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Evolutionary game of green behavior of fresh agricultural product retailers considering public supervision under the perspective theory

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as supply chain finance, financial engineering, and risk management.

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Abstract: Studying the green behavior of fresh agricultural product retailers is of great significance in ensuring high-quality supply and efficient distribution of agricultural products. This article integrates knowledge from prospect theory, evolutionary game theory, and breaks the limitations of traditional game models that assume complete rationality and evolutionary game models that do not involve consumer supervision. It constructs an evolutionary game model for green behavior of fresh agricultural product retailers considering public supervision under prospect theory. By analyzing the evolution trajectory and stability of strategy choices between local governments and retail enterprises, and using Matlab software for simulation analysis, the impact of key parameters on the evolution results was explored, confirming that public participation in supervision has a positive impact on promoting the green development of fresh agricultural product retail enterprises. Finally, based on the evolutionary conclusions, reference suggestions are proposed for government departments and retail enterprises to promote the green development of upstream and downstream enterprises in the fresh agricultural product supply chain.

Key words: Prospect theory; Retailers of fresh agricultural products; Green behavior; Evolutionary game

I. Introduction

Since the reform and opening up, the quality of life of the Chinese people has been continuously improving. At present, our demand for food has shifted from "quantity" to "quality" and then to "green". Consumers are at the end of the fresh agricultural product supply chain and are the main source of revenue for the supply chain. With the deeply rooted consumer concept of "green, organic, and pollution-free", the consumer market has put forward higher standards for various types and high-quality green production requirements for fresh agricultural product suppliers, and higher standards for green storage, transportation, and distribution for fresh agricultural product retailers.

In existing literature, research on green technology and preservation technology mainly focuses on how to coordinate the distribution of benefits among supply chain enterprises and compare and analyze which dominant mode can improve supply chain efficiency and environmental benefits by constructing preservation functions. Most of the research focuses on the analysis of fully rational individuals in static situations, lacking overall consideration of the market environment and the absence of fully rational individuals in reality. Research on prospect theory mainly focuses on analyzing social management and economic issues, and exploring whether prospect theory can be confirmed in real society and introducing utility functions to explain the behavioral strategies and preference choices of a certain subject. There is relatively little research in the field of fresh agricultural products. The research on evolutionary game theory mainly focuses on proving the evolutionary mechanisms and influencing factors of multi-agent games in different situations. In existing research, some scholars have combined prospect theory with evolutionary game models, but there is relatively little literature on fresh agricultural product retailers.

In traditional evolutionary game analysis, benefits are usually measured by the objective benefits of expected utility theory. However, the prospect theory based on bounded rationality suggests that people have different risk preferences for gains and losses, tend to pursue a turnaround in adversity, and are more sensitive to losses. In decision-making, the subjective perception of strategy benefits by both parties in the game is more accurate, while the objective measurement of actual benefits is relatively inaccurate. Therefore, this study introduces prospect theory to construct an evolutionary game model for green behavior strategies of fresh agricultural product retailers. The subjective probability weight function and value function are used to explain the perceived benefits of both parties in the game, in order to more accurately reflect the actual situation of the game participants. By analyzing the evolution trajectory and stability of strategy choices between local governments and retail enterprises, and using Matlab 2021 software for simulation analysis, this study explores the impact of key parameters on the evolution results. Finally, based on the evolutionary conclusions, reference suggestions are proposed for government departments and retail enterprises to promote the green development of upstream and downstream enterprises in the fresh agricultural product supply chain.

II. The concept of green behavior of fresh agricultural product retailers

Green supply chain is a supply chain management method guided by environmental sustainability. By adopting a series of environmental protection measures, we aim to reduce the adverse effects of production and supply chain activities on the environment, thereby achieving effective resource utilization, reducing waste generation, and negative impacts on the ecosystem. The goal of green supply chain management is to minimize the environmental footprint throughout the entire lifecycle of a product or service, including raw material procurement, production, transportation, storage, and terminal processing of the final product. Therefore, enterprises in the supply chain usually choose environmentally friendly raw materials and suppliers to improve the environmental sustainability of the supply chain by optimizing logistics and transportation processes, reducing energy consumption and emissions. This approach not only helps companies fulfill their social responsibilities, but also enhances their competitiveness, as more and more consumers and stakeholders are showing higher concerns about environmental protection and sustainability.

This article studies the green behavior of fresh agricultural product retailers, including the introduction of cold chain logistics and preservation technology, quality inspection technology for fresh agricultural products, blockchain

traceability technology, and innovative packaging and warehousing technology. Through these technologies, sustainable procurement and operation, resource dependence reduction, and environmental impact reduction can be achieved.

(1) Cold chain logistics technology has played a crucial role in improving the sustainability of the fresh agricultural product market, reducing loss rates, and improving product quality. In the process of transportation, storage, and sales of fresh agricultural products, retail enterprises establish and maintain a complete cold chain system to ensure that agricultural products maintain suitable temperature and humidity conditions throughout the entire supply chain, maximize the preservation period of fresh agricultural products, reduce loss rates, and maintain the freshness, nutritional value, and safety of the products. For example, fresh agricultural product retailers purchase modern refrigerated warehouses, refrigerated vehicles, and other cold chain equipment; Deploy advanced monitoring technology and sensors to monitor the temperature, humidity, and other environmental parameters of fresh agricultural products in real time; Utilize information technologies such as the Internet of Things and big data analysis to conduct real-time monitoring, data analysis, and prediction of cold chain logistics processes.

(2) Quality inspection technology refers to the comprehensive, accurate, and efficient testing of physical and chemical indicators, sensory indicators, genetically modified ingredients, pesticide residues, antibiotic content, and other indicators of fresh agricultural products by retailers using high-tech and equipment according to relevant operating standards. Regular sampling and issuing quality inspection reports can gain the trust of consumers.

(3) Using blockchain traceability and other technologies to improve the transparency of the fresh agricultural product supply chain, ensuring the source and the transportation process meets green standards and increases consumer trust in the product. This is crucial for adapting to today's society and maintaining sustainability. The demand for continued development and the requirements for product quality and safety are crucial.

(4) Adopting innovative packaging and warehousing technologies to improve the freshness of agricultural products. For example, modified atmosphere packaging and efficient preservation materials can help extend the shelf life of products, reduce expiration and loss; Using modified atmosphere technology in the warehousing process to adjust the oxygen, carbon dioxide, and humidity in the storage environment to extend the shelf life of goods.

III. Evolutionary game of green behavior of fresh agricultural product retailers considering public supervision under prospect theory

This model involves three stakeholders: local governments, fresh agricultural product retailers, and consumers. Retailers sell agricultural products to consumers, who are the end of the fresh supply chain. Retailers consider both costs and benefits to balance their green behavior strategies, and consumers prefer high-quality, safe, green, and pollution-free agricultural products. Retailers mainly consider their own profits, followed by serving society and corporate responsibility; The government's goal is to maximize social welfare. In reality, there is no completely rational person, but prospect theory can interpret the bounded rational decision-making process of game players considering factors such as risk avoidance and maximizing benefits. In this model, the introduced green technologies are quantified as the costs incurred by fresh agricultural product retailers in adopting green behaviors. The stakeholder relationship diagram is shown in the following figure.

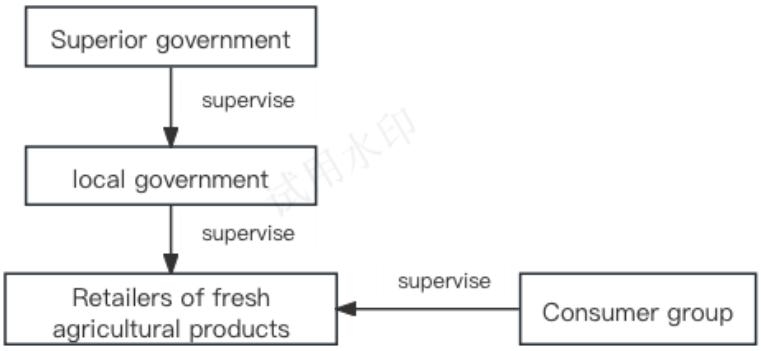


Fig.1 Stakeholder Relationship Diagram

3.1 Basic assumptions of the model

Assumption 1: Fresh agricultural product retailers and local governments are both bounded rationality and have information asymmetry. In behavioral decision-making, consumer groups participate in the green behavior decision-making of retailers in the form of interest coordination mechanisms. The decision-making process of consumer groups follows the principle of perceived value proposed in prospect theory. The product of the value function and the weight function is shown in equation (1). In this model, event P_1 represents that when a retailer passively adopts green behavior and a public trust crisis occurs, it causes upstream enterprises in the supply chain to jointly bear reputation losses, and the probability is represented by p_1. When incident P_1 occurred, the retailer was actually punished by the local government (economic penalties, suspension of business for rectification, official notices, etc.), and the estimated loss was g. Due to the tendency of medium to high probability events to be underestimated and low probability events to be overestimated, there is always a high probability event that occurs, $\omega(p) < p$; When a small probability event occurs, there is always $\omega(p) > p$, $\omega(1) = 1$; $\omega(0) = 0$。The parameters in the value function $\Delta\pi$ represent the difference in returns of the game subject before and after the game, and the parameters represent the risk preference coefficient of the game subject，$0<\alpha<1, 0<\beta<1$。The larger the value, the higher the sensitivity to losses and returns. The parameter $\lambda(\lambda \geq 1)$ is the loss avoidance coefficient, and the larger the value, the higher the sensitivity coefficient to losses compared to returns.

$$U = \sum \omega(p)\, V(\Delta\pi) \tag{1}$$

$$\omega(p) = \frac{p^{\gamma}}{(p^{\gamma} + (1-p)^{\gamma})^{1/\gamma}} \tag{2}$$

$$V(\Delta\pi) = \begin{cases} \Delta\pi^{\alpha}, & \Delta\pi \geq 0 \\ -\lambda(-\Delta\pi)^{\beta}, & \Delta\pi \leq 0 \end{cases} \tag{3}$$

Assumption 2: The decision set of fresh agricultural product retailers is {M_1 actively adopting green behavior, M_2 passively adopting green behavior}. The decision-making set of local governments is {N_1 active regulation, N_2 passive regulation}. Assuming that the probabilities of fresh agricultural product retailers and local governments choosing to actively adopt green behavior and actively regulate are x and y, x、y $\in$ [0,1], then the probabilities of fresh agricultural product retailers and local governments choosing to passively adopt green behavior and passively regulate are 1-x and 1-y.

Assumption 3: When fresh agricultural product retailers choose to actively adopt green behavior, R represents the actual cost of the retailer in the process of green behavior. These costs, in addition to the capital and time, entrepreneurial talent, and green technology costs mentioned in Marshall's production theory elements, also include the psychological value perception of the retailer's cost, and their corresponding prospect value perception is H_1; The actual cost C of human, material, and time invested by the government in actively regulating is represented by H_2, which corresponds to the perceived value of the future.

Assumption 4: Fresh agricultural product retailers and local governments adjust their own strategies based on each other's decision-making changes, and the game behavior is repetitive and dynamic. The system can be adjusted at any time before reaching the Pareto optimal state. And during the adjustment process, the strategic choices of both parties will be influenced by each other, so it is assumed that there is a certain risk coefficient in this process, and there is a linear relationship between risk loss and transmission. When retailers actively adopt green behavior, assuming that the risk transmission cannot be zero, the risk transmission coefficient is $k_1 \in (0,1)$, and the perceived value of the prospect of bearing the risk loss L_1; when retailers passively adopt green behavior, it may bring inconvenience to the consumer market and cause certain hidden dangers to government regulation, and the probability of being spot checked by local governments is ψ. The probability of food safety incidents causing damage to brand image is ε. The actual loss of causing brand image decline is estimated to be q. At this time, the risk transmission coefficient is k_2 greater than or equal to zero, and the perceived value of the prospect of bearing the government penalty and loss L_2 is borne. At this time, the additional income of retailers is A. When local governments adopt active supervision policies, assuming that the risk transmission cannot be zero, the risk at this time is A. The loss cost coefficient is $k_3 \in (0,1)$.

Assumption 5: Assuming there is a necessary guidance and supervision relationship between upper and lower level government agencies. The reputation loss caused by the negative supervision of the local government being investigated and dealt with by the higher-level government is B, and the negative supervision of the local government was exposed after a public health incident occurred.The probability of the superior government investigating and punishing is z, then the reputation loss of the government's passive supervision is zB.

Assumption 6: Consumer groups can indirectly participate in the supervision of green efforts by retail enterprises within a reasonable range (media disclosure, perception of the surrounding environment, etc.). Assuming that the intensity of public supervision is variable, it is assumed that the public has no regulatory power when represented by probability，$\theta \in [0,1]$, $\theta=0$， At the same time, due to the convenience of government regulation, assuming that fresh agricultural product retailers passively adopt green behavior, the government actively regulates and discovers non green behavior of retail enterprises before public supervision. When non green behaviors of retail enterprises are discovered by consumers, the brand reputation and image loss of retail enterprises in the social public image is D_1, and the credibility loss of the government in the social public image is D_2.

3.2 Strategy combination and return matrix

According to prospect theory, the determined costs and expenses do not have any benefits or losses, that is, there is no bias in perceived value, and only when the decision-maker cannot accurately predict the benefits and risks, psychological perceived utility will occur. According to the behavioral strategies of fresh agricultural product retailers and local governments, there are four types of game combinations between the two parties, namely (M_1 actively adopts green

behavior, N_1 actively supervises), (M_1 actively adopts green behavior, N_2 passively supervises), (M_2 passively adopts green behavior, N_1 actively supervises), and (M_2 passively adopts green behavior, N_2 passively supervises). Obtain the income matrix of local governments and fresh agricultural product retailers, as shown in Table 1.

(1) When the strategic choices of local governments and fresh agricultural product retailers are (M_1 actively adopting green behavior, N_1 actively regulating), event P_1 (when retailers passively adopt green behavior and public trust crisis occurs, their upstream enterprises in the supply chain jointly bear reputation losses) cannot occur, and the probability of risk losses for retailers is zero. Local governments only need to pay the perceived value cost H_2; Retailers only have a perceived value H_1 of the prospect of investing costs in actively adopting green behaviors. Therefore, the profit and loss values of local governments and retailers are $-H_2$ 、 $-H_1$.

$$H_1=\omega(1-p_1)v(C_1)+\omega(p_1)v(0)=v(C_1) \tag{4}$$

$$H_2=\omega(1-p_1)v(C_2)+\omega(p_1)v(0)=v(C_2) \tag{5}$$

(2) When the strategic choices of local governments and fresh agricultural product retailers are (M_2 passively adopting green behavior, N_2 passively regulating), due to the responsibility risk of retailers passively adopting green behavior, local governments need to bear joint and several liability losses k_2L_1 and reputation losses zB publicly investigated by higher-level governments; The perceived value of risk loss L_1 for retailers after deducting additional income A. At the same time, both parties may also bear other losses.

Whenθ=0, the consumer group cannot detect and expose the non green behavior of fresh agricultural product retailers, local governments are exempt from the loss of public credibility, and retail enterprises are exempt from the loss of brand reputation, that is, $D_1=0$, $D_2=0$. Therefore, the profit and loss values of local governments and retailers in this situation are $-k_2L_1$-zB、$-L_1$.

Whenθ=1, when the consumer group discovers and exposes the non green behavior of retail enterprises, they not only face punishment from the local government, but also bear the loss of public brand reputation D_1. Similarly, due to dereliction of duty, the local government needs to bear criticism from public opinion, resulting in a decrease in credibility D_2. Therefore, the profit and loss values of local governments and retailers in this situation are $-k_2L_1$-zB-D_2 、$-L_1$-D_1.

When $0<\theta<1$, the profit and loss values of local governments and retail enterprises are an expected function of probability p. The profit and loss values E_1 and E_2 of local governments and retail enterprises are:

$$\begin{aligned}E_1&=\omega(\theta)(-D_2-k_2L_1)+[1-\omega(\theta)](-k_2L_1)-zB\\&=-D_2\omega(\theta)-k_2L_1-zB\end{aligned} \tag{6}$$

$$\begin{aligned}E_2&=\omega(\theta)(-D_1-L_1)+[1-\omega(\theta)](-L_1)\\&=-D_1\omega(\theta)-L_1\end{aligned} \tag{7}$$

$$L_1=\omega(\varepsilon)v(q)+\omega(1-\varepsilon)v(0)=\omega(\varepsilon)v(q) \tag{8}$$

(3) When the strategy choices of local governments and fresh agricultural product retailers are (M_1 actively adopting green behavior, N_2 passively regulating), event P_1 cannot occur. In addition to paying the perceived value cost H_1, retailers may face the risk of cost irrecovery, and therefore need to bear a certain economic risk loss k_1L_1; On the basis of retailer risk losses, the government is required to bear joint and several liability losses of $k_1k_2L_1$ through the risk transmission coefficient of both parties, and reputation losses zB that are publicly investigated by the higher-level government. Therefore, the profit and loss values of the government and retailers are $-k_1k_2L_1$ -zB、 $-H_1$-k_1L_1.

$$H_1=\omega\left(1-p_1\right)v\left(C_1\right)+\pi\left(p_1\right)v(0)=v\left(C_1\right) \tag{9}$$

(4) When the strategy choices of local governments and fresh agricultural product retailers are (M_2 passively adopting green behavior, N_1 actively regulating), the default cost of retailers passively adopting green behavior is zero, and the situation of retailers escaping punishment is not considered. If this process triggers a collective health and safety event for the consumer group or a recession in the consumer market due to rectification, retailers will inevitably face economic penalties under government active regulatory regulations F_2 and risk sharing losses under government active regulatory policies K_3L_1; At the same time, the government not only needs to pay for the perceived value H_2 of human resources and time costs, but also needs to bear the joint liability risk perceived value loss $k_2k_3L_1$ through the risk loss coefficient. Therefore, the profit and loss values of local governments and retailers are L_2-H_2-$k_2k_3L_1$ 、 L_2-k_3L_1.

$$L_2=\omega(\varphi)\nu(g)+\omega(1-\varphi)\nu(0)=\omega(\varphi)\nu(g) \tag{10}$$

$$L_1=\omega(\varepsilon)\nu(q)+\omega(1-\varepsilon)\nu(0)=\omega(\varepsilon)\nu(q) \tag{11}$$

Tab.1 The Income Matrix of Local Governments and Retailer Enterprises Considering Public Regulation

local government	Retailers of fresh agricultural products	
	Actively adopting green behavior	Negatively adopting green behavior
Active supervision	$-H_2$, $-H_1$	$L_2-H_2-k_2k_3L_1$, $-L_2-k_3L_1$
Negative regulation	$-k_1k_2L_1-zB$, $-H_1-k_1L_1$	$-D_2\omega(\theta)-k_2L_1-zB$, $-D_1\omega(\theta)-L_1$

The meanings of each parameter in Table 1 are as follows:

(1) Retailers of fresh agricultural products

C_1: The actual cost of retailers actively adopting green behavior;

H_1: Perception of the prospect value of retailers actively adopting green behavior and investing costs in the process;

L_1: Perception of Future Value of Retailer Risk Losses;

L_2: Perceived value of the prospect of retailers being penalized by local governments for losses;

A: The additional benefits gained by retailers when they passively adopt green behavior;

D_1: Retailers suffer from brand reputation loss in the public image;

g: At the time of incident P1, the retailer suffered actual penalties and losses from the local government;

q: Actual estimation of brand image damage caused by food safety incidents in retailers.

(2) Local government

C_2: The actual cost paid by local governments for active supervision;

H_2: Perception of the Future Value of Local Government's Investment in Regulatory Costs;

B: Reputation losses caused by passive supervision by local governments and crackdowns by higher-level governments;

D_2: The loss of credibility of local governments in the public image of society.

(3) Risk transmission coefficient

k_1: The coefficient of cost loss borne by both parties when retailers actively adopt green behavior;

k_2: Risk transmission coefficient between retailers and local governments;

k_3: Cost loss coefficient borne by both parties under active supervision by local governments.

(4) Probability and Events

x: The probability of retailers actively adopting green behavior;

y: The probability of local governments paying costs and actively regulating;

z: The probability of negative supervision by local governments leading to public health incidents being exposed by the media and investigated by higher-level governments;

θ: Public supervision efforts;

ψ: The probability of being spot checked by local governments when retailers passively adopt green behavior;

ε: The probability of brand image damage caused by food safety incidents in which retailers passively adopt green behavior;

P_1: When retailers passively adopt green behavior and trigger a crisis of public trust, it triggers upstream companies in the supply chain to jointly bear reputation losses.

3.3 Replicated Dynamic Equation

Assuming that the expected return of fresh agricultural product retailers choosing the "actively adopting green behavior" strategy is U_{M1}, and the expected return of choosing the "passively adopting green behavior" strategy is U_{M2}, with an average expected return of $\overline{U_M}$, the expected perceived return and average expected return of fresh agricultural product retailers are as follows:

$$\begin{cases} U_{M1}=\left(-H_1\right)y+\left(-H1-k1L_1\right)(1-y) \\ U_{M2}=\left(-L_2-k_3L_1\right)y+\left(-D_1\omega(\theta)-L_1\right)(1-y) \\ \overline{U_M}=xU_{M1}+(1-x)U_{M2} \end{cases} \tag{12}$$

If the expected benefits of the government's choice of "active regulation" strategy are U_{N1}, and the expected benefits of choosing "passive regulation" strategy are U_{N2}, with an average expected benefit of $\overline{U_N}$, then the expected perceived benefits and average expected benefits of government regulation are obtained as follows:

$$\begin{cases} U_{N1}=\left(-H_2\right)x+\left(L_2-H_2-k_2k_3L_1\right)(1-x) \\ U_{N2}=\left(-k_1k_2L_1-zB\right)x+\left[-D_2\omega(\theta)-k_2L_1-zB\right](1-x) \\ \overline{U_N}=yU_{N1}+(1-y)U_{N2} \end{cases} \tag{13}$$

The evolutionary game replication dynamic equations for fresh agricultural product retailers and local governments are as follows:

$$\begin{aligned} F(x)=\frac{dx}{dt}&=x\left(U_{M1}-\overline{U_M}\right) \\ &=x(1-x)\left(U_{M1}-U_{M2}\right) \\ &=x(1-x)\left[y\left(-H_1+L_2+k_3L_1\right)+(1-y)\left(-H_1-k_1L_1+D_1\omega(\theta)+L_1\right)\right] \end{aligned} \tag{14}$$

$$\begin{aligned} F(y)=\frac{dy}{dt}&=y\left(U_{N1}-\overline{U_N}\right) \\ &=y(1-y)\left(U_{N1}-U_N\right) \\ &=y(1-y)\left[x\left(-H_2+k_1k_2L_1+zB\right)+(1-x)\left(L_2-H_2-k_2k_3L_1+D_2\omega(\theta)+k_2L_1+zB\right)\right] \end{aligned} \tag{15}$$

The equilibrium result of decision-making subject evolution can be obtained.

$$\begin{cases} F(x)=\frac{dx}{dt}=x\left(U_{M1}-\overline{U_M}\right) \\ F(y)=\frac{dy}{dt}=y\left(U_{N1}-\overline{U_N}\right) \end{cases} \tag{16}$$

3.4 Evolutionary Game Analysis

According to the principle of evolutionary game, the stability of local equilibrium points is evaluated by the determinant (det J) and trace (tr J) values of the Jacobian matrix. Usually, when det J>0 and tr J<0, the local equilibrium point of the system is considered stable. Further, based on the positive and negative values of det J and tr J at each equilibrium point, it can be determined whether it is an evolutionarily stable strategy. The Jacobian matrix is represented as J. $det\ J = p_{11} \times p_{22} - p_{21} \times p_{12}$, $tr\ J = p_{11} + p_{22}$.List the expressions for the determinant and trace of the Jacobian matrix corresponding to the equilibrium point based on the Jacobian matrix, as shown in Table 3.

Tab.3 Expression of determinant and trace of Jacobian matrix corresponding to equilibrium point

equilibrium	det J
E_1 (0, 0)	$\left[-H_1+L_1-k_1L_1+D_1\omega(\theta)\right]\left[L_2-H_2-k_2k_3L_1+D_2\omega(\theta)+k_2L_1+zB\right]$
E_2 (0, 1)	$-\left(-H_1+L_2+k_3L_1\right)\left[L_2-H_2-k_2k_3L_1+D_2\omega(\theta)+k_2L_1+zB\right]$
E_3 (1, 0)	$-\left[-H_1+L_1-k_1L_1+D_1\omega(\theta)\right]\left(k_1k_2L_1-H_2+zB\right)$
E_4 (1, 1)	$\left(-H_1+k_3L_1+L_2\right)\left(k_1k_2L_1-H_2+zB\right)$
E_5 (x_0, y_0)	--
equilibrium	tr J
E_1 (0, 0)	$\left[-H_1+L_1-k_1L_1+D_1\omega(\theta)\right]+\left[L_2-H_2-k_2k_3L_1+D_2\omega(\theta)+k_2L_1+zB\right]$
E_2 (0, 1)	$\left(-H_1+L_2+k_3L_1\right)-\left[L_2-H_2-k_2k_3L_1+D_2\omega(\theta)+k_2L_1+zB\right]$
E_3 (1, 0)	$-\left[-H_1+L_1-k_1L_1+D_1\omega(\theta)\right]+\left(k_1k_2L_1-H_2+zB\right)$
E_4 (1, 1)	$-\left(-H_1+k_3L_1+L_2\right)-\left(k_1k_2L_1-H_2+zB\right)$
E_5 (x_0, y_0)	--

(1) Stability analysis of point (0,0)

$$\begin{cases} H_1 > +\left(1-k_1\right)L_1+D_1\omega(\theta) \\ H_2 > L_2+\left(1-k_3\right)k_2L_1+D_2\omega(\theta)+zB \end{cases} \tag{17}$$

It is a unique stable point. At this time, local governments are conducting passive supervision, and fresh agricultural product retailers are adopting green behavior passively. The prospect value perception H_1 of the cost of adopting green behavior by retailers is greater than the sum of the prospect value perception of risk loss and the perceived value of brand reputation loss in the public image; The prospect value perception H_2 of local governments towards regulatory cost investment is greater than the prospect value perception of retailers being punished by local governments and the prospect value perception of retailer risk losses after risk transmission, the credibility loss value perception of local governments in the public image, and the sum of reputation losses publicly investigated by higher-level governments. Retailers have a high perception of the prospect value H_1 of the costs involved in adopting green behavior, so they are unwilling to actively adopt green behavior. The local government's perception of the prospect value H_2 of regulatory cost investment is too high, so they are unwilling to pay the cost for active regulation. This stable point appears in the early stages of the game and generally does not exhibit a Pareto optimal state at that point.

(2) Stability analysis of point (0,1)

$$\begin{cases} H_1 > k_3L_1+L_2 \\ L_2 > k_2L_1\left(k_3-1\right)+H_2-zB-D_2\omega(\theta) \end{cases} \tag{18}$$

It is a unique stable point. At this time, local governments are actively regulating and fresh agricultural product retailers

are passively adopting green behavior. The prospect value perception H_1 of the cost of adopting green behavior by retailers is greater than the sum of the prospect value perception of risk losses after risk transmission and the prospect value perception of losses punished by local governments. If H_1 is too large, retailers are still unwilling to pay the cost and actively adopt green behavior. However, local governments gradually increase their awareness of active supervision, and the system continues to evolve towards point (1,1).

(3) Stability analysis of point (1,0)

$$\begin{cases} H_2 > k_1 k_2 L_1 + zB \\ H_1 < L_1\left(1 - k_1\right) + D_2\omega(\theta) \end{cases} \tag{19}$$

It is a unique stable point. At this time, local governments are conducting passive supervision, while fresh agricultural product retailers are actively adopting green behavior. The prospect value perception H_2 of local governments towards regulatory cost investment is greater than the prospect value perception of risk losses after risk transmission and the sum of reputation losses publicly investigated by higher-level governments. The perception of the prospect value H_2 of regulatory cost investment by local governments is too large, so they are unwilling to pay for active regulation. After negative regulation by local governments, retailers have a mentality of luck, and their willingness to spontaneously adopt green behavior gradually weakens. The system continues to evolve towards point (1,1). The above evolutionary situation is not expected by the general public, but it is a necessary path for the development of fresh agricultural product retail enterprises.

(4) Stability analysis of point (1,1)

$$\begin{cases} H_1 < L_2 + k_3 L_1 \\ H_2 < k_1 k_2 L_1 + zB \end{cases} \tag{20}$$

It is a unique stable point. The only stable point is point (1,1), where local governments actively regulate and fresh agricultural product retailers actively adopt green behavior. The perceived value of the cost of actively adopting green behavior by fresh agricultural product retailers is less than the sum of the perceived value of government penalty losses and economic risk losses that the enterprise may face, i.e. $H_1<k_3L_1+L_2$. The prospect value perception of local governments towards regulatory cost investment is less than the sum of the prospect value perception of risk losses and reputation losses publicly investigated by higher-level governments, $H_2 < k_1 k_2 L_1 + zB$. This stage is the result of joint efforts between the government and retail enterprises, and also the final expected situation of model evolution. The cost investment of green technology shows effectiveness, the government department's reward and punishment system is reasonable, and the profits obtained by retail enterprises meet the expected value. At this point, the system reaches the Pareto optimal state.

(5) Stability Analysis of Single Agent and System Evolution

At that time, if $y_o = \dfrac{H_1 - D_1\omega(\theta) + \left(k_1 - 1\right)L_1}{L_2 - D_1\omega(\theta) + \left(k_3 + k_1 - 1\right)L_1}$, let F (x)=0, it indicates that all x are stable State.

Other times, let F (x)=0, solve for x=0 and x=1 is one of the two possible stable states. The dynamic phase diagram of game replication for fresh agricultural product snack merchants and enterprises is shown in Figure 2.

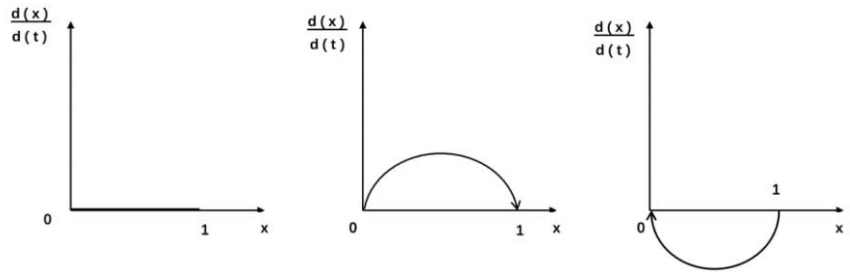


Fig.2 Dynamic phase diagram of game replication for fresh agricultural and snack merchants and enterprises

At that time, $x_o = \frac{H_2 - zB - L_2 + (k_3 - 1)k_1 k_2 - D_2\omega(\theta)}{k_2 L_1(k_1 + k_3 - 1) - D_2\omega(\theta) - L_2}$, let F (y)=0, indicating that all are stable states.

Other times,let F (y)=0, it can be concluded that y=0 and y=1 are two possible stable states. Similarly, when it comes to evolutionary stability strategies, $x > x_0$ 时， $y=1$， fresh agricultural product retailers tend to actively adopt green behavior, local governments will also choose active regulatory strategies, which will achieve Pareto optimality; When it comes to evolutionary stability strategies, $x < x_0$ 时， $y=0$， that is, fresh agricultural product retailers tend to passively adopt green behavior, local governments will also choose risk avoidance and negative regulatory strategies. The strategic choice of retailers largely depends on the strength of local government regulation, and local governments mainly make strategic choices based on their own interests and risk avoidance loss perception. If the perceived value of risk loss is too high, local governments may abandon this strategic choice. The dynamic phase diagram of local government game replication is shown in Figure3. The dynamic phase diagram of system game replication is shown in Figure 4.

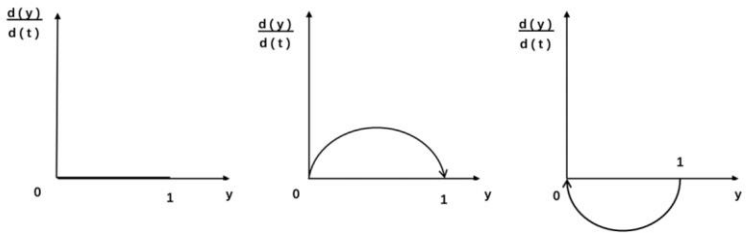
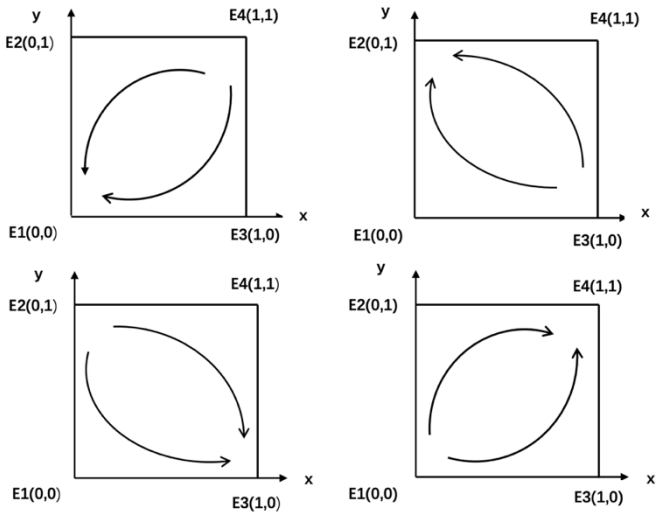


Fig.3 Dynamic phase diagram of local government game replication



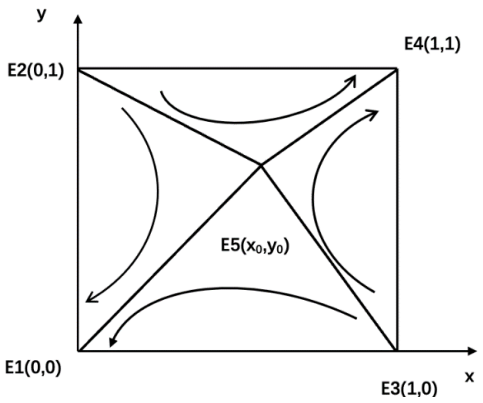


Fig.4 System game replication dynamic phase diagram

IV. Numerical simulation

4.1 Model initial conditions and parameter settings

This section uses Matlab2021 software to simulate the impact of parameter changes in the evolutionary game model of fresh agricultural products on system evolution by assigning values to each parameter.

Assuming that in the early stages of the game, the willingness of fresh agricultural product retailers to actively adopt green behavior is not strong, and the willingness of local governments to actively regulate is not strong, let the initial values of x and y be 0.2 and 0.2, respectively. As the system deduces that the enthusiasm of both parties gradually increases, but when retailers trigger a crisis of public trust, the government also needs to bear the corresponding risk of credibility decline and reputation loss caused by higher level government accountability. Let the initial value of the risk transmission coefficient k_2 between retailers and local governments be 1. At the same time, when fresh agricultural product retailers actively adopt green behavior, the cost loss coefficient k1 borne by both parties is smaller than the cost loss coefficient k_3 borne by both parties under active supervision by local governments. Let the initial value of k_1 be 0.4 and the initial value of k_3 be 0.6. In addition, the perceived value L_1 of the retailer's risk loss is greater than the perceived value L_2 of the retailer's penalty loss by the local government. Let L_1 have an initial value of 1 and L_2 have an initial value of 0.5. The prospect value perception H_1 of retailers actively adopting green behavior costs and the prospect value perception H_2 of local governments investing in regulatory costs are both 1. The initial value of the probability z of a public health incident being exposed by the media and investigated by the higher-level government due to negative regulation by a local government is 0.1, and the initial value of the reputation loss B of negative regulation by a local government being investigated by the higher-level government is 0.2. The initial values of the brand reputation loss D_1 for retailers in the public image and the credibility loss D_2 for local governments in the public image are both 1 and can increase infinitely between the intervals [1,20]. The initial value of public supervision is 0.1. To verify the validity of the parameter hypothesis, the dynamic evolution results of the system are shown in Figure 5. Among them, H_1=1, L_2=0.5, K_3=0.6, L_1=1, K_1=0.4, H_2=1, z=0.1, K_2=1, B=0.2, D_1=1, D_2=1, a=0.1.

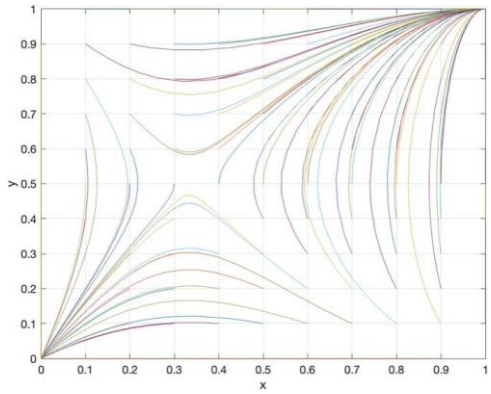


Fig.5 System Dynamic Evolution Diagram

4.2 Model simulation and result analysis

(1) The impact of changes in public supervision on the probability x of retailers actively adopting green behavior

Due to the inability to input parameters in Matlab 2021 software, a is used to represent in Figures 6. As shown in the figure, the critical value of public supervision is between 0.3 and 0.5. When it is greater than 0.5, x gradually converges to 1; Whenθ<0.5, x gradually converges towards 0; Specifically, whenθ>0.7, as the value increases, the convergence speed of x towards 1 also becomes faster. This indicates that an increase in value has a positive driving effect on fresh agricultural product retailers to actively adopt green behavior strategies. In practical situations, increasing public supervision is beneficial for retailers to actively invest in green technology.

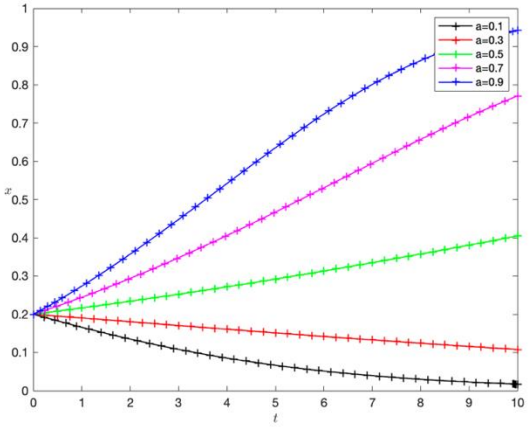


Fig.6 The impact of changes in public supervision intensity θ on the evolutionary results

(2) The impact of changes in public supervision on the probability y of active supervision by local governments

Due to the inability to input parameters in Matlab 2021 software, a is used to represent in Figures 7. As shown in the figure, the critical value of public supervision is between 0.3 and 0.5. When it is greater than 0.5, y gradually converges to 0; Whenθ<0.5, y gradually converges towards 1; Specifically, whenθ>0.7, as the value increases, the convergence speed of y towards 0 also becomes faster and faster; Even when the level of public supervision approaches 1, over time, y approaches 0. This indicates that an increase in value has a negative weakening effect on local governments adopting active regulatory strategies. In reality, as the public increasingly values the green operation and green technology investment of fresh agricultural product retailers in surrounding areas, the regulatory costs of local government departments will also decrease, and the willingness to actively regulate will decrease. Therefore, collaborative public

participation and increased public supervision can effectively reduce the regulatory costs of local governments.

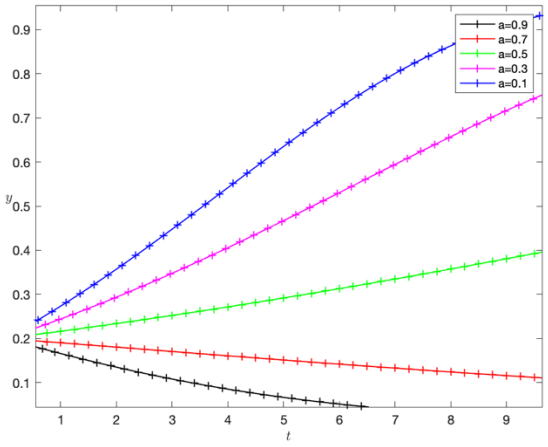


Fig.7 The impact of changes in public supervision intensity θ on the probability y of active supervision by local governments

(3) The Impact of Changes in the Probability x of Retailers Actively Adopting Green Behavior on Evolutionary Results

Due to the fact that the cost loss coefficient k_1 borne by both parties when fresh agricultural product retailers actively adopt green behavior is smaller than the cost loss coefficient k_3 borne by both parties under active supervision by local governments, it is assumed that the value of k_1 is always 0.4, the value of k_3 is always 0.6, the value of z is always 0.1, and the value of B is always 1. As shown in Figures 8, the critical value of the probability x of retailers actively adopting green behavior is between 0.8 and 0.95. When x>0.95, y gradually converges to 0; When x<0.95, y gradually converges towards 1; Specifically, when x<0.8, as the value of x decreases, the convergence speed of y towards 1 also becomes faster. This indicates that over time, the increasing probability x of retailers actively adopting green behavior weakens the probability y of government active regulation. In reality, this situation has formed a good social atmosphere, and the government does not need to spend time and effort taking measures to control retailers and enterprises to actively adopt green behavior.

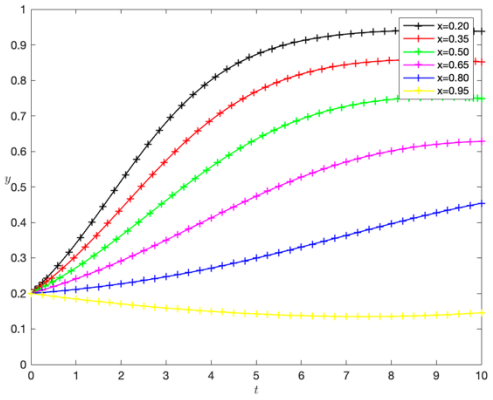


Fig.8 The Impact of Changes in the Probability x of Retailers Actively Adopting Green Behavior on Evolutionary Results

(4) The impact of changes in the probability y of active supervision by local governments on the evolutionary results

Due to the fact that the perceived value L_1 of the retailer's risk loss is greater than the perceived value L_2 of the retailer's penalty loss by the local government, let the value of L_1 remain constant at 1.1 and the value of L_2 remain constant at 1, while keeping the initial values of other parameters unchanged. As shown in Figures 9, the critical value of the probability of active supervision by local governments is around 0.2. When y>0.2, x gradually converges to 1; When y<0.2, x gradually converges towards 0. This indicates that over time, the increase in the probability of active supervision by local

governments has a positive impact on the probability of fresh agricultural product retailers actively adopting green behavior. In real-life situations, when local government regulation is strong, retail enterprises face the risk of being investigated and punished. They dare not rashly have a mentality of luck and can only actively adopt green behavior.

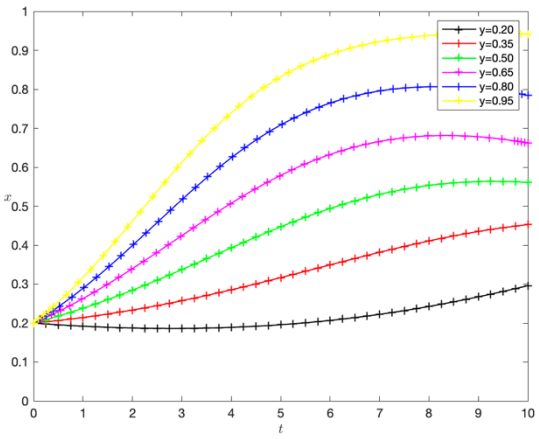


Fig.9 The impact of changes in the probability y of active supervision by local governments on the evolutionary results

(5) The Impact of Changes in Brand Reputation Loss D_1 of Retailers in Social Mass Image on Evolutionary Results

As shown in Figures 10, the critical value of brand reputation loss D_1 for retailers in terms of social image is around 4. When $D_1>4$, x gradually converges to 1; When $D_1<4$, x gradually converges towards 0; Specifically, when $D_1>7$, as the D_1 value increases, the convergence speed of x towards 1 also becomes faster. This indicates that an increase in D_1 value has a positive driving effect on the strategy choices of fresh agricultural product retailers to actively adopt green behavior. In real-life situations, retail enterprises attach great importance to the brand reputation value of their social image. Once they smash their own signs, their reputation is difficult to recover. Therefore, it is consistent with the results of case analysis. The increase in the brand reputation loss D_1 of retailers in social image has a positive promoting effect on their active adoption of green behavior strategies. Local governments can promote scientific knowledge on how to distinguish green agricultural products to the public through official media channels, thereby increasing the brand reputation loss D_1 value of retailers in social image.

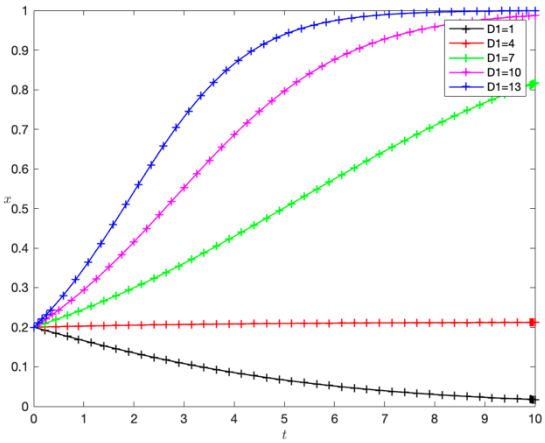


Fig.10 The Impact of Changes in Brand Reputation Loss D_1 of Retailers in Social Mass Image on Evolutionary Results

(6) The impact of changes in the credibility loss of local governments in the public image D_2 on the evolutionary results

As shown in Figures 11, the critical value of the credibility loss D_2 of local governments in the public image is around 4.

When D_2>4, y gradually converges to 1; When D_2<4, y gradually converges towards 0; Specifically, when D_2>7, as the D_2 value increases, the convergence speed of y towards 1 also becomes faster. This indicates that the increase in D_2 value has a positive promoting effect on the selection of active regulatory behavior strategies by local governments. In real-life situations, the government's service purpose is to "serve the people" and attaches great importance to its credibility in the hearts of the people. Once credibility is lost, it may lead to accountability from the higher-level government and inevitable social group events, which is consistent with the results of the case study analysis.

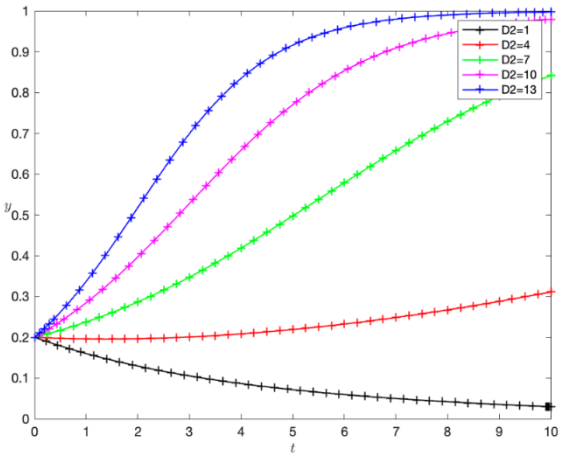


Fig.11 The impact of changes in the credibility loss of local governments in the public image D_2 on the evolutionary results

V. Conclusion and Outlook

5.1 Research conclusions and recommendations

The greening process of the fresh agricultural product market is a systematic project involving the government, supply chain enterprises, and consumers. Currently, supply chain enterprises often reduce their investment in green technology for profit reasons, and even adopt low-cost methods to sell products, posing risks to consumer health and safety. The government plays a crucial role in regulatory functions and needs to guide and supervise at various stages. This article provides an in-depth analysis of the aforementioned issues based on prospect theory and evolutionary game theory. We have successively constructed an evolutionary game model for the green behavior strategy of fresh agricultural product retailers considering higher-level government supervision, and an evolutionary game model for the green behavior strategy of fresh agricultural product retailers considering public participation supervision. And separately study the impact of changes in various influencing factors on the decision-making changes of stakeholders, and ultimately draw the following conclusions:

(1) Public participation in supervision has a promoting effect on the green behavior of fresh agricultural product retailers

The higher the intensity of public participation in supervision, the greater the probability that retail enterprises choose to actively adopt green behavior. When the supervision intensity is high, the public pays more attention to the green issue of agricultural products in the market, but consumers can only contact and supervise retailers. In the Internet era, consumers are active in various short video platforms, and everyone can break explosive news, causing public opinion. Therefore, the greater the perceived loss of brand image by retail enterprises, the more they give up short-term benefits and choose to invest in green technology for long-term sustainable development, which to some extent improves the quality of fresh agricultural products.

(2) There is substitutability between public supervision and local government regulation

When the intensity of public participation in supervision is higher, the probability of local governments choosing active supervision is smaller. There is a certain degree of substitutability between public supervision and local government supervision, which can play a substitute role in government functions. Even if local governments choose negative supervision without considering the probability of being investigated by higher-level governments and the loss of credibility in the public image, fresh agricultural product retailers will still choose to actively adopt green behavior under public supervision to gain consumer recognition and increase their brand influence. But when the intensity of public participation in supervision is lower, it is not enough to change the original strategic choices of local governments and retailers, that is, local governments passively regulate and fresh agricultural product retailers passively adopt green behavior. In real-life situations, local governments should fulfill their responsibilities and establish a good public image, actively and transparently accepting supervision from the public and the media.

(3) Increasing the supervision of higher-level governments can promote the implementation of evolutionary stability strategies

The probability of negative supervision by local governments leading to public health incidents being exposed by the media and investigated by higher-level governments is z and the reputation loss B of a local government that is investigated and dealt with by the superior government can be quantified as a parameter of the supervisory strength of the superior government towards the local government. The analysis of the example shows that an increase in the z-value has a positive driving effect on the active regulatory strategy selection of the local government. The local government values its reputation in the minds of the people and the recognition of the superior government. Therefore, even if there is a small probability of investigation and exposure, the local government is still willing to pay the cost for active supervision; The increase in B value also has a positive driving effect on the selection of active regulatory strategies by local governments. Local governments attach great importance to the recognition of their superiors, so the greater the reputation loss B, the higher the probability of local governments choosing active regulation. At the same time, as local governments gradually pay regulatory costs and actively regulate local fresh agricultural product retailers, the increasing probability of local government active supervision has a positive impact on the probability of fresh agricultural product retailers actively adopting green behavior. Therefore, increasing the supervision of higher-level governments can promote the implementation of evolutionary stability strategies.

(4) The implementation of stable strategies for the evolution of government and fresh agricultural product retailers requires certain conditions

When the public's participation in supervision is weak, the evolutionary results have randomness. The strategy choices for achieving Pareto optimality under different conditions are different. Both fresh agricultural product retailers and local governments belong to the risk preference type. Therefore, the stronger the public participation and supervision, the greater the promoting effect on system stability.

The above theoretical analysis and numerical examples provide good support for policy recommendations to promote the green development of the fresh agricultural product market.

(1) Strengthen the supervision of local governments

The central government often has more than enough effort to control people's livelihoods, and local governments often engage in a game of having a government at the top and countermeasures at the bottom when facing higher-level governments, resulting in an endless phenomenon of local laziness. Firstly, the higher-level government should avoid collusion between local governments and retail enterprises. In the game model, local governments are not only the actual regulatory authorities authorized by the central government, but also have their own perception of cost prospects, value, and considerations of gains and losses. Some lazy local governments choose to respond to the orders and assessments of higher-level governments like retail enterprises, and the losses will be the interests of the general public. The superior government should establish detailed performance evaluation mechanisms and irregular spot checks to avoid collusion as much as possible. Secondly, local governments should increase the punishment for enterprises that fail the spot check and timely release information through official media to attract public attention. Finally, local governments should quickly establish reporting channels, improve reward and punishment systems, and law enforcement and supervision systems, increase requirements for retail enterprises, trace information such as the origin and harvesting date of agricultural products as much as possible, change the perception of losses by fresh agricultural product retailers, and promote retailers to actively adopt green behavior as a strategic choice.

(2) Enhance the expected revenue perception of retailers actively adopting green behavior

The actual benefits of green behavior of fresh agricultural product retailers have a lag. Only when retailers have sufficient perceived benefits will they actively choose green behavior. Local governments should adopt diverse market regulation measures based on the local business environment to reduce the initial costs of retailers' green behavior and increase their expected perceived value of benefits. Firstly, the government provides positive incentives for the green behavior of other retail enterprises in the fresh agricultural product industry. Referring to the green tax support policies of developed countries such as Europe and America, and combining with the actual situation, formulate a series of targeted and innovative green investment management policies that are in line with national conditions, and continuously improve them. For example, through tax assistance policies to support leading enterprises in the fresh agricultural product retail industry to connect their own cold chain systems and green technology research and sales; Subsidizing retail enterprises that want to improve brand service quality through green technology investment through reward and subsidy policies; By promoting policies and providing green technology training to stimulate the enthusiasm of retailers, enterprises that adopt green behaviors have a greater competitive advantage in the fresh agricultural product market. Secondly, enhance the social awareness of green agricultural products. The concept of healthy and healthy green consumption is an important foundation for promoting retailers to actively adopt green behavior. Positive guidance from the consumer level can enhance the social responsibility of retailers, and pay attention to avoiding and cracking down on the phenomenon of "floating green marketing" that retailers develop to win public attention and deceive public trust. Finally, establish an open and transparent supervision and disclosure system to encourage retail enterprises to actively adopt green behavior for their own brand image.

(3) Enhance the enthusiasm of the public to participate in supervision

Under the dual pressure of insufficient subjective initiative of fresh agricultural product retailers and government laziness, strengthening public supervision can adjust the unfavorable situation. Game theory is a dynamic process, and rational enterprises generally pay more attention to their own reputation loss and brand image building. Local governments actively guide consumers to discover the rational disclosure of retailers' non green behaviors, strengthen the

establishment of public supervision and reporting platforms based on the Internet, form a good public supervision direction of fresh agricultural products market, reduce the cost of local government supervision, improve the revenue perception of retailers' risk losses, and achieve a win-win situation for consumers and the government.

(4) Enhance system collaboration capability

For higher-level and local governments, more dimensional supervision and assessment mechanisms should be established to fundamentally change their perception of losses and benefits from active supervision and their preference for lazy governance, and to prevent the occurrence of collusion between government and enterprises; For retail enterprises and local governments, dynamic regulation of reward and punishment measures should be adopted to regulate them, so that there is a huge difference in the perception of cost loss value and profit value of actively adopting green behavior processes among retail enterprises; For consumer groups and retail enterprises, the general public, as the direct beneficiaries of green investment, has a natural driving force for supervision and reporting. Local governments should actively introduce policies to reward and protect consumers who successfully participate in supervision. Therefore, through active regulation by higher-level governments, strong supervision by local governments, green technology investment and research and development by retail enterprises, and active participation by the public, a synergistic organic whole has been formed, promoting the system to reach Pareto optimality as soon as possible and promoting the greening process of the fresh agricultural product market.

5.2 Research Shortcomings and Prospects

Due to the limitations of subjective ability and objective conditions, this article has the following shortcomings:

(1) The research scope is insufficient. This article only considers the three stakeholders of government, consumers, and retailers in the evolutionary game model of green behavior strategies for fresh agricultural product retailers. However, in the fresh agricultural product supply chain system, fresh agricultural product supplier enterprises also play an important role in selecting green behavior strategies and promoting the greening process.

(2) Lack of specific research on reward and punishment mechanisms. In practical life, when stakeholders make strategic choices, the setting of reward and punishment mechanisms is the main consideration criterion for whether they consider active participation. In the future, targeted research on government reward and punishment mechanisms can be conducted in conjunction with other literature.

In the future, with the development of the dual channels of "online+offline" in the fresh agricultural product market, the circulation speed of fresh agricultural products will be greatly improved, and consumers will gradually increase their green requirements for agricultural products. In future research, other upstream and downstream enterprises in the fresh agricultural product supply chain field can be added to the game model one by one, considering how to transparently and efficiently promote green products into the consumer market, establishing an evolutionary game model, setting relevant parameters for green production and operation, and systematically analyzing the evolution mechanism of the entire fresh agricultural product green supply chain; At the same time, based on excellent cases of government regulatory departments in reality, specific assessment indicators and reward and punishment subsidy mechanisms are set up, and a legal and compliant public supervision and reporting channel is established. Experimental zones for different economic levels within 2-3 years are designated, during which government departments need to adjust and optimize the system at any time according to the implementation situation. After the system is mature and stable, it can be opened to the fresh agricultural product market nationwide. Scholars can analyze the effectiveness and feasibility of the regulatory system based on empirical cases. I believe that through the joint efforts of the government, consumers, and upstream and

downstream enterprises in the supply chain, a good atmosphere for the fresh agricultural product market can be created, and the system can reach a stable state as soon as possible.

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