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Does the Digital Transformation of Chinese Agricultural Enterprises Really Improve Green Technology Innovation Performance?

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Abstract

Purpose: This study investigates the impact of digital transformation on green innovation in China's agricultural listed companies, focusing on the moderating role of environmental, social, and governance (ESG) performance. **Research Design, Data and Methodology:** This study uses quantitative research methods, selecting annual report data of China's agricultural listed companies from 2014 to 2023 and Huazheng ESG data, using a regression model of panel data analysis to explore the impact of digital transformation on green innovation and explore ESG moderating effect. **Results:** Digital transformation has a significant negative impact on green innovation (coefficient = -0.048, $p < 0.05$), particularly due to resource reallocation during technology upgrades. ESG performance moderates this relationship (interaction term coefficient = -0.113, $p < 0.05$), intensifying the negative effects rather than mitigating them. **Conclusions:** Digital transformation of agricultural enterprises is crucial to green technology innovation. However, the improvement of ESG performance has not only failed to alleviate this negative impact, but has made the problem worse. Specifically, ESG performance plays a key mediating role in the connection between digital transformation and green innovation, and this mediating role actually helps to amplify the negative consequences of digital transformation rather than reduce them.

Keywords: Digital Transformation, Green technology Innovation, ESG Performance, Agricultural Enterprises

JEL Classification Code: Q55, Q16

1. Introduction

China is dedicated to encouraging energy saving and emission reduction, low-carbon development, and ecological building, and it has suggested the aim of attaining carbon neutrality by the year 2060. Both of these initiatives are environmentally conscious (Fang & Chen, 2024).

Under the constraints of carbon neutrality, Green technology innovation performance is not only a key means to solve current environmental problems, but also an effective path to promote the green transformation of society. As global environmental problems become increasingly severe, while enterprises are pursuing economic benefits, how to achieve green development has become the focus of social attention. From this perspective, the green innovation of firms, particularly that of agricultural publicly traded corporations, is of paramount importance. Green innovation not only efficiently mitigates environmental pollution and enhances resource utilization efficiency, but also bolsters market competitiveness and sustainable growth capacities of

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organizations.

Digital transformation is a series of comprehensive and systematic reform and improvement activities that enterprises proactively carry out in order to survive and prosper in the digital age (Yang, 2024). This process fundamentally changes the way enterprises operate by adopting digital tools, and involves technology application and potential cultural changes. Digital transformation is not just about buying products or solutions, but has a profound impact on everything related to information technology in every industry. Its fundamental purpose is to enhance the competitiveness of enterprises, improve or replace existing business models through the application of new technologies, enhance the competitiveness of products and services, and thus gain greater competitive advantages. The relationship between digital transformation and the achievement of green innovation, as well as the improvement of corporate competitiveness, warrants more examination.

However, the discussion on the relationship between information technology investment and productivity has also led to the famous "information Technology productivity paradox". This paradox refers to the fact that the continuous increase in investment in information technology has not achieved the same proportion of increase in productivity, resulting in a paradox between input and output (Brynjolfsson, 1993). But, Ren et al. (2023) found that the degree of digitalization of an enterprise is significantly positively related to its performance, providing empirical support for digital reform to improve enterprise efficiency. In addition, the author provides a new theoretical framework for how digitalization can optimize enterprise resource allocation and performance improvement by analyzing the "IT production paradox" problem. This laid the data and methodological foundation for subsequent research on the relationship between digitalization and corporate performance.

This research develops indicators for the digital transformation of agricultural listed firms using annual report data from Chinese agricultural listed companies between 2014 and 2023, and examines its influence on regional green innovation and the underlying effect mechanisms.

2. Literature Review and Research Hypotheses

2.1. Digital transformation and green innovation

This literature thoroughly examines the influence of digital transformation on green innovation. Wen (2024) analyzed Chinese transportation sector firms from 2011 to 2021 and discovered that the delayed effects of digital transformation in these enterprises are more pronounced, while the implementation of digital policies positively influences green innovation. He et al. (2023) analyzed green innovation under different motivations and found that digital transformation significantly affects green innovation driven by substance, but has no impact on green innovation driven by strategy. Environmental orientation influences the digital transformation process by fostering green innovation. Liu (2023) explored the mechanism by which internal control quality plays a role in promoting green innovation through digital transformation, and found that high-level internal control quality can significantly improve an enterprise's green innovation capabilities. Cheng et al. (2024) analyzed data from many highly polluting companies and found that digital transformation can transform companies' green innovation strategies from passive to proactive. Internal capabilities and attitudes are key factors, while the impact of environmental regulations is not significant. Wang and Dou (2024) analyzed data from many Chinese A-share listed companies and suggested that carbon market policies and digital transformation exert a dual influence on green innovation, with their combination hindering enterprises' green innovation activities, primarily due to the adverse effects of financing constraints. Zhang and Meng (2023) found that enterprises' digital acquisition, utilization and sharing capabilities significantly promoted the improvement of regional green innovation efficiency, especially in resource integration and information sharing. Together, these studies show that digital transformation helps promote the development of corporate green innovation and improve efficiency through the improvement of internal capabilities, resource integration, and information sharing. Together, these studies show that digital transformation significantly promotes the development of green innovation by improving internal management of enterprises, optimizing resource allocation, and increasing information transparency.

However, digital transformation has an inhibitory effect on corporate green innovation under different scenarios. Sun and He (2023) found that although digital transformation helps to improve enterprises' green innovation, financing constraints inhibit this positive impact, resulting in enterprises being unable to fully utilize digital technology to support green innovation under financial pressure. Wang and Yan (2023) pointed out that digital transformation will have a hysteresis effect in some cases, causing innovation performance to be inhibited in the short term, especially in the absence of corporate social responsibility support. This inhibitory effect is particularly significant. Buck et al. (2023) proposed that in asset-intensive industries, digital transformation faces huge strategic and organizational challenges. These challenges include technological incompatibility and limitations of the asset base. These factors inhibit the advancement of innovation and green development. These studies indicate that the impact of

digital transformation on green innovation may be significantly suppressed under certain conditions. Based on the above literature, in order to explore the relationship between digital transformation and green technology innovation performance, I propose the following hypothesis.

H1: The digital transformation of listed agricultural companies can positively stimulate green technology innovation.

2.2. Moderating Effect of ESG Performance of Listed Companies

The moderating impact of listed firms' ESG performance has been extensively studied in a variety of contexts. Luo and Liu (2023) examined the moderating influence of ESG performance and the impact of analyst attention on corporate tax evasion behavior. The ESG performance of a firm can substantially influence its tax evasion conduct in the context of analyst scrutiny. Specifically, good ESG performance helps to reduce analysts' negative attention to corporate tax avoidance, thereby affecting the company's tax avoidance decision. Yan and Guo (2023) examined the influence of industrial agglomeration on corporate green innovation and discovered that ESG performance moderates this relationship. Their research illustrates that a company's exceptional ESG performance may enhance the advantages of industrial agglomeration on corporate green innovation, promoting creative practices in social responsibility and environmental stewardship. Chen and Xie (2022) investigated the relationship between environmental, social, and governance (ESG) disclosure and financial performance. They emphasized the moderating influence of ESG investors in this context. They found that ESG disclosure may significantly enhance a company's financial performance by attracting ESG investors.

This is especially true when considering the fact that ESG investors are paying a growing amount of attention to the performance of corporations in terms of their corporate social responsibility. Nirino et al. (2021) examined the relationship between corporate disputes and company financial performance, along with the moderating influence of environmental, social, and governance policies within this framework. However, he found that he could not confirm the positive moderating effect of ESG practices on the relationship between controversy and financial performance. Elamer and Boulhaga (2024) examined the impact of environmental, social, and governance (ESG) factors on corporate performance and noted the moderating role of governance frameworks and ESG regulations. The research findings suggest that, alongside actively addressing environmental, social, and governance (ESG) issues, robust governance protocols and effective ESG practices may mitigate the adverse effects of ESG conflicts on corporate performance and potentially enhance the long-term performance of organizations. Corporate environmental, social and governance (ESG) performance is a key factor in driving green innovation. Overall, these findings provide an important basis for exploring the moderating role of ESG performance.

Hypothesis 2: ESG performance has a moderating effect on the relationship between digital transformation and green innovation of listed agricultural companies.

The following figure presents a theoretical framework linking Environmental, Social, and Governance (ESG) considerations with digital transformation and green technology innovation. This model highlights the critical role of ESG in fostering a sustainable and technology-driven business landscape (see Figure 1).

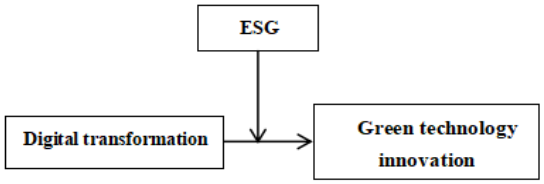

Figure 1: Theoretical framework

3. Research Design

3.1. Sample and Data

For the purpose of evaluating the degree to which listed agricultural enterprises have undergone digital transformation and green innovation, the following data sources have been utilized in this paper. According to the CSMAR database, the measuring data of the digital transformation of agricultural enterprises that are listed on the stock exchange may be retrieved. This study uses agricultural enterprises that are listed on the A-share market in Shanghai and Shenzhen as its research sample, and the time span covered by the sample is from 2014 to 2023. Please see Table 2 for details of sample sizes.

3.2. Model Specification

In order to verify the impact of digital transformation of agricultural listed companies on green innovation, this paper constructs the following model:

$$ln\_GI_{it} = \alpha_0 + \alpha_1 ln\_DT_{it} + \alpha_2 ln\_ESGj_{jt} + \alpha_3 SIZE_{it} + \alpha_4 ROA_{it} + \alpha_5 LEV_{it} + \alpha_6 Tobin_{it} + \alpha_7 IRR_{it} + \gamma_t + \delta_i + \epsilon_{it} \quad (1)$$

ln_GI_{it}: represents the green innovation level of the i-th company in year t, expressed by the natural logarithm of the number of green patent applications. ln_DT_{it} : represents the digital transformation level of agricultural listed companies in year t of the i-th company, expressed by the natural logarithm of the total number of digital word frequencies. ln_ESGj_{jt}: represents the ESG performance of the j-th company in year t, expressed by the natural logarithm of the annual average of the Huazheng ESG score, and centered.

In order to further explore the mechanism of the digital transformation of agricultural listed companies on green innovation, especially whether it is achieved through transmission paths such as improving financing mechanisms and improving the level of financial marketization, this paper constructs a regulatory effect model for testing. The model is as follows:

$$ln\_GI_{it} = \beta_0 + \beta_1 ln\_DT_{it} + \beta_2 ln\_ESGj_{jt} + \beta_3 ln\_DT_{it} \times ln\_ESGj_{jt} + \beta_4 SIZE_{it} + \beta_5 ROA_{it} + \beta_6 LEV_{it} + \beta_7 Tobin_{it} + \beta_8 IRR_{it} + \gamma_t + \delta_i + \epsilon_{it} \quad (2)$$

$ln\_DT_{it} \times ln\_ESGj_{jt}$: represents the interaction term between digital transformation and ESG performance, which is used to test the moderating effect of ESG performance on the relationship between digital transformation and green innovation. β_0: constant term. β_1, β_2, β_3, ... , β_8 : parameters to be estimated. γ_t : Time FE, controlling for Time FE. δ_i : Firm FE, controlling for Firm FE. ϵ_{it}: random error term. Through the above model, this paper will systematically analyze the impact of digital transformation of agricultural listed companies on green innovation, and explore how ESG performance plays a moderating role in it. The construction and empirical test of the model will provide new insights into the relationship between digital transformation and green innovation, and provide reference for policymakers and corporate managers.

3.3. Variable Definitions

This section defines the variables used in this study to explore the impact of digital transformation on green innovation, moderated by ESG performance in table 1.

Table 1 : Explanation of relevant variables

Variable Types	Variable Symbols	Variable Description
Explained variable	Ln_GI	Corporate Green Innovation, Ln (Green patent application +1)
Explanatory variables	Ln_DT	Digital Transformation,Ln (total number of digitized word frequencies + 1)
Moderating variables	ln_ESGj	ESG Performance,Ln (the annual average of Huazheng ESG scores) and centralized.This data is ESG data of Shanghai Huazheng Index Information Service Co., Ltd.
Control variables	SIZE	Enterprise cale,Ln (Total Assets)
Control variables	ROA	Return on Total Assets,Ratio of net profit to average total assets (Wang et al.,2025).
Control variables	LEV	Debt-to-asset Ratio,Used to measure the level of financial leverage of an enterprise, it represents the ratio of total liabilities to total assets of an enterprise(Wang & Sun, 2022).
Control variables	Tobin	Tobin's Q,Tobin Q value is used to measure the ratio of the market value of the enterprise to the replacement cost of assets, reflecting the market performance of the enterprise.
Control variables	IRR	Operating income Growth Rate,It represents the growth rate of annual business revenue, which is used to measure the business growth rate of an enterprise.
Time FE	Year	Annual dummy variables from 2014 to 2023
Firm FE	Code_id	According to the CSRC stock code, take the dummy variable

3.3.1. Explained Variable

Green innovation in business enterprises (Ln_GI): It is represented as the natural logarithm (Ln) of the number of green patent applications that the company has submitted, which is computed as Ln (green patent applications plus one). In the context of technology and goods, the term "green innovation" refers to the actions of businesses that innovate in order to lessen their negative impact on the environment and their consumption of resources (Zou et al., 2023).

3.3.2. Explanatory Variables

It is stated as the natural logarithm of the total number of

digital terms in the annual report of the firm, which is computed as Ln (total number of digital terms + 1). This particular expression is referred to as the digital transformation (Ln_DT). The term "digital transformation" refers to the process by which businesses enhance their operational efficiency and competitiveness by using digital technology (such as big data, artificial intelligence, and other similar technologies). Referring to Zhao Chenyu (2021), I counted the frequency of digital-related words in four dimensions: digital technology application, Internet business model, intelligent manufacturing, and modern information system.

3.3.3. Moderating Variables

ESG performance (ln_ESGj): Expressed as the natural logarithm of the annual average of Huazheng ESG scores, and centered.This data is ESG data of Shanghai Huazheng Index Information Service Co., Ltd. Calculated as Ln (annual average of Huazheng ESG scores).ESG performance, which stands for "environment, society, and governance," is a concept that describes the overall performance of an organization with regard to the preservation of the environment, social responsibility, and corporate governance.The Huazheng ESG Rating is located in close proximity to the Chinese market, its coverage is extensive, and it is quite timely. As a result, the score provided by Huazheng ESG is utilized in this article to evaluate the environmental, social, and governance (ESG) performance of corporations.

3.3.4. Control Variables

The study includes several control variables to account for factors that might influence the relationship between digital transformation and green technology innovation. Enterprise size (SIZE) is expressed as the natural logarithm of total assets, reflecting the size of the enterprise; return on total assets (ROA) is the ratio of net profit to average total assets, measuring profitability; debt-to-equity ratio (LEV) is the ratio of total liabilities to total assets, reflecting the level of financial leverage; Tobin's Q value (Tobin) is the ratio of market value to asset replacement cost, indicating growth potential; operating income growth rate (IRR) is the annual operating income growth rate, reflecting the operating performance of the enterprise(Hong et al., 2023).

3.3.5. Fixed Effect Variables

Time FE (Year): Annual dummy variables from 2014 to 2023, used to control the impact of macroeconomic environment and policy changes in different years on corporate green innovation. Firm FE (code_id): Based on the CSRC stock code, a dummy variable is taken to control the impact of unobservable factors unique to individual companies on green innovation.

3.4. Summary Statistics

The measurement of financial technology indicators for listed agricultural companies in the Guotai An CSMAR database uses a sample interval from 2014 to 2023. an unbalanced panel dataset is obtained. The descriptive statistical results are presented in Table 2.

Table 2: Descriptive Statistics of Main Variables

variable	N	Mean	SD	p25	p75
Ln_GI	577	0.160	0.490	0	0
ln _Dt	585	2.840	0.910	2.300	3.500
ln_ESGj	635	1.300	0.300	1.100	1.450
size	710	21.94	1.280	21.19	22.67
ROA	803	0.0300	0.120	0.0100	0.0800
tobin	650	2.350	2.040	1.380	2.650
Lev	803	0.430	0.270	0.270	0.550
IRR	678	14.87	356.8	-0.0600	0.530

It has been determined through descriptive statistical analysis that the mean value of green innovation (Ln_GI) is 0.160, the mean value of digital transformation (Ln_DT) is 2.840, the mean value of environmental, social, and governance (ESG) performance (ln_ESGj) is 1.300, the mean value of enterprise size (size) is 21.94, the mean value of return on total assets (ROA) is 0.0300, the mean value of Tobin's Q value (tobin) is 2.350, the mean value of debt-to-asset ratio (Lev) is 0.430, and the mean value of operating income growth rate (IRR) is 14.87. These data illustrate the fundamental characteristics and distribution of each variable, indicating that there are significant differences among the businesses in the sample with regard to green innovation, digital transformation, environmental, social, and governance (ESG) performance, scale, profitability, financial leverage, and revenue growth. This information is essential for subsequent regression analysis and model construction.

4. Analysis of Empirical Results

4.1. Benchmark Regression

Examining the baseline regression analysis results shows that the impact of digital transformation (Ln_Dt) on green innovation (Ln_GI) shows different patterns in different analysis models. green innovation is benefited by digital transformation. The results of the benchmark regression can be found in Table 3.

Table 3: Benchmark regression

	(1)	(2)	(3)	(4)	(5)
	Ln_GI	Ln_GI	Ln_GI	Ln_GI	Ln_GI
Ln_Dt	0.101 **	-0.046 **	-0.055 **	-0.047 **	-0.048 **
	(2.146)	(-2.126)	(-2.481)	(-2.121)	(-2.093)
size			0.042	0.053	0.028
			(1.234)	(1.345)	(0.816)
Ln_ESG				-0.077	-0.068
				(-1.649)	(-1.373)
ROA				0.054	0.183
				(0.240)	(0.857)
tobin				0.013	0.016
				(1.207)	(1.303)
Lev					0.165
					(1.181)
IRR					-0.000
					(-0.473)
_cons	-0.128	0.012	-0.890	-1.149	-0.745
	(-1.309)	(0.186)	(-1.162)	(-1.276)	(-0.910)
Time FE	No	Yes	Yes	Yes	Yes
Firm FE	No	Yes	Yes	Yes	Yes
N	575	575	575	545	541
r2	0.036	0.670	0.671	0.695	0.700
r2_a	0.034	0.606	0.607	0.634	0.637
F	4.605	.	.	.	.

t statistics in parentheses, ** $p < 0.05$, *** $p < 0.01$

To be more specific, the coefficient of digital transformation in model (1) is 0.101, which was found to be significant at the 5% level of significance. Following the incorporation of year fixed variables (Year and id) into the analysis, the coefficient in model (2) is found to be -0.046. At a significance threshold of 5%, the coefficient continues to be significant, which indicates that the effect is negative. The adjusted R^2 increases from 0.034 in model (1) to 0.637 in model (5). r2_a in this table represents adjusted R^2. Additional increases in firm Firm FEs (Id) and control variables, such as firm size (SIZE), environmental, social, and governance (ESG) performance (Ln_ESGj), return on total assets (ROA), Tobin's Q (Tobin), asset-liability ratio (Lev), and operating income growth rate (IRR), are still negative. This trend is accompanied by additional increases in firm Firm FEs (Id). Therefore, Hypothesis 1 should be rejected because there is a negative impact here. Hypothesis 1 states that the digital transformation of agricultural listed companies can positively stimulate green technology innovation.

This demonstrates that the link between digitization and environmentally friendly innovation is greatly influenced by elements that are particular to the organization as well as variables that are broader in nature. Furthermore, these data indicate that the influence of digital transformation on environmentally conscious innovation is multidimensional. Its functionality depends not only on the internal variables of the organization but is also influenced by prevailing macroeconomic and policy aspects.

Based on the above data, I think there are several reasons. First, during the digital transformation process, a large number of resources are reallocated to support technology upgrades and infrastructure construction. This has weakened enterprises' capital investment in green innovation in the short term. In particular, agricultural enterprises have relatively limited budgets, so resource allocation often prioritizes improving the digital level of enterprises rather than investing in green innovation. Therefore, with the addition of year fixed effects and firm-specific effects, the positive impact of digital transformation turns into a negative impact.

Secondly, agricultural enterprises often lack relevant experience and professional skills when undergoing digital transformation, causing enterprises to face high learning costs in the process of adapting to new technologies. The baseline regression shows that when the Firm FEs of enterprises are further considered (such as model 3), the negative impact of digital transformation is still significant, which indicates that the operational and learning difficulties faced by enterprises in adapting to digitalization hinder green innovation. effect.

In addition, the unique industry challenges faced by agricultural enterprises are also an important reason why digital transformation fails to effectively promote green innovation. Agribusiness production processes are highly dependent on natural factors such as weather, soil conditions and biodiversity, and the effectiveness of digital technologies may be limited in this complex and uncertain environment. It has been demonstrated through data analysis that the negative impact of digital transformation is still significant in a variety of models, despite the introduction of a number of control variables. This demonstrates that the specificity of the agricultural industry itself has a significant impact on the relationship between digital transformation and green innovation. Therefore, the combination of these reasons explains why digital transformation has a detrimental effect for green innovation in the agricultural sector.

4.2. Endogeneity Test

This study employs explanatory variables to address the endogeneity issue. The regression analysis, using a one-period lag of the dependent variable, indicates that the digital transformation of publicly listed agricultural firms significantly influences corporate green innovation (Ln_GI) in both model (1) and model (2). The results of the endogeneity test can be found in Table 4.

Table 4: Explanatory variables for the first lag period

	(1)	(2)
	Ln_GI	**Ln_GI**
ln_Dt		-0.048 **
		(-2.09)
ln_Dt_lag1	-0.057 **	
	(-2.02)	
ln_ESGj	-0.085	-0.068
	(-1.23)	(-1.37)
size	0.020	0.028
	(0.50)	(0.82)
ROA	0.160	0.183
	(0.72)	(0.86)
Lev	0.172	0.165
	(1.26)	(1.18)
tobin	0.016	0.016
	(1.39)	(1.30)
IRR	0.000	-0.000
	(0.58)	(-0.47)
_cons	-0.479	-0.745
	(-0.54)	(-0.91)
Time FE	Yes	Yes
Firm FE	Yes	Yes
N	474	541
r2_a	0.660	0.637

t statistics in parentheses, ** $p < 0.05$, *** $p < 0.01$

Model (1) indicates that the coefficient for the one-period lag of digital transformation (ln_Dt_lag1) is -0.057, which is statistically significant at the 5% level (t value of -2.02), suggesting that the one-period lag of digital transformation exerts a significant negative effect on green innovation. Model (2) incorporates the present period digital transformation variable (ln_Dt), with a coefficient of -0.048, which is significant at the 5% level (t value of -2.09), hence reinforcing the negative impact of digital transformation on green innovation.

By using the explanatory variables lagged one period, we effectively alleviated the endogeneity problem that may be caused by reverse causality. This approach reduces the possibility of bidirectional causality in the current period by using the previous digital transformation data to explain the current green innovation. In addition, other control variables in the model (such as ESG performance, enterprise size, return on total assets, debt-to-asset ratio, Tobin's Q value, and operating income growth rate) did not show significant effects, indicating that these factors have little direct impact on green innovation after controlling for annual and enterprise Firm FEs. The adjusted R^2 values are 0.660 and 0.637, respectively, indicating that the model has good explanatory power.

This study mitigates the endogeneity issue to some degree by using lagged digital transformation variables and demonstrates that digital transformation can result in the short-term reconfiguration of enterprise resources, consequently hindering green innovation activities. Future study can validate these findings and investigate the long-term relationship between digital transformation and ESG performance.

4.3. Moderating Effect

The moderating effect analysis reveals that the coefficient for digital transformation (ln_Dt) in model (3) is -0.055, significant at the 5% level (t value of -2.08), thereby confirming that digital transformation adversely affects green innovation. The results of the Moderating Effects can be shown in Table 5.

Table 5: Moderating Effects

	(1)	(2)	(3)
	Ln_GI	**Ln_GI**	**Ln_GI**
ln_Dt	-0.046 **	-0.049 **	-0.055**
	(-2.13)	(-2.22)	(-2.08)
size		0.048	0.039
		(1.50)	(1.17)
tobin		0.009	0.017
		(1.16)	(1.45)
Lev		-0.013	0.160
		(-0.17)	(1.17)
ln_ESGj × ln_Dt			-0.113 **
			(-2.07)
ln_ESGj			-0.115 *
			(-1.99)
ROA			0.160
			(0.63)
TAT			-0.009
			(-0.12)
_cons	0.012	-1.073	-1.055
	(0.19)	(-1.40)	(-1.34)
Time FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
N	575	565	545
r2_a	0.606	0.629	0.635

t statistics in parentheses, ** $p < 0.05$, *** $p < 0.01$

The inclusion of the interaction term between environmental, social, and governance (ESG) performance (ln_ESGj) and digital transformation results in a coefficient of -0.113 for the interaction term. This coefficient is statistically significant at the 5% level (t-value = -2.07). It can be deduced from this that environmental, social, and governance (ESG) performance has a key role in moderating

the connection between digital transformation and green innovation. However, this moderation actually serves to amplify the negative consequences of digital transformation rather than to reduce them. Hypothesis 2 should be accepted here, because there is indeed a moderating effect between them. Hypothesis 2 mentions that ESG performance has a moderating effect on the relationship between digital transformation and green innovation of agricultural listed companies.

Specifically, the results show that the negative impact of digital transformation on green innovation intensifies when a company's ESG performance improves. This may be because the process of implementing ESG performance by companies may create additional resource allocation needs, such as an emphasis on compliance and reporting, thereby reducing investment in green innovation. As a result, environmental, social, and governance (ESG) performance does not, contrary to what was anticipated, ameliorate the adverse effects of digital transformation on green innovation; rather, it exacerbates these adverse effects.

This leads to the conclusion that hypothesis H2 is not supported, since environmental, social, and governance (ESG) performance does not mitigate the adverse impact of digital transformation on green innovation, but rather exacerbates this negative impact. This finding reminds companies that when conducting digital transformation and ESG management, they need to pay special attention to the coordination between the two to avoid ESG practices from exacerbating the inhibitory effect on green innovation.

In order to better understand this phenomenon, we can explore it from the following aspects. There is a possibility that the consequences of resource rivalry are a key reason. Companies that are in the process of implementing ESG practices typically need to make significant resource investments in order to meet environmental, social, and governance compliance requirements. These requirements include things like enhancing environmental protection measures, fulfilling social responsibilities, and strengthening corporate governance. These activities may compete with companies' resource needs in digital transformation, thereby undermining companies' investment in green innovation. Especially when financial and human resources are limited, companies may prioritize the need for ESG performance. Investment in green technology innovation may decrease. This resource competition effect may result in that although ESG performance is improved, the negative impact of digital transformation is more significant for green innovation due to insufficient resource allocation.

Secondly, giving priority to short-term benefits is also a possible reason. During digital transformation, companies typically focus more on achieving profitable growth in the short term through increased efficiency and automation. In order to meet ESG performance, companies may increase their compliance investments in related aspects. However, these investments often fail to directly bring short-term economic returns. This has only exacerbated the neglect of green innovation.

In addition, conflicting goals and increased management complexity may also be factors.The primary objective of digital transformation is to enhance the effectiveness and competitiveness of business processes inside an organization. The objective of environmental, social, and governance (ESG) performance is to accomplish environmental protection, social responsibility, and accountable corporate governance. There may be a degree of inconsistency between these two goals.

4.4. Robustness test

When conducting the robustness test, the influence of digital transformation on agricultural listed firms on corporate green innovation and green patent applications is evaluated. This is accomplished by exchanging the factors that describe the phenomenon with the variables that explain the phenomenon.

For the purpose of determining the influence that the digital transformation of listed agricultural firms has on corporate green innovation and green patent applications, the results of the robustness test are shown in Table 6.

Table 6： Robustness test

	(1)	(2)
	Ln_GI	**ln_green_patent_apply_uti**
ln_Dt	-0.056 **	-0.043 **
	(-2.25)	(-2.26)
ln_ESGj × ln_Dt	-0.104 *	-0.073 *
	(-1.80)	(-1.75)
ln_ESGj	-0.107 *	-0.059
	(-1.75)	(-1.21)
size	0.034	0.052
	(0.99)	(1.13)
ROA	0.199	0.082
	(0.90)	(0.45)
Lev	0.166	0.087
	(1.24)	(0.80)
tobin	0.017	0.013
	(1.42)	(1.51)
IRR	-0.000	-0.000
	(-0.94)	(-0.42)
_cons	-0.942	-1.245
	(-1.14)	(-1.21)
Time FE	Yes	Yes
Firm FE	Yes	Yes
N	541	541
r2_a	0.638	0.650

t statistics in parentheses, ** $p < 0.05$, *** $p < 0.01$

This test makes use of the approach of substituting the

explanatory factors with the variables that have been explained. According to the findings of model (1), which demonstrate that the coefficient of digital transformation (ln_Dt) is -0.056 and is significant at the 5% significance level, digital transformation has a substantial negative effect on corporate green innovation (Ln_GI). This is evidenced by the fact that the coefficient of digital transformation is -0.056. It is clear from this that the digital revolution has a significant contribution.

In model 2, the findings show that the coefficient of digital transformation is -0.043, which is significant at the 5% significance level. This is because the explanatory variable was replaced with the green patent application (ln_green_patent_apply_uti), which was the consequence of the replacement. This provides more evidence that the digital revolution has a detrimental effect on the activities that are associated with green innovation.

Overall, the robustness test results show that digital transformation has a significant negative impact on green innovation and patent applications of listed agricultural companies, while ESG performance can regulate this negative impact to a certain extent. The adjusted R^2 values of the model are 0.638, 0.650 in the three models, indicating that the model has good explanatory power.

5. Further Research

According to the usual practice, the sample is divided into 4 groups: all the data,the eastern, central and western regions. It is necessary to execute the benchmark regression once again for each region. An examination of the influence that digital transformation has had on green innovation in various countries is presented in Table 7, which also includes the regional heterogeneity study.

Table7：Heterogeneity analysis

	(1)	(2)	(3)	(4)
	Ln_GI	Ln_GI	Ln_GI	Ln_GI
ln_Dt	-0.056 **	-0.018	-0.092	-0.130 **
	(-2.329)	(-0.539)	(-1.195)	(-2.198)
ln_ESGj	-0.107 *	-0.115	-0.123	-0.114
	(-1.672)	(-1.097)	(-1.226)	(-0.465)
ln_ESGj ×ln_Dt	-0.104 *	-0.102	-0.072	-0.339
	(-1.962)	(-1.527)	(-0.764)	(-1.523)
size	0.034	-0.041	0.115	0.151 **
	(1.075)	(-0.833)	(1.642)	(2.029)
ROA	0.199	0.284	0.040	0.388
	(1.079)	(0.694)	(0.081)	(1.086)
Lev	0.166	0.067	-0.116	0.704 **
	(1.540)	(0.621)	(-0.288)	(2.244)
tobin	0.017 **	0.017	0.018	0.028
	(2.037)	(0.772)	(1.292)	(1.361)
IRR	-0.000	-0.006	0.004	-0.000
	(-1.085)	(-0.574)	(0.250)	(-0.967)
_cons	-0.942	0.760	-2.177	-1.919
	(-1.374)	(0.719)	(-1.634)	(-1.019)
Time FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
N	541	272	138	131
r2	0.701	0.642	0.538	0.792
r2_a	0.638	0.539	0.392	0.729
F	.	.	2.243	11.203

t statistics in parentheses, ** $p < 0.05$, *** $p < 0.01$

In the overall sample (model 1), digital transformation (ln_Dt) has a significant negative impact on green innovation (Ln_GI) (coefficient is -0.056, t value is -2.329, significance level is 5%), whereas Tobin Q (tobin) has a significant positive impact (coefficient is 0.017, t value is 2.037, significance level is 5%). This is because the coefficient for digital transformation is significant, and the t value is significant. In the eastern area (model 2) and the central region (model 3), the influence of digital transformation on green innovation is not significant (the coefficient of the eastern region is -0.018, t value is -0.539; the coefficient of the central region is -0.092, t value is -1.195). Therefore, the impact of digital transformation on green innovation is not significant. The coefficient for digital transformation is -0.130, the t value is -2.198, and the significance level is 5%. This indicates that digital transformation has a considerable negative influence on green innovation in the western area (Model 4). In addition, the enterprise size (size) and leverage ratio (Lev) have a significant positive impact on green innovation in the western region (the coefficient for enterprise size is 0.151, the t value is 2.029, and the significance level is 5%; the coefficient for leverage ratio is 0.704, the t value is 2.244, and the significance level is 5%).

Based on these findings, it is clear that the influence of digital transformation on environmentally conscious innovation differs considerably across different geographies. When it comes to fostering digital transformation and environmentally conscious innovation, authorities must to take into account regional differences and devise policy measures that are more specifically tailored.

6. Conclusion and Implications

This research empirically examines the influence of digital transformation on green innovation, utilizing annual report data from China's agricultural listed firms between 2014 and 2023, while also investigating the moderating effect of ESG performance. The findings indicate that the digital transformation of publicly traded agricultural firms adversely affects green innovation under specific circumstances. The primary explanation may be that the reallocation of resources during digital transformation

temporarily hinders green innovation activity. Moreover, ESG performance substantially influences the correlation between digital transformation and green innovation. ESG performance plays a key role in mediating the connection between digital transformation and green innovation. This mediation actually helps to amplify the negative consequences of digital transformation rather than reduce them.

The negative impact that digital transformation has on environmentally friendly innovation is most noticeable in the central region, whereas its influence is rather minor in the eastern and western areas. The central region is currently going through a significant era of economic change and improvement, during which the new impetus and inventive opportunities given by digital transformation play a vital role in furthering the region's green innovation.

Based on the above conclusions, this study proposes the following implications. Firstly, listed agricultural companies should further promote digital construction, enrich digital financial products, innovate financial service methods, improve information collection and processing efficiency by using technologies such as big data and cloud computing, optimize resource allocation, and promote green innovation. Secondly, firms should concentrate on environmental, social, and governance (ESG) performance and alleviate the adverse effects of digital transformation on green innovation by enhancing ESG performance. Organizations may augment their green innovation capacities by intensifying environmental protection initiatives, meeting social duties, and refining corporate governance frameworks. Policymakers should formulate targeted policies based on regional characteristics to promote inter-regional green innovation cooperation. The central region should continue to strengthen the combination of digital construction and green innovation, while the eastern and western regions should explore suitable digital transformation and green innovation paths based on their own conditions. In the end, the financial business environment should be further optimized, the costs of financing should be reduced, the amount of financing should be expanded, the quality of financing should be improved, the constraints placed on corporate financing should be eased, a market environment that is conducive to green innovation should be built, the synergy between environmental regulation and digital transformation should be enhanced, and the development of green innovation should be the focus of promotion. An investigation of the long-term connection between digital transformation and environmental, social, and governance (ESG) performance, as well as measures to increase the synergistic growth of digitalization and green innovation across a variety of economic contexts, may be pursued in subsequent research.

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