Digital transformation and agricultural green economic resilience in China: A moderating and threshold analysis

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Abstract: Improving the resilience of the agricultural economy is the core proposition of ensuring national food security and achieving sustainable agricultural development. Based on the digital economy's empowerment of agricultural economic resilience, this paper empirically tests the impact mechanism of digital economy on agricultural economic resilience by using panel data from 30 provinces in China from 2012 to 2022. The results show that the digital economy has a significant role in promoting the resilience of the agricultural economy, and the resilience level of the agricultural economy will increase by 0.558 for every 1 unit increase in the development level of the digital economy;(2) the agglomeration of agricultural industry forms a certain scale effect through information integration and transmission, which has a significant positive moderating effect on the resilience of the agricultural economy;(3) there is a single threshold effect on the resilience of rural human capital, and the editing improvement of the digital economy on the resilience of the agricultural economy is expanded by 1.44 times after crossing the critical point. Therefore, this paper puts forward some suggestions to improve the environment for the development of digital economy in rural areas, further adjust the distribution of agricultural industrial resources, and improve the level of rural human capital, so as to promote the coordinated development of digital economy and accelerate the realization of the strategic goal of becoming an agricultural power.

Keywords: digital transformation, digital economy, agricultural green economic

resilience, agricultural industrial agglomeration, rural human capital

1.Introduction

At present, the world economy is undergoing a transform that has not been found in a hundred years, with frequent global geopolitical conflicts, the rise of anti-globalization and trade protectionism, and the rise and fall of extreme weather, among other factors, posing challenges to the construction of the national economic system (Elgåker *et al*.,2012). In order to effectively cope with the risks in various angles and gain stable and sustainable growth of the national economy, the Organization for Economic Cooperation and Development (OECD) has pointed out that all countries in the world should learn from the past and current crises, and make efforts to fill in the loopholes of the economic system and strengthen the resilience of the economy (Duan et al.,2025; Peng et al.,2025). The agricultural economy as the foundation of national economic development and social stability, to achieve stable development of agriculture and enhance the resilience of the agricultural economy is not only to consolidate the sustainable development of the agricultural economy and safeguard basic food security, but also to improve the modernization of the national agricultural sector and the construction of a strong agricultural power of the major practical issues (Ma et al.,2025c). As China enters a critical period of strategic opportunities and risks and challenges, the importance of promoting the agricultural economy's resilience in the development of the country has been further highlighted, and how to enhance the power of the agricultural economy to resist external impacts and achieve stable development has become a crucial consideration in the course of modernization and advancement. Accordingly, the Chinese Government has proposed the strategic aim of "promoting the modernization of agriculture", emphasizing the need to give priority to the advancement of agriculture and countryside, to strengthen the foundation of food security and to promote the development of a strong agricultural country (Ma et al.,2024; Shen et al.,2024).

With the accelerated implementation of China's digital economy growth strategy (Li et al.,2025), the digital economy has gradually transformed into a crucial support for the growth of the national economy, and based on the data of the *Digital China Development Report.* The deep consolidation of the digital economy and agriculture has become a crucial direction in agricultural innovation and development, and provides new chance for sustainable agricultural development (Ma & Appolloni,2025;

Shen et al.,2025). Recently, the Chinese government has established the use of the digital economy to enhance the agricultural economy's resilience as a crucial direction for agricultural development, and has made many efforts, such as the purpose of digital information subject to build digital agriculture and realize the alteration of the agricultural production structure (Rijswijk *et al*.,2021), the development of digital inclusive finance to provide financial sustain for the agricultural sector (Liu & Ren, 2023;Tong et al.,2024), and the utilization of digital technology as a tool for digital remodeling of the countryside (Kurniawan *et al*., 2022). In this background, the booming advancement of the digital economy has injected new development vitality into the agricultural economy, so sorting out the connection between the resilience and the digital economy of the agricultural economy has significant theoretical significance and practical significance for clarifying how the digital economy improves the stable advancement of the agricultural economy, strengthens the risk-resistant ability and stability of the agricultural production, and enhances the resilience of the agricultural economy(Cheng et al.,2025;Wen et al.,2024).

2. Literature review

The principle of toughness first derived from physics, mainly conveys to the capability of resources to absorb energy during plastic deformation and rupture, and has since been continuously extended to the field of engineering restoration and ecology (Tong et al.,2025). Martin *et al*. (2015) creatively applied it to the field of economics based on the first law of geography, pioneering the study of economic resilience. The economic resilience conveys to the capability of an economy to recover to its previous degree of development through adaptive adjustment of economic structure and its social mechanism arrangement after being subjected to shocks from market, competition and environmental shocks, the power of an economy to recover to its previous level of development through adaptive adjustments to the economic structure and its social mechanism arrangements, which is mainly embodied in the four aspects of vulnerability, resistance, robustness and recoverability (Wink, 2012). With the continuous expansion of research on economic resilience, scholars have begun to combine economic resilience with the field of agriculture, deriving the idea of agricultural green economic resilience (Ma et al.,2025a) As the core subsystem of the regional resilience system, the dynamic evolution of agricultural economic resilience follows the "exposure-response-reconstruction" cycle logic of regional resilience. In the risk exposure stage, the agricultural system assumes the function of regional basic support through resistance and recovery ability and reduces the impact intensity of the whole area. In the response and adjustment stage, the adaptability and adjustment ability of agriculture and the regional industrial structure form a synergistic adaptation. In the stage of system reconstruction, the transformation and innovation ability of agriculture triggers the reshaping of regional economic pattern through the transition of industrial chain， and nowadays academic study on agricultural green economic resilience mainly according to the following aspects: (1) in the conceptual definition, academics have reached a basic consensus on the concept of agricultural green economic resilience put forward by Folke (2006), which believes that agricultural green economic resilience is the capability of the agricultural system to maintain economic stability and recovery after suffering from internal and external After the internal and external shocks, the agricultural system is able to maintain economic stability and gradually restore the development of the ability. This concept lays the research foundation of agricultural green economic's resilience. (2) In the examination of spatial effect, scholars take the whole country, region or province as the research unit, and study the agricultural green economic resilience by constructing the evaluation index system. For example, Liu *et al* (2020) found the level measurement and evolution of agricultural green economic toughness of 30 provinces in China, and found that there is a spatial linkage between the degree of Chinese agricultural green economic toughness, and the eastern and central regions are mostly H-H and L-H type agglomerations. (3) In the analysis of influencing factors, scholars through empirical research, found that land transfer, agricultural infrastructure, population aging and other factors will have an influence on agricultural green economic resilience.

The digital economy, as an emerging economic pattern with digital technology as the core element, plays a crucial role in improving traditional economic increase and enhancing the productivity of various sectors (Liu et al.,2025b; Ivanova & Sceulovs, 2018). The Chinese government proposes to promote the incorporation to realize the high-quality advancement of the national economy. The scale economy impact and scope economy effect formed during the advancement of digital economy will play a role through superposition and positively promote the performance of economic growth (Tan *et al*.,2024), thus providing more possibilities for the economic development of rural areas, remote mountainous areas and other regions (Melnykovych *et al*., 2018),Specifically, the digital economy can effectively promote the rapid flow of agricultural factors and technology diffusion(Banna *et al*.,2021), alleviate farmers' financial constraints, and reduce farmers' poverty vulnerability by breaking down information barriers between different regions and industries(Tay *et al*.,2022). In addition, as a new economic method encompassing platform economy, smart economy, and network economy, the advancement of digital economy will increase the popularization of digital framework and enhance the network access rate, which will help to narrow the digital realize the leapfrog development of economically underdeveloped regions (Wijers, 2010; Ding et al.,2025).

Since then, with the advancement of the digital economy (Xia et al.,2024), scholars began to focus on the influence of digital technology on the agricultural economy's resilience. For example, by constructing an evaluation index system, Gao *et al*. (2024) from the viewpoint of digital inclusive finance, investigated that digital inclusive financial research significantly amplifies the agricultural economy's resilience, and can indirectly act on the resilience of the agricultural economy through green innovation. In accordance with the construction of digital infrastructure, Ma *et al*. (2024) examined its influence on the agricultural economy's resilience, and finds that digital infrastructure significantly promotes the agricultural economy's resilience, which is specifically manifested in the enhancement of the resistance and the resilience of agricultural economy (Tong et al.,2024).

In summary, the fruitful research results on agricultural green economic resilience have laid a conjectural ground for the study of this article, but there are still the following flaws: (1) There is less literature on the structure of the influence of the digital economy on the resilience of the agricultural economy, and the examination framework has yet to be improved. (2) Regarding the issue of the digital economy acts on the toughness of the agricultural economy and whether there is a threshold effect between the two, the existing literature does not give an answer, but the relevant research needs to be further explored. Therefore, the main innovation of this paper is to construct an analytical framework for the impact of digital economy on agricultural economic resilience, and to conduct an empirical analysis of the impact of digital economy on agricultural economic resilience, including the following contents: (1) On the basis of combing the existing literature, the evaluation index system of digital economy on agricultural economic resilience was constructed, and the comprehensive measurement of digital economy on agricultural economic resilience was realized (2) Construct a framework for moderating effects. this paper constructs a framework of moderating effect to further explore whether agricultural industrial agglomeration plays a moderating effect (3) Construct a threshold effect framework to analyze whether rural human capital plays a threshold effect in the process of impact.

3.Research hypothesis

3.1 The direct impact of the digital economy on the agriculture's economic resilience:

The manifestation of the digital economy's impact on the agricultural economy's resilience can be observed in the following parts: first, the digital economy helps optimize the allocation of agricultural resources. As the core element of the digital economy era, data has fundamentally reconstructed the logic of agricultural resource allocation with its unlimited supply, zero marginal replication cost and cross-border liquidity. According to Coase's theorem, data-driven accurate information matching greatly reduces transaction costs in agricultural production: real-time monitoring of farmland moisture through the Internet of Things, satellite remote sensing tracking of crop growth, and blockchain to establish a credible traceability system can effectively eliminate the information barriers in land circulation, agricultural machinery scheduling, and production and marketing docking, thereby effectively solving the problem of information asymmetry in agricultural production, accelerating the information circulation and sharing of land, labor and other resources, so as to optimize resource allocation(Long *et al*., 2016). Secondly, the digital economy helps to improve agricultural decision-making ability (Aubert *et al*., 2012). Digital production equipment and advanced environmental monitoring instruments are not only able to carry out real-time detection and analysis of soil, temperature, humidity, etc(Wang et al.,2025). for crop growth, provide data reference for the application of chemical fertilizers and pesticides, and reduce the pollution of the ecological environment, but also realize the forecasting of severe weather, pests and other natural disasters by harnessing big data and other technological advancements, so as to improve the ability of agricultural producers to prepare for, respond to and adjust their agricultural production (Ma et al.,2025b;Wang et al.,2024). Lastly, the digital economy enhances to realize the efficient interoperability of agricultural production information (Teece *et al*.,2018). The expedited progress of the digital economy strongly promotes the widespread adoption of the Internet and other digital platforms, and the utilization of digital platforms speeds up the flow of agricultural production information, and agricultural producers are able to rely on digital platforms to communicate and interact with other producers, and to obtain mature agricultural production experience, improve agricultural production efficiency, and upgrade the agricultural production model(Wang & Ma,2024). Taking into account this, this article puts forward the hypothesis:

Hypothesis 1 (H1): The digital economy facilitates the resilience of the agricultural economy.

3.2 Moderating effects of agro-industrial agglomeration:

Agricultural industrial concentration refers to the organic agglomeration of farmers and enterprises formed in areas with initial agricultural natural resource endowment advantages in the field of agriculture, and with the continuous concentration of farmers and enterprises, it produces demonstration and learning effects, sharing effects and cumulative effects, and eventually forms a specialized and large-scale market organization network integrating cultivation, processing and distribution (Lohosha *et al*., 2023). Drawing on the principles of economies of agglomeration, industrial agglomeration affects economic advancement through a variety of mechanisms, which in turn enhances the ability of territorial external crises and recovering from crises (Battaglia *et al*., 2019). Specifically: firstly,based on the massive market information gathered by the digital platform, the agricultural industry agglomeration has formed an efficient information circulation system by building a multi-subject collaborative network, which accelerates the transmission speed of demand signals in the industrial chain. Relying on geographical proximity and organizational relevance, the business entities in the agglomeration area can quickly integrate elements such as warehousing and logistics, channel resources, etc., and dynamically adapt to changes in market demand through clustering strategies, so as to systematically improve the dynamic adjustment ability of the agricultural industry chain and the efficiency of market risk buffering.Secondly. When a large number of agricultural operators are highly concentrated at the spatial and organizational levels, a threshold for the scale of technology application will be formed (Liu et al.,2025a). The process of innovation diffusion is effectively shortened, so that technological innovation can be quickly transformed from individual practice to group adoption. This leap in technology penetration rate not only directly improves the efficiency of resource allocation at the production end, but also reconstructs the circulation mode of agricultural products through the technological collaboration of all links in the industrial chain, and finally forms a modern agricultural ecology characterized by a digital integrated system (Wen et al.,2025). In addition, the hierarchization of the production process brought about by agricultural industrial agglomeration provides strong support for the agricultural production system to stand up to external disturbances, reduces the vulnerability of the agricultural system and improves agricultural competitiveness by strengthening the resource deployment ability of the agricultural industry chain (Kamble *et al*., 2020). Therefore, in the mechanism of the digital economy affecting the agricultural economy's resilience, agricultural industry agglomeration can play a regulatory effect. Based on this, this article makes the assumptions:

Hypothesis 2 (H2): agro-industrial agglomeration plays a moderating influence in the step of digital economy affecting agricultural economy's resilience.

3.3 Threshold effects of rural human capital:

Rural human capital refers to the non-physical capital expressed with regard to the quantity and appropriateness of the rural workforce, which is formed through education and training, health investment, and migration investment, and condensed in the rural labor force (Dinkelman & Mariotti, 2016). Compared with traditional economic forms, growth and implementation of digital economy puts higher demands on the digital literacy of users, so the influence of the digital economy on the agricultural economy's resilience may be non-linear and will be constrained by rural human capital (Hou *et al*.,2024; Wu *et al*.,2025). In rural areas with low human capital, farmers exhibit obvious technology avoidance behaviors due to cognitive limitations: the elderly group mostly rejects mobile banking due to operational complexity, and relies on traditional experience for production decision-making while ignoring meteorological early warning data; Young people only use e-commerce platforms for consumption, forming a digital skills gap. In areas with high human capital, new agricultural entities show technological internal driving behaviors: adjusting planting parameters by actively calling "data models, and combining drone spectral data with intelligent irrigation systems to achieve precise water and fertilizer control. This depth of technology internalization not only transforms the digital divide into a resilience generation gap, but also drives the surrounding farmers to form a technology learning network through the knowledge spillover effect, which fundamentally strengthens the anti-risk ability of the regional agricultural system.. Based on this, this paper introduces the next hypotheses:

Hypothesis 3 (H3): The influence of the digital economy on the agricultural economy's resilience has a notable threshold effect, conditioned by the degree of rural human capital.

Accordingly, this article constructs the structure of the role of the digital economy on the impact of the resilience of the agricultural economy, as shown in Figure 1.

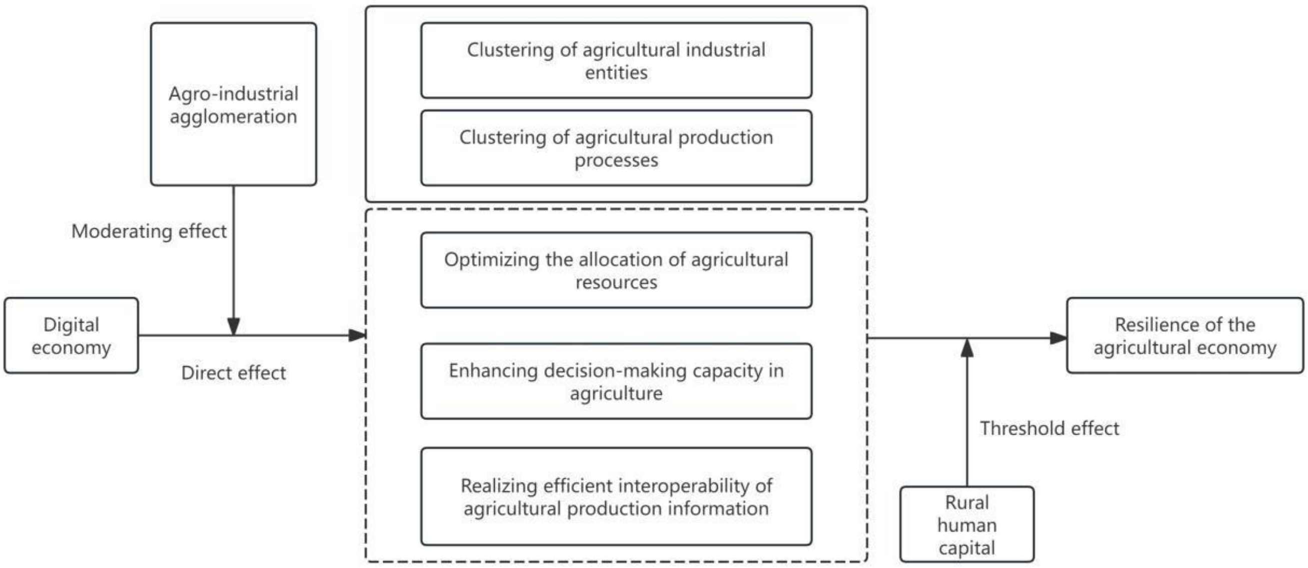

Figure 1. Mechanism of action for the influence of the digital economy on agricultural economy's resilience

4.Results

4.1 Selection of variables:

Explained variables. The explanatory variable of this article is agricultural green economic toughness (Qua). Speaking to the study results of Tsiotas and Katsaiti (2024), this article constructs the agricultural green economic's resilience evaluation index system from three aspects to recovery ability, adaptive adjustment ability, and transformation and innovation ability, totaling 14 secondary indicators, and carries out the entropy weight way to assess the weights. The resilience of agricultural economy, the ability to adapt and adjust, and the ability to transform and innovate constitute a hierarchical resilience pyramid: the resistance and resilience ability of the basic layer is the short-term survivability guarantee, ensuring that the system maintains its basic functions in the shock; The adaptability and adjustment ability of the middle layer realizes the homeostatic maintenance of the system in the changing environment through the dynamic reorganization of production factors (Ma et al.,2025d). The top-level transformation and innovation capability drives fundamental changes, and opens up new development paths through the active innovation of system elements and structures, forming a time-nested synergistic mechanism (Li et al.,2024). Table 1 presents the index system for agricultural green economic's resilience.

Table 1. System of indicators for measuring assessing the agricultural economy's resilience

The First Indicators	The Second Indicators	Unit	Indicator properties
Resistance	Agricultural output per capita	Yuan	+
	Percentage of primary sector	%	+
	Food production per capita	Kilogram	+
	Rural food expenditure / total expenditure	%	-
	The level of disaster	%	-
	Adequate irrigation rate	%	+
adaptive capacity	Number of employees in the main sector	Per 10,000 population	+
	Gross power of agricultural machinery	Kilowatt	+
	Rural disposable income per capita	Yuan	+
	Level of consumer spending from villages	Yuan	+
Transformative innovation capacity	Investment in fixed assets in agriculture	Billions	+
	Agricultural technicians	Per 10,000 Population	+
	Growth rate of agricultural value added	%	+
	Financial support for agriculture	Billions	+

4.2 Explanatory variables:

The explanatory variable of this article is the degree of digital economy development (Dig). Drawing upon the Statistical Classification of the Digital Economy and Its Core Industries (2021) and incorporating the research findings of Bruno *et al.* (2023), this article develops a set of digital economy evaluation indexes encompassing five dimensions: digital network infrastructure, logistics and transportation, digital trade capacity, digital technological innovation, and trade potential. To quantify the degree of digital economy development across China's provinces, the entropy method is employed. The structured digital economy evaluation index system is outlined in Table 2.

Table 2. Index system for evaluating the comprehensive development status of the digital economy

The First Indicators	The Second Indicators	Unit	Indicator properties

Digital network infrastructure	Number of domain names	10,000	+
	Number of websites	10,000	+
	High-speed Internet access port	10,000	+
	Span of long-distance optical fiber cables	Kilometers	+
	Broadband subscriber	Per 10,000 population	+
Logistics	Logistics and transportation-related practitioners	Person	+
	Ownership of road-operating goods vehicles	Ten thousand vehicles	+
	Civilian transportation ship ownership	Classifier for ships	+
Digital trade capacity	E-commerce sales	Billions	+
	Income from express delivery services	Billions	+
	Aggregate telecommunications services	Billions	+
	Revenue derived from software offerings	Ten thousand	+
Digital technology innovation	Research and development (R&D) spending of large-scale industrial enterprises	Ten thousand	+
	Overall revenue from technology contracts	Ten thousand dollars	+
	Count of granted patent applications	Sorter or categorizer for clothing, luggage, and decorations	+
Trade potential	GDP per capita	Yuan	+
	Market openness	%	+
	Total exports and imports	Billions	+

4.3 Moderating variables:

The moderating variable in this article is agricultural industry agglomeration (Aia). In order to minimize the error and improve the precision of data, this paper refers to Wu and Lin (2021) and expresses the agricultural industry agglomeration by location entropy index.

4.4 Threshold variables:

The threshold variable in this paper is rural human capital (Hr). Considering that years of education can represent the cultural level of the workforce, which is closely related to its cultural quality, learning ability and technical application ability, this paper takes the mean years of education of the rural workforce in each province as a proxy for rural human capital.

4.5 Control variables:

In order to reduce the errors that may be induced by omitted variables and to confirm the accuracy of the research results, the control variables used in this article are as follows:(1) Urbanization rate (Urb). Presented as the ratio of the urban populace within a district to the overall populace. (2) Road mileage (Road). Expressed as the number of officially used road miles in the region; (3) Agricultural green economic development level (Gdp). Stated in terms of rural residents' average disposable income. (4) The share of agricultural funding from the government (Gov), represented as the fraction of total governmental spending dedicated to agriculture.

Table 3. Data characteristics of primary variables

Variant	N	Mean	Std	Min	Max
Qua	330	0.2389	0.1242	0.0595	0.7216
Dig	330	0.1273	0.1005	0.0174	0.5903
Aia	330	1.7581	1.0056	0.2184	2.8359
Hr	330	7.8534	0.6235	5.8476	10.1149
Urb	330	0.5987	0.1286	0.2287	0.8960
Gov	330	11.5652	3.5098	4.0404	20.3840
Road	330	156895	83656.11	12541	405390.2
Gdp	330	14205.97	7356.417	4448	42195

4.6 Data sources:

The sample of this article is the panel data of 30 provinces in China from 2012 to 2022, meanwhile, affected by the availability、accessibility and integrity of data, it excludes Tibet, Hong Kong, Macao and Taiwan, The agricultural economy of the four regions is relatively small and will not affect the national sample size. The data are from *China Agricultural Statistical Yearbook*, *China Rural Statistical Yearbook*, *China Statistical Yearbook*, *National Bureau of Statistics and individual local statistical yearbooks*. The text utilizes interpolation to fill in individual missing values within the variables.

4.7 Benchmark regression framework

To study the mechanism of the digital economy on the resilience of agricultural economy, this paper first estimates a benchmark regression model:

$$Qua_{it} = \partial_0 + \partial_1 Dig_{it} + \partial_2 X_{it} + \delta_i + \tau_t + \mu_{it} \quad (1)$$

In equation (1), the Qua_{it} is the explanatory variable agricultural green economic resilience, the Dig_{it} is the core explanatory variable digital economy, and X_{it} is the series of control variables, the δ_i and τ_t represent region and time fixed impacts, and μ_{it} shows the random disturbance parameter.

4.8 Moderating effects model:

So as to verify whether agricultural industry agglomeration has a moderating role in the influence of the digital economy on the resilience of agricultural economy, this work constructs a moderating effect function as follows:

$$\mathrm{Qua}_{it} = \lambda_0 + \lambda_1 \mathrm{Dig}_{it} + \lambda_2 Aia_{it} + \lambda_3 \mathrm{Dig}_{it} \times Aia_{it} + \lambda_4 X_{it} + \delta_i + \tau_t + \mu_{it} \quad (2)$$

In equation (2), the Aia_{it} is the moderating variable agricultural industry agglomeration, the other symbols and variables retain their definitions as in equation (1).

4.9 Threshold effect model:

To further discover the possible indirect role of rural human capital in the nonlinear dynamic spillovers of the digital economy on the agricultural economy's resilience, this paper constructs a threshold effect pattern as follows:

$$Qua_{it} = \alpha_0 + \alpha_1 Dig_{it} I(Hr_{it} \leqslant \gamma) + \alpha_2 \mathrm{Dig}_{it} I(Hr_{it} > \gamma) + \alpha_3 X_{it} + \delta_i + \tau_t + \mu_{it} \quad (3)$$

In equation (3), the Hr_{it} is the threshold variable rural human capital, andγ is the threshold value, and $I(\cdot)$ represents the indicator function, and when the situation inside the parentheses is true, then$I(\cdot)$ = 1, and vice versa $I(\cdot)$ = 0 other symbols and variables with the same formula (1). And formula (3) for the single-threshold scenario, the subsequent test results can be expanded through the sample for the multi-threshold scenario.

5. Empirical analysis

***5.1 Geographical and temporal changes in the advancement of the digital economy and agricultural green economic adaptability*:**

To capture the spatial and temporal evolution characteristics of agricultural green economic resilience more intuitively, this study employs the gathered data on digital economy and resilience of agricultural green economics from every province to depict the spatial and temporal evolutionary patterns of both the digital economy and agricultural green economic resilience for each province, separately, in the years 2012 and 2022.

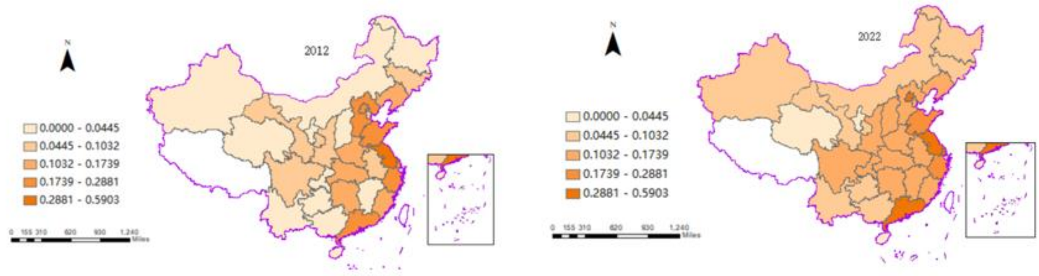

Figure 2. Geographical and temporal changes in China's digital economy index in 2012 (left) and 2022 (right)

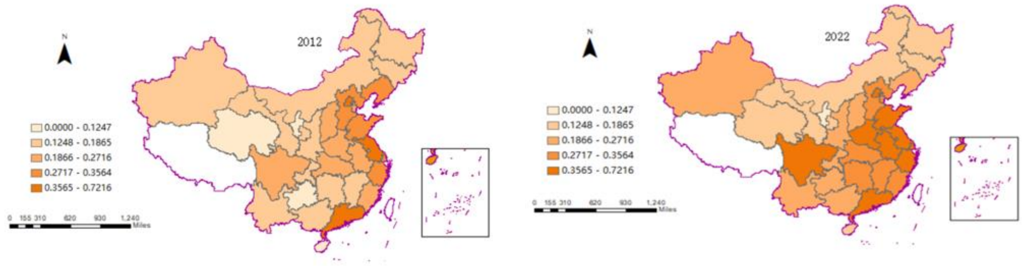

Figure 3. Geographical and temporal changes in China's digital economy index, 2012 (left) and 2022 (right)

From the perspective of the overall pattern of geographical and temporal progression, China's digital economy growth, and the agricultural economy's adaptability have a clear upward trend, but there is a stepped development phenomenon. Specifically, in terms of digital economic development, Shandong, Zhejiang, Guangdong and other coastal provinces are always at a higher degree of digital economic development, Anhui, Henan, Hubei and other regions, followed by Xinjiang, Inner Mongolia, Qinghai and other western regions at a lower level, but the development of the effectiveness of the more obvious. The main reason for this is that coastal areas such as Shandong, Zhejiang, and Guangdong promote international trade and technology introduction by virtue of their coastal location advantages, and the long-term accumulation of port economy and export-oriented industries provides rich application scenarios and capital bases for digitalization, while the density of new infrastructure such as 5G base stations and computing power centers is significantly higher than that of inland, laying a high-efficiency digital foundation.The eastern area of China has consistently led the way in development, but the central and southern regions exhibit robust momentum in their development and the development results are more prominent. In contrast, the northeast and western regions have shown a relatively slower pace of development, and the resilience level of their agricultural economies still requires further enhancement.The main reason may lie in the relatively poor resource conditions in the northeast and western regions, facing greater pressure on ecological resources and natural conditions, compared with the eastern and central regions, there are still large barriers to market connectivity, and there are shortcomings in the industrial chain.

In the regional spatial location and temporal occurrence evolution pattern, in the domain of digital economy, a total of 27 provinces in China showed an upward trend, Shanghai, Anhui, Jiangxi, Guangdong, Shanxi and other twelve areas to improve the influence of the digital economy index in 2022 compared to 2012 to change the digital economy index by more than 100%, of which the digital economic advancement in Shanghai, Anhui and Jiangxi to improve the proportion of more than 200%. In the field of agricultural green economic toughness, a total of 29 provinces in China showed an increase in the state, Jiangxi, Hunan, Anhui, Guizhou and other eighteen regions to improve the proportion of more than 100%, of which Jiangxi Province has made the most significant progress, compared with 2012, 206.71% higher

5.2 Benchmark regression findings:

This paper first performs covariance diagnosis. The diagnostic outcomes indicate that the highest variance inflation factor (VIF) is 2.23, which is much lower than the threshold of 10, and thus there is no interference from multicollinearity in the subsequent regression analysis.

Table 3 shows the outcomes of the fundamental regression model. In column (1) this paper does not add any control variables, only the central explanatory variables and the explanatory variables are regressed and analyzed, and the findings show that the regression coefficient of the digital economy is 0.558 and is significant at the 1% statistical level, suggesting that for every 1% increase in the development of the resilience of digital economy and agricultural economy will be increased by 0.558%. Column (2) and column (3), this article puts the control variables into the regression model to analyze, but only time and province two-way fixed for column (2). The findings reveal that the sign of the regression coefficient for the digital economy remains consistent (either positive or negative), and the great of the digital economy has not undergone significant changes. This further confirms that the digital economy plays a part in bolstering the resilience of the agricultural economy, thereby validating

Hypothesis 1.

Table 4. Analysis of the findings of the baseline regression

Variant	(1)	(2)	(3)
Dig	0.558***	0.581***	1.013***
	(12.782)	(14.148)	(38.635)
Urb		-0.153***	0.068***
		(-2.629)	(2.845)
Gov		-0.005***	0.000
		(-3.647)	(0.462)
Road		0.007***	0.004***
		(6.021)	(14.396)
Gdp		0.038***	0.026***
		(6.206)	(7.440)
cons	0.141***	0.189***	-0.031
	(10.308)	(5.060)	(-1.420)
Year	Yes	Yes	No
Province	Yes	Yes	No
N	330	330	330
R^2	0.948	0.958	0.906

Note: The asterisks *, **, and *** signify significance at the 10%, 5%, and 1% levels, respectively. The figures enclosed in parentheses represent t-values.

6.Robustness tests

6.1 Endogeneity issues:

Taking into account the exclusion of crucial variables or the possible endogeneity problem between the advancement of digital economy and the agricultural economy's resilience, so as to mitigate the interference of the endogeneity problem, this article adopts the two-stage least squares (2SLS) way to further validate the impact of the digital economy on the agricultural economy's resilience. Drawing on the methodology of Chang *et al* (2023), this article adopts the lagged one-stage digital economy as an ineffectual instrumental variable, and the regression findings are shown in columns (1) (2) of Table 4. As can be found from the first stage regression results, the regression parameter of lagged one-period digital economy is positive and the F-statistic is significant, which not includes the possibility of weak instrumental variables. From the findings of the second stage regression, It is evident that after the introduction of instrumental variables, the digital economy can significantly improve the level of agricultural green economic resilience, and the LM statistic rejects the primary hypothesis of instrumental variables", which proves the validity of the lagged digital economy as an instrumental variable. From the endogeneity test results, it aligns with the benchmark regression outcomes, suggesting that the benchmark regression findings are reliable and stable.

6.2 Other robustness tests:

So as to further improve the reliableness and robustness of the regression outcomes, this article adopts the following four parts for robustness testing. (1) Replacing explanatory variables: as a vertical extension of the digital economy in the field of financial services, digital financial inclusion is based on the flow of data elements and follows the reorganization of production factors with digital technology, which has a certain degree of substitutability，this paper replaces the digital financial inclusion index (Dif) with the digital economy for the robustness check, and the findings are shown in column (3) in Table 4. (2) Excluding municipalities: Since there is a big space between municipalities and other provinces in the context of economic advancement level and agricultural green economic base, municipalities are excluded and the data of other provinces are re-tested, and the findings are shown in column (4) in Table 4. (3) Tailoring: So as to eliminate the bias caused by the utmost values on the regression results, this article carries out 1% tailoring on the original data, and the regression findings are provided in column (5) in Table 4. As demonstrated by the regression findings outlined in Table 4, by taking the three ways for robustness testing, the sign of the parameters of the explanatory variables are all positive, which again suggests that benchmark regression results are robust.

Table 5. Robustness test findings

Variant	(1)	(2)	(3)	(4)	(5)
Dif			0.001***		
			(4.733)		
L. Dig	1.087***				
	(34.234)				
Dig		1.013***		1.112***	0.578***
		(38.635)		(39.872)	(12.680)

Controls	Yes	Yes	Yes	Yes	Yes
cons	-0.027	-0.027	0.108**	-0.068***	0.168***
	(-1.034)	(-1.034)	(2.045)	(-3.024)	(4.149)
Kleibergen-Paap rk LM	11.564***				
Kleibergen-Paap rk Wald F	160.458				
Critical value at 10% level of weak identification test	16.35				
Year	Yes	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes
N	330	330	330	287	330
R^2	0.889	0.906	0.934	0.923	0.955

7.Heterogeneity tests:

When examining the dynamics of the agricultural economy's resilience, the differences in regional agricultural green economic development caused by differences in geographic location should be taken into account. Therefore, to investigate the influence of the digital economy's resilience of the agricultural economy across various areas, this article divides China into the eastern, central, western and northeastern regions, and uses the fixed effects model to analyze the results as shown in Table 6. As can be seen from the results, the digital economy has a significant positive effect on the agricultural economy's resilience in the four regions of China, in which the absolute value of the regression finding is the largest in the eastern area, and the absolute value of the regression coefficient is the smallest in the western region, which is probably due to the fact that the eastern region's digital infrastructure is more complete, and the application of digital technology is relatively high, which can enhance the degree of digitization of farming output, agricultural products marketing and agricultural management more effectively, and further improve the agricultural economy and the agricultural economy.

The reason may be that the eastern area has a sophisticated digital infrastructure and a relatively high level of application of digital technology, which can more effectively enhance the level of digitization of agricultural output, agricultural sales and agricultural management, further improve the efficiency of agricultural output, and provide strong support and protection for the agricultural green economic development. However, due to the topography in the western region, the marginal deployment cost of promoting digital infrastructure is high, which makes it impossible for digital tools to achieve localization and adaptation, and it is difficult to achieve effective penetration.

Table 6. Heterogeneity results for area classification

Variant	(1)	(2)	(3)	(4)
Dig	0.583***	0.456***	0.368***	0.428**
	(5.085)	(4.225)	(2.671)	(2.355)
Controls	Yes	Yes	Yes	Yes
_cons	0.564***	0.057	-0.054	0.115**
	(4.108)	(0.434)	(-0.316)	(2.463)
Year	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes
N	110	66	121	33
R^2	0.964	0.954	0.873	0.983

Heterogeneity test of dimensions: The agricultural green economic resilience evaluation index system contains three parts: resistance recovery ability, adaptive adjustment ability and transformation and innovation ability, which responds to the comprehensive dynamic adjustment capability of the agricultural green economic framework when it encounters external uncertainty shocks (Zhang et al.,2025). Therefore, in examining the impact of the digital economy on the agricultural economy's resilience, it should be analyzed from the three dimensions of the resilience of the agricultural economy, and the regression findings are provided in Table 7. Based on the regression outcomes, it can be found that the digital economy has a positive ability to promote the recovery of resistance and transformation and innovation capacity, and shows significance, the main reason is that the digital economy provides a digital platform to help farmers understand the market demand more conveniently and quickly, and when faced with external shocks, the farmers are able to make decisions quickly based on the market feedback to improve the resistance and the agricultural green economic system's resilience. Secondly, through the overview of advanced technology and innovation mode, the digital economy has transcended the industrial boundaries of agriculture, made the integration of agriculture and other high-tech industries possible, effectively realized the gathering of resources and innovation in multiple fields, and greatly promoted the transformation and upgrading of the agricultural economy. However, the digital economy has exhibited a notable dampening effect on the capacity for adaptive adjustment. The reason for this is that the rapid replacement of digital tools has forced the reconstruction of agricultural production logic, resulting in the rapid depreciation of adaptive skills that rely on experience accumulation. When the technical complexity exceeds the threshold of human capital, farmers are unable to adapt to the widespread application of digital technology: on the one hand, they passively accept the production transformation driven by new technologies, and on the other hand, they are unable to effectively cope with sudden disturbances such as real-time weather anomalies and mechanical failures due to the lack of digital skills., thus reducing the adaptive adjustment capacity of the agricultural economy's resilience.

Table 7. Multidimensional heterogeneity test

Variant	(1) Resistance Resilience	(2) adaptive capacity	(3) Transformative innovation capacity
Dig	0.089**	-6.168***	3.773*
	(2.149)	(-3.201)	(1.960)
control variable	Yes	Yes	Yes
_cons	-0.000	-9.747***	18.013***
	(-1.089)	(-5.760)	(12.776)
Year	Yes	Yes	Yes
Province	Yes	Yes	Yes
N	330	330	330
R^2	0.960	0.979	0.883

8. Further analysis

8.1 Moderating effects test:

To check the moderating influence of agricultural industrial accumulation in the impact of digital economy on agricultural green economic resilience, this paper adopts the stepwise regression method to conduct the test, and Table 7 illustrates the findings of the moderating test. Column (1) is the baseline regression model without adding moderating variables, and columns (2) and (3) are the interaction terms of moderating variables agricultural industrial agglomeration and agricultural industrial agglomeration with core explanatory variables digital economy added sequentially on the basis of column (1). From the regression findings in column (3), the regression coefficient of the core explanatory variable digital economy is positive and notably at 1% statistical level, and the regression coefficient of the interaction term between the moderating variable agricultural industrial agglomeration and digital economy is notably positive. Agricultural industry agglomeration helps to upgrade the interaction degree of various aspects of agricultural production and effectively respond to market changes by strengthening agricultural resource allocation, thus enhancing the function of the digital economy in improving the agricultural economy's resilience. Thus, the hypothesis (2) of this article is verified.

Table 8. Results of moderating effects

Variant	(1)	(2)	(3)
Dig	0.611***	0.581***	0.400***
	(14.081)	(14.106)	(7.224)
Aia		0.037***	0.030***
		(6.104)	(4.874)
interaction term			0.169***
			(5.692)
Controls	Yes	Yes	Yes
_cons	0.377***	0.222***	0.455***
	(6.917)	(3.876)	(8.493)
Year	Yes	Yes	Yes
Province	Yes	Yes	Yes
N	330	330	330
R^2	0.953	0.958	0.958

8.2 Evaluation of the results of the threshold effect:

So as to verify whether rural human capital plays a threshold effect in the digital economy impacting the agricultural economy's resilience, this article constructs a threshold effect model and introduces rural human capital as a threshold variable into the model, and then adopts Hansen's threshold effect existence check method, and repeats the sampling 300 times through the Bootstrap method, and the threshold model test F-statistics and p-values are as follows: single threshold (40.18 0.000), double threshold (16.06 0.2867), and triple threshold (15.00 0.5933). From the results, it can be found that the single threshold passed the test of significance at the 10% statistical level, while the double and triple tests failed the test of significance, denoting that there is only a single threshold in the model and the threshold value is 8.1695.

After passing the threshold effect test, the effect is further analyzed by regression, and Table 10 statements the regression results of the threshold effect. When the threshold variable rural human capital is less than or equal to the threshold value (8.1695), the regression parameter of the digital economy is 0.384 and is significant at 1% statistical level, suggesting that every 1% increase in the degree of development of the digital economy will raise the degree of agricultural green economic resilience by 0.384%; when the threshold variable rural human capital is greater than the threshold value (8.1695), the regression coefficient of the digital economy is raised to 0.554 and is significant at the 1% statistical level, suggesting that when rural human capital develops to a certain level, the advancement of the digital economy on the agricultural economy's resilience is more significant, the possible reason for this is that, with the continuous investment in rural education level and skills training, the overall human capital of the rural group has been significantly improved. This is directly reflected in their acceptance of the digital economy and related technologies, and their more solid application capabilities. More and more farmers are beginning to grasp and use big data for market analysis, production planning and field management. using cloud computing to optimize the allocation of agricultural resources and information sharing; With the help of artificial intelligence technology, precision planting, intelligent irrigation and early warning of pests and diseases can be realized. Under this trend, the improvement of human capital and the development of the digital economy have strongly promoted the in-depth popularization of the digital economy in rural areas. Financial services such as mobile payment, online credit, and digital insurance are widely accessible through convenient digital channels, effectively alleviating the long-standing core bottlenecks in agricultural production, such as financing difficulties, expensive financing, and low mortgages. This provides a stable, efficient and affordable source of funds for family farms, cooperatives and various agricultural-related business entities, significantly enhances the ability to cope with risks, and lays a solid financial foundation for the resilient growth and long-term stability of the entire agricultural economy.

Table 9. Threshold effect regression results

Variant	Ratio	Standard	P > |t|	95% confidence

		error		interval	
Digital economy (Hr < 8.1695)	0.384***	(4.212)	0.000	0.1974	0.5700
Digital economy (Hr > 8.1695)	0.554***	(7.322)	0.000	0.3991	0.7085
Urbanization	-0.053	(-0.536)	0.596	-0.2569	0.1502
Percentage of support for agriculture	-0.003	(-1.514)	0.141	-0.0074	0.0011
Roads	0.009***	(4.045)	0.000	0.0045	0.0137
Economic development	0.053***	(7.192)	0.000	0.0377	0.0678
_cons	0.031	(0.677)	0.504	-0.0630	0.1253

9.Conclusions and implications

9.1 Conclusion:

This article adopts the panel data of 30 provinces in China from 2012 to 2022, systematically analyzes the direct impact and the process of the digital economy on the agricultural economy's resilience by using the fixed effect model, the moderating effect model and the threshold effect model. The findings suggest that (1) the digital economy has a notably positive influence on agricultural green economic resilience and plays a role in enhancing agricultural green economic resilience, and the robustness test further supports this finding. (2) agricultural industrial agglomeration can play a positive moderating role in the process of the digital economy affecting the agricultural green economic resilience. (3) there is a threshold influence in the digital economy affecting the agricultural green economic resilience, and when the threshold variable rural human capital level reaches the threshold value, the promotion effect of the digital economy on the agricultural economy's resilience will be further enhanced. (4) from the findings of the heterogeneity test, it should be found that the promotion effect of the digital economy in the eastern and central areas of China will be better than that in the western and northeastern regions. Additionally, when analyzing the dimensions of agricultural green economic resilience, the digital economy has a notably positive promotion on resistance to recovery and innovation and transformation, and an inhibitory effect on adaptive adjustment.

9.2 Policy implications:

(1) Enhance the environment for the digital economy's advancement in countryside areas give full utilization to the enabling role of the digital economy on the

agricultural economy. First of all, the progress of network infrastructure in rural areas should be intensified, the network access capacity in rural areas should be upgraded, and rural e-commerce platforms, logistics networks and other digital information service platforms should be constructed to expand the sales channels of agricultural goods and enhance the resilience of the agricultural economy (Guo *et al*.,2023). In addition, digital technologies such as the Internet of Things and big data should be promoted and applied vigorously in the agricultural field. While using digital technology to enhance the efficiency of agricultural production, market sales and other links, the agricultural industry's transformation and upgrading should be realized, and digital technology should be integrated into the basis of the agricultural industry's advancement, so as to establish a digital agricultural industry development model (Jiang *et al*.,2022).

(2) Emphasize the important role of agricultural industrial accumulation in the agricultural economy's resilience. In the process of agricultural advancement, it is necessary to further optimize the layout, system of agricultural industry, and always take the realization of the advanced and rationalized structure of agricultural industry as the goal of agricultural industry development, as well as to innovate the agricultural green economic model, accelerate the formation of the mechanism and system in line with the supporting comprehensive development of agriculture (Luo, 2018).In addition, through the reconstruction effect of geographical space, it has become a strategic fulcrum to strengthen the resilience of agricultural economy. The enterprise communities and production factors formed at the physical level are highly concentrated, which naturally constitutes a large-scale buffer pool for risk resistance. The multi-agent collaboration network built at the organizational level, relying on the leading enterprises to drive the bond with cooperatives, integrates fragmented smallholder farmers into flexible supply chain units, realizes rapid coordination from sowing decisions to market response, comprehensively improves the resilience level of agricultural economy in various provinces, and effectively resists economic shocks.

(3) Enhance the rural human capital and the resilience of the digital economy-enabled agriculture. Based on the threshold effect of human capital, a dynamic intervention system with hierarchical empowerment should be constructed. Implement the basic capacity breakthrough project for the groups that have not yet reached the standard, and focus on removing the obstacles to the application of technology for the elderly farmers through localized digital micro-courses and the neighborhood mentor

system (Chen *et al*., 2023); For those who cross the critical value, the vocational ability advancement plan will be launched, and the customized training and skill certification system of the enterprise will be transformed into the backbone of smart agriculture. Supporting the new infrastructure of digital education in the whole region, immersive learning terminals are set up at village-level nodes, and artificial intelligence characteristic courses are embedded at the county level, so as to simultaneously establish a sustainable mechanism for market feedback.

(4) Forging differentiated regional development policies. For the eastern and central provinces where the enhancement effect is more obvious, the continued promotion of integrated growth between the digital economy and agricultural economy should be prioritized, so that the digital economy becomes a support and driving force for the agricultural economy (Pan *et al*., 2022).Specifically, it is necessary to build a core area for agricultural artificial intelligence research and development, build an unmanned farm demonstration base, realize independent decision-making in the whole process of field production, and increase the support of private scientific and technological innovation policies to create a coordinated agricultural development pattern with the participation of multiple subjects. The western provinces need to implement the coordinated development of digital infrastructure, talents, and agricultural industry: priority should be given to building an agricultural Internet of Things sensing network with global coverage to break through signal obstruction in high-altitude mountainous areas; Set up a digital agricultural technology commissioner system, and dispatch compound talents to the village to solve the bottleneck of technology adaptation; Supporting the Western Digital Agricultural Innovation Fund, it will focus on supporting the development of a blockchain traceability system for special crops such as quinoa and highland barley. The Northeast region should focus on the digital transformation of heavy equipment: relying on the Agricultural Reclamation Group to set up an intelligent agricultural machinery sharing platform to provide full-process digital hosting services for corn and soybean continuous cropping areas; Establish a big data monitoring network for soil fertility in black soil to dynamically warn of soil degradation risks.

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