Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 3
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Evolutionary Game Analysis of Digital and Intelligent Transformation of Livestock Enterprises

Weipeng Qiao*, Hang Guo*

Hebei University of Economics and Business, Shijiazhuang 050061, Hebei, China

**Author to whom correspondence should be addressed.*

Abstract: The livestock farming is an important pillar of the rural economy in China. To explore the impact of government technical subsidies and pollution penalties on the digital and intelligent transformation of livestock enterprises, an evolutionary game theoretical model between the government and livestock enterprises is constructed. The interaction mechanism of the game between the government and breeding enterprises is explored, and simulation is conducted. The research results show that the combined strategy of pollution penalties and technical subsidies is the optimal strategy for the government; the system is jointly driven by government subsidies, technical costs of transformation input, public willingness, and enterprise willingness.

Keywords: Government; Livestock enterprises; Evolutionary game; Willingness constraint

Online publication: July 14, 2025

1. Introduction

Digital and intelligent construction is an inevitable trend for achieving the modernization of agriculture and an intrinsic need for the comprehensive realization of rural revitalization in China. The livestock industry is becoming a hot spot in the development of rural economy in China with the aid of digital and intelligent technologies. As of 2023, the income from the livestock breeding industry has accounted for more than 40% of farmers' income, and the output value of the livestock breeding industry has accounted for 34% of the total output value of China's agriculture [1, 2]. However, large-scale breeding generates a huge volume of waste. When the efficiency of waste treatment cannot keep up with the output efficiency, it will cause environmental pollution. With the development of digital and intelligent technologies, some livestock enterprises have attempted to implement digital and intelligent transformation to realize real-time automatic treatment of waste and improve the efficiency of waste treatment [3–5].

Due to the particularity of the livestock industry, on the one hand, the livestock residues have certain pollution to the environment, and on the other hand, they can also be used as fertilizers. Livestock enterprises utilize digital

and intelligent technologies to reduce the pollution of pollutants to the environment and can also protect the nutrients of manure and sewage to a greater extent. Generally, the government will encourage livestock enterprises to implement digital and intelligent transformation to improve the pollutant treatment capacity, and will subsidize the livestock enterprises that implement digital and intelligent transformation, while punishing enterprises whose pollutant discharge does not meet the standards. In addition, the concept of enterprises and the government undertaking social responsibilities has been valued by all levels of society [6, 7]. For example, when an enterprise implements digital and intelligent transformation but the government does not provide support, the government's reputation will be damaged. When an enterprise does not carry out digital and intelligent transformation and causes excessive pollutant discharge, its reputation will also be damaged [8, 9]. To sum up, the digital and intelligent transformation issue of the government and livestock enterprises under the pollutant treatment mechanism is complex and unpredictable. How both sides will choose in terms of strategies, what kind of interaction will occur between the strategies and how they will evolve are currently unclear, and it is necessary to conduct in-depth research.

At present, there are few studies on the digital and intelligent transformation of livestock enterprises. Cheng *et al.*, from the perspective of collaborative governance, discussed the impact of tax and fee reduction policies on the digital transformation of traditional resource-based enterprises [10]. Wang *et al.* deeply analyzed the key roles of two mechanisms, namely sewage discharge fines and government rewards, on the emission reduction behaviors of enterprises [11]. Song *et al.* based on the evolutionary game theory, verified the positive impact of government subsidies on the effect of environmental emission reduction [12]. Zhuo found that digital transformation can significantly improve the innovation quality of enterprises [13]. Xu *et al.* further explored the promoting effect of digital transformation on ecological innovation and sustainable performance [14]. However, there are few studies on the digital and intelligent transformation of livestock enterprises in the existing research. Based on the evolutionary game theory, this paper deeply explores the impact of government subsidies and punishment measures on the strategic choice of digital and intelligent transformation of livestock enterprises, which has important theoretical significance and practical value.

The main contributions of this paper include:

(1) Constructing an evolutionary game model between the government and livestock enterprises under the digital and intelligent transformation mechanism, revealing the equilibrium mechanism among all stakeholders.

(2) Based on the evolutionary path and direction of the game between the government and enterprises, proposing targeted strategic suggestions.

2. Model construction

(1) In the digital and intelligent transformation of the government, the strategy set is A = {Support, Not Support}, and the probability of support is $x(0 \leq x \leq 1)$; the strategy set of breeding enterprises is B = {Active Transformation, Passive Transformation}, and the probability of active digital and intelligent transformation is $y(0 \leq y \leq 1)$, as shown in **Table 1**.

(2) When the livestock enterprises actively transform, they enhance the ability to handle pollutants and reduce environmental pollution. At this time, the pollutant treatment income of the enterprises is I and the comprehensive income is R_1, and the government's income is respectively G_1. The cost of implementing

digital and intelligent transformation for enterprises is C_2, and the government's income is respectively G_2. When the livestock enterprises passively transform, they do not invest any cost. The cost required for handling pollutants is recorded as W, and the comprehensive income of the enterprises is R_2. Environmental pollution is caused, and the loss to the government's reputation is V.

(3) The government offers tax deductions (denoted a S) to enterprises undergoing digital and intelligent transformation, as well as cost subsidies for digital and intelligent transformation (denoted as C_1 The negative constraint is the penalty (denoted as F) imposed on enterprises for passive transformation and causing pollution.

(4) When breeding enterprises actively carry out digital and intelligent transformation but receive no support from the government, it will cause certain reputation losses D_1. When breeding enterprises are not active in digital and intelligent transformation, the enterprises will suffer image losses D_2. When the government does not support enterprises in digital and intelligent transformation, the government will suffer reputation losses D_3 [15].

Table 1. Evolutionary game payoff matrix

Both sides of the game		Livestock enterprise	
		Positive transformation (y)	**Negative transformation (1-y)**
Government	Support(x)	G_1-C_1-S R_1+S+C_1-C_2-C_3+I	G_1-C_1-S R_2+S+C_1-C_3-D_2-W
	Not supported (1-x)	G_2-D_1 R_1-C_2-C_3+I	G_2-V-D_3 R_2-C_3-D_2

3. Sensitivity analysis

In order to present more intuitively the role of government technology and tax subsidies, as well as the technical costs that enterprises need to invest for active transformation in the digital and intelligent transformation process of livestock enterprises. In this paper, the MATLAB 2016a software is used to conduct numerical simulation of various parameters. The ode45 instruction is used to solve the replicator dynamic equations. Combined with the setting rules of numerical simulation in the existing literature, the initial assignment of each parameter is set as follows.

Table 2. Initial assignment of each parameter

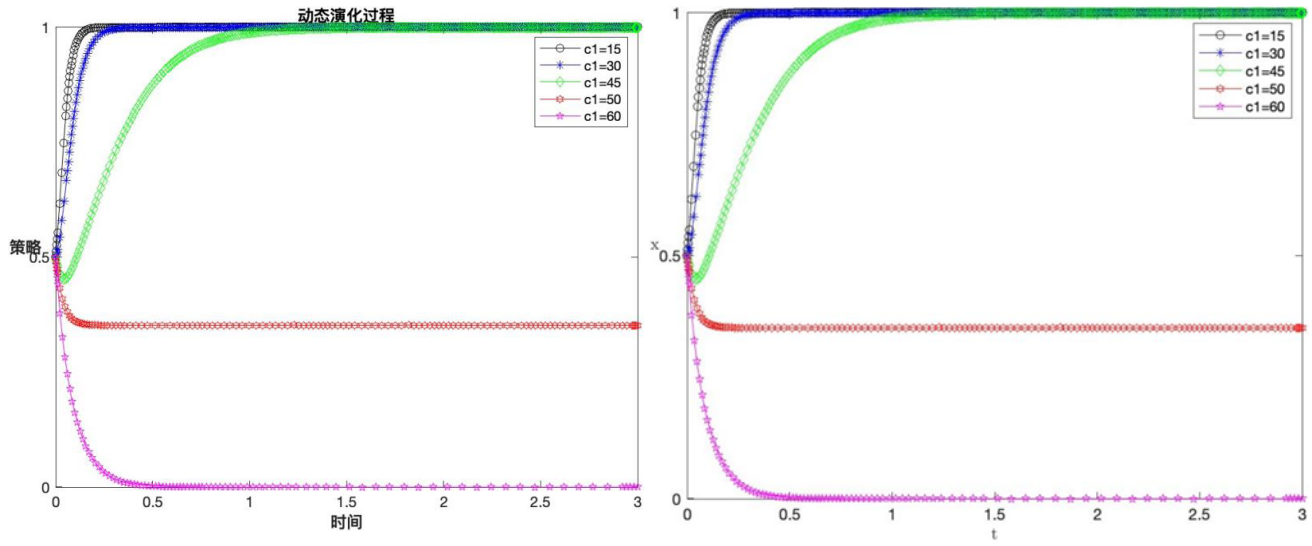
Argument		R_1	R_2	C_1	C_2	D_1	D_2	D_3	S	I	W	V
Assign	120	100	30	60	80	30	10	30	10	20	40	

3.1. The influence of technical subsidy costs C_1

Under the condition that other factors remain unchanged, let the values C_1 be set at 15, 30, 45, 50, and 60, respectively, and examine the impact of technical subsidy costs C_1 on the digital and intelligent transformation strategies of the government and breeding enterprises. As shown in **Figure 1(a)**, when the value C_1 is less than 50, the strategy evolution of the government tends to 1. As the value C_1 increases, when it is greater than 50, the strategy evolution of the government gradually tends to 0. Thus, within a certain range, the impact of government

technical subsidies C_1 on the government's strategy is positive. However, as the government subsidy increases and the government cost exceeds a certain threshold, the government is no longer inclined to support breeding enterprises in their digital and intelligent transformation.

In **Figure 1(b)**, as the value C_1 increases, the slope of the curve becomes smaller and smaller, that is, the probability that breeding enterprises actively carry out digital and intelligent transformation will gradually decrease. Thus, it can be known that although the impact of government technical subsidies on the strategic choice of digital and intelligent transformation of breeding enterprises is positive, as the technical subsidies for breeding enterprises increase, the probability of government support for the transformation of breeding enterprises becomes smaller, resulting in less expected benefits for the transformation of breeding enterprises, and ultimately weakening the willingness of breeding enterprises to actively transform.



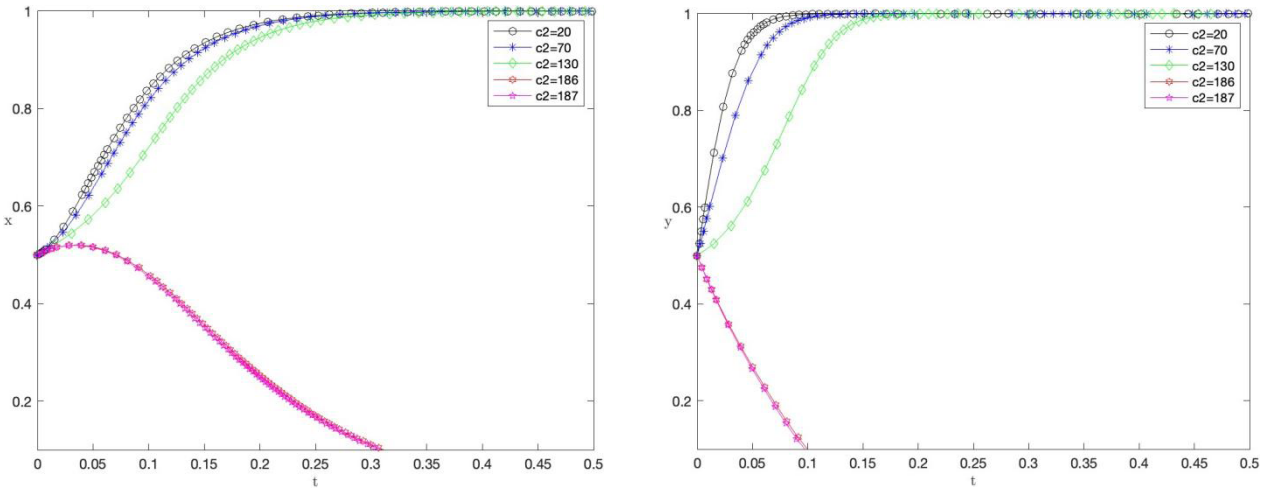
(a) (b)

Figure 1. The influence of technical subsidy costs C_1

3.2. The influence of investment cost C_2 in digital and intelligent transformation technology

Under the condition that other factors remain unchanged, let the values C_2 be set as 20, 70, 130, 186, and 187, respectively. The impact of the simulation enterprise's transformation technology investment cost on the digital and intelligent transformation strategies of the government and enterprises was investigated. The simulation results are shown in **Figures 2(a)** and **(b)**. When the value C_2 is relatively small (less than 186), the strategy evolution of both the government and the breeding enterprises tends to 1. As the value C_2 increases, the slopes of the curves of both decrease, that is, the probability that both support the digital and intelligent transformation of enterprises gradually decreases. It should be noted that when the value is close to 186, due to the high upfront investment cost and the lag in the benefits brought by waste treatment, the intention of enterprise digital and intelligent transformation shows a downward trend at the beginning. As the benefits brought by waste treatment become increasingly significant, enterprises gradually tend to adopt an active transformation strategy. When the value C_2 is large (greater than 186), because the investment cost required for digital and intelligent transformation is too high and has exceeded the benefits brought to the enterprise by the transformation, the attitude of enterprises towards transformation becomes negative. Therefore, as time goes by, the cost for the government to promote enterprises'

digital and intelligent transformation becomes higher and higher, eventually leading the government to tend not to support enterprise transformation.



(a) (b)

Figure 2. The influence of investment cost C_2 in digital and intelligent transformation technology

4. Conclusion

This paper starts from the background of the digital and intelligent transformation of livestock enterprises, constructs an evolutionary game model between the government and livestock enterprises, and conducts research and analysis on the evolutionary process and influencing factors of both sides. The research results show that:

(1) The increase in government subsidies is an important factor promoting the digital and intelligent transformation of enterprises. The higher the direct technical subsidy, the more inclined the livestock enterprises are to undergo digital and intelligent transformation. However, as the subsidy cost increases, when it exceeds the benefits brought to the government by the transformation of enterprises, the benefits obtained by the government are not enough to cover the costs paid, and the government will choose not to support the digital and intelligent transformation of enterprises.

(2) With the increase in the technical cost required for the digital and intelligent transformation of enterprises, the willingness of enterprises and the government to support digital and intelligent transformation will weaken. When it exceeds a certain threshold, the government and enterprises will tend to choose the {unsupported, passive transformation} strategy.

(3) It is worth noting that in the entire digital and intelligent transformation process, the environmental impact has a relatively obvious lagging characteristic, so that the improvement effect of pollutant pollution in the early stage of digital and intelligent transformation cannot be fully reflected, resulting in the government choosing the non-support strategy in the early stage. However, as the effect of pollutant treatment gradually emerges, the government begins to choose to support the digital and intelligent transformation of enterprises.

To sum up, in order to further promote the implementation of the digital and intelligent transformation plan of livestock enterprises and promote the comprehensive and high-quality development of China's livestock industry,

the following countermeasures and suggestions are put forward:

(1) For enterprises, by increasing investment in digital and intelligent systems, improving the overall economic benefits and environmental protection benefits of the industry, and focusing on the research and development of enterprise waste treatment and value-added products, efforts should be concentrated on solving the bottleneck problems of process technology and procedures that restrict the waste treatment capacity.

(2) For the government, it is necessary to build a digital and intelligent platform to provide information and digital and intelligent services for the livestock industry, such as establishing a data center for the livestock industry and an intelligent livestock demonstration base. Furthermore, it is necessary to optimize the business environment, improve the efficiency of policy implementation and administrative efficiency, encourage livestock enterprises to actively carry out digital and intelligent transformation, and at the same time, strengthen the government's supervision of the livestock industry to promote the green, healthy and sustainable development of the livestock industry.

Disclosure statement

The authors declare no conflict of interest.

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