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Government–Enterprise Collaboration Strategy for the Digital Transformation of Agricultural Enterprises Based on Evolutionary Game Theory

Xiaowei Hai[1], Shenglan He[1], and Chanchan Zhao[2,*]

Abstract
Local governments play an important role in the digital transformation of agricultural enterprises. An effective government–enterprise collaboration strategy can enable the successful digitalization of agricultural enterprises. However, efficient collaboration between the local government of a place and agricultural enterprises is difficult to achieve because of the complexity of influencing factors, evolutionary processes, and stability strategies. To address this issue, we propose a government–enterprise collaboration strategy based on evolutionary game theory. First, we build an evolutionary game model based on local governments' guidance behavior and agricultural enterprises' digital transformation decision-making. Second, we analyze the evolutionary stability strategy of the local government and agricultural enterprises using the Jacobian matrix. The influence of related parameters on strategy evolution is also discussed. Third, we use numerical simulation to verify the effectiveness of the proposed model. Finally, some managerial implications are proposed for local governments to promote the digital transformation of agricultural enterprises.

Keywords
Agricultural Enterprises, Collaboration Strategy, Digital Transformation, Evolutionary Game, Local Government

1. Introduction

Various industries have gradually embarked on a digital transformation journey with the emergence and advancement of the digital economy and digital technologies, such as the Internet of Things and artificial intelligence. The utilization of digital technologies has placed different industries in a complex and open environment. In the new win–win era of co-creation, collaboration between local governments and agricultural enterprises has become inevitable. Local governments assist agricultural enterprises with digital transformation, which enhances a company's product competitiveness, production efficiency, and market responsiveness. Simultaneously, digital transformation promotes a company's pro-land behavior and effectively protects the environment [1].

Regarding the digital transformation of enterprises, scholars have conducted discussions on the connection between enterprises and the local government of a place. Xie et al. [2] studied different government and enterprise strategies in cooperative, non-cooperative, and Stackelberg games and found

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* **Corresponding Author:** Chanchan Zhao (cczhao@imut.edu.cn)
[1] School of Economics and Management, Inner Mongolia University of Technology, Hohhot, China (xwhai@imut.edu.cn, 20221100294@imut.edu.cn)
[2] College of Information Engineering, Inner Mongolia University of Technology, Hohhot, China (cczhao@imut.edu.cn)

that government subsidies have the power to boost enterprises' digital transformation. In addition to government subsidies, digital infrastructure policies can also facilitate enterprises' digital transformation and improve their operating conditions [3]. Government subsidies and related policies can aid enterprises in transformation; notably, this behavior is influenced by different factors such as social benefits, environmental protection, and publicity [4]. A healthy government–enterprise relationship primarily enhances the transformation level of enterprises by reducing financing constraints [5]. Therefore, it is essential to manage the connection between the government and enterprises.

Previous studies have shown that agricultural enterprises' digital transformation can be greatly aided by local governments. In particular, a healthy government–enterprise relationship can effectively promote enterprises' digital transformation levels. However, most studies have focused on the unilateral endeavors of the government or enterprises; few studies have analyzed the collaboration between the two in the digital transformation process, and fewer still have considered this collaboration in agricultural enterprises. This study examines the digital transformation collaboration between agricultural enterprises and local governments using evolutionary game theory. We explore relevant factors affecting the evolution of strategies and propose an effective collaboration strategy for digital transformation.

The remaining sections of this paper are arranged as follows. An overview of the pre-modeling work is given in Section 2, and the evolutionary game model is explained in Section 3. Section 4 discusses the evolutionary stability strategy. Section 5 presents a numerical example, and Section 6 provides a summary and outlines some managerial implications.

2. Problem Analysis

2.1 Game Relationship of Both Parties

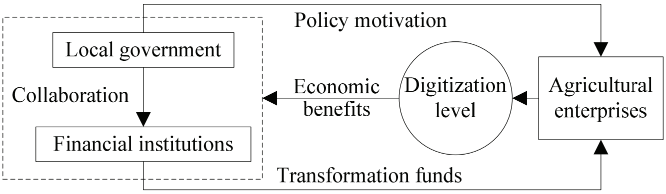

Fig. 1. Game relationship between a local government and agricultural enterprises.

Local governments encourage agricultural enterprises to undergo digital transformation, which helps these enterprises break through the limitations of traditional agricultural production and operations and optimize agricultural inputs [6]. However, in the early phases of digital transformation, agricultural enterprises have to make significant cost investments, including those for technology and employee's digital training [7]. Therefore, sufficient funding is a vital prerequisite for agricultural enterprises to transform. As agricultural enterprises rely on natural conditions, have lengthy production cycles, and face certain limitations in the assessment and mortgage of assets such as land, they have a relatively weak anti-risk ability and face greater difficulties in financing. Therefore, they rely on the injection of external credit funds. Local governments usually provide more support because the development of agricultural enterprises is closely related to the national agricultural strategy. When a local government cooperates with financial institutions to design credit services suitable for agricultural enterprises, these enterprises can easily obtain funding for digital transformation [8]. Another source of funding for digital transformation is the local government's incentives. By helping agricultural enterprises transform, a local government can mitigate the degradation of the ecological environment caused by traditional agricultural enterprises' overuse of chemicals, such as pesticides and fertilizers, and manage land and other resources more efficiently, thereby reducing social costs and obtaining related environmental benefits. Further, the government can enhance credibility and gain public recognition [4]. Correspondingly, the local government must invest in digital infrastructure and transformation publicity and encourage the digital transformation of agricultural enterprises through incentives such as government subsidies [9]. Based on the above, Fig. 1 depicts the game relationship between agricultural enterprises and local governments.

2.2 Basic Assumptions

Depending on local governments' relationship and interaction with agricultural enterprises, this study proposes the following assumptions for building the evolutionary game model.

1) The main players in the game are all boundedly rational. During digital transformation, local governments and agricultural enterprises continue to learn and adjust strategies to maximize their interests.
2) The initial likelihood that a local government will select guidance is x, and the initial likelihood that it will select non-guidance is $1-x$. The initial likelihood that agricultural enterprises will select positive transformation is y, and the initial likelihood that they will select negative transformation is $1-y$. x and y are both functions of time t, with values in the range of 0 to 1.
3) The basic profit that agricultural enterprises can obtain by continuing to operate in the same way as before is R_0. When agricultural enterprises choose transformation, they pay C_1, and the profit they obtain is R_1. Without external help, the investment will exceed the income: $C_1 > R_1$.
4) When a local government enables the transformation of enterprises, it has to pay the cost C_2 and obtains credibility benefits R_2 and environmental benefits U. Conversely, the local government should bear the social costs (H) of the ecological environment pollution caused by traditional agricultural enterprises.
5) When agricultural enterprises choose digital transformation, they can receive government rewards W. In contrast, agricultural enterprises that fail to seize development opportunities will pay regret costs C_h.
6) When a local government cooperates with financial institutions, agricultural enterprises can obtain funds $\delta_1 D$. Otherwise, enterprises can obtain funds $\delta_2 D$. δ stands for financial inclusion, and the value of δ is between 0 and 1. The value of δ_2 is less than the value of δ_1.

3. Evolutionary Game Model

3.1 Model Development

Based on the above assumptions, agricultural enterprises have two strategies: positive transformation and negative transformation. Local governments also have two strategies: guidance and non-guidance. The strategic selection symbols for both parties are as follows.

L_1: The strategy in which agricultural enterprises choose positive transformation
L_2: The strategy in which agricultural enterprises choose negative transformation
A_1: The strategy in which a local government chooses guidance
A_2: The strategy in which a local government chooses non-guidance
Table 1 displays the payment matrix between agricultural enterprises and local governments.

Table 1. Evolutionary game payment matrix

Strategy combinations	Profit and loss	
	Local governments	**Agricultural enterprises**
(L_1, A_1)	$R_2 + U - W - C_2$	$R_0 + R_1 + W + \delta_1 D - C_1$
(L_1, A_2)	$R_2 - C_2$	$R_0 - C_h$
(L_2, A_1)	0	$R_0 + R_1 + \delta_2 D - C_1$
(L_2, A_2)	$-H$	R_0

3.2 Model Solving

The analysis of evolutionary stability strategies (ESS) relies on the replicator dynamic equation. The following is the solution.

The expected payoff to a local government choosing guidance is E_{L_1}.

$$E_{L_1} = y(R_2 + U - W - C_2) + (1 - y)(R_2 - C_2) \tag{1}$$

The expected payoff to a local government choosing non-guidance is E_{L_2}.

$$E_{L_2} = -H(1 - y) \tag{2}$$

The average payoff to a local government is $\overline{E_L}$.

$$\overline{E_L} = xE_{L_1} + (1 - x)E_{L_2} \tag{3}$$

The expected payoff to agricultural enterprises that choose positive transformation is E_{A_1}.

$$E_{A_1} = x(R_0 + R_1 + W + \delta_1 D - C_1) + (1 - x)(R_0 + R_1 + \delta_2 D - C_1) \tag{4}$$

The expected payoff to agricultural enterprises that choose negative transformation is E_{A_2}.

$$E_{A_2} = x(R_0 - C_h) + (1 - x)R_0 \tag{5}$$

The average payoff to agricultural enterprises is $\overline{E_A}$.

$$\overline{E_A} = yE_{A_1} + (1 - y)E_{A_2} \tag{6}$$

Eq. (7) are the replicated dynamic equations for the local government and agricultural enterprises.

$$\begin{cases} F(x) = \dfrac{dx}{dt} = x\left(E_{L_1} - \overline{E_L}\right) = x(1 - x)G \\ F(y) = \dfrac{dy}{dt} = y\left(E_{A_1} - \overline{E_A}\right) = y(1 - y)Z \end{cases} \tag{7}$$

where $G = yU - yW - yH - C_2 + R_2 + H$ and $Z = xW + x\delta_1 D + xC_h - x\delta_2 D - C_1 + R_1 + \delta_2 D$.

4. Analysis of the Evolutionary Stability Strategy

We analyze the ESS of local governments and agricultural enterprises using the Jacobian matrix. We can acquire equilibrium points $O(0,0), A(0,1), B(1,0), C(1,1)$, and $D(x^*, y^*)$ by setting $F(x) = 0$ and $F(y) = 0$. Here, $x^* = \frac{C_1 - R_1 - \delta_2 D}{W + C_h + \delta_1 D - \delta_2 D}$ and $y^* = \frac{C_2 - R_2 - H}{U - W - H}$. $D(x^*, y^*)$ is the equilibrium point when both x^* and y^* have values between 0 and 1. The Jacobian matrix is obtained according to replication dynamic equations, as shown in Eq. (8):

$$J = \begin{bmatrix} \frac{dF(x)}{dx} & \frac{dF(x)}{dy} \\ \frac{dF(y)}{dx} & \frac{dF(y)}{dy} \end{bmatrix} = \begin{bmatrix} (1-2x)G & x(1-x)(U-W-H) \\ y(1-y)(W + C_h + \delta_1 D - \delta_2 D) & (1-2y)Z \end{bmatrix} \tag{8}$$

According to the Jacobian matrix, $Det(J)$ and $Tr(J)$ are as follows:

$$Det(J) = (1-2x)(1-2y)GZ - xy(1-x)(1-y)(U-W-H)(W + C_h + \delta_1 D - \delta_2 D) \tag{9}$$

$$Tr(J) = (1-2x)G + (1-2y)Z \tag{10}$$

Each equilibrium point's determinant and trace are displayed in Table 2.

Table 2. Values of the determinant and trace at equilibrium points

Equilibrium points	$Det(J)$	$Tr(J)$
$O(0,0)$	$(R_2 + H - C_2)(R_1 + \delta_2 D - C_1)$	$(R_2 + H - C_2) + (R_1 + \delta_2 D - C_1)$
$A(0,1)$	$-(U - W - C_2 + R_2)(R_1 + \delta_2 D - C_1)$	$(U - W - C_2 + R_2) - (R_1 + \delta_2 D - C_1)$
$B(1,0)$	$-(R_2 + H - C_2)(W + \delta_1 D + C_h - C_1 + R_1)$	$-(R_2 + H - C_2) + (W + \delta_1 D + C_h - C_1 + R_1)$
$C(1,1)$	$(U - W - C_2 + R_2)(W + \delta_1 D + C_h - C_1 + R_1)$	$-(D - W - C_2 + R_2) - (W + \delta_1 D + C_h - C_1 + R_1)$
$D(x^*, y^*)$	$-(C_1 - R_1 - \delta_2 D)(C_2 - R_2 - H)(1 - x^*)(1 - y^*)$	0

If $Det(J)$ is greater than 0 and $Tr(J)$ is less than 0, both are satisfied simultaneously, and the equilibrium point is an ESS. $D(x^*, y^*)$ is not an ESS. Only equilibrium points $O(0,0), A(0,1), B(1,0)$ and $C(1,1)$ need to be analyzed.

When the conditions of $x^* = \frac{C_1 - R_1 - \delta_2 D}{W + C_h + \delta_1 D - \delta_2 D} < 1$ and $0 < y^* - \frac{C_2 - R_2 - H}{U - W - H} < 1$ are met, $W + \delta_1 D + C_h - C_1 + R_1 > 0$ and $U - W - C_2 + R_2 > 0$ always hold. When the parameter values change, the evolutionary game's stability analysis results likewise fluctuate. Table 3 displays the equilibrium points' stability analysis for each of the four situations.

The ESS in different scenarios are as follows:

1) Scenario 1: $R_1 + \delta_2 D - C_1 > 0$, $C_2 - R_2 - H < 0$, and $U - W - H < 0$. As shown in the phase diagram in Fig. 2(a), $C(1,1)$ is the only ESS point.
2) Scenario 2: $R_1 + \delta_2 D - C_1 > 0$, $C_2 - R_2 - H > 0$, and $U - W - H > 0$. As shown in Fig. 2(b), $C(1,1)$ is the only ESS point.

3) Scenario 3: $R_1 + \delta_2 D - C_1 < 0$, $C_2 - R_2 - H < 0$, and $U - W - H < 0$. As shown in Fig. 2(c), $C(1,1)$ is the only ESS point.
4) Scenario 4: $R_1 + \delta_2 D - C_1 < 0$, $C_2 - R_2 - H > 0$, and $U - W - H > 0$. As shown in Fig. 2(d), $O(0,0)$ and $C(1,1)$ are both ESS points.

Table 3. Stability analysis of equilibrium points

		Equilibrium points			
		$\boldsymbol{O(0,0)}$	$\boldsymbol{A(0,1)}$	$\boldsymbol{B(1,0)}$	$\boldsymbol{C(1,1)}$
Scenario 1	$Det(J)$	+	–	-	+
	$Tr(J)$	+	Uncertain	Uncertain	–
	Stability	Unstable point	Saddle point	Saddle point	ESS
Scenario 2	$Det(J)$	–	–	+	+
	$Tr(J)$	Uncertain	Uncertain	+	–
	Stability	Saddle point	Saddle point	Unstable point	ESS
Scenario 3	$Det(J)$	–	+	–	+
	$Tr(J)$	Uncertain	+	Uncertain	-
	Stability	Saddle point	Unstable point	Saddle point	ESS
Scenario 4	$Det(J)$	+	+	+	+
	$Tr(J)$	–	+	+	–
	Stability	ESS	Unstable point	Unstable point	ESS

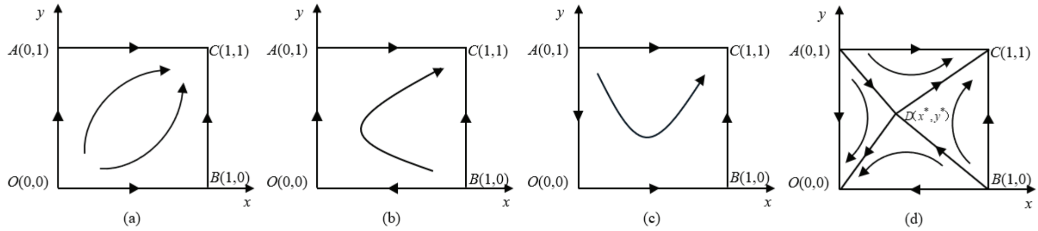

Fig. 2. Evolutionary game phase diagram. diagram: (a) Scenario 1, (b) Scenario 2, (c) Scenario 3, and (d) Scenario 4.

The evolutionary game phase diagram of Scenario 4 is analyzed as follows. When a local government and agricultural enterprises are initially located in the region $OBDA$, the final evolution of the two will converge at point O, where the local government chooses nonguidance and agricultural enterprises choose negative transformation. When the local government and agricultural enterprises are initially located in the region $ADBC$, the two will converge at point C, where the local government chooses guidance and agricultural enterprises choose positive transformation. The areas of regions $OBDA$ and $ADBC$ will be impacted by the location of the saddle point $D(x^*, y^*)$. The larger the area of $OBDA$ is, the greater is the possibility of the system converging on point $O(0,0)$; the smaller its area is, the greater is the possibility of the system converging on point $C(1,1)$. Assume that the areas of regions $OBDA$, OAD, and OBD are S_{OBDA}, S_{OAD}, and S_{OBD}, respectively. The following is the area formula for S_{OBDA}.

$$S_{OBDA} = S_{OAD} + S_{OBD} = \frac{x^* + y^*}{2} = \frac{1}{2}\left(\frac{C_1 - R_1 - \delta_2 D}{W + C_h + \delta_1 D - \delta_2 D} + \frac{C_2 - R_2 - H}{U - W - H}\right) \tag{11}$$

Eq. (11) shows that S_{OBDA} is closely related to C, R, U, H, W, C_h, D, and δ. Table 4 shows the influence of relevant parameters on S_{OBDA}.

Table 4. Impact of relevant parameters on S_{OBDA}

	Restrict condition	Parameter status	S_{OBDA}	Impact
C		↑	↑	Negative
R		↑	↓	Positive
H	$W + C_2 < U + R_2$	↑	↓	Positive
	$W + C_2 > U + R_2$	↑	↑	Negative
W	$W < W^*$ (a value that maximizes S)	↑	↓	Positive
	$W > W^*$	↑	↑	Negative
C_h		↑	↓	Positive
D		↑	↓	Positive
δ		↑	↓	Positive
U		↑	↓	Positive

5. Numerical Example

Based on constraints $R_1 + \delta_2 D - C_1 < 0$, $C_2 - R_2 - H > 0$, and $U - W - H > 0$, this study sets parameters to analyze the effects of various starting states and related variables on agricultural enterprises' and local governments' strategy selection. The initial value of government rewards is determined based on guidelines provided by Feng et al. [10] (assume that $W = 3$). Under the guidance of the local government of a place, it is assumed that agricultural enterprises can easily obtain digital transformation funding. Without the guidance, it will be difficult to obtain funding (assume that $\delta_1 = 1$ and $\delta_2 = 0.5$). In addition, agricultural enterprises can effectively reduce pollution through digital transformation and make important contributions to the ecological environment (assume that $U = 9$). Other parameters refer to Yang et al.'s method [9] of assigning values to parameters related to enterprises' digital transformation. Here, $R_1 = 2$, $R_2 = 1$, $C_1 = 7$, $C_2 = 6$, $C_h = 5$, $H = 4$, and $D = 4$.

5.1 Impact of the Initial Value of (x, y) on the Evolutionary Results

Suppose that the initial values of (x, y) are $(0.2,0.3)$, $(0.3,0.7)$, $(0.1,0.5)$, $(0.6,0.6)$, $(0.4,0.1)$, and $(0.8,0.5)$. Numerical simulation is performed using MATLAB to analyze the evolution results of game strategies of local governments and agricultural enterprises under varied initial states. Fig. 3 shows that local governments should adjust their strategies based on the states of agricultural enterprises. When enterprises are unwilling to transform, the local government should actively assist them and try to change their perspective. When enterprises are actively transforming, the local government can relax its assistance and allow them to transform independently.

5.2 Impact of the Parameters on the Evolutionary Results

This section mainly assesses the four parameters of government rewards (W), credit funds (D), regret costs (C_h), and environmental benefits (U) to observe the impact of changes in the values of these variables on local governments' and agricultural enterprises' strategic choices. In the game's early phase, setting the probability that both parties choose different strategies is 50%. The detailed analysis is as follows.

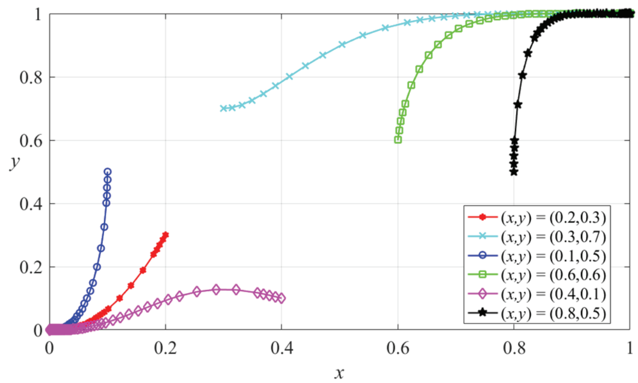

Fig. 3. Evolution results of the two-party game under different initial states.

5.2.1 Government rewards (W)

Considering that all other factors remain unchanged, the values of W are 1, 3, 5, and 7. Fig. 4 presents the simulation of the impact of government rewards (W) on the two parties' strategy selection. When W= 1 or 3, the curve gradually converges to 1; when W = 5 or 7, the curve gradually converges to 0. This result shows that appropriate rewards can boost agricultural enterprises' desire to undergo digital transformation. Further, these rewards positively impact local governments' decisions.

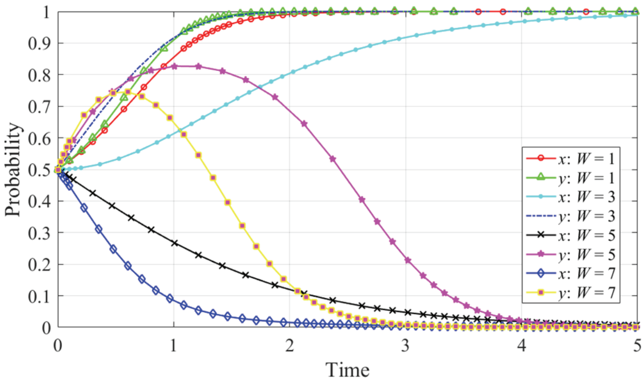

Fig. 4. Impact of W on evolutionary results.

5.2.2 Credit funds (D)

Keeping all other factors unchanged, the values of D are 2, 4, 6, and 8. Fig. 5 presents the simulation of the impact of regret costs (D) on the two parties' strategy selection. When D = 2, the curve gradually converges to 1. With increased funds obtained on credit, the curve converges to 1 at an increasing pace. This finding shows that with the assistance of the local government of a place, the more funds agricultural enterprises obtain through credit, the stronger the promotion effect on their positive transformation is.

Additionally, the government's desire to provide assistance gradually strengthens with an increase in the amount of funds obtained by agricultural enterprises through credit.

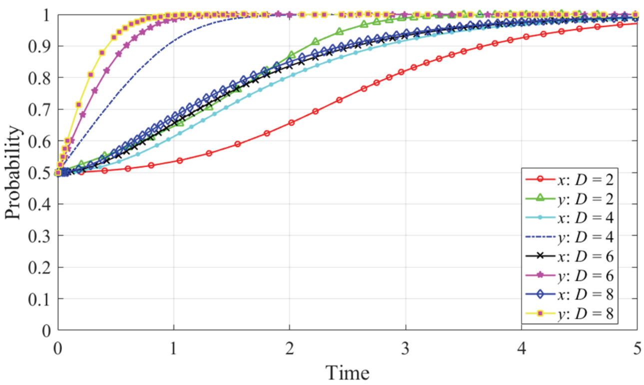

Fig. 5. Impact of D on evolutionary results.

5.2.3 Regret costs (C_h)

Keeping all other factors unchanged, the values of C_h are 1, 3, 5, and 7. Fig. 6 presents the simulation of the impact of regret costs (C_h) on the two parties' strategy selection. When C_h = 1, the system lacks an ESS. As the regret costs increase to 3, the decisions of local governments and agricultural enterprises shift, and the curve gradually converges to 1. This outcome shows that under the assistance of a local government, the higher regret costs paid by agricultural enterprises are, the stronger the promotion effect on their positive transformation is.

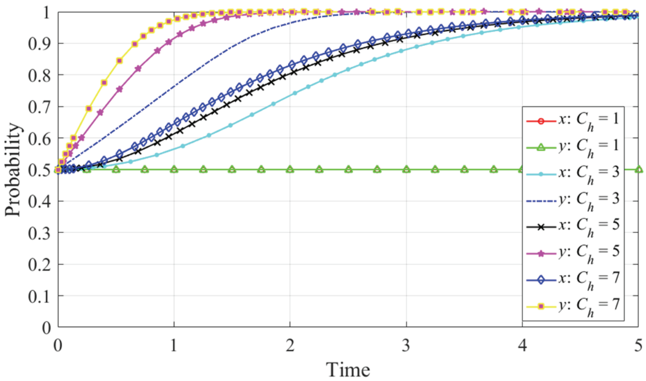

Fig. 6. Impact of C_h on evolutionary results.

5.2.4 Environmental benefits (U)

Keeping all other factors unchanged, the values of U are 9, 10, 11, and 12. Fig. 7 presents the simulation of the impact of environmental benefits (U) on the two parties' strategy selection. When U= 2, the curve gradually converges to 1. As environmental benefits increase, the curve converges to 1 at an increasing pace. This result shows that the local government of a place is inclined to assist enterprises undergoing digital transformation with increasing environmental benefits. Simultaneously, owing to government assistance, agricultural enterprises' willingness to transform also gradually strengthens.

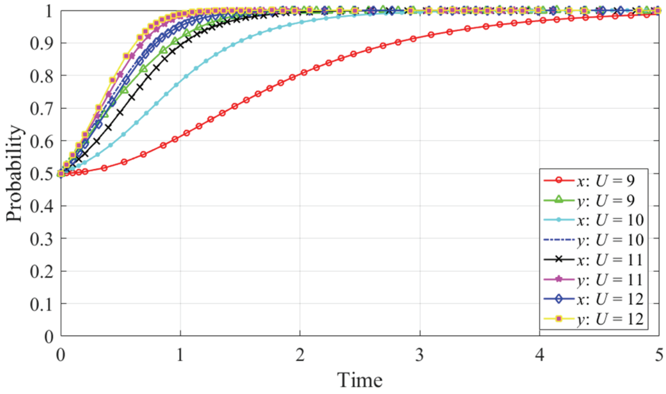

Fig. 7. Impact of U on evolutionary results.

6. Conclusion and Managerial Implications

Considering the digital transformation dilemma of agricultural enterprises, this study develops a two-party evolutionary game model involving a local government and agricultural enterprises and analyzes the stability of the system's evolutionary strategy combination and key variables' effects on strategy evolution and stable results. It further simulates the effectiveness of the analysis process. The findings are as follows. First, the increased initial participation willingness of the two parties will help agricultural enterprises make decisions faster and undergo digital transformation. Second, agricultural enterprises will seize advancement opportunities to avoid being left behind the market if they do not keep up. However, they require local government assistance to overcome challenges. Finally, improving financial inclusion allows agricultural enterprises to obtain funding and promotes their willingness to transform.

The study presents the following management implications in light of the aforementioned findings.

- Improving the digital capabilities of agricultural enterprises can create more economic benefits. Local governments can invest in new infrastructure projects and promote the construction of 5G facilities to create a shared platform for the exchange of information, thereby enhancing enterprises' digital capabilities and enabling their digital transformation.
- Local governments should develop reasonable incentive policies. However, excessive rewards overburden the government financially, and slightly reducing the incentive amount will not affect the system's stability. Local governments can provide incentives to agricultural enterprises through gradual investment. When the willingness of agricultural enterprises to transform reaches a certain level, local governments can relax their assistance and allow the enterprises to transform independently to create a good market development environment.
- Ensuring efficient financial channels will mitigate agricultural enterprises' financial difficulties. Local governments can target the proprietary characteristics of agricultural enterprises, such as variety rights and gene patents, and the demand for loan mortgages for agricultural facilities and equipment to encourage financial institutions to develop innovative credit products.

This study has certain limitations. The study considered the positive influence of agricultural enterprises' digital transformation on the relevant parties under bounded rationality; however, it did not consider the impact of the scale of agricultural enterprises and their level of digital transformation on the costs and benefits of relevant parties. Future research should introduce digital transformation maturity, improve the benefit matrix, and provide more suggestions for agricultural enterprises to transform.

Conflict of Interest

The authors declare that they have no competing interests.

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References

[1] Y. Xie, Z. Chen, F. Boadu, and H. Tang, "How does digital transformation affect agricultural enterprises' pro-land behavior: the role of environmental protection cognition and cross-border search," *Technology in Society*, vol. 70, article no. 101991, 2022. https://doi.org/10.1016/j.techsoc.2022.101991

[2] W. Xie, D. Zheng, J. Luo, Z. Wang, and Y. Wang, "of cooperation strategy of government-enterprise digital transformation based on differential game," *Open Mathematics*, vol. 20, no. 1, pp. 791-808, 2022. https://doi.org/10.1515/math-2022-0480

[3] H. Wang, Z. Yan, G. Guo, and J. Yin, "Digital infrastructure policy and digital transformation of enterprises: "empowerment" or "negative energy"?," *Journal of Quantitative & Technology Economics,* vol. 40, no. 5, pp. 5-23, 2023.

[4] J. Luo, M. Hu, M. Huang, and Y. Bai, "How does innovation consortium promote low-carbon agricultural technology innovation: an evolutionary game analysis," *Journal of Cleaner Production*, vol. 384, article no. 135564, 2023. https://doi.org/10.1016/j.jclepro.2022.135564

[5] J. Liu and H. Liu, "Government–business relationship and strategic transformation of enterprises: evidence from China," *Finance Research Letters*, vol. 58, article no. 104614, 2023. https://doi.org/10.1016/j.frl.2023.104614

[6] R. Abiri, N. Rizan, S. K. Balasundram, A. B. Shahbazi, and H. Abdul-Hamid, "Application of digital technologies for ensuring agricultural productivity," *Heliyon*, vol. 9, no. 12, article no. e22601, 2023. https://doi.org/10.1016/j.heliyon.2023.e22601

[7] K. Oh, H. Kho, Y. Choi, and S. Lee, "Determinants for successful digital transformation," *Sustainability*, vol. 14, no. 3, article no. 1215, 2022. https://doi.org/10.3390/su14031215

[8] F. A. Kitole, E. Mkuna, and J. K. Sesabo, "Digitalization and agricultural transformation in developing countries: empirical evidence from Tanzania agriculture sector," *Smart Agricultural Technology*, vol. 7, article no. 100379, 2024. https://doi.org/10.1016/j.atech.2023.100379

[9] L. Yang, G. H. Pan, and G. S. Hou, "Behavior evolution of key participants in digital transformation of small and medium-sized enterprises," *Science and Technology Management Research*, vol. 42, no. 6, pp. 112-123, 2022.

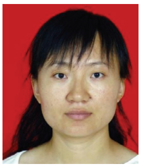
[10] C. Feng, B. Feng, and Z. M. Zhang, "Evolutionary game of financing empowerment mechanism for small and medium-sized enterprises' digital transformation: a supply chain finance approach," *Economy and Management*, vol. 2024, no. 1, pp. 36-44, 2024.

Xiaowei Hai **https://orcid.org/0000-0003-3406-7150**

He received a Ph.D. from the School of Economics and Management at Beijing Jiaotong University in 2014. He is currently an associate professor at the School of Economics and Management, Inner Mongolia University of Technology in Hohhot, China. His research interests include digital economy, supply chain management and information management.

Shenglan He **https://orcid.org/0009-0005-1770-8042**

She received a B.S. from the School of Business at Sias University in 2022. She is currently pursuing a master's degree from the School of Economics and Management, Inner Mongolia University of Technology in Hohhot, China. Her research interests include digital economy and business management.



Chanchan Zhao **https://orcid.org/0000-0002-5441-4597**

She received a Ph.D. from the School of Computer and Information Technology at Beijing Jiaotong University in 2018. She is currently an associate professor in the College of Information Engineering, Inner Mongolia University of Technology in Hohhot, China. Her research interests include optimization theory and methodology.