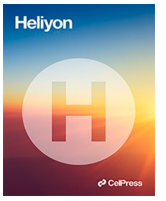
Heliyon 10 (2024) e30283

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Research article

Research on the impact of digital transformation on innovative high-quality development in the context of environmental regulation in agricultural enterprises

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ARTICLE INFO

Keywords:
Environmental regulation
Digital transformation
Enterprise innovation
Sustainable agriculture
"Violating agricultural operation"

ABSTRACT

Digital transformation is an important strategic choice for agricultural enterprises to adapt to economic development in the new era. The innovation quality of patents with core technology and high commercial value is significantly higher than that of low-quality patents such as weak patents developed through technological imitation. This study investigates the impact of digital transformation on innovative high-quality development in the context of environmental regulation in agricultural enterprises for the timeframe from 2012 to 2020. The purpose of this study is to examine whether the goal of improving innovation quality can be achieved through digital transformation in agricultural companies. The results show that digital transformation can effectively promote the improvement of innovation quality in companies, and environmental regulation has a significant positive moderating effect on the relationship between them. "Violating agricultural operation" is a specific appellation for the diversified management of listed agricultural companies, and it is one of the management modes of agricultural enterprises. For listed agricultural companies, the greater the degree of enterprise diversification, the greater the degree of "violating agricultural operation". The influence mechanism test shows that "violating agricultural operation" plays a part in mediating effect in the process of digital transformation promoting innovation quality improvement.

1. The introduction

Although China is a big agricultural country, there is still a big gap between China and the agricultural powerhouse in breeding theory and key core technology. The shortage of technical reserve is the most "bottleneck" problem affecting the long-term healthy development of Chinese agriculture. Digital transformation has strong scale effects and positive externalities. It can provide a good carrier for the acceleration of enterprise agglomeration of innovative elements, promote the increase of income and output of agricultural enterprises, improve the efficiency of product circulation and product quality, and help enterprises realize the accurate allocation of resources and the efficient docking of information technology.

It is worth noting that high-quality innovation with core technologies and high commercial value is an important basis for Chinese

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https://doi.org/10.1016/j.heliyon.2024.e30283
Received 17 January 2024; Received in revised form 17 April 2024; Accepted 23 April 2024
Available online 26 April 2024

agricultural enterprises to grow bigger and stronger. In this context, it is particularly important to explore the relationship between enterprises' digital transformation and innovation quality. Therefore, this study will deeply explore the relationship between digital transformation and the innovation quality of agricultural listed companies. Different from previous studies of scholars, this study combined the industry characteristics of listed agricultural companies and, an in-depth analysis of the unique characteristics of the impact of digital transformation on innovation quality in listed agricultural companies.

On the one hand, from the perspective of the exclusive characteristics of the internal operation of listed agricultural companies, to adapt to the development needs, agricultural enterprises adopt diversified management methods, which are different from enterprises in other industries. The implementation of diversified management strategies in agricultural companies can be classified into "violating agricultural operation" and "non-violating agricultural operation". "Violating agricultural operation" refers to the diversified expansion of listed companies in non-agricultural industries; "non-violating agricultural operation" refers to the vertical expansion of listed companies in the agricultural industry. It can be seen from this that back-farming management is a special management mode aiming at the diversified management strategy of agricultural enterprises. Given this, this study will deeply explore the mediating role of "violating agricultural operation" in the digital transformation and innovation quality of agricultural listed companies.

On the other hand, from the perspective of the external environmental characteristics of agricultural companies, agricultural pollution control has always been a relatively weak field in the implementation of social responsibility of agricultural enterprises. The level of scientific and precise pollution control in agricultural enterprises is still low. In particular, the reduction of chemical fertilizers and pesticides, pollution prevention and control of livestock and poultry breeding, and aquaculture tail water treatment foundation are still weak. Therefore, environmental protection should also be considered when discussing the mechanism of digital transformation to promote agricultural enterprise innovation. Given this, this study will explore in depth the regulatory role of environmental regulations in the digital transformation and innovation quality of agricultural listed companies.

Unfortunately, few scholars have put the digital transformation of agricultural enterprises, "violating agricultural operation", technological innovation, and ecological environmental protection into a research framework. This situation is not conducive to the overall planning of agricultural enterprise development strategy. Given this, this study integrates the digital transformation of agricultural enterprises, technological innovation "violating agricultural operation", and ecological environmental protection into a research framework for systematic analysis and research, which is likely to become an important innovation in this study. The possible marginal contribution of the study includes the following aspects.

In terms of research topics, the study integrates the digital transformation of agricultural enterprises, environmental regulation, and innovation quality into a theoretical framework. The study deeply analyzes the internal relationship between them, breaks through the existing scholars' research ideas, and has a high degree of novelty. At the same time, it deeply discusses agricultural issues, responds to public concerns, and plays a great role in guiding practice.

In terms of data acquisition, the core variables of this study were collected manually from patent websites, government work reports, annual financial reports of enterprises, and other media. The difficulty and workload of data collection and collation are relatively large, which provides a useful reference for studying the economic effects of digital transformation of agricultural enterprises.

In terms of research content, the study takes "violating agricultural operation" as the intermediary to deeply study the influence mechanism of agricultural enterprises' digital transformation and innovation quality improvement. The "black box" of the relationship between digital transformation and the innovation quality of agricultural enterprises is opened through the effective empirical method.

The remainder of this paper is organized as follows: Section 2 presents the existing literature and exposes the research hypotheses; Section 3 is the research design; the empirical analysis is in Section 4; the robustness test is in Section 5; the discussion and research implications are in Section 6, and Section 7 draws our main conclusions and suggestions.

2. Literature review and research hypotheses

2.1. Digital transformation and innovation quality improvement of agricultural enterprises

Digital transformation of enterprises refers to the activities of enterprises using digital technologies such as artificial intelligence, blockchain, cloud computing, and big data to improve production, operation, and management [1].

At present, scholars have made some progress in the research on the relationship between enterprise digital transformation and R&D innovation. Ma Ling found through research that enterprises' digital transformation can significantly improve their carbon performance and positively affect their carbon performance through green innovation [2]. Ouyang Juan also found through research that digitalization can significantly promote the improvement of regional innovation efficiency [3]. Financial subsidies can promote enterprises' green innovation, and the digital economy plays a positive regulating role between financial subsidies and enterprises' green innovation [4]. Furthermore, enterprises' digital transformation has an incentive effect on innovation input and output, but it will also lead to the loss of innovation efficiency [5].

However, existing scholars are still rough in studying the relationship between them. On the one hand, scholars have not yet studied the relationship between digital transformation and innovation quality. On the other hand, the relationship between digital transformation and innovation quality in agribusiness has not been thoroughly studied. This also provides the possibility of innovation for this research.

Innovation quality is a comprehensive concept. The patents with core technology and high commercial value in the innovation

achievements of enterprises are high-quality innovations, while the innovation quality of weak patents and design patents developed through technological imitation is lower.

The digital transformation of enterprises takes digital technology as an important driving force, and it is a comprehensive transformation in the fields of enterprise products, services and business processes [6]. Digital transformation has broken the original management mode and reconstructed the organizational structure and operation system of enterprises [7]. While improving the performance of enterprises, it will also produce a subversive change to the mode of enterprise value creation [8]. The application of digital technology accelerates the efficiency of internal information processing [9], accumulates innovation potential, increases growth opportunities [10], improves the ability of enterprise management and resource allocation, and also alleviates the "principal-agent" conflict to a certain extent [11]. Especially when the traditional production mode reorganizes and optimizes production resources with the help of digital technology, digital transformation shows important value functions. The application of "data--intelligence" decision-making model based on big data and artificial intelligence can help enterprises make more accurate decisions [12]. The Internet, artificial intelligence and other digital technology tools have transformed the business model and production process of enterprises. While completing digital transformation, enterprises have also realized industrial upgrading [13].

Digital transformation has accelerated the process of enterprise information. The Internet significantly improves the efficiency of information exchange between enterprises and external organizations, helps enterprises obtain external resources, and lays a foundation for the realization of enterprise innovation strategies [14,15]. Based on the resource-based view, the resource difference between different enterprises is the main reason for the performance gap. Digital transformation helps enterprises break physical resource barriers and effectively alleviate the long-standing resource constraint problem [16]. Indeed, digital transformation has brought companies closer to their customers. Technologies such as the Internet help enterprises quickly obtain customer data and better understand customer needs, making their customers become important participants in enterprise innovation. The increasing involvement of customers in the production and value creation of enterprises has accelerated the pace of product and technology improvement.

The application of new technologies such as block chain, cloud computing and Internet of things makes traditional enterprises more intelligent and promotes technological innovation of enterprises [17,18]. Digital transformation helps enterprises shift to the direction of data mining and intelligent analysis when analyzing data [19], improve the operation efficiency of enterprises, and improve the scientific nature of innovation decision-making [20]. The application of digital technology shortens the R&D cycle of intangible assets and improves the internal R&D capability of enterprises to a certain extent.

The transmission and sharing of data and knowledge elements among the internal systems of enterprises helps enterprises realize the synergistic effect between internal innovation and R&D and enterprise supply chain [21], and enterprises achieve more output under the original R&D resource boundary [22].

It can be seen that in the process of enterprise digital transformation, the ability to integrate internal and external resources is improved, the innovation and collaboration of industrial chain is promoted, the enterprise technology research and development cycle is constantly shortened, and the difficulties faced by R&D activities is easier to be solved. Based on the above analysis, enterprise innovation level can be effectively improved after enterprise digital transformation. Therefore, research hypothesis 1 is put forward: digital transformation of agricultural listed companies is positively correlated with innovation quality improvement.

2.2. The moderating effect of environmental regulation

Different from other countries, China mainly adopts administrative orders or government performance appraisal as environmental regulation means.

The Chinese government emphasized in its 20th National Report on environmental pollution prevention and control. It embodies the determination and strength of the government to protect the ecological environment. At present, scholars have not reached a consensus on the relationship between environmental regulation and technological innovation. On the one hand, scholars believe that environmental regulation will inhibit enterprise innovation. "Compliance Cost Hypothesis" holds that the investment of enterprises in environmental pollution control may crowd out the R&D funds of enterprises and hamper the innovation of enterprises [23]. The expenditure of environmental governance exceeds the benefits of environmental protection work carried out by enterprises using new technologies, increasing the burden on enterprises [24]. Especially when the innovation ability of enterprises is weak, environmental regulation will hinder the development of enterprises [25]. Feres et al. [26]believe that the government's strict environmental regulation on enterprises does play a certain role in reducing pollution emissions, but it will also affect the effect of government subsidy policies and even go against the green innovation of enterprises. Technological progress itself cannot reconcile the contradiction between economic development and environmental protection, and strict environmental regulations may weaken the competitiveness of enterprises [27].

On the other hand, scholars believe that environmental regulation can promote enterprise innovation. "Porter Hypothesis" [28] believe that strict and reasonable environmental regulations can stimulate enterprise innovation, offset the compliance costs of environmental regulations, and further improve the market competitiveness of enterprises. Robert et al. [29] also confirmed the rationality of "Porter hypothesis". Li Yuanyuan et al. [30] believe that enterprises will actively adjust their development strategies and stimulate innovation potential according to the relevant requirements of the government on environmental protection.

Although scholars have not reached a consensus on the relationship between environmental regulation and enterprise innovation, it is undeniable that environmental regulation has obvious positive externalities. With the help of the Internet and other digital technologies, social citizens have gradually become the supervising force for the implementation of environmental regulations, effectively making up for the lack of government supervision of enterprise pollution emission [31]. The relatively hidden emission

behavior of enterprises makes it more difficult for the government to supervise enterprises, and the public can just complement the lack of government supervision and create a good social supervision environment for the implementation of environmental regulation [32]. Internet dissemination of information is timely and extensive. These characteristics help the public to quickly discover and timely disclose enterprises' environmental pollution behaviors, and play an important role in preventing enterprises' pollution [33]. Digital technology plays an important supporting role in the process of government's environmental regulation of enterprises. In the short term, it may increase the cost of enterprises, but in the long term, environmental regulation can promote the technological innovation of enterprises and improve their competitive position.

With the development of digital technology and the continuous promotion of enterprise digital transformation, the positive externality of environmental regulation will continue to expand. According to the knowledge spillover theory, policy making and institutional arrangements will affect the innovation mode of enterprises [34]. Digital transformation can transmit the policies, regulations and industry trends related to environmental protection to enterprises in time. Environmental regulation and digital transformation jointly optimize the innovation environment of enterprises, provide good external conditions for technological innovation of agricultural enterprises, and promote the improvement of enterprise innovation and development level.

Based on the above analysis, hypothesis 2 is put forward: environmental regulation has a positive moderating effect on the relationship between digital transformation and innovation quality in listed agricultural companies.

2.3. The mediating effect of "violating agricultural operation"

2.3.1. The production and value effect of "violating agricultural operation"

Agricultural enterprise diversification management has obvious industry characteristics and attribute of The Times. There is a special phenomenon in the research on the diversification of listed agricultural companies, which has aroused scholars' keen attention. Agricultural listed companies invest part of the capital into other industries other than agriculture, and this phenomenon is relatively common. Scholars refer to listed agricultural companies that carry out unrelated diversification strategies to expand operations in other industries other than agriculture as "violating agricultural operation".

Different from other industries, agricultural enterprises have the following objective reasons for the phenomenon of "violating agricultural operation". Firstly, agricultural production is mostly carried out under natural and semi-open conditions, which are greatly affected by force majeure factors such as natural environment and climatic conditions. Secondly, changes in the government's macroeconomic policies (especially subsidy policies) have a significant impact on the performance and behavior in listed agricultural companies [35]. As the foundation of the national economy, agriculture is very important to the country, so there are many policies to regulate and control, and agricultural enterprises are more likely to face policy changes. Finally, influenced by the growing period of agricultural products such as crop planting, animal husbandry and aquatic product breeding, agricultural enterprises generally have a long production cycle, which significantly increases the possibility of agricultural listed companies facing risks.

Based on the above analysis, agricultural enterprises pursue high profits due to their high risks, small profit space and many force majeure factors [36,37]. Preventing risks [38], strengthening internal synergies [39], adapting to external environment and improving internal governance structure are the main motivation for listed agricultural companies to develop new business and carry out diversified operations in "violating agricultural operation" [40].

After the emergence of "violating agricultural operation" has been a wide concern by scholars, and has produced the "discount effect", "premium effect" and other views. Scholars who support the view of the "discount effect" believe that back-farming will reduce enterprise performance [41]. "Violating agricultural operation" makes the resource allocation structure of listed agricultural companies unreasonable and the efficiency of resource use low, so it can not play a synergistic role. At the same time, as entering other industries requires breaking through industry barriers and consuming a lot of resources, the original main business resources are crowded out, and the coordination cost and management costs will further increase [42]. Furthermore, the complexity of "violating agricultural operation" will lead to problems such as information asymmetry between major shareholders and management, low efficiency of capital allocation in the internal capital market, and intensified agency costs, which will lead to the discount of enterprises [43].

Scholars who support the "premium effect" view analyze the value effect of "violating agricultural operation" from the perspective of synergistic effect and scope economy. Liu Kechun et al. [44] found that "violating agricultural operation" business strategy can promote the improvement of enterprise performance, but the premise is to ensure a moderate scale.Portfolio theory holds that the lower the return correlation of various assets in the asset portfolio held by investors, the more obvious the role of diversifying the specific risk of individual assets, and the smaller the overall risk of the portfolio [45]. Unrelated diversification can disperse business risks, optimize capital structure, increase profitability and enhance market value [46]. Li et al. [47] further studied and concluded that the combination of diversification and the improvement of financial leverage is conducive to the enterprise's value maximization.

Synergy can promote enterprises to achieve economies of scale, reduce costs and increase profits to a certain extent. Alchian [48] believes that the internal capital market has more advantages in information and supervision, and diversified enterprises can make project investment at a lower cost and reduce potential risks by virtue of the internal capital market [49]. Diversified operation saves transaction costs of enterprises through internal transactions, makes more efficient use of resources such as brands and technologies [50], helps enterprises search for the most suitable way of resource allocation for enterprise development, improves the efficiency of resource input and output, and embodies the realization of synergistic value. In particular, in terms of the allocation of rare resources, diversification can more flexibly help enterprises to flow capital into more high-quality investment fields in the internal capital market [51]. In addition, when enterprises adopt relevant diversification strategies, there is upstream and downstream relationship or complementary relationship between a number of businesses in the supply chain, which has a positive impact on the improvement of

corporate performance.

Although scholars have not formed a unified opinion on the conclusion of the value effect of "violating agricultural operation", the author believes that the "violating agricultural operation" strategy will produce both positive and reverse effects, and finally reflect the net effect. Due to the different degrees of the two opposite roles in different backgrounds, as well as the differences in data, models and other aspects, the research on the impact of diversified business strategy on firm performance has not yet reached a consistent conclusion. However, it should be seen that whether an enterprise implements the strategy of "violating agricultural operation" has "premium effect" or "discount effect" depends on the difference between the value created by "violating agricultural operation" and the cost generated. The net effect of "violating agricultural operation" is finally reflected in the conclusion of the study. Although the positive and negative effects of the net effect are closely related to the era and region of the enterprise, certainly, the "violating agricultural operation" can indeed become a link between various economic factors of the enterprise.

2.3.2. The mediating role of "violating agricultural operation" in the relationship between digital transformation and innovation quality

At present, scholars have reached different conclusions on the relationship between diversification and innovation. On the one hand, under the effect of knowledge sharing and scope economy, enterprises can obtain patents through diversified merger and acquisition [52], and diversification has a significant promoting effect on innovation performance [53]. Sun Haitao believes that digital inclusive finance is conducive to the diversification of agricultural enterprises [54]. Wang Xiangning [55] also found that the continuous development of digitalization can significantly reduce the degree of information asymmetry of enterprises and ease the financing constraints of enterprises. Sufficient cash flow is an important basis for enterprises to carry out "violating agricultural operation". On the other hand, some scholars believe that diversified operation may be difficult to coordinate the conflicts between new technologies and core technologies of enterprises, which will have a negative impact on enterprise innovation [56]. Due to the inconsistency of previous research results, the relationship between diversification and innovation needs to be analyzed more deeply. From the research results of scholars, few scholars have studied the "violating agricultural operation" in listed agricultural companies in the framework of digital transformation and innovation quality. Digital technology is considered as a measure to overcome risks [57]. As digital technologies continue to mature, diversification strategies can help enterprises build platform ecosystems and achieve horizontal expansion [58]. Enterprises can allocate knowledge and other resources to more productive areas through diversified management of products to obtain scope economic benefits of technology and knowledge assets [59,60].

In view of this, digital transformation not only has a direct impact on the innovation quality in listed agricultural companies, but also has an indirect impact on enterprise performance through risk diversification and resource coordination. "Violating agricultural operation" can just become the carrier of agricultural enterprises to disperse, share and coordinate resources. Digital transformation will affect the implementation of the strategy of "violating agricultural operation", and at the same time, "violating agricultural operation" will also become an important means to realize the diversification of risks and resource coordination of digital transformation enterprises. Therefore, "violating agricultural operation" is an important link and bridge for the digital transformation of agricultural enterprises to affect the quality of innovation. The research model of the study is shown in Fig. 1.

Based on the above analysis, hypothesis 3 is put forward: "violating agricultural operation" plays a partial mediating effect on the mechanism of digital transformation affecting innovation quality in listed agricultural companies.

3. Research design

3.1. Sample and data source

The data of listed agricultural companies in Shanghai and Shenzhen Stock exchanges from 2012 to 2020 were selected as samples to study the relationship between digital transformation and innovation quality. Working on the context of listed Chinese agricultural companies is not an arbitrary choice.China is a big agricultural country, and the development of Chinese agricultural listed companies

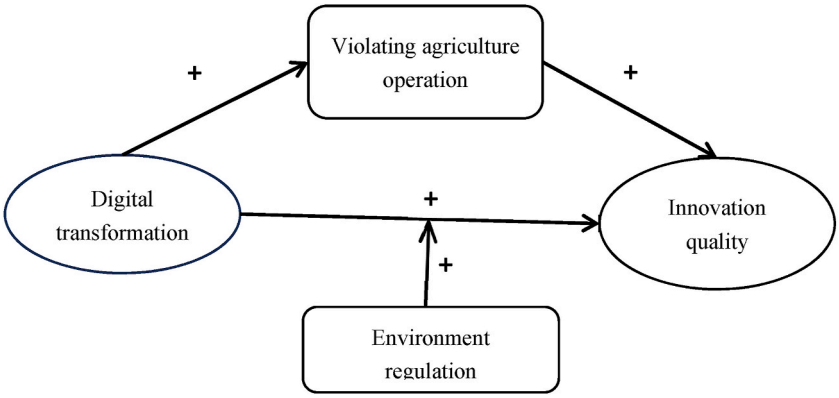

Fig. 1. The research model.

has an important impact on world agriculture. The data of innovation quality is mainly collected manually from the patent data published by Baiteng (www.baiten.cn). As one of the world's intellectual property big data platforms, Baiteng (www.baiten.cn) aims to provide the world's leading one-stop services such as intellectual property search, data mining, statistical analysis, data interface and productized software. Many scholars use the innovative data of the platform for academic research, and it has a high degree of recognition. The data of digital transformation is mainly collected manually from the audited annual reports of listed agricultural companies. Environmental supervision data are mainly collected manually from government work reports published on the official websites of cities. The data involved in the Digital Economy Comprehensive Index are from the open data of the *Digital Financial Inclusion Index of Peking University* and *The Statistical Yearbook of Chinese Cities*. Other control variables in the model are mainly from the database of China Stock Market & Accounting Research Database (CSMAR).

Because R&D investment requires a long R&D cycle, to ensure the continuity of research, we choose to balance panel data. From the process of sample collection, there is less missing data, which has little impact on the whole sample. On the premise of ensuring the balance of panel data, the sample with individual missing data and the sample with individual discontinuous data are deleted, and finally 270 balanced panel data of 30 agricultural listed companies are obtained. In order to exclude the interference of extreme values on the research results, winsorize the variables at 1 % and 99 % quantiles in this study.

3.2. Setting the model

Model (1) is established to test the impact of digital transformation on innovation quality in listed agricultural companies. The model controls the annual variables, and the definitions of each variable are shown in Table 1.

$$\underset{\text{Model}}{\text{Inv}_{i,t} = \alpha_0 + \alpha_1 \text{Lev}_{i,t} + \alpha_2 \text{Age}_{i,t} + \alpha_3 \text{SOE}_{i,t} + \alpha_4 \text{Digit}_{i,t} + \alpha_5 \text{Inten}_{i,t} + \alpha_6 \text{Roa}_{i,t} + \alpha_7 \text{Capint}_{i,t} + \alpha_8 \text{Growth}_{i,t} + \sum \text{Year} + \varepsilon_{i,t}} \quad (1)$$

In the model (1), the explanatory variable is $\text{Inv}_{i,t}$, representing the innovation quality of agricultural listed company i in year t. The explanatory variable $\text{Digit}_{i,t}$ represents the digital transformation level of agricultural listed company i in year t. α_0 is the intercept term. $\varepsilon_{i,t}$ is the random error term. The control variables mainly refer to the research of Zheng Tingting et al. [61] and other scholars, combined with the theme of this research, to better improve the fitting effect of the model.

Model (2) was established to test the moderating effect of environmental regulation on the impact of digital transformation on innovation quality in listed agricultural companies. The interactive items of digital transformation ($\text{Digit}_{i,t}$) and environmental regulation ($\text{Envir}_{i,t}$) are added. $\text{Digit}_{i,t}$ represents the digital transformation level of the city where the agricultural listed company is located. When $\beta 4>0$, it indicates that environmental regulation has a positive regulatory effect, and when $\beta 4<0$, it indicates that environmental regulation has a negative regulatory effect.

$$\underset{\text{Model}}{\text{Inv}_{i,t} = \beta_0 + \beta_1 \text{Lev}_{i,t} + \beta_2 \text{Age}_{i,t} + \beta_3 \text{SOE}_{i,t} + \beta_4 \text{Digit}_{i,t} * \text{Envir}_{i,t} + \beta_5 \text{Inten}_{i,t} + \beta_6 \text{Roa}_{i,t} + \beta_7 \text{Capint}_{i,t} + \beta_8 \text{Growth}_{i,t} + \sum \text{Year} + \varepsilon_{i,t}} \quad (2)$$

Taking "violating agricultural operation" (VAO) as a mediating variable, and referring to the practice of Wen Zhonglin et al. [62], a step-by-step regression method was used to analyze the mediating effect between digital transformation and innovation quality. In the first step, model (1) is used to examine the total effect of digital transformation on innovation quality. In the second step, model (3) is used to test the influence of digital transformation on "violating agricultural operation". In the third step, model (4) was used to test the

Table 1
Variable definition table.

Type	Symbol	Name	Definition
Explained variable	Inv	Innovation quality	Ln(number of invention patents +1)
Explanatory variable	Digit	Enterprise digitization level	Ln(keyword frequency +1)
	Digit1	Enterprise digitization level (robustness check)	Digit1 = 1 when Digit>0; Digit1 = 0 when Digit = 0
Adjusting variable	Envir	Environmental regulation	The proportion of environmental protection related words in the municipal government annual work report in the whole government work report
Mediating variable	VAO	Violating agricultural operation	1-HI
Instrumental variable	DIG	Comprehensive development Index of digital economy	Five core indicators reflecting the digital development were obtained by principal component analysis
Control variable	Lev	Asset-liability ratio	Total liabilities at year-end/total assets at year-end
	Age	Time of incorporation	Ln(number of years of incorporation)
	SOE	Nature of company property right	The value is 1 for state-owned enterprises and 0 for non-state-owned enterprises
	Inten	Asset income ratio	Total assets/operating income
	Roa	Return on equity	Net profit/Total assets
	Capint	Capital intensity	Net fixed assets/total assets
	Growth	The company to grow	(Current year's operating income - last year's operating income)/Last year's operating income
	Year	The annual effect	Year dummy variable

relationship between digital transformation, "violating agricultural operation" and innovation quality by using both digital transformation and "violating agricultural operation" as explanatory variables in regression. In order to improve the robustness of the mediating effect results, Sobel test and Bootstrap test were used to test the mediating effect.

$$\underset{\text{Model}}{VAO_{i,t} = \gamma_0 + \gamma_1 Lev_{i,t} + \gamma_2 Age_{i,t} + \gamma_3 SOE_{i,t} + \gamma_4 Digit_{i,t} + \gamma_5 Inten_{i,t} + \gamma_6 Roa_{i,t} + \gamma_7 Capint_{i,t} + \gamma_8 Growth_{i,t} + \sum Year + \varepsilon_{i,t}} \quad (3)$$

$$\underset{\text{Model}}{Inv_{i,t} = \varphi_0 + \varphi_1 Lev_{i,t} + \varphi_2 Age_{i,t} + \varphi_3 SOE_{i,t} + \varphi_4 Digit_{i,t} + \varphi_5 Inten_{i,t} + \varphi_6 Roa_{i,t} + \varphi_7 Capint_{i,t} + \varphi_8 Growth_{i,t} + \varphi_9 VAO_{i,t} + \sum Year + \varepsilon_{i,t}} \quad (4)$$

3.3. Variable definition and description

3.3.1. Explained variable: innovation quality

The innovation results that can reflect the quality of innovation should be patents with core technology and high commercial value, rather than weak patents developed through technical imitation. It is also not just low-quality patents produced to obtain preferential subsidies [61]. Patent Law divides patents into design patents, utility model patents and invention patents in China. On the one hand, compared with the other two types of patents, invention patents invest more manpower and money and the research and development results are innovative and high quality. The time period from application, publication to authorization of utility model patents and design patents is significantly shorter than that of invention patents, and there is no substantial examination stage in the application process [63]. On the other hand, the protection time of appearance patent and utility model patent is only 10 years, and the annual maintenance fee and agency fee are lower than that of invention patent. Therefore, invention patent can better show the innovation quality of enterprises. The number of invention patents filed is a better indicator of the level of innovation than the number granted. Patent grant requires testing and payment of annual fees, which is more uncertain and unstable [64] and susceptible to bureaucratic factors [65]. Therefore, because the number of invention patent applications is more stable, reliable and timely, it is taken as a surrogate variable of innovation quality.

Referring to the practice of scholars [66,67], the invention patents in listed agricultural companies are taken as the proxy variable for high-quality innovation. The specific method is to manually collect the invention patents of listed agricultural companies on Baiteng network (www.baiten.cn), and take the logarithm of the number of invention patents after adding 1 as a surrogate variable of innovation quality.

3.3.2. Explanatory variable: digital transformation

At present, the measurement of digital transformation is still a frontier problem in academia. Digital transformation uses cutting-edge digital technologies and hardware systems to promote the digitalization of enterprises' production materials and processes [68]. This study uses data related to digital transformation obtained from the annual financial data of listed companies, rather than a questionnaire survey. The most important reason is that listed companies treat annual financial reports much more seriously than questionnaires. At the same time, the financial reports of listed companies need to be disclosed to the public and have high credibility. In addition, the annual financial report of the listed company reflects the arrangement and implementation of the current and future business strategy of the enterprise. If the frequency of a certain type of keywords in financial reports is high, it often reflects the key investment of enterprises in this field. This provides support for word frequency statistics to measure the degree of digital transformation of enterprises. In the absence of more effective quantitative index system, the text analysis and word frequency statistics of the annual financial reports of listed agricultural companies can better reflect the level of digital transformation of the company.

This study draws lessons from the practices of scholars [69,70]. By manually mining the keywords involved in digital transformation in the annual financial reports of listed companies, combining with the industry characteristics of listed agricultural companies, the keywords involved in digital transformation are summarized as follows: artificial intelligence, intelligence, intelligent manufacturing, automation, robotics, digital technology, digitalization, digital economy, big data, cloud computing, cloud platform, cloud manufacturing, Internet of Things, block chain, Internet, "Internet + ", informatization, information technology, etc. The natural logarithm of the frequency of keywords involved in digital transformation was added by 1 as a surrogate variable for digital transformation of listed agricultural companies.

3.3.3. Moderating variable: environmental regulation

As an important external condition of enterprises, environmental regulation mainly includes command-control environmental regulation, market incentive environmental regulation and voluntary environmental regulation. According to the practice of Chen et al. [71], since China mainly adopts command-control environmental regulation, the study takes the proportion of environmental protection-related words in the annual work reports of municipal governments at various levels in the whole government work reports as a surrogate variable to measure the intensity of local governments' environmental regulation.

3.3.4. The mediating variable: "violating agricultural operation" (VAO)

Referring to Fan Libo's [72] practice of using the income Herfindahl index (HI) to measure the degree of enterprise diversification (Model 5), the larger the HI, the smaller the degree of enterprise diversification and the smaller the degree of "violating agricultural operation" that is, the smaller the HI, the greater the degree of diversified management and the greater the degree of "violating

agricultural operation". In order to make indicators and variables increase and decrease in the same direction, and the HI range is between 0 and 1, VAO can be used to represent the degree of "violating agricultural operation" of listed agricultural companies (Model 6). When the VAO is larger, the enterprise "violating agricultural operation" degree is larger, and the smaller the VAO, the smaller the degree of "violating agricultural operation".

$$\underset{\text{Model}}{HI} = \sum_{i=1}^{n} P_i^2 \tag{5}$$

$$\underset{\text{Model}}{VAO} = 1 - HI \tag{6}$$

In model (5), "n" represents the number of industries involved in the operation of listed agricultural companies, and "P_i" represents the proportion of the income of the "i" industry in the total income of the company. The main variables in the models are defined as shown in Table 1.

4. Empirical analysis

4.1. Descriptive statistics

According to the descriptive statistical results (Table 2), the maximum value of Inv is 2.708, the minimum value is 0, and the average value is 0.375, indicating that the innovation quality of China's listed agricultural companies is quite different. The maximum value of Lev is 0.980, and the average value is 0.439, indicating that the financial risk in listed agricultural companies is generally large, which is consistent with the research conclusion of high risk in listed agricultural companies drawn by scholars above. The mean and median of Digit are 1.541 and 1.609, respectively, indicating that the degree of digital transformation of listed agricultural companies is generally low, and the future development space is relatively large. The minimum value of Roa is −0.284, indicating that listed agricultural companies have a loss year. The maximum value of Roa is 0.289, and the mean and median value are 0.013 and 0.015, respectively, indicating that the average rate of return of listed agricultural companies is low, which is consistent with the conclusion that listed agricultural companies have less profit space.

4.2. Correlation analysis

Table 3 shows the Spearman correlation coefficient test results of the main variables in the model. The correlation coefficient between Digit and Inv is 0.176, which is significant at the 1 % level, preliminarily indicating that there is an obvious positive correlation between digital transformation and innovation quality. The correlation coefficient between digital transformation and environmental regulation (Digit*Envir) and innovation quality is 0.199, which is significant at the 1 % level. This preliminary result indicates that there is also a significant positive correlation between digital transformation and innovation quality, which lays a foundation for further regression analysis.

Before regression, it is also necessary to test whether there is a multicollinearity problem among various variables. Therefore, the variance inflation factor (VIF) and multicollinearity tolerance (TOL) of each variable are calculated in this study, and the test results are shown in Table 4. The variance inflation factor (VIF) of each variable was between 1.06 and 1.31, far less than 10, and the tolerance of multicollinearity (TOL) was between 0.761 and 0.942, greater than 0.1. The test results show that there is no multicollinearity problem in each variable in the model, which lays a foundation for obtaining reliable analysis results by regression analysis.

4.3. Regression analysis

As shown in Table 5, regression (1) results show that the regression coefficient of Digit is 0.108, which is significant at the 1 % level,

Table 2
Descriptive statistics.

Variable	N	Mean	Median	Standard Deviation	Minimum	Maximum
Inv	270	0.375	0	0.696	0	2.708
Lev	270	0.439	0.411	0.214	0.056	0.980
Age	270	2.779	2.833	0.316	2.079	3.178
SOE	270	0.463	0	0.500	0	1.000
Digit	270	1.541	1.609	1.084	0	3.850
Envir	270	0.056	0.051	0.026	0.016	0.142
VAO	270	0.366	0.410	0.241	0	0.873
Inten	270	2.806	2.141	2.120	0.444	12.131
Roa	270	0.013	0.015	0.080	−0.284	0.289
Capint	270	0.262	0.229	0.152	0.012	0.676
Growth	270	0.100	0.050	0.445	−0.619	2.710
DIG	270	1.241	1.135	0.755	0.121	4.503

Table 3
Spearman correlation coefficient.

	Inv	Lev	Age	SOE	Digit	Digit*Envir	Inten	Roa	Capint	Growth
Inv	1									
Lev	0.042	1								
Age	−0.281***	−0.198***	1							
SOE	−0.207***	−0.037	0.190***	1						
Digit	0.176***	0.115*	−0.099	0.072	1					
Digit*Envir	0.199***	0.055	−0.055	0.066	0.838	1				
Inten	−0.074	−0.103*	0.300	0.019	−0.047	−0.062	1			
Roa	0.113*	−0.317	−0.031	−0.081	−0.011	−0.005	−0.217***	1		
Capint	0.048	0.194***	−0.205***	−0.073	−0.057	−0.008	−0.363***	0.028	1	
Growth	0.119*	−0.021	−0.068	−0.121**	0.073	0.147**	−0.361	0.268	0.018	1

Note:*** denotes P < 0.01, ** denotes P < 0.05, * denotes P < 0.1.

indicating that digital transformation of listed agricultural companies has a significant positive correlation with innovation quality. Hypothesis (1) is verified. According to the results of regression (3), the coefficient of Digit*Envir is 1.551, which is significant at the 5 % level, indicating that environmental regulation has a positive regulating effect on the relationship between digital transformation and innovation quality. Hypothesis (2) is verified. Considering the possible lag effect of digital transformation, Digit was included in model (1) and model (2) for testing after one lag. The regression results are shown in (2) and (4) in Table 5. The coefficient of Digit lagged one period (L.Digit) is 0.091, which is significant at 5 %. The coefficient of Digit lag one (L.Digit) and the multiplication term (L. Digit *Envir) is 1.389, which is significant at the 10 % level. It also proves that digital transformation of listed agricultural companies has a significant positive correlation with innovation quality. Moreover, environmental regulation has a significant positive moderating effect on the relationship between digital transformation and innovation quality in listed agricultural companies.

The first step is to test the relationship between digital transformation and innovation quality. The results are shown in regression (1) in Table 5. It has been proved that digital transformation and innovation quality have a significant positive correlation. The second step is to test the relationship between digital transformation and "violating agricultural operation" (VAO). The result is shown in regression (5) in Table 5. The coefficient of Digit is 0.056, and it is significant at the 1 % level, indicating that digital transformation has a significant positive correlation with "violating agricultural operation". The third step is to test the relationship among digital transformation, "violating agricultural operation" and innovation quality. The results are shown in regression (6) in Table 5. The coefficient of Digit is 0.086 and significant at 5 %, and the coefficient of VAO is 0.398 and significant at 10 %. "Violating agricultural operation" plays a part in mediating the relationship between digital transformation and innovation quality.

5. Robustness test

5.1. The instrumental variable approach mitigated the endogeneity problem

Two-stage least squares method (2SLS) is used to reduce the possible endogeneity problem between digital transformation and innovation quality in listed agricultural companies. Digital Economy Synthesis Index (DIG) is constructed as the instrumental variable of digital transformation.

Referring to the practice of many scholars [73,74], the Digital Economy Development Comprehensive Index is constructed from five indicators including the inclusive development level of digital finance, Internet penetration rate, Internet-related output, Internet-related employees and mobile Internet users through dimensionality reduction processing of principal component analysis. The development level of digital financial inclusion is measured by the China Digital Financial Inclusion Index, Internet penetration rate is measured by the number of people with Internet broadband access per 100 people, Internet-related output is measured by the proportion of the number of people in information transmission, software and information technology services to the number of people employed in urban units, Mobile Internet users are measured by the number of mobile phone users per 100 people (Data were manually obtained from *the Peking University Digital Financial Inclusion In*dex and the China Urban Statistical Yearbook).

The results of the two-stage regression are shown in Table 6. After the first-stage regression, the fitted values of the first-stage regression are included in the second-stage regression as explanatory variables. In the validity test of instrumental variables, F value is 46.72, greater than 10, indicating that instrumental variables are effective. In the second-stage regression, the coefficient of Inv is 0.225, which is significant at the 5 % level, indicating that the conclusion that digital transformation can promote the improvement of innovation quality in the listed agricultural companies still holds after considering the influence of endogeneity.

Table 4
The VIF and TOL of variances.

	Lev	Age	SOE	Digit	Inten	Roa	Capint	Growth
VIF	1.23	1.08	1.06	1.17	1.31	1.31	1.22	1.20
TOL	0.816	0.927	0.942	0.858	0.761	0.762	0.821	0.836

Table 5
Analysis of regression results.

	(1)	(2)	(3)	(4)	(5)	(6)
	Inv	Inv	Inv	Inv	VAO	Inv
Lev	0.102	0.121	0.148	0.178	0.258***	−0.001
	(0.584)	(0.648)	(0.829)	(0.936)	(3.542)	(-0.003)
Age	−0.218*	−0.283**	−0.224**	−0.289**	0.123**	−0.267**
	(-1.872)	(-2.172)	(-1.972)	(-2.278)	(2.524)	(-2.162)
SOE	−0.245***	−0.239***	−0.238***	−0.232***	0.043	−0.262***
	(-3.129)	(-2.864)	(-3.020)	(-2.758)	(1.492)	(-3.179)
Digit	0.108***				0.056***	0.086**
	(2.598)				(4.543)	(1.987)
L.Digit		0.091**				
		(2.020)				
Digit*Envir			1.551**			
			(2.468)			
L.Digit*Envir				1.389*		
				(1.946)		
VAO						0.398*
						(1.731)
Inten	0.013	0.007	0.012	0.005	0.014*	0.008
	(0.497)	(0.256)	(0.451)	(0.190)	(1.673)	(0.308)
Roa	0.736	0.657	0.826	0.721	−0.263	0.841*
	(1.391)	(1.193)	(1.547)	(1.290)	(-1.408)	(1.656)
Capint	0.344	0.234	0.247	0.136	0.302**	0.224
	(0.826)	(0.532)	(0.596)	(0.310)	(2.502)	(0.615)
Growth	−0.001	0.018	−0.018	0.008	0.084**	−0.034
	(-0.013)	(0.213)	(-0.252)	(0.097)	(2.126)	(-0.439)
constant	0.664	0.962**	0.716*	0.997**	−0.345**	0.801*
	(1.532)	(1.983)	(1.711)	(2.127)	(-2.187)	(1.831)
N	270	240	270	240	270	270
YEAR	control	control	control	control	control	control
R^2	0.105	0.094	0.103	0.095	0.208	0.120
F value	2.656***	2.515***	2.269***	2.136***	5.522***	2.678***

Note: ***, **and * denote rejection of the test at the 1 %,5 % and 10 % level, respectively.

5.2. Propensity score matching method to alleviate the endogeneity problem

Propensity score matching (PSM) was used to reduce the endogeneity problem caused by sample self-selection. Digit was divided into high digital transformation group and low digital transformation group according to the median. The high digital transformation group was taken as the treatment group, and the low digital transformation group was taken as the control group.

Different matching methods have certain measurement bias, so scholars have not reached a consensus on which matching method

Table 6
Endogeneity test results (2SLS).

	The first stage	The second stage
DIG	0.573***	
	(6.830)	
Inv		0.225**
		(2.011)
Lev	−0.834*	0.026
	(-1.960)	(0.077)
Age	−3.407	0.164
	(-1.400)	(0.085)
SOE	0.126	0.345
	(0.420)	(1.486)
Inten	0.035	0.002
	(0.780)	(0.053)
Roa	0.250	−0.068
	(0.380)	(-0.134)
Capint	1.134	−1.452**
	(1.360)	(-2.205)
Growth	0.073	−0.009
	(0.700)	(-0.115)
constant	10.199	−0.219
	(1.500)	−0.04

Note: ***, **and * denote rejection of the test at the 1 %,5 % and 10 % level, respectively.

has the best result. If the results of multiple matching methods are similar or consistent, it indicates that the matching results are robust and the sample validity is good. In order to improve the robustness of the research results, four matching methods are used for matching. ①K-nearest neighbor matching. Considering the mean square error and other factors, k = 6, a pair of six matching is carried out. ②Caliper matching. After comprehensive analysis, the caliper range is set to 0.02. ③ K-nearest neighbor matching in calipers. Set the caliper range to 0.02 for a pair of 6 matching. ④ Kernel matching. The default kernel and bandwidth are used for matching.

Before PSM matching, balance test is required. Balance test results are shown in Fig. 2. K-nearest matching balance test result, Caliper matching balance test result, K-nearest neighbor matching in calipers balance test result, and Kernel matching balance test result are included in Fig. 2. In the stationarity test of the four matching methods, the absolute values of the deviation values of most variables decrease. At the same time, although the deviation value of individual variables has increased, the absolute value of the deviation value of all variables after matching is less than 10 %, which indicates that the matching result is good.

The balance test results of the above four matching methods are good. After matching, the average treatment effect (ATT) of the experimental group was shown in Table 7. The ATT values in the four matching results are all greater than 0, and are all significant at the level of 5 % or 10 %. It indicates that after considering the endogeneity of sample self-selection, the conclusion that digital transformation promotes the improvement of innovation quality in listed agricultural companies still holds.

5.3. Other robustness tests

Referring to the practice of Huang Hualing [74], Digit1 was taken as the alternative variable of digital transformation Digit. When Digit>0, Digit1 = 1; When Digit = 0, Digit1 = 0, and the regression results are shown in Table 8.

The result of regression (1) in Table 8 shows that the regression coefficient of Digit1 is 0.246, which is significant at the level of 1 %, indicating that the conclusion that digital transformation of listed agricultural companies has a significant positive correlation with innovation quality has certain robustness. The result of regression (3) in Table 5 shows that the coefficient of Digit1*Envir is 3.572, which is significant at 1 % level, indicating that the conclusion that environmental regulation has a positive regulating effect on the relationship between digital transformation and innovation quality has certain robustness.

Similarly, considering the possible lag effect of digital transformation, Digit1 was included in model (1) and model (2) for testing after one period lag. The regression results were shown in Table 5 (2) and (4). The coefficient of Digit1 lagged one period (L.Digit1) was 0.167, which was significant at the 10 % level. The coefficient of L.Digit1 *Envir is 3.059, which was significant at the level of 5 %, indicating that there was a significant positive correlation between digital transformation and innovation quality in listed agricultural companies. Moreover, the conclusion that environmental regulation has a significant positive moderating effect on the relationship between digital transformation and innovation quality of listed agricultural companies has certain robustness.

5.4. Robustness test of mediating effect (Sobel test and Bootstrap test)

In the mediation test, the study adopted Sobel test and Bootstrap test in addition to stepwise regression test. Sobel test shows that

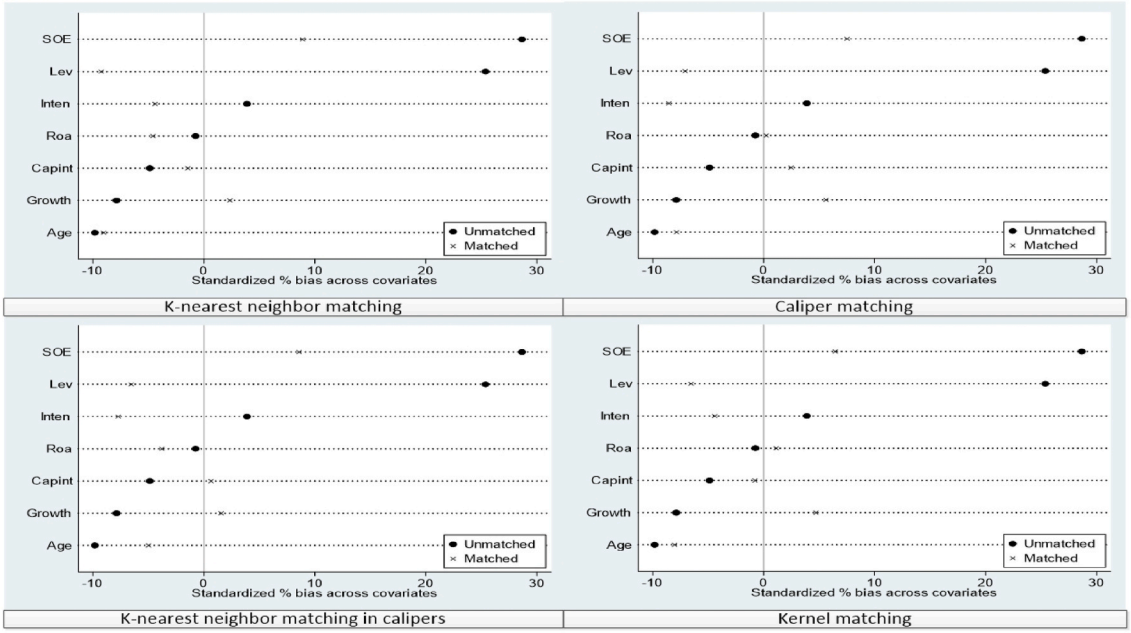

Fig. 2. Balance test results.

Table 7
Propensity score matching.

Matching method	ATT	Standard error	T value
K nearest neighbor matching	0.210**	0.093	2.250
Caliper match	0.199**	0.091	2.180
K-nearest neighbor matching in calipers	0.207**	0.094	2.200
Nuclear match	0.188*	0.089	2.120

Note: ***, **and * denote rejection of the test at the 1 %,5 % and 10 % level, respectively.

Table 8
Regression analysis.

	(1)	(2)	(3)	(4)	(5)	(6)
	Inv	Inv	Inv	Inv	VAO	Inv
Lev	0.165	0.184	0.218	0.238	0.290***	0.043
	(0.910)	(0.945)	(1.192)	(1.236)	(3.962)	(0.208)
Age	−0.239**	−0.298**	−0.248**	−0.303**	0.112**	−0.286**
	(-2.076)	(-2.307)	(-2.166)	(-2.359)	(2.326)	(-2.360)
SOE	−0.259***	−0.246***	−0.249***	−0.243***	0.036	−0.274***
	(-3.175)	(-2.808)	(-3.093)	(-2.812)	(1.192)	(-3.233)
Digit1	0.246***				0.127***	0.192**
	(2.775)				(3.871)	(2.315)
L.Digit1		0.167*				
		(1.709)				
Digit1*Envir			3.572***			
			(2.765)			
L.Digit1*Envir				3.059**		
				(2.273)		
VAO						0.420*
						(1.917)
Inten	0.009	0.004	0.009	0.003	0.012	0.004
	(0.365)	(0.140)	(0.357)	(0.114)	(1.435)	(0.181)
Roa	0.693	0.596	0.833	0.671	(0.286)	0.813
	(1.249)	(1.048)	(1.517)	(1.193)	(-1.407)	(1.556)
Capint	0.305	0.205	0.201	0.123	0.282**	0.187
	(0.742)	(0.463)	(0.504)	(0.290)	(2.396)	(0.511)
Growth	−0.002	0.032	−0.024	0.019	0.083**	(0.037)
	(-0.027)	(0.371)	(-0.337)	(0.228)	(2.112)	(-0.470)
constant	0.647	0.960*	0.722*	0.974**	−0.354**	0.796*
	(1.493)	(1.965)	(1.719)	(2.047)	(-2.266)	(1.839)
N	270	240	270	240	270	270
YEAR	control	control	control	control	control	control
R^2	0.100	0.087	0.107	0.097	0.196	0.117
F value	2.547***	2.296***	2.226***	2.242***	4.884***	2.501***

Note: ***, **and * denote rejection of the test at the 1 %,5 % and 10 % level, respectively.

the total effect is 0.108, the direct effect is 0.086, the indirect effect is 0.022, and the Z value is 1.862, P value is 0.063, which is significant at the 10 % level, proving that "violating agricultural operation" plays a partial mediating effect between the transformation and innovation quality of agricultural listed companies. In the Bootstrap test, there were 1000 repeated sampling times with put back, and the confidence interval was between 0.003 and 0.066, excluding 0, indicating the existence of mediating effect. The above two methods all prove that "violating agricultural operation" plays a partial mediating effect on the relationship between transformation and innovation quality of listed agricultural companies. The robustness test of mediating effect results is shown in Table 9.

6. Discussion and research implications

6.1. Discussion on key findings

This study focuses on listed agricultural companies to explore the relationship between corporate digital transformation and innovation quality improvement, a previously relatively unexplored area. There are three main findings in this study.

Firstly, digital transformation has a positive impact on the quality of innovation. This provides a solid basis for the amplification and multiplication of the digital economy on agricultural development. In the agricultural field, the verification of the value realization of digital economy provides important support for the development of digital economy theory. Digital transformation of agricultural

Table 9
Robustness test of mediating effect.

Variable	Sobel test	Bootstrap test		
	Z value	P value	95 % lower bound of confidence interval	95 % upper limit of confidence interval
VAO	−2.464	0.063	0.003	0.066

companies is an important measure to realize the development of digital economy, stimulate the innovation potential of agricultural enterprises, and realize the value of digital.

Secondly, environmental regulation has a positive regulatory effect on the digital transformation and innovation quality improvement of agricultural listed companies. Different from previous studies, previous scholars paid attention to the direct impact of environmental regulation on innovation and reached different conclusions due to different background conditions [23]. In this study, environmental regulation is limited to the framework of digital transformation and innovation of listed agricultural companies, and the background of the study is very clear. This study verifies that "Porter hypothesis" is still valid under the background of the development of agricultural digital economy in the new era, and lays the foundation for the scientific decision-making of enterprises.

Finally, "violating agricultural operation" plays a partial mediating role in the relationship between digital transformation and innovation quality improvement. Scholars have always had different opinions on the behavior of "violating agricultural operation" in listed agricultural companies, and this study provides an important basis for the positive effect of "violating agricultural operation" in the company. In the context of traditional economy, some scholars believe that "violating agricultural operation" is the source of "discount" in listed agricultural companies that deviate from the main business [43,75]. With the vigorous development of digital economy, data elements have made up for the drawbacks of traditional agriculture. This study assisted to verify that under the background of the development of digital economy, "violating agricultural operation" would not cause "discount" effect, which is exactly similar to the views of scholars such as Belen [76] and John [77]. The findings of this study provide an important reference for the strategy of rearranging the main business structure of agricultural companies under the background of the development of digital economy.

6.2. Thinking about the motivation of "violating agricultural operation"

There is a significant positive adjustment effect between digital transformation and innovation quality of agricultural enterprises. The paper has analyzed the causes of "violating agricultural operation" in this study, but the exploration of the decision-making motivation of "violating agricultural operation" is relatively small. Based on the analysis of rational deviation, Lu believe that the decision-making motivation of "violating agricultural operation" can be divided into rational factors and irrational factors [78]. When managers are overconfident, the behavior of listed companies may be irrational. What is worth further consideration is whether the mediating effect between digital transformation and innovation quality is also different when the managers of listed companies are overconfident or not and there are differences in risk preferences.

This study is a good way to analyze the possible intermediary role from the perspective of the net effect of "violating agricultural operation". No matter what kind of motive "violating agricultural operation" is based on, the final effect of aggregation is the "net effect". This also indicates that the result of the rational motivation of "violating agricultural operation" may be positive or negative. In the same way, the results of "violating agricultural operation" out of irrational motives may be positive or negative. Thus, it can be seen that the result of irrational "violating agricultural operation" is not necessarily better than that of rational "violating agricultural operation". The analysis from the perspective of net effect can avoid the preconceived thinking pattern and only pay attention to the final economic effect produced by "back-farming operation".

Of course, from the perspective of guiding practice, paying attention to the "net effect" can directly and efficiently make decisions, and in this study, paying attention to the "net effect" is more in line with the theme and purpose of this study. However, it has to be admitted that only the multi-angle analysis of "violating agricultural operation" can make the study of this problem more thorough, so any form of in-depth analysis is meaningful. Therefore, in future research, the authors will also explore more dimensions related to "violating agricultural operation", and expect to obtain more research conclusions with more academic value.

6.3. Research significance

This study is of great significance to the development of many fields, mainly including three aspects.

Firstly, these findings are of immense practical importance to policymakers at both national and international levels. This study explores in depth "digital economy", "enterprise innovation driven", "ecological and environmental protection", "agricultural development" and other topics related to the long-term and healthy development of the national and international community. This study incorporates these concerns into a research framework that plays an important role in enabling policy makers to make systematic and comprehensive strategic decisions.

Secondly, this study is of great significance for the digital transformation of agricultural companies in the context of the development of digital economy. Compared with companies in other industries, agricultural companies are relatively small in size and market capitalization, but they are closely related to people's lives. In this context, based on agricultural companies, this study provides suggestions for the operation structure, transformation and upgrading of agricultural companies, which is very important for the

healthy and long-term development of agricultural listed companies.

Thirdly, this study points out the direction for the management of agricultural companies. On the one hand, it enhances the confidence of the management of agricultural companies to carry out "violating agricultural operation". In the context of digital economy, "violating agricultural operation" can also play an important role in the long-term development of enterprises. On the other hand, environmental protection plays a positive role in enterprise innovation and enhances the determination and motivation of enterprises to fulfill their social responsibilities.

6.4. Research deficiencies

①Wu Fei et al. [68] found that enterprises are likely to disclose characteristic information such as digital transformation in their annual reports. Therefore, it is scientific and feasible to measure the degree of enterprise digital transformation by the disclosure times of digital-related words in the annual report. However, it must be noted that the digital transformation index constructed by this method has its drawbacks. Some of the information in the annual report is forward-looking and may reflect the expectation or early investment of the listed company's digital transformation, rather than the results of the digital transformation. Although the above methods have errors in characterizing the degree of digital transformation of enterprises, most company annual reports may have such problems. This error is more of a systematic error, and the digital transformation index is still comparable between different enterprises and between different years. In view of the research topic of this paper, it can be assumed that it will not seriously interfere with the research results. Of course, after this study, we will continue to look for variables that can better measure the digital transformation of enterprises, reduce research noise, and ensure that future research is more scientific.

②In the study of the article, a key point is worth paying attention to. "Violating agricultural operation" plays a partial mediating effect in the relationship between digital transformation and innovation quality improvement. Then what is the relationship between digital transformation and farm management? Due to the limitation of the topic and length of this research, it was not further discussed. Relatively speaking, the value of the research on the relationship between "violating agricultural operation" and the digital transformation of agricultural listed companies is not as important as the research in this paper, so it has not been conducted in depth in this study. Of course, in the following research, the relationship between "violating agricultural operation" and digital transformation of listed agricultural companies will be further discussed, so as to provide an important basis for the long-term healthy development of listed agricultural companies.

7. Conclusions and suggestions

Digital transformation is conducive to the improvement of innovation quality of agricultural listed companies. Therefore, in order to improve the innovation quality of agricultural enterprises, accelerating the digital transformation of agricultural enterprises can be regarded as an effective way. Indeed, the digital transformation of agricultural enterprises is a long-term systematic project, which must be scientifically planned from the top-level design of agricultural digital transformation, infrastructure construction, resource integration and other aspects to continuously accelerate the process of agricultural enterprise digitalization.

Environmental regulation has a significant moderating effect on the digital transformation of agricultural enterprises to promote the improvement of enterprise innovation quality. Therefore, agricultural enterprises should pay special attention to the guarantee effect of external environment in the process of digital transformation. The government has a dominant position in environmental regulation, so enterprises must change their thinking mode and complete the role change from passively accepting the government's environmental regulation measures to actively adjusting the strategic layout and actively adapting to the environmental regulation measures. Through digital means, we can timely understand the public's requirements for environmental protection, give full play to the synergistic effect of digital transformation and environmental regulation, and accelerate the improvement of enterprise innovation quality.

"Violating agricultural operation" plays a partial mediating effect in the relationship between digital transformation and innovation quality improvement, indicating that data as production factors can better make up for the possible shortcomings of "Violating agricultural operation". Digital transformation can give better play to the advantages of diversified management, which provides an important theoretical basis for agricultural enterprises to implement the strategy of "Violating agricultural operation".

Funding

This work was supported by Heilongjiang Province Philosophy and Social Science Research Planning Project (22JYC335)

Data availability statement

The datasets used and analyzed during the present study are available from the Corresponding author upon reasonable request.

CRediT authorship contribution statement

Jia Wang: Writing – original draft, Software, Funding acquisition. **Lin Zhang:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to

influence the work reported in this paper.

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