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How to promote the adoption of intelligent spray technology in farmers' cooperatives? ——Based on the perspective of evolutionary game

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A R T I C L E I N F O

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A B S T R A C T

In order to accelerate the development of smart agriculture and realize the green transformation of agriculture, the coupling of prospect theory and evolutionary game theory is introduced. Construct a two-party evolutionary game model for the adoption of intelligent spray technology in farmers' cooperatives, analyze the evolution of farmers' cooperatives and government strategy selection and its influencing factors according to the replication dynamic equation, and conduct numerical simulation experiments through Matlab software. The results show that the adoption of intelligent spray technology by farmers' cooperatives and the government's choice of subsidies are the two optimal stable states of the evolutionary system. The government's subsidy policy can effectively stimulate farmers' cooperatives to adopt intelligent spray technology, but when the government subsidy coefficient is greater than or equal to 70%, the decision-making evolution of the government and farmers' cooperatives is unstable. The increase in farmers' awareness of pesticide hazards, the scale of operation of farmers' cooperatives, the price of high-quality agricultural products, and the sensitivity of farmers' cooperatives to profits and losses contribute to the promotion of intelligent spray technology, and the damage probability of intelligent spray technology has a restraining effect.

1. Introduction

With the development of modern information technology and intelligent technology, modern agriculture represented by big data, Internet of Things, smart agriculture and precision agriculture is trying to subvert today's agricultural production methods, of which intelligent spray technology is a representative technology of modern agriculture mainly applied to the agricultural application of pesticides. Intelligent spray technology is based on the Internet, traditional telecommunications network and other information bearers, so that the spray system can address independently, to achieve interconnection, it has three important characteristics of ordinary object equipment, autonomous terminal interconnection and pervasive service intelligence, providing safe, controllable and personalized real-time online monitoring, equipment management, remote control, remote maintenance, online upgrade and other management and service functions, realize the "management and control" of "high efficiency, energy saving, safety and environmental protection" of "spray", battalion" integration. Therefore, the large-scale application of intelligent spray technology is an important direction for the change of agricultural production technology in the future [1–3]. On the one hand, the problems of "marginalization"

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and "aging" of agriculture are becoming increasingly serious, the large loss of young rural labor and the decline of the physical strength of elderly workers hinder the normal production of agriculture [4]. On the other hand, the negative externalities of pesticide application are gradually emerging and the marginal output contribution of pesticides is weakening, the reduction of pesticides has reached a consensus around the world [5]. Correspondingly, the application and promotion of intelligent spray technology can not only reduce labor input and labor intensity through intelligent production, but also reduce the use of pesticides and avoid pesticide abuse through precise means. However, compared with traditional spray technology, the transformation of intelligent spray technology means more demands for capital, technology and talents, which cannot be met by individual farmers, and farmers' cooperatives, as one of the new agricultural management entities in China, have conditions that individual farmers cannot have. Farmers' cooperatives have realized the alliance of the weak of small farmers through the form of "huddles", and solved the problems of capital, technology and talent in the process of agricultural digitalization [6]. Second, farmers' cooperatives are an important organizational form of Chinese agriculture. According to information released by the Ministry of Agriculture and Rural Affairs, as of the end of November 2021, China has legally registered 2.219 million farmers' cooperatives, and the radiation has driven nearly half of the farmers. Therefore, it is an effective path to promote the adoption and promotion of intelligent spray technology with farmers' cooperatives as the carrier.

The Chinese government has been striving to promote the widespread application of digital technology in the agricultural sector, and has taken a series of measures to build a good superstructure and create a good social atmosphere for the digital transformation of agriculture. The "Digital Agriculture and Rural Development Plan" issued by the Ministry of Agriculture and Rural Affairs of China in 2020 emphasizes the need to accelerate the digital transformation of agriculture, accelerate the application of agricultural artificial intelligence, build a digital agricultural service system, and the "Key Policies for Strengthening Agriculture and Benefiting Farmers in 2022" gradually includes more eligible smart agricultural machinery products into the scope of agricultural machinery purchase subsidies to help the development of smart agriculture. In addition, the Chinese government also supports the construction of a series of facilities such as the "Agricultural and Rural Cloud" and other agricultural and rural big data platforms, the National Digital Agriculture and Rural Innovation Center, the National Digital Agriculture Innovation and Application Base, which are committed to creating a rural digital transformation ecosystem.

With the strong support of the government, the application of digital technology in the agricultural field in China has shown a new development trend. In 2020, the number of plant protection drones reached 110,000, the operating area reached 60 million hectares, and the application crops achieved a leap from a single rice to more than 100 crops, and the application scenarios were also extended to fertilizer, feed spreading, farmland surveying and mapping, and other fields [7,8]. The proportion of information technology applications such as agricultural Internet of Things increased from 10.2% in 2015 to 17% in 2020, and the penetration of agricultural Internet of Things technology in the agricultural field has deepened the digital empowerment of agricultural production, and promoted the realization of a series of functions such as environmental control, supervision, early warning, diagnosis, and traceability [9]. The accuracy and density of remote sensing technology has been further improved, and it has been gradually applied to the agricultural situation monitoring business of winter wheat, corn, rice and other bulk grain crops across the country, which has promoted the construction of China's space-ground integrated agricultural situation monitoring system [10]. Despite this, China's smart agriculture is still relatively backward. In 2021, the penetration rate of China's agricultural digital economy was only 9.7%, and the Internet penetration rate in rural areas was only 59.2%, far lower than that of developed countries such as the United States and Germany. The application of technology is mainly concentrated in the eastern coastal areas, among which the top three registered smart agricultural enterprises are Shandong Province, Jiangsu Province and Guangdong Province [11]. It can be seen that China's smart agriculture has problems such as unbalanced regional development, insufficient digital integration, and lagging farmers' digital skills.

Many scholars have tried to analyze the influencing factors of China's backward development of smart agriculture from the aspects of national system, economic structure, natural environment and social conditions [12]. China's agriculture has long been in a dual economic structure, and a large number of rural labor forces cannot be effectively transferred, resulting in the inability to socialize agricultural production [13]. Further from the actual situation of China's agriculture, Chinese farmers have low cultural quality, insufficient digital talents, imperfect agricultural data sharing system, and weak rural infrastructure, which restricts the development of smart agriculture in China [14–16]. In particular, the topography has a blocking effect on China's agricultural modernization, and China's mountainous terrain, which lead to the fragmentation of arable land, is also an important factor hindering the development of smart agriculture [17]. Compared with the European Union, the United States and other countries, the development of smart agriculture in China still has problems such as low degree of integration, lack of incentives for digital technology innovation, single innovation subject, and homogeneous innovation practice [18–20]. Therefore, many scholars have explored and proposed feasible paths for the realization of smart agriculture based on experience accumulation or development models, which provides reference for China to solve the above problems. From the level of value chain, food system and innovation system, the development of smart agriculture should combine social-network-physical-ecosystem aspects to solve the current problem of independent and decentralized digital agriculture research [21]. From the legal policy level, the formulation of smart agriculture policies should pay more attention to strengthening the dynamic connection between farmers, retailers and consumers [22]. From the level of innovation incentives, the government should pay attention to the financial structural reform and financial system construction in rural areas, and promote the efficiency of China's agricultural scientific research output and achievement transformation with financial agglomeration [23]. From the level of industrial integration, the realistic path of deep integration of digital economy and agriculture should be explored from multiple dimensions such as direction, division of labor, transformation of achievements, and cultivation of market players [24]. In general, promoting the development of smart agriculture requires multi-subject coordination and multi-mechanism integration. Obviously, the implementation of smart agriculture is a long and complex process that requires great costs. However, digitalization can bring new opportunities for the high-quality development of China's agriculture, and is the key to China's agricultural transformation. Digitalization is the main way to empower the realization of the functions of the new agricultural management system, the path to support the new agricultural management system, and the main way to develop green agriculture [25–27].

In summary, it can be seen that the existing literature provides a rich theoretical basis for this paper, but there are still some shortcomings. First of all, as an important new agricultural management entity, farmers' cooperatives are the main carrier of digital agriculture development, but there is less attention paid to the importance of the adoption of digital technology by farmers' co-operatives. Second, most of the existing literature discuss the digitalization of agriculture from a static perspective, and the adoption of digital technology is a dynamic development process, and few studies analyze it from a dynamic perspective. Finally, some studies have mostly discussed the issue of digital agriculture from the perspective of a single subject, ignoring that the development of digital agriculture is a process involving multiple subjects. Based on this, this paper uses evolutionary game methods and prospect theory to dynamically analyze the behavioral interaction of multiple agents in the process of intelligent spray technology adoption, and mainly makes the following research contributions: First, using evolutionary game theory to integrate farmers' cooperatives and governments into the same complex system, and studying the key influencing factors of China's farmers' cooperatives' adoption of intelligent spray technology, it provides a theoretical basis for the formulation of government policies and has strong practical significance. Second, based on the prospect theory of the expected utility of different decisions of farmers' cooperatives, incorporating the psychological factors of farmer cooperatives into the decision-making analysis can effectively improve the scientificity of the adoption of intelligent spray technology by farmers' cooperatives.

This paper focuses on how to promote the adoption of smart spray technology, and mainly answers the following questions: First, what is the stable state of evolution in the replication dynamic system composed of farmers' cooperatives and governments? Second, can the government's subsidy policy effectively promote the adoption of smart spray technology? Third, under the government's subsidy policy, what are the key factors for farmers' cooperatives to adopt smart spray technology? The progress of this paper is as follows: The second section introduces the theoretical basis of this paper and constructs the theoretical model. The third section proposes the model construction and stability analysis. In the fourth section, the simulation experiment and result analysis are carried out respectively. The fifth section discusses the research results. The sixth section draws conclusions and makes recommendations.

2. Method

2.1. Theoretical basis

2.1.1. Evolutionary game theory

Evolutionary game theory is an extension of traditional game theory and the product of the combination of rational economics and evolutionary biology. It examines economic problems from the perspective of biology. Evolutionary game theory believes that game participants are bounded rational, so participants' decisions should be affected by subjective factors such as human cognition and perception [28]. Evolutionary game theory has changed the harsh assumption of complete rationality and complete information of participants in traditional game theory, and introduced the concept of bounded rationality. Compared with traditional game theory, evolutionary game theory is more realistic. Evolutionary game mainly includes three parts: income matrix, replication dynamic equation and evolutionary stable state [29]. This paper uses the benefit matrix and the replication dynamic equation as the basis to analyze under what conditions the government and farmers' cooperatives can reach a stable state in a bounded rational state by continuously learning, imitating and improving their decisions in the game.

2.1.2. Prospect theory

The prospect theory, jointly proposed by Tversky and Kahneman, is the application of psychology in economics and one of the four major research results of behavioral finance. Compared with the hypothesis of rational people that has been used for a long time, prospect theory pays more attention to the use of empirical research methods, and reveals some irrational psychological factors in the process of making decisions by studying people's psychological characteristics and behavioral characteristics. This theory suggests that individuals with different reference points for profit and loss will have different attitudes toward risk. Prospect theory uses value function and weight function to describe people's subjective overall value [30].

(1) Value function. An important feature of prospect theory is that the value carrier is the change of wealth or welfare rather than the final state. Human perception and judgment are also consistent with this assumption. Therefore, our estimation of the value of things is often relative rather than absolute. The value function reflects the amount of change to a reference point, which is determined by the decision-maker's personal subjective impression [31]. The research shows that the value function is concave in profit and convex in loss, which means that people are more risk averse to income, and the degree of risk aversion is related to the risk aversion coefficient and the sensitivity of decision makers to profit and loss. When people's wealth is closer to the reference point, the marginal change of value is smaller. Therefore, this function has three important properties: reference dependence, loss aversion, and decreasing sensitivity. The expression of the value function is shown in formula (1), where x_i is the difference between the actual income and the reference point income, λ is the risk aversion coefficient of decision makers, α is the sensitivity of decision makers to losses.

$$v(x_i) = \begin{cases} {x_i}^{\alpha}, x_i \geq 0 \\ -\lambda(x_i)^{\alpha}, x_i < 0 \end{cases} \quad (1)$$

(2) Weight function. The weight of each result is also an important factor affecting different decision choices. According to prospect theory, the weight function is a nonlinear function with the following characteristics: 1. The weight function $w(p_i)$ is an increasing function of the probability p_i. 2. People usually assign a weight of 0 to low probability events and a weight of 1 to high probability events, so $w(0) = 0, w(1) = 1$. 3. People will underestimate small probability events and overestimate medium or large probability events. The expression of the weight function is shown in formula (2), where when ε is smaller, the function is more curved.

$$w(p_i) = \frac{p_i^{\varepsilon}}{[(p_i^{\varepsilon} + (1 - p_i^{\varepsilon})^{\varepsilon})]^{1/\varepsilon}} \tag{2}$$

The prospect value V is determined by the value function and weight function, and its specific expression is shown in formula (3).

$$V = \sum w(p_i)v(x_i) \tag{3}$$

in this paper, farmers' cooperatives and the government, as game participants, have bounded rationality. For farmers' cooperatives, they are self-employed organizations with weak risk resistance, while for the government, they have an absolute advantage of capital, information and strong power with risk resistance, so according to the prospect theory, the government can be assumed to be risk neutral, while for farmers' cooperatives, the prospect theory can be applied to estimate their profit and loss influenced by subjective factors.

2.2. Problem description

According to evolutionary game theory, in order to make decisions that maximize their own interests and ultimately remain in a stable state, players in the game need to constantly change their own behavior according to the behavior of others. Therefore, we can use the evolutionary game model to analyze the interest game relationship between farmers' cooperatives and the government in the decision-making of intelligent spray technology adoption under different circumstances.

China has always attached importance to the development of agriculture. In recent years, in order to optimize the environment and realize the mutual promotion and development of agriculture and environmental protection, the Chinese government has continuously increased the management of agriculture, especially the constraints on agricultural resources and environment. The government, as the maker of public policy and the manager of public resources, implements agricultural policy with the main goal of improving the rural environment, improving the quality of cultivated land and realizing the sustainable development of planting industry [32]. However, because of many problems in traditional farming methods, resulting in the waste of pesticides and ultimately the rapid deterioration of the environment, the government should use subsidies to guide farmers to replace traditional technology and adopt intelligent spray technology, which can improve the efficiency of pesticide use and alleviate environmental degradation, but also accelerate the process of agricultural digitization in China, At the same time, the government can also benefit from environmental improvement and agricultural economic development [33]. However, the application of the subsidy policy also means that the government needs to bear the corresponding financial expenditure. For farmers' cooperatives, the decrease in the number of rural labor force and the rise in prices in recent years have led to difficulties in employment and increased labor costs and drug costs. The adoption of intelligent spray technology can avoid these costs while requiring farmers' cooperatives to pay the purchase costs [34]. According to the prospect theory, farmers' cooperatives are more difficult to bear risks than the government, and farmers' cooperatives are more sensitive to profits and losses. Therefore, farmers' cooperatives' perceived losses from adopting spray technology are greater than their actual losses [35]. Under the condition that the government implements the subsidy policy, the decisions made by farmers' cooperatives will also be affected by whether the perceived utility of agricultural digital subsidies can cover the perceived loss of adopting spray technology. Both parties make the decision to adopt and promote spray technology based on costs and benefits. Although the interests of the government and farmers' cooperatives are consistent in some aspects, they choose to cooperate based on different logic, which shows that there is still a game relationship between them.

In the initial stage, the government and farmers' cooperatives do not cooperate due to the asymmetry of information between them. When the government does not establish a subsidy policy and farmers' cooperatives refuse to adopt intelligent spray technology, the government needs to pay the cost of environmental remediation due to environmental pollution caused by pesticide waste, and receives a relatively low return on agricultural economic development, farmers' cooperatives maintain the traditional equipment and agricultural product income, but need to pay the labor and pesticide costs, as well as the loss caused by the labor shortage and untimely farming due to farmers' aversion to pesticides. When the environment is deteriorating and the cost of environmental governance is rising rapidly, the government takes the lead in advocating a program for farmers' cooperatives to replace traditional spray equipment and formulates corresponding subsidy policies. Under this policy, some farmers' cooperatives have responded to the call of the state by adopting intelligent spray technology, while others have a wait-and-see attitude. This part of farmers' cooperatives that choose to adopt intelligent spray technology need to pay for purchase costs, corresponding maintenance costs and technician training costs while obtaining benefits from labor and pesticide savings, government subsidies and agricultural products under new technology, and the government will receive the benefits of environmental improvement and high agricultural economic development with paying the corresponding subsidies. If the profits of adopting intelligent spray technology can cover the losses, then another part of the cooperatives that choose to wait and see will imitate this strategy, and finally all farmers' cooperatives choose to adopt intelligent spray technology, so that the government and cooperatives can achieve a win-win situation. If the profits from the adoption of spray intelligent technology cannot cover the losses, it will lead to the deterioration of the economic situation of some cooperatives, resulting in negative social effects, leading to the loss of the credibility of the government, causing another part of cooperatives to flinch, finally no one responds to the call, and the government cancels the subsidy policy. If the government subsidies meet the psychological expectations of farmers' cooperatives, farmers' cooperatives will choose to adopt intelligent spray technology, and both sides will achieve win-win results. If the government subsidy is lower than the psychological expectation of farmers' cooperatives, farmers' cooperatives refuse intelligent spray technology. The farmers' cooperatives and the government will adjust their respective strategies until the balance is achieved.

2.3. Model assumptions

Based on the current situation of China's farmers' cooperatives, the following assumptions are made about the profits and losses of farmers' cooperatives and the government in the evolutionary game model.

Assumption 1. The farmers' cooperatives are participant 1, and the government is participant 2. Both are participants with bounded rationality. The decisions they make will eventually stabilize in the optimal strategy over time.

Assumption 2. The strategic space of farmers' cooperatives is $\alpha = (\alpha_1, \alpha_2)$, α_1 means that farmers' cooperatives adopt smart spray technology, and the probability is x, α_2 means that farmers' cooperatives reject smart spray technology, and the probability is $(1 - x)$, $x \in [0, 1]$. The government's strategic space is $\beta = (\beta_1, \beta_2)$, β_1 means that the government formulates subsidy policy, and the probability is y, β_2 means that the government does not formulate subsidy policy, and the probability is $(1 - y)$, $y \in [0, 1]$.

Assumption 3. According to the prospect theory, farmers' cooperatives and governments have different sensitivities to profit and loss, but at the same time, they have no deviation between perceived value and actual utility for the determined profit and loss. Only when the profit and loss are uncertain, their perceived value and actual utility for profit and loss are different.

2.4. Model analysis

In the process of research on the adoption of intelligent spray technology by farmers' cooperatives, since farmers' cooperatives and the government have two strategies, there are four possible strategy combinations.

(1) The government chooses subsidies, while farmers' cooperatives choose to adopt intelligent spray technology. As a result, the cooperatives gain benefits from replacing labor with machines and improving agricultural efficiency, including saved pesticide costs R_1S and labor costs R_2S, as well as the income from the sale of agricultural products under the cultivation of intelligent spray technology $W_2 (W_2 = P_2Q)$. In addition, they also receive government subsidies $\theta A_1 Cf_3$. At the same time, cooperatives have to pay the cost of purchasing intelligent spray technology $A_1 Cf_3$, as well as related maintenance costs $nA_1 Cf_4$ and training costs Cf_5. Accordingly, the government needs to pay relevant subsidies while obtaining environmental benefits and agricultural economic development benefits R_g. Due to the uncertainty of the price of agricultural product under the cultivation of intelligent spray technology, subsidy coefficient and technology damage probability, these factors are measured by the prospect theory value function.

Among them, the cost saved by farmers' cooperatives is positively correlated with its scale S; R_1 and R_S are the pesticide cost and labor cost saved per unit, respectively; A_1 represents the number of intelligent spray technology to be purchased by the cooperatives; Q is the yield; Cf_3 represents the purchase cost of a single intelligent spray technology; Cf_4 and Cf_5 respectively represent the single maintenance cost and the training cost of technical personnel for spray technology; P_2, θ and n represent the perceived expectations of cooperatives on agricultural product price under intelligent spray technology cultivation, government subsidy coefficient and technology damage probability, respectively. $n, \theta \in [0, 1]$.

(2) When the government chooses to subsidize and the farmers' cooperatives refuse the intelligent spray technology, the cooperatives will get the profit from selling the agricultural products cultivated with the traditional spray equipment $W_1 (W_1 = P_1Q)$, but need to pay the cost of purchasing traditional spray equipment $A_2 Cf_2 (Cf_2 < Cf_3)$ and the cost of moral hazard caused by the information asymmetry of cooperatives and employed workers R_3. In addition, it is also necessary to pay for the difficulties in recruiting workers in cooperatives due to the gradual increase of people's awareness of pesticide hazards, and they will eventually suffer from reduced production, the loss is expressed as iCf_1. Accordingly, the government will increase the cost of governance due to environmental degradation Cg_2. Since people's awareness of pesticide harm is also uncertain, the value function of prospect theory is used to measure it.

Among them, P_1 represents the price of agricultural products under traditional spray technology $(P_1 < P_2)$; A_2 represents the quantity of traditional spray technology to be purchased by the cooperatives; Cf_1 represents the cost of reduced production due to crop not being dusted in time; i represents people's perceived expectation of pesticide hazard awareness. $i \in [0, 1]$.

(3) When the government chooses not to subsidize and farmers' cooperatives choose to adopt intelligent spray technology, the cooperatives will also get benefits from labor and pesticide saving R_1S and R_2S, as well as earnings from selling agricultural products cultivated by intelligent spray technology W_2. At the same time, farmers' cooperatives also should pay the technology cost $A_1 Cf_3$, maintenance cost $nA_1 Cf_4$ and training cost Cf_5, but there is no government subsidy income. Accordingly, the government will also gain the benefits of environmental improvement and agricultural economic development R_g, but it needs to pay for the loss of public trust resulting in increased administrative costs Cg_1.

(4) When the government refuses to provide subsidies and the farmers' cooperatives refuse to adopt intelligent spray technology, the cooperatives will get the income from selling agricultural products under the traditional spray equipment W_1, but it will

Table 1
The payoffs of the two-part players evolutionary game based on prospect theory.

		Government	
		Formulate subsidy policy (y)	Reject subsidy policy (1-y)
Farmers' Cooperatives	adopt intelligent spray technology (x)	$(R_1 + R_2)S + (W_2)^\alpha + (\theta A_1 Cf_3)^\alpha - A_1 Cf_3 - \lambda(nA_1 Cf_4)^\alpha - Cf_5$, $Rg - \theta A_1 Cf_3$	$(R_1 + R_2)S + (W_2)^\alpha - A_1 Cf_3 - \lambda(nA_1 Cf_4)^\alpha - Cf_{5g-} Cg_1$
	Reject intelligent spray technology (1-x)	$W_1 - A_2 Cf_2 - \lambda(iCf_1)^\alpha - R_3$, $- Cg_2$	$W_1 - A_2 Cf_2 - \lambda(iCf_1)^\alpha - R_{3-} Cg_1 - Cg_2$

have to pay the technology cost A_2Cf_2, the moral hazard cost R_3 and the cost of reducing production due to people's increased awareness of pesticide hazards iCf_1. Accordingly, the government needs to pay the cost of environmental treatment Cg_2 and the cost caused by the loss of public credibility Cg_1.

Based on the prospect theory, the return matrix composed of farmers' cooperatives and the government is constructed as shown in Table 1.

3. Evolutionary game analysis

3.1. Model solving

According to the evolutionary game theory and the constructed income matrix, the expected income and average income of farmers' cooperatives and the government under different decisions can be calculated. The contents are as follows:

The expected return of farmers' cooperatives for adopting intelligent spray technology and rejecting intelligent spray technology are E_{11} and E_{12} respectively, and the average return is $\overline{E_1}$, which are expressed by formula (4), formula (5) and formula (6) respectively.

$$E_{11} = (R_1 + R_2)S + (W_2)^\alpha + y\left(\theta A_1 C_{f3}\right)^\alpha - A_1 C_{f3} - \lambda\left(nA_1 C_{f4}\right)^\alpha - C_{f5} \tag{4}$$

$$E_{12} = W_1 - A_2 C_{f2} - \lambda\left(iC_{f1}\right)^\alpha - R_3 \tag{5}$$

$$\overline{E_1} = x\left[(R_1 + R_2)S + (W_2)^\alpha + y\left(\theta A_1 C_{f3}\right)^\alpha - A_1 C_{f3} - \lambda\left(nA_1 C_{f4}\right)^\alpha - C_{f5}\right] + (1 - x)\left[W_1 - A_2 C_{f2} - \lambda\left(iC_{f1}\right)^\alpha - R_3\right] \tag{6}$$

Based on this, the replication dynamic equation of farmers' cooperatives is calculated and expressed by formula (7).

$$\begin{gathered} F(x) = \frac{dx}{dt} = x(E_{11} - \overline{E}_1) \\ = \left(x - x^2\right)\left[(R_1 + R_2)S + (W_2)^\alpha + y\left(\theta A_1 C_{f3}\right)^\alpha + A_2 C_{f2} + \lambda\left(iC_{f1}\right)^\alpha + R_3 - A_1 C_{f3} - \lambda\left(nA_1 C_{f4}\right)^\alpha - C_{f5} - W_1\right] \end{gathered} \tag{7}$$

The expected return of government subsidies and non-subsidy are E_{21} and E_{22} respectively, and the average return is $\overline{E_2}$, which are expressed by formula (8), formula (9) and formula (10) respectively.

$$E_{21} = xR_g - x\theta A_1 C_{f3} + (x - 1)C_{g2} \tag{8}$$

$$E_{22} = xR_g - C_{g1} + (x - 1)C_{g2} \tag{9}$$

$$\overline{E_2} = y\left[xR_g - x\theta A_1 C_{f3} + (x - 1)C_{g2}\right] + (1 - y)\left[xR_g - C_{g1} + (x - 1)C_{g2}\right] \tag{10}$$

Similarly, according to the above formula, the government's replication dynamic equation can be expressed as formula (11).

$$F(y) = \frac{dy}{dt} = y(E_{21} - \overline{E_2}) = \left(y - y^2\right)\left(C_{g1} - x\theta A_1 C_{f3}\right) \tag{11}$$

According to the basic assumptions of evolutionary game theory, the optimal decision can only be achieved through multiple games of both sides of the game. When the majority of individuals in the group choose the same decision, it means that the decision is the optimal decision. When both sides of the game experience multiple games without changing their decisions, it means that the replication dynamic system is stable. In this stable state, the decision combination of both sides of the game is evolutionary stability strategy (ESS).

3.2. Dynamic system stability analysis

When the decisions of both sides of the game no longer evolve with time, the choice of both sides of the game is the optimal strategy. If equation (7) and equation (11) are set to 0, the local stagnation point and the system stability point (ESS) of the game parties in the dynamic system can be obtained, namely the optimal strategy point.

$$\begin{cases} F(x) = \dfrac{dx}{dt} = (x - x^2)\left[(R_1 + R_2)S + (W_2)^{\alpha} + y(\theta A_1 C_{f3})^{\alpha} + A_2 C_{f2} + \lambda(iC_{f1})^{\alpha} + R_3 - A_1 C_{f3} - \lambda(nA_1 C_{f4})^{\alpha} - C_{f5} - W_1\right] = 0 \\ F(y) = \dfrac{dy}{dt} = (y - y^2)(C_{g1} - x\theta A_1 C_{f3}) = 0 \end{cases} \tag{12}$$

One of the conditions of evolutionary stability strategy is that pure strategy Nash equilibrium must be satisfied, while other forms of Nash equilibrium are unlikely to be stable strategy in the system [36]. Therefore, this paper only discusses the stable points of the system under pure strategy, namely E_1 (0,0), E_2 (1,0), E_3 (0,1), E_4 (1,1). According to Lyapunov indirect method, the evolution stability of four local stationary points can be judged by the eigenvalues of Jacobian matrix, and the eigenvalues of Jacobian matrix generally appear in three cases: all are negative real parts, all are positive real parts, alternating positive and negative real parts, and the real part is 0. Only when the eigenvalues are all negative real parts, the local stationary points are evolutionary stable points.

Based on the above analysis, the Jacobian matrix can be constructed by calculating the first-order partial derivatives of x and y for equation (7) and equation (11) respectively, and expressed by formula (13). By substituting four local stagnation points into the Jacobian matrix, four groups of different corresponding eigenvalues can be obtained, as shown in Table 2.

$$J = \begin{pmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{pmatrix} = \begin{pmatrix} \dfrac{d(F(x))}{dx} & \dfrac{d(F(x))}{dy} \\ \dfrac{d(F(y))}{dx} & \dfrac{d(F(y))}{dy} \end{pmatrix}$$

$$= \begin{pmatrix} (1-2x)\left[(R_1+R_2)S + (W_2)^{\alpha} + y(\theta A_1 C_{f3})^{\alpha} - A_1 C_{f3} - \lambda(nA_1 C_{f4})^{\alpha} - C_{f5} - W_1 + A_2 C_{f2} + \lambda(iC_{f1})^{\alpha} + R_3\right] & (x-x^2)(\theta A_1 C_{f3})^{\alpha} \\ -(y-y^2)\theta A_1 C_{f3} & (1-2y)(C_{g1} - x\theta A_1 C_{f3}) \end{pmatrix} \tag{13}$$

Based on the above analysis, the eigenvalue C_{g1} of the local stagnation point (0,0) is greater than 0, so the point (0,0) must not be an evolutionary stable point. The other three local stagnation points may realize that the eigenvalues are all negative real parts, so these three points may be evolutionarily stable points. By comparing the different eigenvalues of the four points, it can be determined that the system has three evolution states. In order to further verify our conclusions, we use Matlab software to simulate the evolution process of farmers' cooperatives and government strategies, as shown (a), (b) and (c) in Fig. 1.

Case1. $(R_1 + R_2)S + (W_2)^{\alpha} + A_2Cf_2 + \lambda(iCf_1)^{\alpha} + R_3 > A_1Cf_3 + \lambda(nA_1Cf_4)^{\alpha} + Cf_5 + W_1$, $Cg_1 < \theta A_1Cf_3$.

When the evolution system satisfies the above constraints, the system can achieve local stability. We assign values to the parameters as follows: $R_1 = 0.02, R_2 = 0.064, S = 200, R_3 = 5, Cf_1 = 10, Cf_2 = 0.01, Cf_3 = 1.5, Cf_4 = 0.2, Cf_5 = 2, P_1 = 4, P_2 = 8, Q = 2.4, Cg_1 = 3, A_1 = 20, A_2 = 50, i = 0.5, n = 0.3, \theta = 0.5, \alpha = 0.88, \lambda = 2.25$. As shown in Fig. 1(a), when the constraints of situation 1 are met, the system eventually evolves towards point (1,0) and tends to be stable, that is, over time, farmers' cooperatives tend to adopt intelligent spray technology, while the government tends to refuse subsidies.

Case2. $(R_1 + R_2)S + (W_2)^{\alpha} + (\theta A_1Cf_3)^{\alpha} + A_2Cf_2 + \lambda(iCf_1)^{\alpha} + R_3 < A_1Cf_3 + \lambda(nA_1Cf_4)^{\alpha} + Cf_5 + W_1$.

When the evolution system satisfies the above constraints, the system will reach another kind of local stability. We assign values to the parameters as follows: $R_1 = 0.02, R_2 = 0.064, S = 100, R_3 = 5, Cf_1 = 10, Cf_2 = 0.01, Cf_3 = 1, Cf_4 = 0.2, Cf_5 = 2, P_1 = 4, P_2 = 5, Q = 2.4, Cg_1 = 3, A_1 = 20, A_2 = 50, i = 0.2, n = 0.3, \theta = 0.2, \alpha = 0.7, \lambda = 2.25$. As shown in Fig. 1(b), when the constraints of situation 2 are met, the system eventually evolves towards point (0,1) and tends to be stable, that is, over time, farmers' cooperatives tend to refuse to adopt intelligent spray technology, and the government tends to choose subsidies.

Case3. $(R_1 + R_2)S + (W_2)^{\alpha} + (\theta A_1Cf_3)^{\alpha} + A_2Cf_2 + \lambda(iCf_1)^{\alpha} + R_3 > A_1Cf_3 + \lambda(nA_1Cf_4)^{\alpha} + Cf_5 + W_1$, $Cg_1 > \theta A_1Cf_3$.

When the evolution system meets the above constraints, the system will also reach a local equilibrium, and we still assign each parameter as follows: $R_1 = 0.02, R_2 = 0.064, S = 200, R_3 = 5, Cf_1 = 10, Cf_2 = 0.01, Cf_3 = 1.5, Cf_4 = 0.2, Cf_5 = 2, P_1 = 4, P_2 = 8, Q = 2.4, Cg_1 = 3, A_1 = 10, A_2 = 50, i = 0.5, n = 0.3, \theta = 0.2, \alpha = 0.8, \lambda = 2.25$. As shown in Fig. 1(c), when the constraints of situation 3 are met, the system eventually evolves towards point (1,1) and tends to be stable, that is, over time, farmers' cooperatives tend to adopt intelligent spray technology, while the government tends to choose subsidies.

4. Simulation analyses of the evolutionary game

In the scenario analysis, we achieved the evolution from scenario 1 to scenario 2 to scenario 3 b y changing the degree of farmers' awareness of pesticide hazards *i*, the damage probability of the spray technology *n*, the government's subsidy coefficient θ, the

Table 2
Local stagnation points and their eigenvalues.

Local stagnation points	Eigenvalues
(0,0)	$(R_1 + R_2)S + (W_2)^{\alpha} - A_1Cf_3 - \lambda(nA_1Cf_4)^{\alpha} - Cf_5 - W_1 + A_2Cf_2 + \lambda(iCf_1)^{\alpha} + R_3$, Cg_1
(1,0)	$-[(R_1 + R_2)S + (W_2)^{\alpha} - A_1Cf_3 - \lambda(nA_1Cf_4)^{\alpha} - Cf_5 - W_1 + A_2Cf_2 + \lambda(iCf_1)^{\alpha} + R_3]$, $Cg_1 - \theta A_1Cf_3$
(0,1)	$(R_1 + R_2)S + (W_2)^{\alpha} + (\theta A_1Cf_3)^{\alpha} - A_1Cf_3 - \lambda(nA_1Cf_4)^{\alpha} - Cf_5 - W_1 + A_2Cf_2 + \lambda(iCf_1)^{\alpha} + R_3$, $-Cg_1$
(1,1)	$-[(R_1 + R_2)S + (W_2)^{\alpha} + (\theta A_1Cf_3)^{\alpha} - A_1Cf_3 - \lambda(nA_1Cf_4)^{\alpha} - Cf_5 - W_1 + A_2Cf_2 + \lambda(iCf_1)^{\alpha} + R_3]$, $-(Cg_1 - \theta A_1Cf_3)$

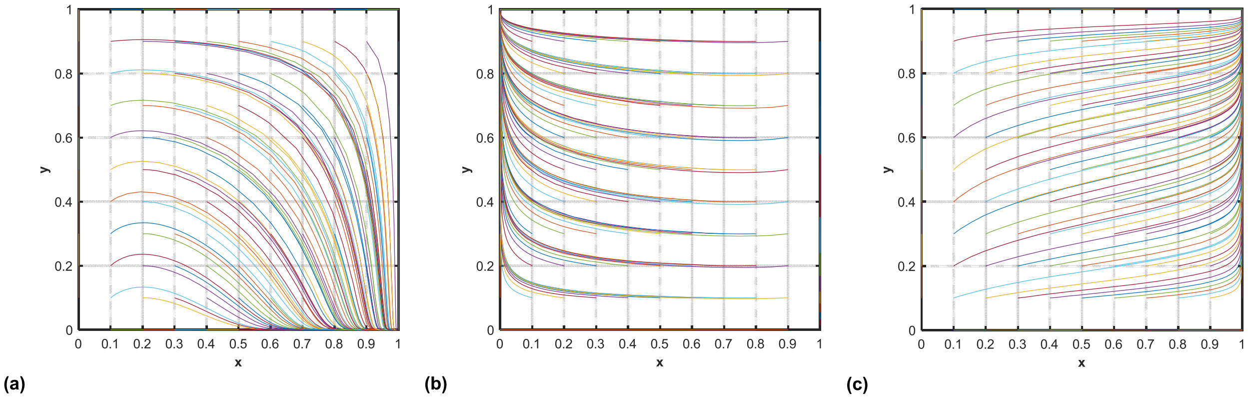

Fig. 1. Simulation of the evolution of farmers' cooperatives and government strategies.

sensitivity of farmers' cooperatives to profit and loss α, the price of high-quality agricultural products P_2, and the scale of farmers' cooperatives operations S. Combined with the author's field research, it is found that the above factors are the key elements affecting the decision-making of each subject. This section discusses the impact of these key parameters on evolutionary systems.

4.1. Data sources

This article uses the market information and planting information of tomatoes as a reference. On the one hand, in the planting industry, economic crops such as vegetables and fruits have the characteristics of high production efficiency. Compared with food crops, they are more in line with the economic conditions for the adoption of intelligent spray technology. As a facility vegetable, tomato not only ranks first in the planting area, but also has the attributes of fruits, with fruit and vegetable dual-purpose crops accepted by the market [37]. On the other hand, tomato cultivation requires high cultivation techniques and is vulnerable to late blight, bacterial wilt, gray mold, cotton bollworm, whitefly and many other diseases and insect pests, its prevention and control depends on the timeliness of pesticides. And farmers often deal with experience, which often brings uncertainty about pesticide application results. Intelligent spray technology based on big data can intelligently and accurately solve this tomato planting problem. In addition, this paper chooses Wenzhou as the research area. First of all, Wenzhou's tomato planting scale and output value are relatively large. In 2021, Wenzhou's tomato planting area reached 5133 ha, with an annual output of 257,200 tons of tomatoes. In 2022, the output value reached more than 1.5 billion yuan. It occupies a very important position in the province's and even the country's tomato supply. Therefore, Wenzhou is known as the "tomato kingdom". Secondly, Wenzhou's agriculture has a high degree of digitalization, and its digital planting is representative. In recent years, Wenzhou City has vigorously promoted the "No. 1 Project" of the digital economy, and Cangnan County, Ruian City, and Yueqing City were awarded the "2020 National County-level Digital Agriculture and Rural Development Advanced Counties". The Hengxi Industrial Base in Baoyang Township, Taishun County has introduced digital technologies such as digital greenhouses and big data on the basis of the original small tomato planting, which has achieved a substantial increase in farmers' income. Finally, the members of the research team have conducted long-term follow-up research on Wenzhou tomatoes, and obtained a large amount of first-hand data on tomato planting, growth and sales in Wenzhou. Moreover, most of the members of the research team are from Wenzhou, which provides great convenience for the research.

The parameters of this paper are mainly obtained through four channels: The first is field research. The author has conducted detailed research interviews with a number of local farmers' cooperatives in Wenzhou, and averaged the results of a number of surveys, in which the parameters are based on a growth cycle of crops as the time unit. The survey found that the quality of tomatoes cultivated under intelligent spray technology is higher, while the quality of tomatoes cultivated under traditional spray equipment is poor, after market inquiry, the price of high-quality tomatoes is about 8 yuan per kilogram, and the price of ordinary quality tomatoes is about 4 yuan per kilogram. Through interviews, we found that farmers' cooperatives with intelligent spray technology are generally large, ranging from 7 ha to 14 ha. With or without intelligent spray technology, tomato yields are close, so we set the yield to be the same in different cases, with a yield of 360,000 kg per hectare. However, if farmers do not apply pesticides in time, it will cause a decrease in yield, and according to past conditions, the cost is about 25,000 yuan. In terms of cost, the acquisition cost of an intelligent spray technology and related installation costs are about 15,000 yuan, the operating range per device is about 0.67 ha, and the project subsidy is 50% of the purchase cost. Correspondingly, the purchase cost of a traditional spray equipment is about 100 yuan, and the area of 0.33 ha can only be covered per day with labor. The average daily wage of each short-term worker is about 200 yuan, but because each crop needs 4–5 sprays in one growth cycle, it is assumed that each agricultural worker can only cover 0.07 ha of farming in one cycle. In addition, we use the ratio of the number of times the intelligent spray technology is damaged to the number of times it is used as its probability of damage, according to the results of the study estimated the probability of damage is 30%, and the cost associated with each repair is about 2000 yuan. The second is the public information on government affairs. According to Wickramarathne, Premaratne [38], government credibility loss can be roughly estimated as the increase in the annual administrative cost of Wenzhou's agriculture. According to the "2020 Annual Department Final Account Report" and "2021 Annual Department Final

Table 3
The initial values of all variables.

Parameters		Assignment
R_1	Labor cost saved per hectare	0.3
R_2	Pesticide cost saved per hectare	0.21
R_3	Moral hazard cost	0.5
S	Farmers' cooperative operation scale	13.33
Cf_1	Cost of crop yield reduction due to untimely application of pesticides	2.5
Cf_2	Cost of acquisition per conventional spray equipment	0.01
Cf_3	Cost of acquisition per smart spray technology	1.5
Cf_4	Cost per repair of smart spray technology	0.2
Cf_5	Operation training cost of smart spray technology	2
P_1	The price per kilogram of common quality agricultural products	4
P_2	The price per kilogram of high-quality agricultural products	8
Q	Crop yield per hectare	36
Cg_1	Cost of lack of credibility	18
A_1	Number of smart spray technology required	20
A_2	Number of conventional equipment required	50
i	Perceived expectations of people's pesticide hazard awareness	0.5
n	Perceived expectations of damage probability for smart spray technology	0.3
θ	Government subsidy coefficient	0.5
α	Sensitivity of farmers to losses	0.88
λ	Risk aversion coefficient of farmers	2.25

Account Report" published by the Wenzhou Municipal Bureau of Agriculture and Rural Affairs and related adjustments to the data, the added value of agriculture business management expenses in Wenzhou City from 2020 to 2021 is about 180,000 yuan. According to the "Wenzhou Agricultural Technology Extension Center 2021 Final Account Disclosure Form" released by the Wenzhou Municipal Bureau of Agriculture and Rural Affairs, combined with the inquiries of relevant personnel, it was learned that the training cost of technical personnel to be equipped by each farmer cooperative was roughly estimated to be 20,000 yuan. The third is classic literature. According to Saleem, Zaman [39], intelligent spray technology can save up to 75% of pesticide application and according to the "National Agricultural Product Cost and Benefit Compilation Data 2022″, the pesticide cost per hectare of tomatoes in facilities in Zhejiang Province is 2870.4 yuan, so the cost of pesticides saved per hectare under intelligent spray technology can be roughly estimated at 2100 yuan. In addition, in prospect theory, the risk aversion coefficient of the decision-maker and the sensitivity of the decision-maker to the loss are usually identified as 2.25 and 0.88, respectively [40]. The fourth is questionnaire surveys and the opinions of experts in the field of agricultural economics. The author surveyed 37 farmers in the form of questionnaires, and nearly half of them said they resisted pesticides and refused to work in related jobs. In addition, the moral hazard cost is obtained by consulting experts. In order to quantify these parameters scientifically and accurately, we invited 1 professor, 1 associate professor and 4 doctoral students, totaling 6 experts in agricultural economics, and carried out scenario simulation and repeated valuation optimization, and obtained the relevant assignment. Finally, we assume that farmers' cooperatives and government have no particular preference for spray technology and subsidy choices, respectively, so we set the starting probability of farmers' cooperatives adopting intelligent spray technology and government subsidy policies to 0.5. In order to facilitate the subsequent analysis of this article, the assignment of the above parameters is simplified, as shown in Table 3.

4.2. The degree of farmers' awareness of pesticide hazards i

We assign the degree of farmers' awareness of pesticide hazards as 0, 0.2, 0.5, 0.7, and 1, indicating that the number of farmers who refuse pesticide-related operations accounts for 0,20%, 50%, 70%, and 100% of the total number of farmers. With other variables unchanged, the influence of farmers' awareness of pesticide hazards on the system is tested. The evolution process of the system is shown in Fig. 2. The degree of farmers' awareness of pesticide hazards has a significant impact on the decision-making of farmers' cooperatives, but has almost no significant impact on the government's choice. For the government, regardless of the level of farmers' awareness of pesticide hazards, the government always chooses subsidy policy. But for farmers' cooperatives, although the higher the level of farmers' awareness of pesticide hazards, the more inclined the cooperatives are to adopt intelligent spray technology, but when the level of farmers' awareness of pesticide hazards is less than or equal to 0.2, the cooperatives refuse to choose intelligent spray technology.

4.3. The damage probability of the spray technology n

In order to analyze the influence of the damage probability of intelligent spray technology on the system, we also assign the damage probability of spray technology as 0, 0.2, 0.5, 0.7 and 1, indicating that the damage probability of the technology within the life cycle is from low to high. 0 means that the technology will hardly be damaged within the life cycle, and 1 means that the technology has a 100% probability of damage within the life cycle. With other variables unchanged, the influence of the damage probability of spray technology on the system is tested. The evolution process of the system is shown in Fig. 3. The lower the damage probability of the spray technology, the more inclined the farmers' cooperatives are to adopt the intelligent spray technology. The critical value of the

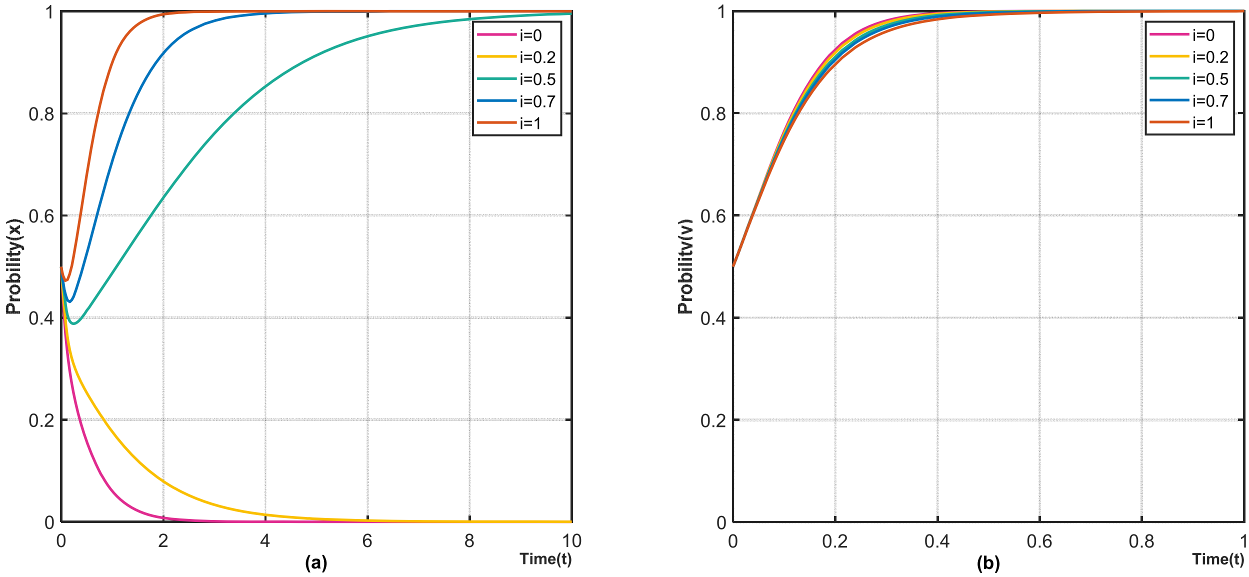

Fig. 2. Effect of farmers' awareness of pesticide hazards on the system.

damage probability of the farmers' cooperatives to accept the intelligent spray technology is 0.5. When the damage probability of the spray technology is higher than 0.5, the cooperatives tend to refuse to choose the intelligent spray technology. However, for the government, the damage probability of intelligent spray technology will not affect its final evolution results, but only improve the evolution rate of the government when the damage rate of technology is lower.

4.4. The price of high-quality agricultural products P_2

In order to analyze the influence of the price of agricultural products cultivated by intelligent spray technology on the system, we assign values of 6, 7, 8, 9 and 10 to the prices of high-quality agricultural products, and respectively indicating that the prices of high-quality agricultural products is 150%, 175%, 200%, 225% and 250% of the price of traditional agricultural products. With other variables unchanged, the evolution process of the replicated dynamic system is shown in Fig. 4. The higher the price of agricultural products cultivated by intelligent spray technology, the more inclined farmers' cooperatives are to adopt intelligent spray technology. However, when the price of agricultural products is less than or equal to 7, the cooperatives tend to refuse to adopt intelligent spray technology. For the government, when the price range of agricultural products is between 6 and 10, the government always chooses the subsidy strategy, indicating that the price factor of agricultural products is not the key factor affecting the government's decision-making.

4.5. Government subsidy coefficient θ

In order to reflect the influence of the government subsidy coefficient on the evolutionary system, we assign the government subsidy coefficient as 0, 0.2, 0.5, 0.7 and 1, respectively indicating that the government subsidy accounts for 0, 20%, 50%, 70% and 100% of the purchase cost of intelligent spray technology. With other variables unchanged, the evolution process of the replicated dynamic system is shown in Fig. 5. The effect of the government subsidy coefficient on both farmers' cooperatives and government decisions is significant. When the government subsidy coefficient is not greater than 0.2, farmers' cooperatives tend to refuse to adopt intelligent spray technology, while when the government subsidy coefficient is equal to 0.5, farmers' cooperatives will tend to choose to adopt intelligent spray technology, but for the government, the subsidy coefficient is not higher than 0.5 are its acceptable domain, and the government will choose the subsidy policy. However, when the subsidy coefficient is greater than 0.7, both the evolution of farmers' cooperatives and the government are in an unstable state, which indicates that the government's wavering decision on whether to provide subsidies when the subsidy coefficient is greater than 0.7 will also lead to the instability of farmers' cooperatives'

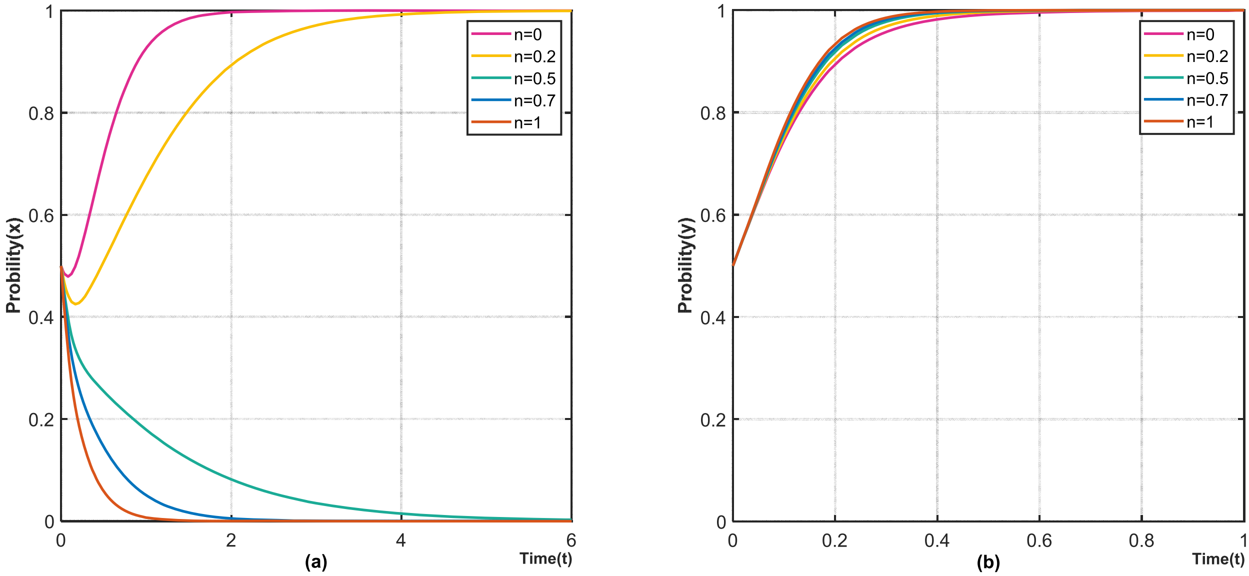

Fig. 3. Effect of the damage probability of the spray equipment on the system.

decision. According to the sensitivity analysis of subsidy coefficient to the system, the optimal value of government subsidy coefficient should be between 0.2 and 0.5.

4.6. Sensitivity of farmers' cooperatives to profit and loss α

We assign the sensitivity of farmers' cooperatives to profit and loss as 0,0.2, 0.5, 0.7, 1, indicating that the sensitivity of farmers' cooperatives to profit and loss goes from shallow to deep. 0 indicates that farmers' cooperatives are completely insensitive to profit and loss, and 1 indicates that farmers' cooperatives are completely sensitive to profit and loss. With other variables unchanged, the evolution process of the replicated dynamic system is shown in Fig. 6. For farmers' cooperatives, the less sensitive they are to profit and loss, the more inclined they are to refuse to adopt intelligent spray technology. For the government, no matter how sensitive farmers' cooperatives are to profit or loss, the evolution state of the government will eventually be stable, indicating that the government will eventually choose to implement subsidy policies. However, when farmers' cooperatives are most sensitive to profit and loss ($\alpha = 1$), the evolution state of farmers' cooperatives eventually stabilizes at 1, and the evolution curve of the government under this sensitivity will converge to 1 at a lower speed than other evolution curves. This indicates that when farmers' cooperatives are most sensitive to profit and loss, the government will slow down the pace of subsidy policies, and farmers' cooperatives will eventually choose to adopt intelligent spray technology.

4.7. The operation scale of farmers' cooperatives S

When the operating scale of the farmers' cooperatives is 10, 11.67, 13.33, 15 and 16.67, it is expressed as 7 5%, 87.5%, 100%, 112.5% and 125% of the existing business scale of the farmers' cooperatives, respectively. With other variables unchanged, the evolution process of the replicated dynamic system is shown in Fig. 7. For farmers' cooperatives, the larger the operation scale, the more inclined to choose to adopt intelligent spray technology, and farmers' cooperatives tend to adopt intelligent spray technology when the operation size is greater than 11.67. This indicates that the larger the operation scale of farmers' cooperatives, the stronger the scale effect, and the better the farmer cooperatives can realize the allocation of decision-making risks and the reduction of costs caused by the adoption of intelligent spray technology. However, for the government, the impact of government decisions on the operation scale of farmers' cooperatives is not significant, which means that although the larger the operation scale of farmers' co-operatives, the more subsidy expenditure, this only affects the rate of evolution of government subsidy decisions and cannot change the government's willingness to make decisions about subsidies.

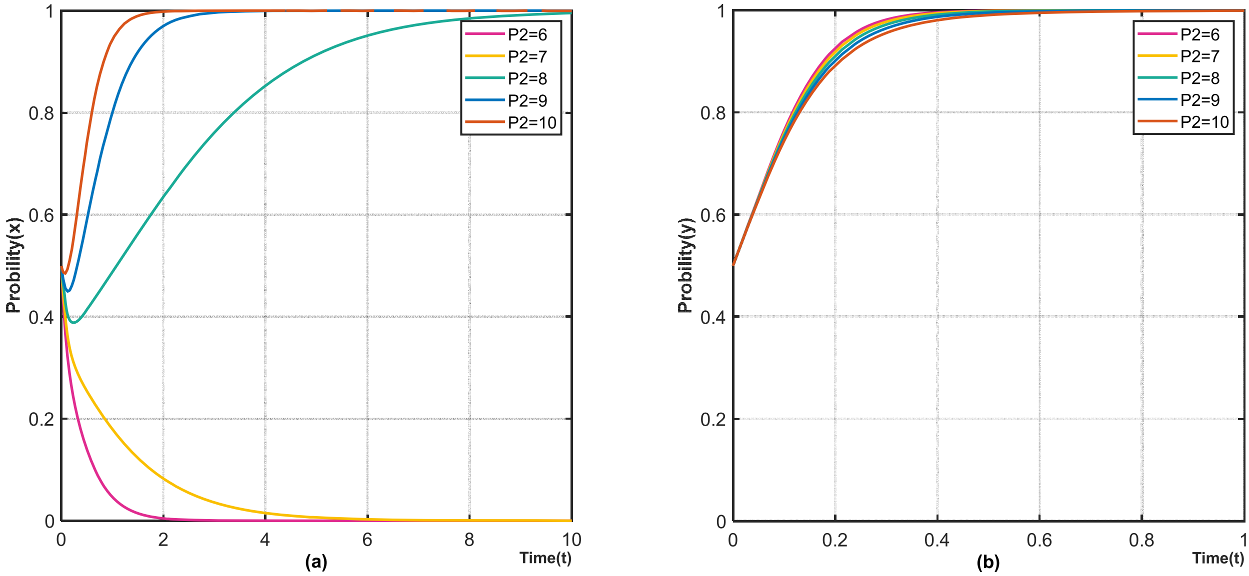

Fig. 4. Effect of the price of agricultural products cultivated by intelligent spray equipment on the system.

5. Discussion based on prospect theory

The Chinese government is an important participant in the digitalization of Chinese agriculture and plays a leading role in the digitalization process of Chinese agriculture. Our research results show that the degree of farmers' awareness of pesticide hazards, the damage probability of intelligent spray technology, the price of agricultural products cultivated by intelligent spray technology, the sensitivity of farmers' cooperatives to profit and loss, and the operation scale of farmers' cooperatives do not greatly affect the government's decision-making. First of all, compared with the fiscal expenditure of reasonable subsidies, the deterioration of agricultural environment and the weakening of government credibility cause greater losses to the government [41,42], therefore, under a reasonable subsidy scale, the government is more inclined to implement subsidies. Secondly, due to the information asymmetry between the government and farmers, farmers' awareness of pesticide hazards and farmers' cooperatives' sensitivity to profit and loss and other psychological factors cannot directly affect the government's decision-making. Finally, the government is different from the "weak union" farmers' cooperatives, which have absolute advantages in terms of capital, cognition and information. Therefore, the government has the ability to bear the potential risks brought by the adoption of intelligent spray technology by cooperatives. However, for the subsidy coefficient, it has a significant impact on the implementation of government policies. The reasonable subsidy coefficient of the government should be between 50% and 70% of the purchase cost of intelligent spray technology. On the one hand, the excessive subsidy coefficient means huge financial expenditure, and the financial pressure of the government is aggravated. It will also have a distorting effect, making the incentive effect of subsidies deteriorate, resulting in the waste of resources [43]. On the other hand, too low subsidy factor will increase the cost of farmers' cooperatives to adopt intelligent spray technology and reduce the willingness of farmers' cooperatives to implement digital transformation. However, it is worth noting that the demonstration effect formed by "agents" is one of the purposes of the government's early subsidy input, but when the farmers' cooperatives are completely sensitive to profit and loss ($\alpha = 1$), the promotion of intelligent spray technology is more difficult, it is difficult to form a good demonstration case, and the cost of agency increases, so the government is more cautious in the choice of "agent" than other conditions. In this case, the government's evolution curve will converge at a slower rate than other evolution curves to 1 [44].

From the perspective of farmers' cooperatives, all sensitivities have a significant impact on the decision of farmers' cooperatives to adopt spray technology. The results show that farmers' awareness of pesticide hazards, the scale of operation of farmers' cooperatives, the price of high-quality agricultural products, and sensitivity of farmers' cooperatives to profits and losses all have a positive and significant impact on the decision-making of farmers' cooperatives, and the damage probability of intelligent spray technology has a negative and significant impact on the decision-making of farmers' cooperatives. For farmers' cooperatives, the essence of the adoption of digital technology is a matter of cost and benefit trade-offs, and decision-making often presents the characteristics of

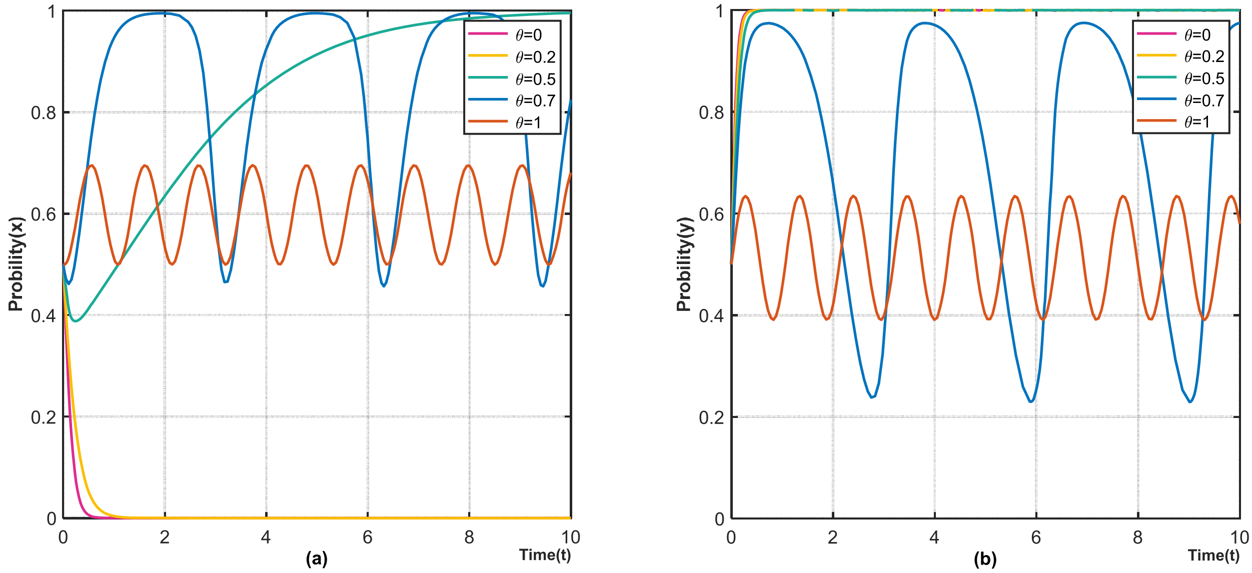

Fig. 5. Effect of the government subsidy coefficient on the system.

maximizing benefits and minimizing costs. The benefits of digital technology adoption come from market and government policy support, and the price of agricultural products after technology adoption and the government's subsidy coefficient directly affect the decision-making of farmers' cooperatives, which is the key to forming a positive incentive for farmers' cooperatives to adopt intelligent spray technology. At the same time, with the development of traceable agriculture, the popularization of the concept of "green agriculture", and the improvement of rural information dissemination media, farmers' awareness of pesticide hazards has gradually increased. Farmers' avoidance of pesticides is not only reflected in farmers' refusal to engage in relevant labor, but also in market purchases. Farmers have the dual identity of producers and consumers, and studies have shown that the higher the green awareness of the harm of pesticides, the more likely consumers are to buy facility-grown agricultural products [44]. Therefore, the adoption of intelligent spray technology will also bring potential market benefits to farmers' cooperatives in a social environment where farmers' awareness of pesticide hazards is increasing, as well as in a market environment where labor prices are rising and consumers increasingly prefer organic produce. In terms of cost, the damage probability of intelligent spray technology is an inevitable problem for farmers' cooperatives to adopt spray technology, China's farmers have a low cultural quality, which leads to low technical adaptability, too high damage probability will not only increase maintenance costs, but also cause certain operational risks, to hinder the promotion process of intelligent spray technology. Business scale is an important attribute associated with costs and benefits of farmers' cooperatives, and moderate operating scale can bring economies of scale and mitigate the risks and costs of technology adoption by farmers' cooperatives [45]. Facts have proved that scale operation is a prerequisite for the promotion of digital technology. The Chinese government has continuously optimized land transfer policies, encouraged scale operation, and is committed to promoting the digitalization of China's agriculture with the scale of cultivated land [46]. The expansion of land operation scale caused by land transfer can effectively promote farmers' willingness to adopt digital technologies [47]. The research in this paper shows that the larger the scale of operation without considering the impact on government decision-making, the higher the enthusiasm of farmer cooperatives to adopt intelligent spray technology, which is consistent with the reality of research. From the perspective of the main characteristics of farmers' cooperatives, rural China is a typical small-scale peasant economy, and farmers' cooperatives are more sensitive to profit and loss than ordinary non-agricultural economic subjects. Moreover, The more sensitive the subject is to profit and loss, the more prudent the investment and the more rational it can be [48], digitalization is the trend of future agricultural development from the perspective of policy environment, market environment and internal organizational environment, so the more rational farmers' cooperatives are, the better they can form expectations of technology adoption income. Therefore, farmers' cooperatives with a high level of sensitive profit and loss, even if the government slows down the pace of subsidies, will choose to adopt intelligent spray technology based on "cost-benefit" considerations. In addition, in order to avoid risks and reduce the variability of income, the production decisions of farmers' cooperatives tend to deviate from economic optimization, so based on the simulation scenario in this paper and considering the dependence of farmers' cooperatives on government decision-making, we propose a

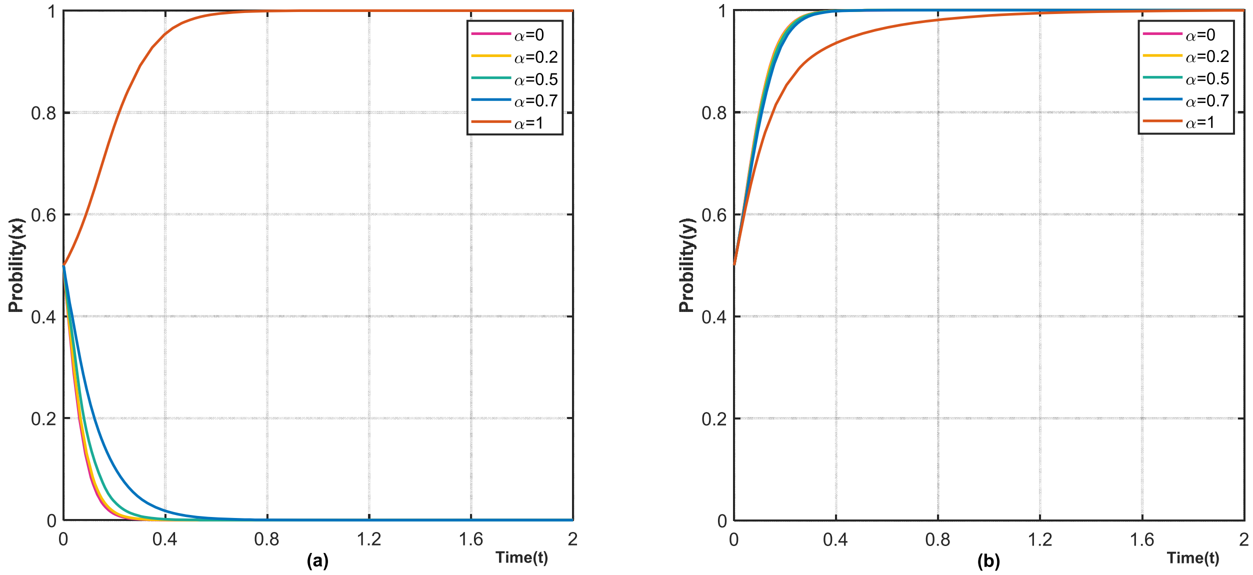

Fig. 6. Effect of the sensitivity of farmers' cooperatives to profit and loss on the system.

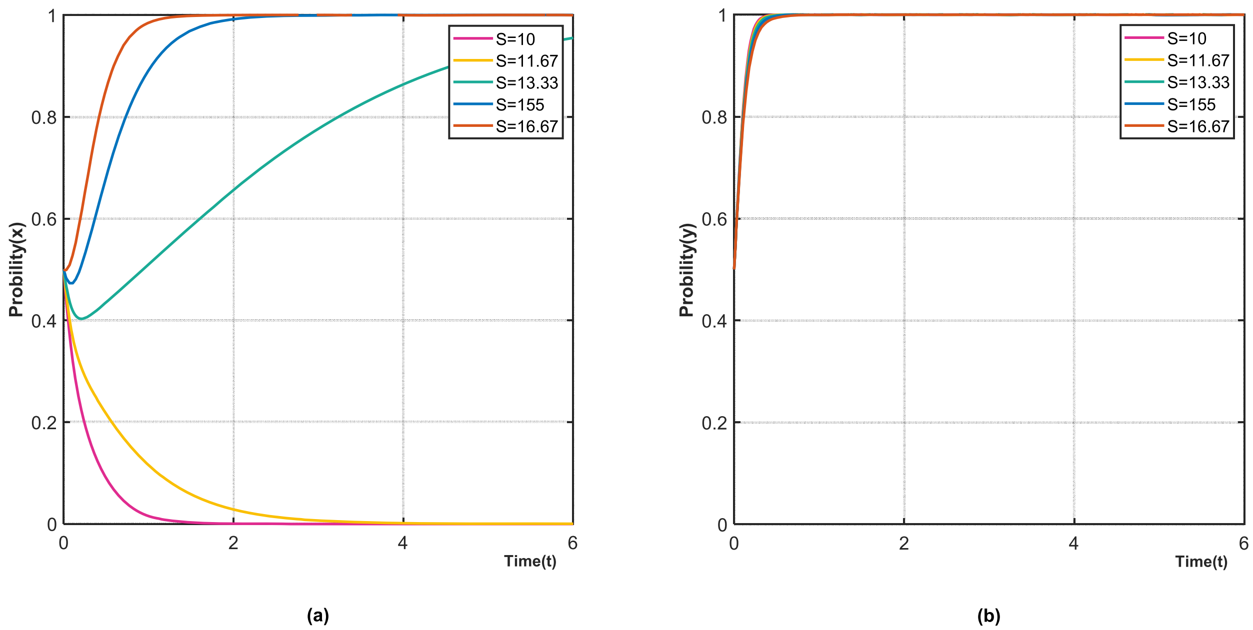

Fig. 7. Effect of the operation scale of farmers' cooperatives on the system.

reasonable reference interval for corresponding sensitive factors. Specifically, the optimal values of government subsidy coefficient, farmers' awareness of pesticide hazards, and damage probability of intelligent spray technology should be 0.2–0.5; The optimal value of profit and loss sensitivity should be 0.7–1; The scale of operation of farmers' cooperatives should be 87.5%–100% of the existing scale; The price of high-quality agricultural products should be set at 175%–200% of the price of traditional agricultural products.

The weak nature of agriculture determines that the government's agricultural digital subsidy plays a key role in the decision of farmers' cooperatives to adopt intelligent spray technology [49]. However, the decision-making behavior of farmers' cooperatives is also regulated by the market price mechanism, and they will measure the profit and loss of adopting intelligent spray technology based on market prices, thus forming the expected standard for government digital subsidies [50]. Therefore, although the government introduced the relevant digitization subsidy policy early on, the effect of the policy implementation is subject to the adjustment of the expected standard of digitization subsidy by farmers' cooperatives [51]. Studies have found that farmers' expectations of government digital subsidies are generally higher than the actual number of subsidies. Through the investigation of 143 new agricultural operating entities in Zaozhuang City, Sun, Liu [52] found that there were 118 operating entities whose digital investment accounted for less than 10% of the 143 operating entities, and most of these operating entities could only enjoy about 5000 yuan of support. According to the Evaluation Report on the Development Level of Agricultural and Rural Informatization at County Level in 2021, the per capita amount of financial funds invested in agricultural and rural informatization in rural areas is 46 yuan. One of the main reasons for the low level of digitization in Chinese agriculture is that the support of government funds is not strong enough to meet the expectations of farmers [53]. Based on prospect theory, farmers' cooperatives have reference points for perceived benefits of government digital subsidies [54], When the government's digital subsidy is lower than the expected standard of farmers' cooperatives, the perceived effect of farmers' cooperatives adopting intelligent spray technology is negative. In this case, farmers' cooperatives would rather choose to reject smart spray technology to bear the risk of maintaining the original production level and agricultural product quality. Conversely, when the government's digital subsidy is higher than the expected standard of farmers' cooperatives, the government's subsidy policy will promote the adoption of smart spray technology by farmers' cooperatives. Therefore, benign guidance of farmers' expected standards for government subsidies and formulation of stable and reasonable subsidy policies can often promote the adoption of smart spray technology by farmers' cooperatives.

6. Conclusions and policy recommendations

With the development of science and technology and the popularity of the Internet, it has become a trend that the Internet has penetrated into every field of agriculture. In order to improve the popularity rate of smart spray technology, the government and farmers' cooperatives should take actions. From the reality, the overall agricultural digitization degree of Chinese farmers' co-operatives is low at present, and the implementation effect of government subsidy policies is not good. This paper takes farmers' cooperatives and government as the research object, establishes evolutionary game model based on prospect theory, and studies the adoption of smart spray technology in Chinese agriculture. The main conclusions of this paper are as follows.

(1). Under different parameter Settings, different strategy combinations of the government and farmers' cooperatives will be presented, and all kinds of different strategy combinations may occur. According to the evolutionary game stability principle, there are two optimal stable states in the evolutionary system, namely, the adoption of smart spray technology by farmers' cooperatives and the selection of subsidies by the government.
(2) The optimal value of government subsidy coefficient should be between 0.2 and 0.5. When the subsidy is lower than 20%, it cannot effectively relieve the financial pressure of cooperatives to adopt smart spray technology; when the subsidy is higher than 70%, the financial burden of the government will increase. The unstable state of government subsidy decision-making leads to the unstable state of farmers' cooperatives' adoption decision-making.
(3) The higher the farmers' awareness of pesticide hazards, the more inclined the cooperatives are to adopt smart spray technology. When the farmers' awareness of pesticide hazards is less than or equal to 0.2, the cooperatives refuse to choose smart spray technology. No matter how aware farmers are of the dangers of pesticides, the government always chooses subsidy policies.
(4) The critical value of the cooperatives to accept the damage probability of smart spray technology is 0.5. When the damage probability of smart spray technology is higher than 0.5, the maintenance cost of farmers' cooperatives will increase, so the cooperatives tend to refuse to choose smart spray technology.
(5). The price of agricultural products under the condition of adopting smart spray technology is 1.75 times of the traditional price, which is the critical value of whether farmers' cooperatives adopt smart spray technology. Too low market price cannot effectively make up for the cost of adopting smart spray technology in cooperatives.
(6) The less sensitive farmers' cooperatives are to profit and loss, the more inclined they are to refuse to adopt smart spray technology. When the farmers' cooperatives are most sensitive to profit and loss ($\alpha = 1$), the farmers' cooperatives choose to adopt smart spray technology, and the evolution curve of the government under this sensitivity will converge to 1 at a lower speed than other evolution curves.
(7). The operating scale of 175 mu is the critical value for farmers' cooperatives to adopt smart spray technology. When the operating scale is greater than or equal to 175, farmers' cooperatives are more inclined to adopt smart spray technology. It shows that the larger the scale of farmers' cooperatives, the stronger the scale effect.

Based on the above research conclusions, this paper puts forward the following four policy recommendations.

(1). Build an incentive system under the dual role of government support and market guidance. First of all, the government should increase the input of digital subsidies under the condition of financial support. Secondly, local governments should adapt to local conditions and strengthen the supporting role of local financial institutions in promoting policies. Finally, government should strengthen the price management and regulation of digital spray technology, standardize the quality standard of spray industry, avoid the price disorder of spray industry, and guide the farmers' cooperatives to the benign development of government subsidies.

(2). Strengthen the safety awareness of farmers' cooperatives and guide farmers to construct safety barriers subjectively. On the one hand, farmers' cooperatives should strengthen their workers safety awareness of health by publicizing the knowledge of pesticide hazards; On the other hand, through the establishment of an effective monitoring and evaluation mechanism, the economic status and performance of farmers' cooperatives are regularly tracked and evaluated, and real-time feedback and data are provided to help farmers' cooperatives better understand their operations and enhance their sensitivity to profit and loss.

(3). Formulate a stable subsidy policy. The first is to pursue the stability of subsidy content and object, to achieve long-term accurate subsidies for smart spray technology. Secondly, pursue the stability of subsidy effect, government should adjust subsidy policy according to the macro-economic background and pursue the stability of subsidy effect. The formulation of stable subsidy policies can form forward guidance for farmers' cooperatives' expectations and help their expectations to be self-fulfilling.

(4). Encourage farmers' cooperatives to operate on a large scale. On the one hand, encourage farmers' cooperatives with good economic returns to expand their operations. On the other hand, small and medium-sized farmers' cooperatives should be advocated to carry out joint operation within a reasonable scope. The government should develop an operation mechanism which promotes the promotion of smart spray technology by means of cost and risk allocation, and improves profitability by means of improvement of product quality with advanced technology.

It should be noted that the study in this paper has certain limitations. First, to a certain extent, this paper simplifies the decision-making space of each participant in the game model, and also simply sets the correlation between individual parameters, and does not include factors such as spray technology depreciation into the model construction for the time being. Second, this paper is based solely on farmers' cooperatives and governments, without considering the impact of other stakeholders. Third, considering the impact of epidemic control in China, the author only visited the southern part of Zhejiang Province and did not have an in-depth understanding of the situation in other parts of China. However, different economic development conditions in different regions lead to spatial heterogeneity of agricultural planting conditions, market conditions and implementation effects of government policies in different regions. Therefore, in the future, we will make the following changes as soon as data is available: First of all, we can optimize the parameter settings according to the situation in different places in China, modify the parameter assignment, and re-simulate the model. Secondly, we will introduce model variables such as spray technology depreciation and government publicity degree into the game model to examine the impact on farmers' cooperatives' willingness to adopt intelligent spray technology. Finally, other stakeholders such as consumers and spray technology producers will also be added to the game.

Data availability

The data that has been used is confidential.

Notice

Informed consent has been obtained from all participants for this article.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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