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Original Research

Does the Chinese Government's System of Rewards and Punishments Encourage Farmers to Use Green Agricultural Technologies? Analysis Based on Three-Party Evolutionary Game

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Abstract

Increasing farmers' willingness to adopt green technologies is an important precondition for driving agricultural modes of production to adjust and achieve green development in agriculture. However, their willingness to adopt green technologies is influenced by their own government and consumer behavior. Based on the assumption of bounded rationality, this paper constructs a dynamic evolutionary game model among farmers, government, and consumers and analyzes the optimal stability strategy. The influence of the change in adoption intention from weak to strong on the choice of optima government behavior is investigated by numerical simulation. The results show that there is an evolutionarily stable strategy combination (farmer adoption, government intervention, consumer purchase) under the premise of controlling the government subsidy. The effect of consumers' willingness to consume on farmers' green adoption is greater than that of the government's intervention. The larger the proportion for farmers' green income distribution, the higher the enthusiasm for farmers' green production. Government subsidies are more suitable for low-willing farmers. When the willingness of farmers increases, the role of government fines becomes greater than subsidies. Therefore, the government should strengthen the quality supervision and publicity of green products, set up a service platform to smooth the channels of production and marketing, and at the same time make appropriate use of subsidies, fines, and other policies.

Keywords: Green technology adoption, government action, consumer willingness, tripartite evolutionary game, simulation analysis

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Introduction

Compared with the developed countries in the west, China's green agriculture started relatively late. In recent years, China has gradually attached importance to the development of the environment and has drawn a bright future of harmonious coexistence between man and nature. This concept further puts forward more extensive new requirements for the green development of agriculture in the new era. As the primary industry, agriculture is the basis of our people's survival and is an important industry related to national survival and development. Traditional agricultural modes of production, which are low in technology and low in mechanization, result in inefficient agricultural production, reduce the competitiveness of China's agricultural products, and waste water and land resources, limiting the development of modern agriculture in our country [1]. At the same time, the supply of green agricultural products on the market cannot meet the demand of consumers, which leads to the price fluctuation of green agricultural products [2]. This reduces their market competitiveness [3]. The adoption behavior of farmers' green production technology directly affects the extension effect of agricultural green production technology and the development of green agriculture in our country. But at present, Chinese agriculture is in a critical period of transition, and traditional agricultural modes of production are severely restricting the green development of agriculture. Facing the dual pressure of resources and environment, as well as the demand for green consumption, to promote the green development of China's agriculture, we must break the dilemma of traditional agricultural production.

Promoting the development of green agriculture is the only way to realize the high-quality development of agriculture and rural areas. At present, household production is the main form of agricultural production in our country, so the key to promoting green production in agriculture is to change the production behavior of farmers from extensive production to intensive green modes of production [4]. In the current era, the effective use of green agricultural production technologies to promote the transformation and upgrading of agricultural industry development [5] is an important way to promote green agricultural development [6]. At present, the majority of our farmers are adopting traditional modes of production because they are less willing to adopt green agricultural production technologies. Therefore, in order to popularize agricultural green production technology, improve farmers' willingness to adopt it, and realize agricultural green development, it is necessary to carry out research on the willingness to adopt agricultural green technology.

Literature Review

Green agricultural production technology refers to a series of environment-friendly and efficient tools and technologies used in the agricultural production process to protect the ecological environment and promote sustainable agricultural development. For example, soil testing formula technology, green pest control technology, and water and fertilizer integration technology [7]. The promotion of agricultural green production technology is an effective way to promote agricultural green development, and the willingness of farmers to adopt it is influenced by various factors.

First of all, farmers' willingness to adopt agricultural green production technology will be affected by their own conditions. Economic benefit is the basic starting point of farmers' production and management activities [8]. This profit-seeking has led to farmers generally paying more attention to economic benefits than to environmental and ecological benefits, so if farmers are to take the initiative to adopt Green Production Technologies, at the very least, the interests of farmers after green production should be protected [9]. At the same time, farmers' individual educational level, environmental awareness [10], and family characteristics [11] also affect to a certain extent their willingness to adopt green production technologies [12]. Other researchers have found that the scale of farming also has an impact on the adoption of agricultural green technology [7].

Second, government intervention is necessary to promote the adoption of green production technologies by farmers [13]. By providing subsidies to reduce the costs and increase the income of farmers who use green production technologies, the government can increase the motivation of farmers to adopt green production technologies from the point of view of their behavior [14]. At the same time, the government's incentive policy can promote the green production of farmers using appropriate policy incentives, improve the factor market, and promote the optimization and upgrading of green production in agriculture [15]. At the same time, farmers' adoption of agricultural green production technologies is influenced by government advocacy and policies [16]. In addition to the above-mentioned positive government intervention, some scholars believe that the government's punitive measures can help the main body reach an ideal state of evolutionary stability [17]. Different types of government behavior can significantly promote green technology innovation, and it should play its role well, improve the policy system, and make rational use of punishment and incentive measures [18]. Huang et al. [19] found that the combination of government supervision and subsidies could promote the green production of peach farmers. From the analysis of function distribution among different levels of government, Du et al. [20] believe that the government's extra incentives and punishments play a key role in the spread of green agricultural production. Xu et al. [21]

proposed that the central government should strengthen the reward amount to the local government, so as to realize coordinated governance among multi-subjects, Luo et al. [22]. The study found that appropriate government subsidy policies are conducive to promoting green production among farmers.

Finally, as consumers are buyers of green products and beneficiaries of the social environment, farmers' willingness to engage in green production is positively influenced by consumers' green consumption preferences [23]. In the process of adopting green production technology and promoting agricultural green development, farmers should fully consider the influence of consumers. Consumers' green consumption consciousness is an important means to achieve green development and an important factor to influence green development [24].

To sum up, the existing research, more from a static perspective, the development of the status quo for green technology adoption, subject participation, and internal relations of interest to carry out theoretical research, provides a solid theoretical basis. However, the development of agricultural green production is a dynamic evolutionary process, and there are still the following aspects worth further exploration: 1. Under the premise of different demands from farmers, consumers, and the government, will a stable strategy for promoting agricultural green production be formed? 2. When farmers' willingness to adopt green technology evolves from weak to strong, will the government's optimal intervention behavior remain unchanged? 3. In the process of promoting green production and consumption, the government should formulate and adjust its intervention policies in time so as to achieve a stable state of green production and green consumption for farmers and consumers.

This paper mainly has the following contributions:

(1) In the research angle, the existing research on agricultural green technology adoption is more from a static angle; this paper constructs a three-party evolutionary game model of farmers, government, and consumers from a dynamic perspective.

(2) In terms of research methods, many studies focus on the relationship between government and farmers and farmers and consumers. Therefore, on the basis of the former study, this paper will combine the three pieces of research.

(3) In terms of research contents, this paper explains the optimal behavior choice of the government in the process of the dynamic change of such parameters as farmers' green production will and consumers' green consumption will. This paper puts forward some countermeasures and suggestions for the government to make an intervention policy in time.

Evolutionary Game Analysis

Problem Description

Based on the above analysis, the main stakeholders to promote the promotion and adoption of agricultural green production technologies are farmers, governments, and consumers, and the logical diagram is shown below. Promoting agricultural green production is a process in which farmers, governments, and consumers participate in coordination. It is necessary for farmers, governments, and consumers to reach a tripartite agreement to promote the adoption of agricultural green production technology.

Farmers: as the main body of agricultural production, the use of green production technology for agricultural green development is very important, but for farmers, whether they choose to adopt green production technology depends on economic benefits. Farmers decide whether to adopt green production technologies based on external incentives, regulatory policies, service acceptance, the cost of green production, and market purchasing power [25]. However, in the early stages of green production, the use of green production technologies does not bring immediate benefits to farmers and may lead to a decline rather than an increase in income [26]. At the same time, insufficient funds and a lack of knowledge and awareness of green production technologies [27] have, to some extent, discouraged farmers from pursuing green production.

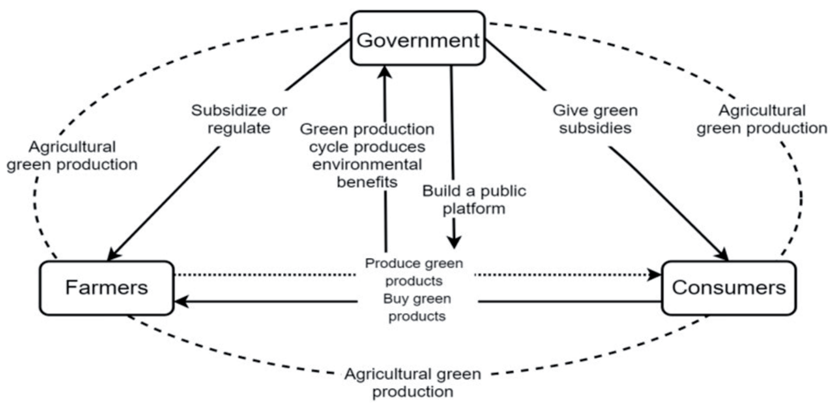

Fig. 1. The logical relationship diagram of the evolutionary game among farmers, government, and consumers.

Government: The government plays a key role in the three-party game. In order to promote and expand the adoption of green agricultural production technology, government behavior is extremely important. There are three main policy options for the government to promote green agricultural production: First, it is possible to provide incentives and subsidies to farmers who adopt green production technologies to reduce production costs and stimulate their active green production [28]. Farmers who violate agricultural green production may also be fined and urged to passively accept green production [29]. Second, for consumers, it is possible to provide both green agricultural product publicity services and Green Standard appraisal services to stimulate their active green consumption and to provide green agricultural product consumption subsidies to promote their passive green consumption [30]. Third, strengthen public services, unblock the production and marketing channels of green agricultural products, and build a service platform.

Consumers: consumers are buyers of green agricultural products, and their choice to buy green agricultural products is influenced by the pursuit of Utility maximization problem, but in practice is also subject to external environmental constraints. When buying agricultural products, consumers first consider the price, and if the price of certain agricultural products is higher, they may choose to buy similar products [31]. Secondly, the safety of the green consumption market is also a concern for consumers, and farmers' "free rider" behavior may affect consumers' willingness to buy green agricultural products [32].

Model Assumption

Based on the above situation, this paper selects the government, farmers, and consumers as the main players and establishes a three-party dynamic evolution game model. But before that, the basic model assumes the following:

Assumption 1: Participant and behavioral strategy. Based on the hypothesis of trilateral bounded rationality, this paper constructs a trilateral dynamic evolutionary game model consisting of farmers, government, and consumers and analyzes its behavioral strategies. The three sides have two strategic choices, namely, the evolutionary stability strategy of farmers is (adopt, on-adopt), the probability of farmers choosing green production technology is x, and the probability of choosing non-adopt Green Production Technology is $1-x$. The government's evolutionary stabilization strategy (intervention, non-intervention) divides government intervention into technology innovation incentives or pollution taxes, subsidies for consumers to buy green agricultural products, and public service platforms. If the probability of intervention is y, the probability of the government choosing not to intervene is $1-y$. The evolutionary stable strategy of consumers is (buy,non-buy). The probability of consumers buying green agricultural products is z, and the probability of consumers not buying green agricultural products is $1-z$. All three parties have bounded rationality and will change their strategic choices according to the choices of other subjects.

Assumption 2: cost. The adoption of green production technology requires higher costs. The cost of adopting agricultural green production technology for farmers (innovation cost) is Ca, and when farmers do not adopt green production technology, it is necessary to pay a fine for the resulting pollution, set as γK. Government participation in the green agricultural production process will provide subsidies to the proportion of farmers who adopt green production technologies and consumers who buy green agricultural products, so the total amount of subsidies is set at S. Among them, the subsidy distribution coefficient of the farmers who adopt green production technology is β, and the subsidy distribution coefficient of the consumers who buy green agricultural products is $(1-\beta)$. At the same time, if farmers do not adopt green production technology, there will be some environmental losses, set as Sg. Consumers also need to pay more for green produce, set as Cp, where the extra costs are divided between farmers and the government in a ratio of α for farmers and $(1-\alpha)$ for the government.

Assumption 3: Revenue scenario. When farmers do not adopt green production technology, their original income is set as P, and the incremental income generated by farmers after green production is set as αCp. The adoption of green production technology makes the environment better, and the environmental benefit generated is set as Ps. The original income obtained by consumers from purchasing non-green products is set as Pc, and the incremental income obtained by consumers after purchasing green agricultural products is set as b.

Assumption 4: In the case of farmers' green production, government intervention, and consumers' purchases of green products, economic development; and social development can be promoted, and the benefits to all three parties are set as A.

Assumption 5: The economic man hypothesis. The hypothesis of economic man means that everyone aims to maximize their own interests, and everyone engaged in economic activities is self-interested and always wants to obtain the maximum economic benefits with the minimum economic cost. Based on this, the purpose of farmers is to maximize their own economic benefits, the purpose of government intervention is to maximize social and environmental benefits, and the purpose of consumers is to maximize consumption utility. So set $b-Cp>0$, $Ca-\alpha Cp-\beta S-\gamma K-A<0$, $\alpha Cp-Ca<0$.

Based on the above assumptions, the strategy combination of the three-party dynamic evolutionary game model is shown in Table 2, where the detailed parameter settings and their descriptions are shown in Table 1.

Table 1. Description of model variables.

Variable	Definition
Ca	Costs incurred by farmers implementing green technologies (innovation costs)
γK	A tax imposed by the government on farmers for pollution
S	Subsidies provided by the government to participate in green agricultural production
β	The share of government subsidies allocated to farmers
$1-\beta$	The share of government subsidies allocated to consumers
Sg	The environmental loss caused by farmers not adopting green production technology
Cp	The extra cost that consumers spend to buy green products
αCp	The incremental benefit of farmers choosing green production depends on the extra cost that consumers are willing to pay for green agricultural products
$(1-\alpha)Cp$	The extra cost paid by consumers to buy green agricultural products flows to the market and generates tax revenue for the government through reproduction
P	Farmers do not implement the original benefits of green technology
Ps	Environmental benefits of implementing green technologies
Pc	The original income that consumers get from buying non-green products
b	Incremental utility of consumers buying green products
A	When the government intervenes, farmers adopt green technologies, and consumers buy green products, economic development and social progress can be promoted, thus bringing benefits to all three parties

Table 2. Game strategy combination of farmers, government, and consumers.

Consumer	Government	Farmers	
		Adopt (*x*)	Non-adopt (*1-x*)
Buy (z)	Intervention (*y*)	(F1,G1,P1)	(F5,G5,P5)
	Non-intervention (*1-y*)	(F2,G2,P2)	(F6,G6,P6)
Non-buy (*1-z*)	Intervention (*y*)	(F3,G3,P3)	(F7,G7,P7)
	Non-intervention (*1-y*)	(F4,G4,P4)	(F8,G8,P8)

Table 3. Game profit value of government, farmers, and consumers.

Strategy	Government	Farmers	Consumer
(F1,G1,P1)	$Ps-S+A+(1-\alpha)Cp$	$P+\alpha Cp+\beta S-Ca+A$	$Pc+b-Cp+A+(1-\beta)S$
(F2,G2,P2)	$Ps+(1-\alpha)Cp$	$P+\alpha Cp-Ca$	$b-Cp+Pc$
(F3,G3,P3)	$Ps-\beta S$	$P+\beta S-Ca$	Pc
(F4,G4,P4)	Ps	$P-Ca$	Pc
(F5,G5,P5)	$\gamma K-Sg-(1-\beta)S+(1-\alpha)Cp$	$P-\gamma K$	$b-Cp+(1-\beta)S+Pc$
(F6,G6,P6)	$-Sg+(1-\alpha)Cp$	P	$b-Cp+Pc$
(F7,G7,P7)	$\gamma K-Sg$	$P-\gamma K$	Pc
(F8,G8,P8)	$-Sg$	P	Pc

According to the basic assumption, the corresponding income matrix of government, farmer, and consumer is shown in Table 3.

Model Construction

The Replication Dynamic Equation of Farmer Strategy Selection

In agricultural production, the expected return of farmers adopting green production technology is E_{11}, the expected return of farmers not adopting green production technology is E_{12}, and the average expected return is E_1.

$$\begin{aligned} E_{11} &= yz\left(P+\alpha Cp+\beta S-Ca+A\right)+\left(1-y\right)z(P+\alpha Cp-Ca) \\ &+y(1-z)(P+\beta S-Ca)+(1-y)(1-z)(P-Ca) \\ &= P+z\alpha Cp+y\beta S-Ca+yzA \end{aligned} \tag{1}$$

$$\begin{aligned} E_{12} &= yz\left(P-\gamma K\right)+\left(1-y\right)zP+y\left(1-z\right)\left(P-\gamma K\right) \\ &+\left(1-y\right)\left(1-z\right)P \end{aligned} \tag{2}$$

$$\begin{aligned} E_1 &= xE_{11}+(1-x)E_{12} = P+x(z\alpha Cp-Ca+y\beta S \\ &+yzA)-(1-x)y\gamma K \end{aligned} \tag{3}$$

The replication dynamic equation of farmers' strategy selection is as follows:

$$\begin{aligned} F(x) &= dx/dt = x\left(E_{11}-E_1\right)=x\left(1-x\right)\left(z\alpha Cp\right. \\ &\left.+y\beta S-Ca+yzA+y\gamma K\right) \end{aligned} \tag{4}$$

The Replication Dynamic Equation of Government Policy Selection

Suppose that the expected return of government intervention in the green production process is E_{21}, the expected return of no intervention is E_{22}, and the average expected return is E_2.

$$\begin{aligned} E_{21} &= xz[Ps-S+A+(1-\alpha)Cp]+x(1-z)(Ps-\beta S) \\ &+(1-x)z[\gamma K-Sg-(1-\beta)S+(1-\alpha)Cp]+(1-x)(1-z)(\gamma K-Sg) \\ &= xPs+xzA+\left(1-x\right)\gamma K-\left(1-x\right)Sg-zS+\left(z-x\right)\beta S+z\left(1-\alpha\right)Cp \end{aligned} \tag{5}$$

$$\begin{aligned} E_{22} &= xz\left[Ps+\left(1-\alpha\right)Cp\right]+x\left(1-z\right)Ps \\ &+\left(1-x\right)z\left[-Sg+\left(1-\alpha\right)Cp\right]+\left(1-x\right)\left(1-z\right)(-Sg) \\ &= xPs+z\left(1-\alpha\right)Cp-\left(1-x\right)Sg \end{aligned} \tag{6}$$

$$\begin{aligned} E_2 &= yE_{21}+\left(1-y\right)E_{22} \\ &= xPs+z\left(1-\alpha\right)Cp-\left(1-x\right)Sg+y\left[xzA+\left(1-x\right)\gamma K\right. \\ &\left.-zS+\left(z-x\right)\beta S\right] \end{aligned} \tag{7}$$

The above equation can be obtained as the government's replication dynamic equation:

$$\begin{aligned} F(y) &= dy/dt = y\left(E_{21}-E_2\right)=y(1-y)[zxA \\ &+(1-x)\gamma K-zS+(z-x)\beta S] \end{aligned} \tag{8}$$

The Replication Dynamic Equation of Consumer Strategy Choice

Suppose that the expected return of consumers who choose to buy green products is E_{31}, the expected return of consumers who do not buy green products is E_{32}, and the average expected return is E_3.

$$\begin{aligned} E_{31} &= xy[Pc+b-Cp+A+(1-\beta)S]+x(1-y)(Pc+b-Cp) \\ &+y(1-x)[b+(1-\beta)S-Cp+Pc]+(1-x)(1-y)(b-Cp+Pc) \\ &= Pc+b-Cp+y(1-\beta)S+xyA \end{aligned} \tag{9}$$

$$E_{32} = Pc \tag{10}$$

$$\begin{aligned} E_3 &= zE_{31}+\left(1-z\right)E_{32} = Pc+z\left[b-Cp\right. \\ &\left.+y\left(1-\beta\right)S+xyA\right] \end{aligned} \tag{11}$$

The replication dynamic equation of consumer strategy selection is as follows:

$$\begin{aligned} F(z) &= dz/dt = z\left(E_{31}-E_3\right)=z(1-z)\left[b-Cp\right. \\ &\left.+y(1-\beta)S+xyA\right] \end{aligned} \tag{12}$$

Analysis of an Optimal Stability Strategy for Tripartite Evolutionary Game Systems

According to the method proposed by Friedman [33], the stability of the equilibrium point of the system can be analyzed by using the differential equation. The Jacobian matrix of the system is shown as follows:

$$J=\begin{pmatrix}\frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z}\\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z}\\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z}\end{pmatrix}$$

The Jacobian matrix of the tripartite evolutionary game system is obtained by calculation as follows:

$$J=\begin{pmatrix}(1-2x)(z\alpha Cp-Ca+y\beta S+yzA+y\gamma K) & x(1-x)(\beta S+\gamma K+zA) & x(1-x)(\alpha Cp+yA)\\ y(1-y)(zA-\beta S-\gamma K) & (1-2y)\left[xzA-zS+(z-x)\beta S+(1-x)\gamma K\right] & y(1-y)(xA-S+\beta S)\\ z(1-z)yA & z(1-z)\left[(1-\beta)S+xA\right] & (1-2z)\left[b-Cp+y(1-\beta)S-xyA)\right]\end{pmatrix}$$

Based on the analysis of the strategic stability of a single player, the equilibrium point of the three-player evolutionary game system is further analyzed, and the equilibrium point of the system is solved from $F(x) = F(y) = F(z) = 0$. Since the asymmetric game requires that the evolutionarily stable strategy be a strict Nash equilibrium, the only the stability of E1(0,0,0), E2(0,1,0), E3(1,0,0), E4(0,0,1), E5(1,1,0), E6(0,1,1), E7(1,0,1), and E8(1,1,1) are discussed. The following first analyzes the case where the equilibrium point is E1(0,0,0), and the Jacobian matrix is:

$$J1=\begin{bmatrix}-Ca & 0 & 0\\ 0 & \gamma K & 0\\ 0 & 0 & b-Cp\end{bmatrix}$$

It can be concluded that the eigenvalues of the Jacobian matrix are respectively $\lambda_1 = -Ca$, $\lambda_2 = \gamma K$, $\lambda_3 = b - Cp$ and so on, and then the corresponding eigenvalues of the Jacobian matrix can be calculated by bringing the remaining 7 equilibrium points into the Jacobian matrix of the above-mentioned three-player evolutionary game system, as shown in Table 4.

According to Lyapunov's first method, if all the eigenvalues of the Jacobian matrix are negative real parts, that is, the determinant of the matrix is greater than 0 and the trace is less than 0, then the equilibrium point is an evaluatively stable strategy (ESS) of the evolutionary game system; otherwise, it is an unstable point. The results of the asymptotic stability of 8 pure strategy equilibrium points can be seen in Table 5.

According to the judgment results in Table 5, two possible equilibrium points are analyzed, and cases 1 and 2 are obtained, respectively.

Scenario 1: According to the model hypothesis, when $\beta s+\gamma K-S<0$ is $\gamma K<(1-\beta)S$, at this time, it can be seen from Table 5 that the eigenvalues of the Jacobian matrix corresponding to the equilibrium point E4(0,0,1) are all negative. In this case, the system has a stable point (0,0,1), and its corresponding evolutionary strategy is (non-adoption, non-intervention, buy).

As can be seen from scenario 1, when the penalty levied by the government is lower than the subsidy given by the government to consumers, farmers will not choose to adopt green production technology because the low penalty is not enough to affect the overall interests of farmers. Because consumers get certain subsidies when they buy green agricultural products, they will increase their purchase intention, so their choice tends to be to buy. From the perspective of the government, the fines received may not be enough

Table 4. Eigenvalues of equilibrium points of the Jacobian matrix.

Equalization point	Eigenvalue λ_1	Eigenvalue λ_2	Eigenvalue λ_3
E1(0,0,0)	$-Ca$	γK	$b-Cp$
E2(0,1,0)	$\beta S+\gamma K-Ca$	$-\gamma K$	$(1-\beta)S+b-Cp$
E3(1,0,0)	Ca	$-\beta S$	$b-Cp$
E4(0,0,1)	$\alpha Cp-Ca$	$\beta S+\gamma K-S$	$Cp-b$
E5(1,1,0)	$Ca-\beta S-\gamma K$	βS	$(1-\beta)S+b-Cp+A$
E6(0,1,1)	$\beta S+\gamma K-Ca+\alpha Cp+A$	$(1-\beta)S-\gamma K$	$Cp-b-(1-\beta)S$
E7(1,0,1)	$Ca-\alpha Cp$	$A-S$	$Cp-b$
E8(1,1,1)	$Ca-\alpha Cp-\beta S-\gamma k-A$	$S-A$	$Cp-b-(1-\beta)S-A$

Table 5. Local stability of equilibrium points[1].

Equalization point	Eigenvalue λ_1	Eigenvalue λ_2	Eigenvalue λ_3	Stability	Conditions
E1(0,0,0)	-	+	+	Unstable point	
E2(0,1,0)	*	-	+	Unstable point	
E3(1,0,0)	+	-	+	Unstable point	
E4(0,0,1)	-	*	-	ESS	$\beta s+\gamma K-S<0$
E5(1,1,0)	*	+	+	Unstable point	
E6(0,1,1)	+	*	-	Unstable point	
E7(1,0,1)	+	*	-	Unstable point	
E8(1,1,1)	-	*	-	ESS	a

to cover the subsidies they give to consumers. Therefore, farmers cannot be effectively encouraged to adopt green production technology and government actions, and the system is difficult to evolve into a stable and balanced state of cooperation among farmers, government, and consumers.

Case 2: When $Ca-\alpha Cp-\beta S-\gamma K-A<0$ and $S-A<0$, it can be seen from the above table that the eigenvalues of the Jacobian matrix corresponding to the equilibrium point E8(1,1,1) are all non-positive, then the system in this case has a stable point (1,1,1), and its corresponding evolutionary strategy is (adopt, intervene, buy).

As can be seen from scenario 2, first, when the cost of farmers adopting green production technology is lower than the income after adoption and the total amount of subsidies provided by the government is lower than the common benefits when the three parties all act, farmers will be motivated to adopt green production technology under the strong supervision of the government, complete the sales, and obtain more income. Second, through green production, farmers can produce high-quality green agricultural products to meet consumers' green purchasing needs and improve environmental pollution and environmental damage to improve consumers' support and trust in the government. Third, ensuring government subsidies is the key to promoting the adoption of green production technologies by farmers to achieve tripartite cooperation. The government should increase the green subsidies provided to farmers and consumers, effectively reduce the cost to farmers and consumers, and at the same time stabilize the market, ensure the fairness of the consumer market, and finally achieve a stable and balanced state of tripartite cooperation.

[1] * symbol is unknown. Condition a is $Ca-\alpha Cp-\beta S-\gamma K-A<0$ and $S-A<0$

Simulation Analysis

The mathematical derivation of the system model only from the theoretical level cannot directly reflect the influence of the change in parameters on the evolutionary stability of the system. Therefore, numerical simulation analysis was conducted using Matlab2022a to analyze the impact of the initial intentions of the three party game players and important parameters in the replication dynamic equation system on the evolution of behavioral strategies of farmers, governments, and consumers. Referring to related papers, combined with the stability analysis of the equilibrium point of a three-party dynamic evolutionary game system, the data published in the National Statistical Yearbook and the multi-subject questionnaire and field survey on green agricultural production in Hebei province were analyzed and preprocessed. The initial values of the relevant variables are thus determined, as shown in Table 6.

The Influence of Initial Intention Change in Tripartite Subjects on System Evolution

Referring to Luo et al. [22] and Jin [34] for the system parameters setting method, the initial willingness of farmers to adopt green technology for production, the government to promote green production, and consumers to buy green products is set into three levels: low, medium, and high, that is, $x, y, z \in \Omega(0.2, 0.5, 0.8)$. The results of behavioral strategy evolution are shown in Figs 1 to 3. At the same time, to ensure that the parameter settings are complete, this section analyzes the settings.

Influence on the Evolution of Farmer Behavior Strategies

It can be seen from Fig. 2. that consumers' willingness to purchase green agricultural products and the intensity of government supervision on green production

Table 6. Definitions and values of related variables.

Variable	Definition and value	Variable	Definition and value
γK	The government imposes a tax of 30 on pollution caused by farmers' failure to adopt green production	S	The total amount of subsidies provided by the government to promote green production is 50
Ca	When farmers choose green production, the new cost is 40	Ps	When farmers adopt green technology, the environmental benefit that the government can get is 30
b	The incremental utility obtained by consumers buying green products is 40	Cp	The added cost for consumers to buy green products is 30
P	The original income of farmers who do not implement green technology is 30	Sg	When farmers do not carry out green production, the environmental loss suffered by the government is 20
Pc	The original income obtained by consumers from purchasing non-green products is 10	A	If the government acts, farmers adopt green technology, and consumers buy green products, economic development and social development progress can be promoted, and the benefits to the three parties are 60

will not change the evolution direction of farmers' behavioral strategies, but will change the evolution speed of farmers' adoption of green technologies. The stronger the initial willingness of farmers to adopt green technology is, the faster x eventually tends to 1. As shown in Fig. 2a), the improvement of government supervision intensity will significantly accelerate the evolution rate of green technology adoption by farmers. Moreover, the lower the initial willingness of farmers to adopt green technology, the more obvious the acceleration effect of government regulation is. If the intensity of government supervision is greater, the speed of farmers' final convergence to 1 will be faster. However, when the intensity of government supervision is low (y = 0.2), the evolution process will experience a process of first decreasing and then increasing. As shown in Fig. 2b), with an increase in consumers' initial willingness to choose and purchase green agricultural products, the evolution rate of farmers' adoption of green technology is gradually accelerating. From the comparative analysis of Figs. 2a) and 2b), it can be seen that the evolution time of the change in consumers' willingness to improve farmers' willingness is shorter than the impact of government regulation.

Conclusion: Both government regulation and consumer willingness can improve farmers' green adoption willingness, especially when farmers' initial willingness is low. The more effective the two behaviors are, and the positive impact of consumer green consumption on producers is greater than the impact of government regulation.

Influence on the Evolution of Government Behavior Strategy

As can be seen from Fig. 3, the initial willingness of consumers to buy green agricultural products and farmers to adopt green production technologies will

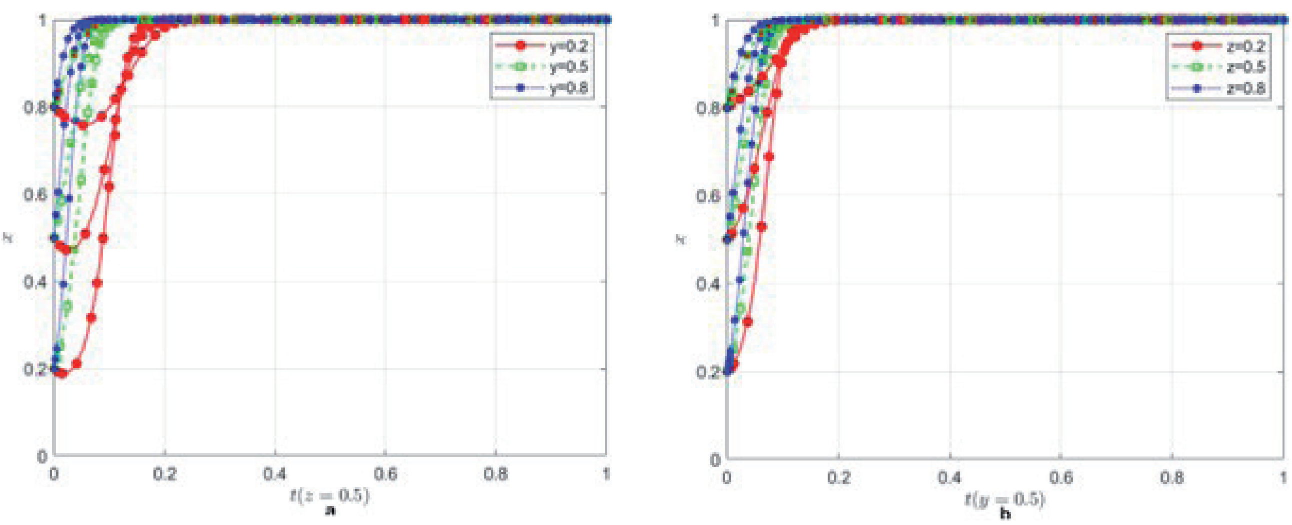

Fig. 2. Evolution trajectory of farmers' behavioral strategies under different initial intention levels of subjects.

not change the evolution direction of the government's regulatory behavior strategy, but will affect the evolution speed of the government's regulatory behavior strategy, and the government's decision will eventually tend to 1. With the increase in the initial willingness of the government to promote green production, the intensity of the influence of farmers and consumers on the evolution of the government's behavioral strategy decreases. However, compared with Figs. 3a) and 3b), consumers' initial willingness to buy green agricultural products and farmers' initial willingness to adopt green products have different influences on the evolution speed of government regulatory selection strategies. As shown in Fig. 3a), when the initial intention of government regulation is high ($y \geq 0.5$), with the continuous improvement of the initial intention of consumers, the evolution of the government's behavioral strategy is rapidly approaching 1, and the evolution speed is significantly higher than that of the initial intention of government regulation is low ($y = 0.2$). At this time, the government's strategy selection will fall back to the early stages of evolution and then rise. Compared with Fig. 3a), the change in Fig. 3b) is more obvious. When the government's intention to intervene in green production is low ($y = 0.2$), with the increase in farmers' willingness to adopt agricultural green production technology, the evolution rate is slow. When $t = 0.5$, their strategy choice has not completed the evolution. At the same time, when the initial willingness of the government and farmers is high, the evolution of the government's strategy first decreases slightly in the early stages, and then increases. In Fig. 3b, when the initial will of the government is unchanged, the evolution speed of farmers with a low initial will is faster than that with a high initial will, because when the initial will of farmers is low, the government needs to provide fewer subsidies and receive more fines. To sum up, changes in the will of farmers and consumers can only slightly accelerate or delay the evolution of the government's behavioral strategy.

Conclusion: Both farmers' green adoption intention and consumers' green purchase intention are conducive to improving government supervision intention. However, the government has a strong leadership role, and its final decision is less influenced by farmers and consumers. When the government is at a low level of initial willingness, the effect of consumer choice willingness on government behavior is greater than that of farmers.

Influence on the Evolution of Consumer Behavior Strategies

As can be seen from Fig. 4., the initial willingness of the government to promote agricultural green production and the choice of farmers to adopt green production technology will not change the evolution direction of consumers' behavioral strategies, but will affect their evolution speed. Specifically, when the initial willingness of the government to intervene in green production is higher ($y = 0.8$), the evolution rate of consumers' choice to purchase green agricultural products is slower (Fig. 4a). Changes in the willingness of farmers and the government will slightly accelerate the evolution of consumers' strategies because consumers' consumption behavior of buying green products has strong inertia, and once consumers have established the consumption habit of buying green agricultural products, their purchasing behavior is difficult to be affected by changes in the strategies of farmers and the government.

Conclusion: Farmers' green adoption intention and government supervision behavior are conducive to the evolution of consumers' green purchasing strategies. When consumers are at a low level of initial willingness, government regulation is more effective. Compared with the change in government supervision behavior, the change in farmers' green adoption has a greater impact on consumers' purchase intentions.

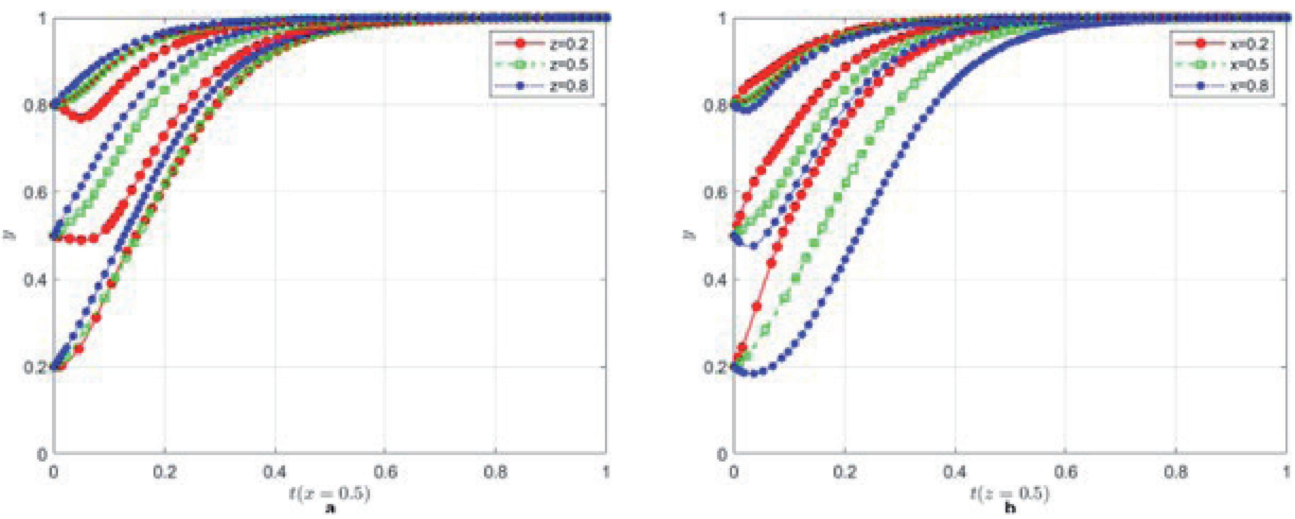

Fig. 3. The evolution track of government behavior strategy under different initial will levels.

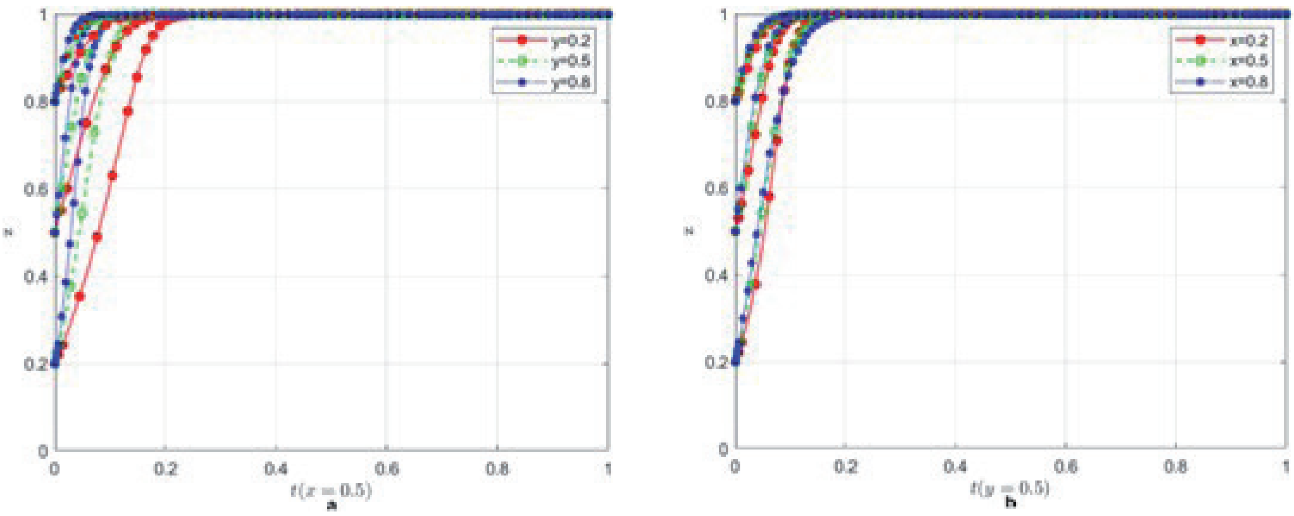

Fig. 4. Evolution trajectory of consumer behavior strategies under different initial intention levels.

Effects of Important Parameter Changes on System Evolution

The Effect of Income Distribution of Green Products on System Evolution

In the process of promoting the adoption of green production technologies by farmers, the government should provide public services, build platforms for the purchase and sale of green agricultural products, and smooth production and marketing channels. When the channel is more smooth, the distribution ratio of green production income obtained by farmers is higher. This distribution ratio is rarely involved in existing studies. This part will discuss the influence of α on system evolution. When other parameters remain unchanged, the value of the income distribution coefficient $\alpha \in \Omega(0.2, 0.5, 0.8)$ of green products is changed, respectively, to obtain the strategy evolution trajectory of the change in value α under different initial willingness levels of farmers, governments, and consumers, as shown in Fig. 5.

As shown in Fig. 5, the change in the value of α has a certain impact on the evolution of behavioral strategies of farmers and governments, but has no significant impact on the evolution of consumer behavioral strategies. The value of α affects the incremental benefits that farmers and the government can get from the income distribution of green products. As can be seen from Fig. 5a), when $\alpha = 0.2$, farmers take a lower proportion of the cost overpaid by consumers, and farmers' willingness to adopt green production technology will decrease slightly, but then increase. When the proportion of farmers is high ($\alpha \geq 0.5$), regardless of the level of farmers' initial willingness to adopt green production technology, farmers' behavioral strategies evolve at a fast pace. Fundamentally speaking, as a rational economic person, farmers' choice of behavioral strategies changes mainly because of the continuous increase in income. As can be seen from Fig. 5b), with the continuous improvement of the government's willingness to promote green production, the change of α improves the evolution speed of the government's behavioral strategy. As can be seen from the figure, when the government's initial willingness to promote green production is at a low level ($y = 0.2$), it has not completely turned to promoting green production when time $t \in (0,0.5)$. When the initial willingness of the government to promote green production is at a high level ($y = 0.8$), when $t = 0.3$, the behavioral strategy

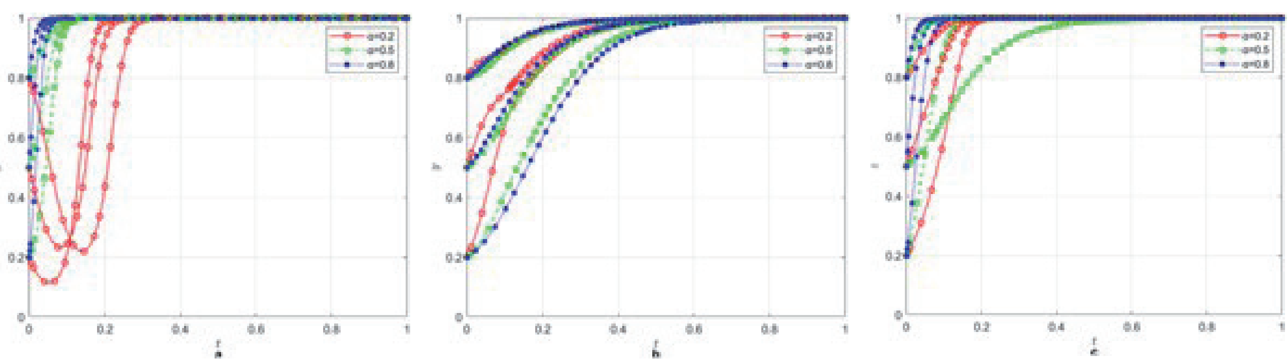

Fig. 5. Influence of change of α on system evolution under different initial intention levels of three parties.

of the government to promoting green production tends to 1. Moreover, in Fig. 5b), we can see that in the evolution process of the government's behavioral strategy to promote green production, the evolution speed is faster when α = 0.2 than when α = 0.8. As can be seen from Fig. 5c), when the initial intention of consumers is not very clear, in the middle of the deviation (z = 0.5), then α = 0.8 is the best choice for the evolution of consumer strategy, followed by α = 0.2 and finally α = 0.5. When the intention of consumers is at the level of low or high intention, the change of α shows a progressive trend.

Conclusion: Farmers, as rational economic people, are more sensitive to income distribution. Farmers' pursuit of maximum profit is more affected by the distribution coefficient. When α is low, it will have a negative effect on farmers' green adoption. When the government's regulatory intention is low, the larger the α, the smaller the impact on the evolution of the government's regulatory behavior strategy selection, and the more obvious the impact difference.

The Impact of Government Penalties and Subsidies on System Evolution

In the tripartite game between the government, farmers, and consumers to promote green agricultural production, the government's participation is mainly manifested in two aspects: one is to reduce the cost to farmers and consumers through subsidies, and the second is to fine farmers for environmental damage caused by traditional production [25]. Therefore, on the basis of the analysis in 3.1, the influence of the intensity of government punishment and subsidy on the system's evolution is further explored. By changing the values of S (subsidy) and γK(fine) respectively, the strategy evolution trajectory of farmers, government, and consumers under different initial willingness levels is obtained, as shown in Figs. 6 and 7.

1. The influence of S (subsidy) changes on system evolution under different initial willingness levels of tripartite subjects

According to Tian et al. [3] and Luo et al. [22], in the parameter setting method, the S (subsidy) is adjusted to 30, 50, and 80, respectively, under certain conditions of other parameters, and the influence of different initial willingness levels of farmers, government, and consumers on system evolution under different values is analyzed. As can be seen from Figs. 6a) and 6b), after S is increased from 30 to 50, the increase in subsidies will not change the direction of the evolution of the behavioral strategies of farmers, governments, and consumers, but will change their evolution speed. That is, the evolution speed of farmers and consumers will increase, and the evolution time will shorten. It also slows the pace of government evolution. As can be seen from Fig. 6c), with the continuous increase of subsidies, that is, from 50 to 80, it also has a great impact on the strategic evolution direction of the three parties. For farmers, when the initial willingness of the farmers is at a low level ($x \leq 0.5$), the strategic choice of farmers shifts from adopting green production technology to not adopting it. When the initial intention of farmers is at a high level (x = 0.8), they still maintain the strategic choice of adopting green production technology. As for the government, with the continuous increase in subsidies, the government's strategic choice has changed from action to inaction. For consumers, the increase in subsidies does not affect the direction of their strategic evolution.

Analysis conclusion: The continuous increase of government subsidies will not change the evolution direction of consumer behavior strategies, mainly because once consumers form the habit of buying green products, the increase of subsidies will only reduce the purchase cost and do no harm to consumers, so consumers will keep buying green agricultural products. In the case of low initial willingness among farmers, it is not advisable for the government to provide high financial subsidies to farmers only. Farmers may evolve to adopt in the early stages, but will be driven by interests in the later stages and only accept money. Therefore, it is not that the higher the financial subsidy provided by the government, the more conducive to the adoption of green production technology by farmers. It is necessary to formulate appropriate financial support according to the initial willingness of farmers to adopt green production technology.

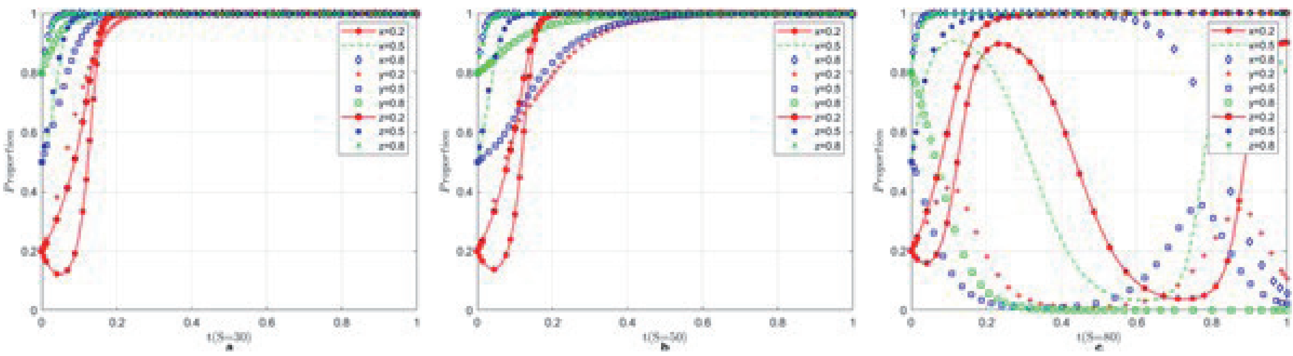

Fig. 6. Influence of S changes on system evolution under different initial intention levels of tripartite agents.

2. The influence of the change of γK (penalty) on the system's evolution under different initial willingness levels of three parties

According to Ma et al. [35] and Zuo [36] to the parameter setting method, under the condition that other variables are determined, by adjusting γK (penalty) to 10, 30, and 50, respectively, the impacts of different initial willingness levels of farmers, government, and consumers on the system evolution under different fines are analyzed. From Fig. 7, we can learn that when the initial willingness of farmers, governments, and consumers is low ($x/y/z$ = 0.2), the speed of evolution gradually increases with the continuous increase of the fine amount. However, in the early stages of the evolution of farmers, there will be a declining process, but with the evolution of time, the participation of farmers also begins to rise, and they finally choose to adopt green production technology. When the initial willingness of farmers, government, and consumers is high ($x/y/z \geq 0.5$), the change in penalty value does not significantly affect the behavioral evolution strategies of farmers, government, and consumers, mainly because when farmers, government, and consumers have reached a state of tripartite equilibrium to promote green production, the increase in penalty will not affect the interests of the three parties.

Conclusion: The change in penalty intensity has no effect on the evolution stability point of the system, but only has a certain effect on the speed of the system's evolution to the stability point. The government adopts punitive policies to regulate farmers' production and improve enforcement, which is more conducive to promoting farmers' adoption of green production technology as soon as possible. However, when the penalty intensity is weak, farmers' green adoption willingness will show a downward trend in the early stage, and then when the penalty intensity is increased, farmers' green willingness will also increase. The main reason is that farmers' goal is to pursue interests, and once they feel that it is not good for them, their willingness to participate will change. When the penalty is small, farmers will weigh the fine and the cost of adopting green production technology, and there will be a decrease in willingness.

Main Conclusions and Suggestions

Based on the practical background of promoting the green development of agriculture, this paper constructs a tripartite evolutionary game model among farmers, government, and consumers and combines numerical simulation to investigate the influence of the initial intention of the tripartite subjects and the evolution of important parameters on the strategic equilibrium. The results of the analysis are shown in Table 7.

The following main conclusions are drawn from Table 7.

(1) In the tripartite evolutionary game system of farmers, government, and consumers, there exists an evolutionary stable strategy combination (adoption, intervention, and purchase) under the premise of a good grasp of the intensity of government subsidies; that is, when farmers adopt green production technology, the government intervenes in green production and consumption, and consumers buy green agricultural products, it will be the best path for the three parties to jointly promote the green development of agriculture. This provides theoretical support for further research on government intervention behavior.

(2) Under the evolutionary game model, the strengthening of the initial willingness of any of the three parties will not affect their final strategy choice, but will affect the speed of each agent's evolutionary game to varying degrees. The consumer's consumption intention has the greatest effect on promoting farmers' green adoption and government intervention. The green adoption intention of farmers has the greatest influence on the evolution of consumer strategies.

(3) In the analysis of the revenue distribution ratio α of green products, the better the effect of public services provided by the government, the higher α will be. With the continuous increase of α, the evolution speed of farmers' strategies showed a trend of increasing in different development stages. The proportion of income from green products has a greater impact on farmers. Therefore, in order for farmers to adopt green production technology more quickly, the government should increase the construction of public platforms to ensure the enthusiasm of farmers.

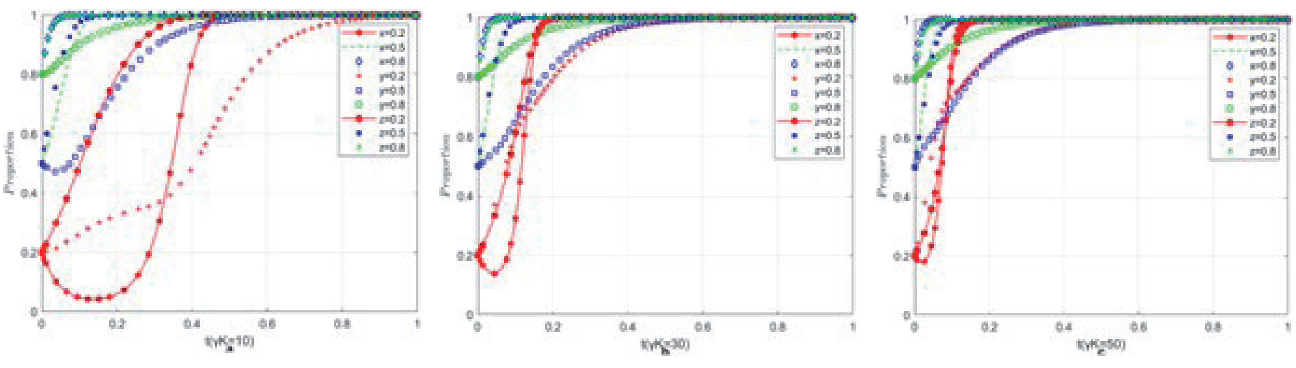

Fig. 7. Influence of the change of γK on system evolution under different initial intention levels of three parties.

Table 7. Fig. 2.-Fig. 7. Summary analysis.

Fig. 2.-Fig. 4	As shown in Fig. 2. to Fig. 4, the initial willingness of different agents has some influence on the system's evolution. For farmers, the positive impact of consumer green consumption on producers is greater than the impact of government regulation; for the government, the impact of consumer choice on government behavior is greater than the impact of farmers; for consumers, government regulation is more effective when the initial willingness of consumers is low.
Fig. 5.	As shown in Fig. 5., profit maximization farmers are more affected by the distribution factor α. When α is lower, it will have a negative effect on farmers' adoption of green production technology.
Fig. 6.	As shown in Fig. 6., increasing government subsidies will not change the direction of the evolution of consumer behavior strategies, while for farmers, it is necessary to pay attention to their initial willingness level, and formulate appropriate financial support; otherwise, a reaction may occur.
Fig. 7.	The government adopts the punishment policy to regulate the production of farmers and improve execution, which is more conducive to promoting the adoption of green production technology by farmers. When the penalty is small, the farmers' willingness will be reduced when they weigh the cost of the fine against the cost of adopting green production technology.

(4) In the early stages of green agriculture development, when farmers are less willing to adopt green production technology, the government's measures to increase subsidies are more conducive to the evolution of farmers' strategies than fines. When the development of green agriculture reaches a certain stage, the continuous increase in government subsidies will have a negative effect, affecting the direction of farmers' strategic choices. At the same time, the continuous increase in punishment will accelerate the speed of farmers' evolution. It can be seen that the higher the intensity of government subsidies, the better the rational use of subsidies and punitive measures to achieve the purpose of green development and avoid unreasonable and inefficient resource loss.

In order to better promote the promotion of agricultural green technology, promote the green development of agriculture, and build an agricultural green development ecosystem of tripartite cooperation among farmers, government, and consumers, based on the above research conclusions, the following suggestions are put forward:

(1) In the early stages of agricultural green development, farmers' initial willingness to adopt green production technology and consumers' initial willingness to buy are low. The government should play a leading role and focus on improving the willingness of both by increasing subsidies. First of all, formulate supporting government support policies to provide subsidies for farmers and consumers in the early stages of development to avoid the situation of declining willingness due to high costs. Secondly, professional personnel can be arranged to teach farmers new technologies and popularize green concepts through knowledge dissemination and other means, so as to improve the public's overall cognition of green agriculture, enhance policy publicity efforts, broaden publicity channels, adopt various and flexible publicity methods, and maximize farmers' understanding of relevant policies. Finally, in the consumer market, the development of a unified standard of green agricultural products is necessary to ensure the interests of consumers, regulate the fairness of the consumer market, and avoid the appearance of shoddy phenomena, so as to improve green consumption demand.

(2) In the middle stage of agricultural green development, the initial willingness of farmers and consumers to participate in the green production process gradually increases, and the government should strengthen public services and build service platforms. At this stage, ensure the proportion of farmers' green product income distribution and ensure the interests of farmers who have adopted green production technology. At the same time, the punishment for farmers who do not adopt green production technology should be increased. For example, economic pressure can be exerted on farmers through fines and other policies to encourage them to adopt green production technology. And continue to encourage consumers to buy green agricultural products in order to reduce consumption inertia. To the maximum extent to encourage the supply side of farmers to vigorously produce green agricultural products, so as to increase the effective supply of green agricultural products in the market to meet the consumer consumption upgrade demand policy effect.

(3) In the middle stage of agricultural green development, the initial willingness of farmers and consumers to participate in the green production process gradually increases, and the government should strengthen public services and build service platforms. At this stage, ensure the proportion of farmers' green product income distribution and ensure the interests of farmers who have adopted green production technology. At the same time, in the later stage of green agricultural development, green agricultural development has reached a mature stage, consumers have established the consumption habit of buying green agricultural products, and the tripartite cooperation between farmers, governments, and consumers in green agricultural development has taken shape. The government should continue to maintain the current environment, ensure that the balanced state has been maintained continuously, and promote the gradual improvement of green agricultural development.

Limitations and Prospects

In this paper, we enrich the existing research from a new point of view, using evolutionary game analysis to analyze the impact of the initial willingness of the subjects, the distribution of green product income, and the government's reward and punishment policy on the adoption of agricultural green technology. This paper analyzes the policy implementation of the government to promote the maximization of the green production benefit of farmers, to promote the green development of agriculture, to realize the maximization of the economic, social, and environmental benefits, and to provide some opinions for promoting the adoption of green technology in agriculture.

However, this study also has some limitations. First of all, the three-party evolutionary game model only considers the government, farmers, and consumers and does not involve the influence of other subjects. For example, the lack of banks, cooperatives, and other main considerations. In fact, farmers adopting green production technology will be affected by all sides. So it's very important to think in many ways. Secondly, this paper only uses numerical simulation to simulate its evolution trend, and the parameters used in the model are based on previous research and rely on more assumptions, which cannot fully reflect the actual situation. In future research, we should combine the field survey to set its parameters and focus on case and empirical research. Finally, due to the consideration of universality, the author did not take specific agricultural products as the direction of analysis, which may limit the final results to some extent. In the future, we can use the econometric method to calculate the range of the main parameters and put them into the model to predict the evolution direction and speed.

Nomenclature

Variable	Definition
x	The probability of farmers choosing green production as their strategic choice
y	The government chooses to intervene in the probability of agricultural green development in the strategy choice
z	The probability of consumers choosing green consumption in their strategic choice
Ca	Costs incurred by farmers implementing green technologies (innovation costs)
γK	A tax imposed by the government on farmers for pollution
S	Subsidies provided by the government to participate as green agricultural production
β	The share of government subsidies allocated to farmers
$1-\beta$	The share of government subsidies allocated to consumers
Sg	The environmental loss caused by farmers not adopting green production technology
Cp	The extra cost that consumers spend to buy green products
αCp	The incremental benefit of farmers choosing green production depends on the extra cost that consumers are willing to pay for green agricultural products
$(1-\alpha)Cp$	The extra cost paid by consumers to buy green agricultural products flows to the market and generates tax revenue for the government through reproduction
P	Farmers do not implement the original benefits of green technology
Ps	Environmental benefits of implementing green technologies
Pc	The original income that consumers get from buying non-green products
b	Incremental utility of consumers buying green products
A	When the government intervenes, farmers adopt green technologies, and consumers buy green products, economic development and social progress can be promoted, thus bringing benefits to all three parties

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Conflict of Interest

The authors declare no conflict of interest.

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