new ideas. This process is called "digital transformation," and it involves changing how businesses work, how they are managed, and how they use technology. This study looks at how often 76 terms related to digitalization appear in five groups: artificial intelligence, big data, cloud computing, blockchain, and the use of digital technologies [7].

3.2.3. Moderating variable: government subsidies

Government subsidies (GS) reflect financial assistance provided by national or local governments to support innovation, transformation, and sustainable development of enterprises, and are important incentives to promote green innovation and digital transformation of enterprises [8].

Table 1: Definitions of key variables

Variable category	variable name	Variable Interpretation
explanatory variable	Green Innovation 1 (Green1)	Ln (number of green inventions independently filed in the year+ number of green utility models independently filed in the year +1)
	Green Innovation 2 (Green2)	Ln (number of green inventions independently filed in the year + 1)
explanatory variable	Digital Transformation (Dig)	Text mining of annual reports of listed companies using Python to form dummy variables for digital transformation
control variable	Enterprise size (Size)	Ln (total assets)
	Shareholding concentration (Toph)	Shareholding ratio of top ten shareholders (%)
	Business Growth (Gro)	Main revenue growth rate
	Cash holdings (Cash)	Net cash flows from operating activities
	Return on total assets (Roa)	Return on Assets= Net Profit/Average Total Assets
heterogeneity test	Nature of shareholding (State)	State-controlled enterprises take the value of 1, others 0
	Nature of Pollution (Pollution)	Polluting enterprises take the value of 1, non-polluting enterprises take the value of 0

3.3. Modeling

In the whole process of the research, in order to truly and comprehensively test the specific impact of digital transformation on enterprises, a multiple regression model with green innovation (green) as explanatory variable and enterprise digital transformation (Dig) as explanatory variable was established on this basis. This study controls the model for industry effect (Industry) and year effect (Year).

$$\text{Green}_{i,t+1} = \alpha + \beta_1 \text{Dig}_{i,t} + \text{Controls} + \sum \text{Industry} + \sum \text{Year} + \varepsilon_i \tag{1}$$

Where Green denotes the firm's green innovation, Dig represents the degree of digital transformation, Controls are control variables including firm size, equity concentration, firm growth, cash holdings, return on total assets, and nature of equity, i denotes the firm, and t denotes time.

4. Empirical analysis

4.1. Descriptive statistics

Statistics that describe the main factors are shown in Table 2. It shows that there is a big difference in green innovation between the sample businesses. This difference could be due to the size of the business, the nature of the industry, policy support, or the business's own sustainable development

strategy. The mean value of green innovation for businesses is 0.36, the lowest value is 0, and the highest value is 3.61. We can see from the data that the standard deviation is 1.41 and the average digital transformation (Dig) for the whole company is 1.58. The least possible number is 0 and the most possible value is 5.04. We can see from these numbers that the amount of digital transformation varies a lot between businesses. An example of this is that study shows that some businesses are still in their early stages. Government support (GSw) ranges in value from 11.67 to 20.19, with 16.32 being the average value and 20.19 being the highest value. Such data can clearly show that different enterprises receive different levels of government subsidy. In general, there are relatively large differences among the sample enterprises, which in a real sense provides a certain research basis for the subsequent empirical analysis.

Table 2: Descriptive statistics

variant	sample	average	standard	minimum	P50	maximum
state	29591	0.370	0.480	0	0	1
Pollution	29591	0.290	0.450	0	0	1
Size	29591	22.26	1.290	19.90	22.08	26.23
Cash	29591	7.100	21.83	-17.76	1.450	162.9
Gro	29591	0.160	0.420	-0.590	0.100	2.620
Roa	29591	0.0300	0.0700	-0.310	0.0400	0.200
GS	29591	16.32	1.540	11.67	16.34	20.19
Dig	29591	1.580	1.410	0	1.390	5.040
Green1	29591	0.360	0.770	0	0	3.610
Green2	29591	0.240	0.610	0	0	3.140

4.2. Regression analysis

Table 3: Model regression results

	(1) Green1	(2) Green2
Dig	0.0512***	0.0494***
	(0.00403)	(0.00331)
Controls	Yes	Yes
Year	Yes	Yes
indcode	Yes	Yes
_cons	-2.427***	-1.919***
	(0.115)	(0.0945)
N	29591	29591
R^2	0.187	0.171
adj. R^2	0.184	0.169

$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

The table shows the results of the multiple regression model used in this study to look at how digital transformation affects green innovation in businesses.

From the data we have, we can see that digital transformation (Dig) does have a good effect on green innovation to some degree (Green1) (coefficient = 0.0512, p<0.01). This information also makes it clear that digital transformation is the main factor that determines how green an innovation level a company has. In terms of specific control variables, the size of the business has a good effect

on green innovation (coefficient = 0.109, p<0.01), which can help green innovation grow. In addition, we can clearly see that the specific cash holdings are actually very significant for green innovation in nature (coefficient =0.00333, p<0.01), and this data can clearly indicate that enterprises with sufficient capital have more advantages in investing in green technology research and development.

4.3. Robustness tests

Through analysis, in order to accurately test the robustness of baseline regression results to the greatest extent, this paper mainly used green innovation (Green2) instead of green innovation (Green1) to replace explanatory variables in the whole process of research. The specific robustness test regression results show that digital transformation (Dig) fundamentally contributes to the specific and significant positive impact of Green2. Therefore, on the whole, the robustness test results further validate the reliability of the core research results of this paper in a real sense.

4.4. Heterogeneity analysis

Table 4: Heterogeneity test results (nature of equity)

	(1) Green1	(2) Green1	(3) Green1	(4) Green1
Dig	0.0307 ***	0.0610***	-0.000283	0.0625 ***
	(0.00745)	(0.00470)	(0.00706)	(0.00484)
Controls	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
indcode	Yes	Yes	Yes	Yes
_cons	-2.831***	-2.102 ***	-1.701***	-2.838 ***
	(0.180)	(0.160)	(0.170)	(0.136)
N	11046	18545	8481	21110
adj. R^2	0.243	0.173	0.184	0.180

To learn more about how the digital transformation of businesses might have different effects on their green innovation, this paper uses group regression analyses to look at two factors: the nature of equity and the characteristics of polluting industries. The results are shown in Tables 5 and 6.

The first thing to look at is how equity works. (1) is a state-owned enterprise, and (2) is a non-state-owned business. The regression results show that digital transformation (Dig) has a smaller effect on green innovation in SOEs (coefficient=0.0307, p<0.01) than it does on non-SOEs (coefficient=0.0610, p<0.01). This means that digital transformation is more helpful for non-SOEs. This could be because non-SOEs rely more on technological innovation and green upgrading to stay competitive in a market where prices are high, while SOEs may depend more on government guidance in green innovation rather than just digital transformation because of rules that govern them. Also, the size (Size) and return on total assets (Roa) of SOEs have a bigger effect on green innovation than those of non-SOEs. This suggests that size and revenue are more helpful for SOEs' green innovation.

Second, in terms of the characteristics of polluting industries, (1) is a polluting industry firm and (2) is a non-polluting industry firm. The regression results show that digital transformation does not have a significant effect on green innovation in industries that pollute (coefficient = -0.000283, p>0.1). However, digital transformation does have a significant positive effect on green innovation in industries that do not pollute (coefficient = 0.0625, p<0.01). This finding shows that digital transformation has a bigger impact on encouraging green innovation in industries that don't pollute, while in polluting industries it is weaker or insignificant. The possible reasons for this are that firms

in polluting industries rely more on external environmental policy constraints for green innovation than on their own digital development, while green innovation in polluting industries often involves high environmental technology transformation costs, which makes the marginal effect of digital transformation weakened.

This finding further emphasizes the importance of corporate governance structure and industry characteristics in the process of digital transformation to promote green innovation, and provides a reference basis for governments to formulate differentiated policy support measures.

4.5. Tests for moderating effects

Table 5: Moderating effects test

	(1) Green1	(2) Green1
Dig	0.0490 ***	-0.306 ***
	(0.00404)	(0.0325)
GS	0.0290 ***	-0.00196
	(0.00389)	(0.00479)
Controls	Yes	Yes
Year	Yes	Yes
indcode	Yes	Yes
DG		0.0218 ***
		(0.00198)
_cons	-2.339 ***	-1.786 ***
	(0.116)	(0.126)
N	29591	29591
adj. R^2	0.186	0.189

This paper adds a new term, DG (Dig × GS), to test the moderating effect and show the regression results in Table 7. This is done to learn more about the role of government subsidies (GS) in the link between businesses' green innovation (Green1) and digital transformation (Dig).

In fact, the full regression results show that for (Column 1), the mainly digital transformation (Dig) has a fundamental effect on green innovation of 0.0490 ($p<0.01$), which also shows the growth effect. On the other hand, we can see from a different set of data that government funds also have a big positive effect on green innovation (coefficient = 0.0290, $p<0.01$), which also shows the promotion effect. In the model (column 2), the regression coefficient of digital transformation (Dig) goes down, while the regression coefficient of the intermediate term DG (Dig×GS) is 0.0218 ($p<0.01$), which means that the two are significantly linked. This shows that government subsidies have lessened the bad consequences and helped keep things in check in a mostly good way. The bottom line is that digital change can help businesses grow to a certain point and provide some benefits to businesses.

5. Conclusions and policy recommendations

In fact, This study is mostly based on using a lot of thorough data sets to look into the effect of certain digital transformations on business growth. The detailed findings of the study show that (1) The biggest thing that actually encourages green innovation in businesses is going digital. Heterogeneity analysis shows that digital transformation is actually pretty important for businesses that aren't run by the government and don't pollute, which can help them grow. (3) In a real sense, government subsidies have made the link between digital change and green innovation less strong.

Based on what the study found, the following policy ideas are made to help businesses grow in both digital transformation and green innovation: To boost productivity, better resource management, and the role of digitalization in green innovation, the government should push companies to use cutting-edge digital technologies like AI, big data, cloud computing, and the Internet of Things (IoT). It should also establish industry-specific standards and guidelines, promote the deeper integration of digital technologies with green development strategies, encourage companies to incorporate green goals during their digital transformation, and support the overall green upgrading of industries.

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