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Digital Economy Development, Agricultural Technology Innovation and Agricultural Economy Resilience

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Abstract

Based on the provincial data of 2013-2022, this paper discusses the mechanism of agricultural economy resilience affected by the development of digital economy. The results are obtained by using fixed effect, intermediary effect and threshold effect as follows: (1) the development of digital economy can improve the resilience of agricultural economy, and the conclusion passes the robustness test. (2) Mechanism test shows that agricultural technology innovation indirectly acts between the digital economy and the resilience of the agricultural economy. (3) Through the threshold model, it is found that the non-linear characteristics of agricultural technology innovation appear. Therefore, in order to improve the resilience of agricultural economy, the paper puts forward suggestions on strengthening regional infrastructure construction and enhancing the support for agricultural technology innovation.

Keywords

Digital economy, resilience of agricultural economy, innovation of agricultural technology, the threshold effect

As the cornerstone of supporting the development of national economy, the development of agriculture in recent years has been gradually influenced by external risks (Zhao & Xu, 2023), market fluctuations (ADAMOPOULOS, BRANDT, LEIGHT et al., 2022), and the diversity of agricultural production scale and type (BUITENUIS, CANDEL, TERMEER et al., 2020), and the development situation has become more and more complex. In order to minimize the impact and damage of unknown risks on agriculture, it is necessary to maximize the economic resilience of agriculture itself.

Measurement, spatial difference analysis and influencing factors are the main aspects involved in the resilience of agricultural economy. In terms of measurement, Hao Aimin and Tan Jiayin have systematically constructed the comprehensive evaluation index system of agricultural resilience from three dimensions, such as resistance, resilience and reconstruction power (Hao & Tan, 2023). Zhang

Mingdou and Hui Liwei used the entropy method to empower the index and calculate the agricultural economic resilience index (Zhang & Hui, 2020). In terms of spatial difference, Jiang Hui found that the agricultural economic system could use the spatial network system to maintain the stable of its structure and function when it encounters risks (Jiang, 2022). Yu Wei and Zhang Peng found that the resilience trend of agricultural development within provinces has been steadily improving, but the difference in the development trend between provinces is increasing (Yu & Zhang, 2019). In terms of influencing factors (Tian & Mao, 2024), industrial integrated development, infrastructure improvement (Tang & Chen, 2023), population aging impact (Gao, Li & Gan, 2024), innovation and entrepreneurship (Sun, Xia, Huang etc., 2024), all have an impact on the resilience of agricultural economy.

After sorting out relevant literature, it is found that few scholars have deeply analyzed the role of digital economy development on the resilience of agricultural economy from the perspective of agricultural technology innovation. In this regard, the paper may have the following academic value: first, study the effect of the development of digital economy on the resilience of agricultural economy, and enrich the research in related fields; second, deeply analyze the heterogeneity and temporal heterogeneity of the influence of digital economy development on the resilience of agricultural economy, and provide the policy basis for formulating the development strategy; third, using the intermediary effect model and threshold model to explore and find that agricultural technology innovation has both intermediary variable and nonlinear characteristics. On this basis, the corresponding policy suggestions are put forward to provide an important reference for enhancing the resilience of the agricultural economy.

1. Theoretical Analysis and Research Hypotheses

1.1 Direct Influence

First, the development of digital economy can improve the resistance ability of agricultural economy. When the economy is impacted, the digital economy industry is less affected by economic fluctuations, so the digital agricultural industry has a strong ability to resist risks (Mao, Hu & Wei, 2022). Second, the development of digital economy to improve the adaptability of agricultural economy. Digital technologies can help producers to obtain key data, effectively prevent and respond to risks, and ensure the sustainable agricultural development of (Jin & Ren, 2022). Third, the development of digital economy can improve the reform ability of agricultural economy. The digital economy helps to develop scientific and technological innovation in the agricultural field, thus promoting the efficiency of agricultural production. Secondly, the deepening of the digital economy into the vast rural areas will help reduce the loss of rural labor force and greatly improve the ability of innovation and transformation. Thus, the article puts forward the following assumptions: Suppose H1: Digital economy development is positively promoting the resilience of the agricultural economy.

1.2 Indirect Effects

On the one hand, the development of the digital economy is enough to stimulate innovation vitality and

improve innovation capacity. Li Haiyan found that agricultural related subjects use digital technology to carry out technological innovation and improve the transformation and innovation ability of agricultural system (Li, 2022). Nie Xiuhua's research shows that digital finance can stimulate the consumer demand of cities and promote the improvement of urban innovation ability in (Nie & Wu, 2022). On the other hand, the development of digital economy strengthens investment in innovation. Yang Qi found that the sustainable development of the digital economy can help lower the financing threshold and stimulate the activity of innovation and entrepreneurship in (Yang & Qiao, 2023). Technological innovation and technological investment also have a significant impact on the resilience of the agricultural economy. Li Zhou found that agricultural technology innovation is conducive to strengthening agricultural production efficiency and has a positive effect on the development of agricultural economy (Li, 2023). Li Zhaoliang found that the input and output of agricultural technology innovation contribute to technological innovation to drive agricultural economic growth (Li, Luo, Zhang et al., 2020). Thus, the article puts forward the following assumptions: Hypothesis H2: Agricultural technology innovation has an intermediary role in the impact of digital economy development on the resilience of agricultural economy.

1.3 Threshold Effect

From the theoretical analysis, when technological innovation is in the early stage, the development of digital economy will promote production innovation activities, and then drive economic growth. At a certain stage, the risk and difficulty will increase, and the marginal income of technological innovation will decrease by (Yang, Li, & Sun, 2024). When reaching the mature stage, the regional innovation network gradually expands, enabling many innovation subjects to enjoy innovation benefits in a larger scope (Feng & Li, 2019). The innovation value of digital economy has an obvious improvement effect on improving the resilience of agricultural economy. In addition, in the process of digital transformation, funds need to invest in research and development, the initial cost of obtaining information is still in a high stage, and the investment in research and development is less (Hu, Dai, & Zhang, 2022). The development of digital economy in this stage has little impact on the promotion of agricultural economy. When R & D investment is stronger, the impact increases. Thus, the article puts forward the following assumptions: Suppose H3: There is a nonlinear threshold effect in agricultural technology innovation.

2. Model Design

2.1 Data Sources

The research scope of this paper includes 31 provinces in 2013-2022. The data used are from the State Intellectual Property Office, provincial Statistical Yearbook, China Rural Statistical Yearbook, Peking University Digital Financial inclusion Index and other official ones. Part of the missing data is supplemented by interpolation method. The descriptive statistical results for each variable are as follows:

Table 1. Descriptive Statistics

variables	Mean	sample capacity	mean value	standard deviation	Min	Max
Aer	Agricultural economy resilience	310	0.196	0.102	0.0434	0.482
Dig	Digital economy level	310	0.205	0.137	0.0277	0.812
Agdp	Economic development level	310	12717	8262	5692	49335
Urb	Urbanization level	310	0.597	0.116	0.239	0.896
Gov	Government intervention	310	0.285	0.205	0.107	1.379
Road	Transportation infrastructure	310	11.72	0.841	9.444	12.91
Hum	human capital	310	7.722	0.828	3.804	9.915

2.2 Variable Selection

2.2.1 Explained Variable

Agricultural economic resilience (Aer). Based on the research of Zhang Mingdou, Jiang Hui and other scholars, 16 representative indicators are selected for construction. The details are shown in Table 2.

Table 2. Evaluation Index System of Agricultural Economic Resilience

Level 1 indicators	Level 2 indicators	Level 3 indicators
Agricultural economy resilience	resistivity	Total output value of agriculture, forestry, animal husbandry and fishery
		People working in the primary industry
		Effective irrigation rate
		grain yield
		agricultural acreage
		mileage in highway open to traffic
	adaptability	The growth rate of agricultural added value
		Crop disaster rate
		multiple-crop index
		Rural household Engel's coefficient
		Per capita disposable income of rural residents
		Per capita consumption expenditure of rural residents
	Change ability	Investment in agricultural fixed assets
		Total power of agricultural machinery
		Financial support for agriculture
		Investment in agricultural science and technology

2.2.2 explaining Variable

Level of digital economy development (Dig). Based on the study of He Leihua et al., this paper proposes the evaluation index system [22] for the development level of digital economy. The specific indicators are shown in Table 3.

Table 3. Evaluation Index System of Digital Economy Development

Level 1 indicators	Level 2 indicators	Level 3 indicators
The development level of the digital economy	Internet penetration rate	Number of Internet broadband access users per 100 people
	Number of Internet-related employees	The proportion of computer service and software employees in the unit at the end of the year
	Internet-related output	Total telecommunications business per capita
	Mobile phone penetration rate	Number of mobile phones users per 100 people
	Digital finance development	The Digital Financial Inclusion Index

2.2.3 Mechanism Variables

Agricultural technology innovation (Ati). At present, technological innovation is mostly measured from the two directions of input and output. This paper uses agricultural science and technology capital investment (Ati _ 1) to represent innovation input, and agricultural science and technology patent authorization (Ati _ 2) to represent innovation output.

2.2.4 Controlled Variable

(1) Level of economic development (Agdp), as measured by per capita GDP.(2) Urbanization level (Urb), expressed as the proportion of the urban population to the total population at the end of the year.(3) The degree of government intervention (Gov) is expressed by the proportion of fiscal expenditure in the government's general public budget and regional GDP.(4) Transportation infrastructure (Road), measured as the logarithm of highway mileage.(5) Human capital (Hum), expressed by the average level of education of rural residents.

2.3 Model Building

2.3.1 Benchmark Regression Model

This paper selects two-way fixed effects to construct an empirical model, and discusses the impact of the development of digital economy on the resilience of agricultural economy. The specific forms are as follows:

$$Aer_{i,t} = \alpha_0 + \alpha_1 Dig_{i,t} + \alpha_j X_{ij} + u_i + \delta_t + \varepsilon_{i,t} \quad (1)$$

i represents the provinces; t represents the year; Aer represents the resilience of agricultural economy; Dig represents the development level of digital economy; X ij represents the collection of control variables; μ i represents the fixed individual; δ t represents the fixed time, ε it is the random disturbance

term; α 1, α j represents the regression coefficient.

2.3.2 Mechanism Model

To further explore the indirect effect of agricultural technology innovation (Ati), the following mediation effect model is constructed:

$$\mathrm{Ati}_{i,t} = \beta_0 + \beta_1 Dig_{i,t} + \beta_j X_{it} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (2)$$

$$A\mathrm{er}_{i,t} = \gamma_0 + \gamma_1 Dig_{i,t} + \gamma_2 A\mathrm{ti}_{i,t} + \gamma_j X_{i,t} + u_i + \delta_t + \varepsilon_{i,t} \quad (3)$$

The presence of a mediation effect was determined based on the significance of parameters such as β and γ.

2.3.3 Threshold Model

(1) A single threshold exists, and the following model is constructed:

$$A\mathrm{er}_{i,t} = \varphi_0 + \varphi_1 Dig_{i,t} \times I(A\mathrm{ti}_{i,t} \le \theta) + \varphi_2 Dig_{i,t} \times I(A\mathrm{ti}_{i,t} > \theta) + \varphi_n x_{i,t} + \varepsilon_{i,t} \quad (4)$$

Ati is the threshold variable, θ is the threshold estimate; I(·) is the schematic function, representing different influence mechanisms due to the threshold effect.

(2) There is a double threshold, constructing the following model:

$$A\mathrm{er}_{i,t} = \varphi_0 + \varphi_1 Dig_{i,t} \times I(A\mathrm{ti}_{i,t} \le \theta_1) + \varphi_2 Dig_{i,t} \times I(\theta_1 < Ati_{i,t} \le \theta_2) + \varphi_3 Dig_{i,t} \times I(Ati_{i,t} > \theta_2) + \varphi_n X_{i,t} + \varepsilon_{i,t} \quad (5)$$

Ati is the threshold variable; θ 1, θ 2 is the threshold estimate; I(·)is the schematic function, representing the different influence mechanisms due to the threshold effect.

3. Empirical Results Analysis

3.1 Benchmark Regression

Table 4 shows the regression results, and column (1) shows the regression results of only two-way fixation. The estimated coefficient of the development level of digital economy is 0.201 at 1%, indicating that the development of digital economy has a significant effect on promoting the resilience of agricultural economy. Column (2) shows the regression results of the control variable, and the estimated coefficient of the digital economy level is 0.208 at the 1% level, verifying hypothesis 1.

Table 4. Benchmark Regression Results

variables	(1)	(2)
	Aer1	Aer2
Dig	0.201***	0.208***
	(7.11)	(6.92)
Agdp		0.000
		(1.18)

Urb		-0.110***
		(-3.16)
Gov		0.022
		(0.86)
Road		0.015
		(1.17)
Hum		-0.007*
		(-1.68)
Provincial fixed	yes	yes
Time fixed	yes	yes
Constant	0.152***	0.077
	(49.76)	(0.52)
sample	310	310
R2	0.753	0.764

Note. *, * *, * * * represent significant at the 10%, 5%, and 1% levels.

3.2 Robustness Test

Replace the explanatory variable. The development level of digital economy is replaced by the main component analysis method. Table 5 column (1) shows the empirical results, and the coefficient of digital economy development is positive at the 5% level, indicating that the regression results support the null hypothesis.

Excluding municipalities. The sample data from Beijing, Tianjin, Shenzhen, and Chongqing are excluded, and the regression results are shown in Table 5 (2). The regression coefficient of the digital economy is significantly positive at the level of 5%, proving that hypothesis 1 is robust.

The explanatory variables lag behind the one phase. In this paper, the development level of digital economy will lag behind a regression. As shown in column (3) of Table 5, the regression coefficient is significantly positive at the level of 1%, which proves that the conclusion is true.

Table 5. The Robustness Test

variables	(1) Replace explanatory variables	(2) Excluding municipalities	(3) The explanatory variables lag behind the one phase
Dig	0.076**	0.206***	
	(2.03)	(6.84)	
L.Dig			0.138***
			(4.21)

Constant	0.224	0.319**	-0.022
	(1.40)	(2.07)	(-0.13)
controlled variable	yes	yes	yes
Provincial fixed	yes	yes	yes
Time fixed	yes	yes	yes
sample	310	270	279
R2	0.725	0.791	0.723

Note. *, * *, * * * represent significant at the 10%, 5%, and 1% levels.

3.3 Heterogeneity Test

Heterogeneity in grain-producing areas. In this paper, the samples are divided into three categories: main grain producing areas, main grain selling areas and production and marketing balance areas. Table 6 columns (1), (2) and (3) are the regression results of the three groups respectively. It can be seen that the development of digital economy plays a stronger role in promoting the resilience of agricultural economy in major grain producing areas and production and marketing balance areas. The reason may be the advantages of agricultural infrastructure and agricultural science and technology level in major grain producing areas and balanced production and marketing areas, enabling them to promote digital construction and further enhance the resilience of the agricultural economy.

Time heterogeneity. Based on the G20 Digital Financial Inclusion Principles in 2016, the sample was divided into before 2016 and after 2016, and the regression results show that the impact of the digital economy on the resilience of the agricultural economy is not as effective as after 2016. The reason is that, after the promotion of digital construction, digital inclusive finance has gone deep into the vast rural areas, releasing digital dividends for the rural areas, and promoting the resilience of the agricultural economy.

Table 6. Shows the Tests of Heterogeneity

variables	(1)	(2)	(3)	(4)	(5)
	producing area	sales area	balance area	Before 2016	After 2016
Dig	0.329***	0.270**	0.136***	0.167**	0.136***
	(6.06)	(2.08)	(3.04)	(2.39)	(4.24)
Constant	0.293	0.360	-0.501**	0.609**	-0.131
	(1.24)	(0.91)	(-2.49)	(2.08)	(-0.61)
controlled variable	yes	yes	yes	yes	yes
Provincial fixed	yes	yes	yes	yes	yes
Time fixed	yes	yes	yes	yes	yes
sample	130	70	110	124	186

R2	0.886	0.718	0.819	0.741	0.676

Note. *, * *, * * * represent significant at the 10%, 5%, and 1% levels.

3.4 Mechanism Effect

As shown in Table 7 are the regression results for the mediation variables. Column (1) shows that the coefficient of digital economy development is significantly positive at the level of 1%, indicating that the development of digital economy can increase the input of agricultural science and technology funds; column (2) shows that the coefficient of agricultural science and technology investment is significantly positive and the intermediary effect is established. It can be seen from the data of column (3) that the influence coefficient of digital economy development has passed the significance test of 1%, indicating that the development of digital economy has increased the number of agricultural science and technology patents granted. Column (4) Data show that the development of the digital economy affects the resilience of the agricultural economy by increasing the number of agricultural science and technology patents granted. The results prove that the mediation effect of agricultural technology innovation holds, and that hypothesis 2 is robust.

Table 7. Mechanism Analysis

variables	(1)	(2)	(3)	(4)
	Ati_1	Aer_1	Ati_2	Aer_2
Dig	8.226***	0.123***	11.217***	0.186***
	(4.54)	(5.02)	(3.55)	(6.17)
Ati_1		0.010***		
		(12.96)		
Ati_2				0.002***
				(3.36)
Constant	17.527**	-0.105	45.503***	-0.011
	(1.97)	(-0.90)	(2.93)	(-0.08)
controlled variable	yes	yes	yes	yes
Provincial fixed	yes	yes	yes	yes
Time fixed	yes	yes	yes	yes
sample	310	310	310	310
R2	0.357	0.856	0.528	0.773

Note. *, * *, * * * represent significant at the 10%, 5%, and 1% levels.

3.5 Threshold Effect

The threshold effect of agricultural innovation input. This paper will agricultural science and

technology investment as the proxy variable of agricultural innovation investment, using the practice of Hansen (He, Wang, & Wang, 2022), using sampling method (Bootstrap) repeated sampling, the results are shown in table 8, among them, the agricultural science and technology investment at 1% level through the double threshold test, the corresponding sampling P value is 0.000, therefore, the double value model is analyzed.

Table 8. Estimation Results of Agricultural Innovation Input Threshold

model	F	P	The 10% cut-off value	The 5% cut-off value	The 1% cut-off value
Single threshold	72.8	0.0033	34.0782	38.1027	48.7904
Double threshold	70.69	0.0000	32.3192	37.4586	47.7798
Triple threshold	19.02	0.7733	48.8021	52.8953	67.0547

Table 9 reports the regression results of the two-threshold panel model. When the first threshold value is lower than 0.0425, the development of digital economy shows a significant positive impact on the resilience of agricultural economy. At this time, the corresponding coefficient is 0.133, within the range (0.0425,3.3931), the positive impact of digital economy is still on the level of 1%, and the coefficient reaches 0.183. When the investment of agricultural science and technology exceeds 3.3931, there is still a positive impact between the two and the coefficient increases to 0.248 again. It shows that the investment of agricultural science and technology plays a non-linear role in the process of digital economy development and promoting the resilience of agricultural economy.

Table 9. Regression Results of the Threshold Model of the Agricultural Innovation Input Panel

threshold variable	(1) Investment in agricultural science and technology
dig · I(t≤0.0425)	0.133***
	(5.42)
dig · I(0.0425 <t≤3.3931)	0.183***
	(7.24)
dig · I(t>3.3931)	0.248***
	(10.01)
controlled variable	yes
Provincial fixed	yes
Time fixed	yes
sample	310
R2	0.855

Note. *, * *, * * * represent significant at the 10%, 5%, and 1% levels.

The threshold effect of agricultural innovation output. Table 10 reports the results of the model test of agricultural science and technology patent authorization as the threshold variable. The results show that it passed the significance test of the double threshold at the 5% level, and the triple threshold failed the significance test. Therefore, the double-value model is analyzed.

Table 10. Estimated Results of Agricultural Innovation Input Threshold

模型	F	P	The 10% cut-off value	The 5% cut-off value	The 1% cut-off value
Single threshold	36.88	0.0067	23.5357	27.5304	35.3888
Double threshold	26.4	0.0167	19.6423	23.1239	31.2959
Triple threshold	11.37	0.4633	23.5826	29.7372	48.2965

Table 11 shows the threshold effect results of the agricultural science and technology patent authorization amount. Below the first threshold of 0.157, the estimated coefficient of agricultural economic resilience to the development of the digital economy was 0.396 at 1%. When it is within the interval (0.157,3.545), the corresponding coefficient is reduced to 0.177, and the action effect is significantly reduced. When the amount of agricultural science and technology patents granted exceeds 3.545, the coefficient is 0.216, and the influence effect is strengthened. According to the test results, agricultural technology innovation has a threshold effect between the digital economy and the resilience of agricultural economy, and the hypothesis of H3 is verified.

Table 11. Regression Results of the Threshold Model

`threshold variable	(1) Agricultural science and technology patents granted quantity
dig· I(t≤0.157)	0.396***
	(5.06)
dig· I(0.157 <t≤3.545)	0.177***
	(6.39)
dig· I(t>3.545)	0.216***
	(7.87)
controlled variable	yes
Provincial fixed	yes
Time fixed	yes
sample	310
R2	0.814

Note. *, * *, * * * represent significant at the 10%, 5%, and 1% levels.

4. Conclusions and Recommendations

Based on the panel data of 31 provinces from 2012 to 2022, this paper discusses the mechanism of the impact of digital economy development on the resilience of agricultural economy, and draws the following conclusions: First, the stable development of digital economy is promoting the resilience of agricultural economy. The paper measures the development level of digital economy and the resilience of agricultural economy by entropy method, and conducts regression analysis. It is found that the development level of digital economy significantly affects the resilience of agricultural economy, and the conclusion is still valid after the robustness test. Second, the impact of digital economy on the resilience of agricultural economy has heterogeneity and temporal heterogeneity in grain producing areas. Digital economy has a more significant impact on the main grain producing areas and balanced areas of production and marketing. The reason may be that the digital economy has developed in the main grain producing areas and balanced areas of production and marketing better, with relatively perfect infrastructure, and the digital economy is more embedded in agricultural economy. In terms of temporal heterogeneity, due to the introduction of digital inclusive finance related content in 2016, the development of digital economy after 2016 played a more significant role in promoting the resilience of agricultural economy. Third, agricultural technology innovation has an intermediary effect between the development of digital economy and the resilience of agricultural economy. Moreover, the innovation ability of agricultural technology shows non-linear characteristics in the process of the impact of digital economy on the resilience of agricultural economy. Based on the above research conclusions, the following countermeasures and suggestions are proposed.

First, we will strengthen the development of the digital economy. Through heterogeneity comparison, it is found that the development of digital economy in different grain yield regions affects the resilience of agricultural economy. In order to achieve the balanced development of digital economy in different regions, different strategies should be adopted according to local conditions. First, for the areas with good development situation, the government should first improve the local regulatory system and improve the coordinated development. Secondly, we will further promote the integration of mathematics and agriculture, embed digitalization in the production process, and build a smart agriculture industrial chain. Second, for the underdeveloped areas, the government should first strengthen infrastructure construction and provide policy support related to the development of the digital economy. Secondly, we should vigorously promote the implementation of digital technology and exchange, learning and cooperation with developed areas, to explore a new agricultural development model.

Second, we will increase support for agricultural technological innovation. Strengthen the intermediary effect of agricultural technology innovation in the development of digital economy and the resilience of agricultural economy, so that agricultural technology carries out the whole process of agricultural production. First, relevant incentive policies should be introduced to encourage enterprises and investors to conduct larger-scale research and development and investment in the field of agricultural

technology, improve the enthusiasm of innovators, and enhance the coverage, dissemination and digitalization of the digital economy in rural agriculture. Second, the implementation of talent introduction policy, attract more agricultural innovation professional knowledge and skills of talent, at the same time according to the local characteristics of agricultural development, adjust measures to local conditions to carry out the relevant technology innovation, for the region's agricultural development to provide talents, high and new technology and innovation consciousness, development vitality, promote the development of agricultural multi-dimensional, high quality.

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