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# Research on the Evolutionary Decision-Making Behavior Among the Government, Farmers, and Consumers: Based on the Quality and Safety of Agricultural Products

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**ABSTRACT** The primary factors that impact food safety are the quality and safety of agricultural products. The quality and safety of agricultural products are closely related to farmers' decision-making behavior. In addition, the decision-making behavior of the government and consumers is the key factor of farmers' decision-making behavior. The study explores the ideal state among the government, farmers and consumers to promote the improvement of the quality of agricultural products, thereby contributing to food safety. The study includes the government, farmers and consumers in an evolutionary game model to explore game relationships and evolution paths of decision making among the three stakeholders. The dynamic analysis of the decision replication, the stability analysis of strategy evolution, and the numerical simulation experiment verify the following: the evolutionary process of the decision-making behavior of the three stakeholders to an ideal state is affected by many factors, and the value ranges of the different factors have different impacts on the convergence speed of the three stakeholders to an ideal state; When certain conditions are met, the decision-making behaviors of the three stakeholders can evolve to an ideal state, and effective government supervision can promote the transformation of farmers from nongreen to green pesticide application behavior, and encourage consumers to purchase high-quality agricultural products.

**INDEX TERMS** Food safety, quality and safety of agricultural product, behavior of farmers, green application, evolutionary game.

## I. INTRODUCTION

It is urgent that the improve quality and safety of agricultural products be improved [1], [2]. Food safety is an important strategic issue related to national economic development and people's livelihoods. The quality and safety of agricultural products is the fundamental guarantee for food safety. However, in recent years, incidents such as poisonous cabbage, poisonous rice, poisonous cotton, and poisonous cowpea, have occurred frequently, causing high attention and general concerns among all sectors of society [3], [4]. The quality and safety of agricultural products involves a game between the government, consumers and farmers [5]. The ''National Strategic Plan for Promoting Agriculture by Quality (2018-2022)'' stated that the direction of increasing production will be turned to the direction of improving the quality, the pursuit of output will be turned to the pursuit of quality, and there will be adherence to quality and green agriculture. Promoting the evolution of farmers' behavior from nongreen to green pesticide application is a key link

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in improving the quality and safety of agricultural products [6], [7]. The pesticide application behavior of farmers is one of the key factors that determines the quality and safety of agricultural products. Whether the government takes reasonable and effective measures to promote the green pesticide application of farmers is crucial [8]. In addition, whether consumers are willing to pay higher fees for high-quality agricultural products [9], and whether the government can guide consumers to choose high-quality agricultural products [10] have become a motivation for farmers to adopt green pesticide application. Currently, China's economic and social development is in a complex environment of multicenter interdependence [11]. It is necessary to explore the decision-making game behavior and evolutionary laws between the government, consumers, and farmers, then, build an effective driving mechanism, and finally encourage farmers to take the initiative to adopt green pesticide application, using the theoretical support and practical reflection.

As economic men, farmers pursue their best interests, and farmers mainly care about whether high-quality agricultural products can bring greater profits. Many scholars have called on the government to implement agricultural product quality and safety subsidy policies, combined with reasonable reward and punishment measures to form a consequence mechanism for farmers' green pesticide application behaviors, and effectively encourage and guide farmers to take the initiative to adopt green pesticide applications [12]. Furthermore, whether the government supervises the safety of agricultural products also affects consumers' purchasing behavior. Whether consumers are willing to pay higher fees for high-quality agricultural products, and consumers' acceptance of high-quality agricultural products have become important factors in promoting farmers' green pesticide application. Evolutionary stable strategies have been widely used in the field of agricultural product quality and safety. The decision-making behavior of the government and consumers is the key influencing factor of farmers' behavioral decision. Therefore, this study includes the government, farmers and consumers in an evolutionary game model to explore the game relationships and evolutionary paths of the decision making among the three stakeholders.

Supply of safe food affects the decision-making process of related stakeholders, which is essential at various levels, such as stakeholders, national and global [13]. Based on the food safety and quality safety of agricultural products, the study includes the government, farmers and consumers in an evolutionary game model to explore game relationships and evolution paths of decision making among the three stakeholders. Existing research focuses on the analysis of game evolution between two stakeholders under food safety and quality and safety of agricultural product [14], [15], a small amount of research focuses on the game evolution among government, farmers, and consumers, ignoring the important role of consumers. Therefore, this research has used a $2 \times 2 \times 2$ dynamic evolutionary game model including the characteristics of incomplete information and the bounded rationality of government, consumers, and farmers to determine under the quality and safety of agricultural products. This can reveal the evolution paths and evolutionary laws of the decision-making behavior of the government, consumers and farmers, and find the ideal state. The goal formulating a reward and punishment mechanism for the decision-making of the three stakeholders for farmers' green pesticide application behaviors, and encourage consumers to purchase high-quality agricultural products and provide helpful suggestions.

## II. THEORETICAL HYPOTHESIS AND GAME MODEL

Evolutionary game theory, which assumes that the game parties hold bounded rationality and imitative and learning abilities, might be more applicable for some realistic issues [16]. Evolutionary game theory combines the strategy choices in a game with the dynamic evolutionary process to analyze how groups with incomplete information choose and adjust their strategies in the case of bounded rationality. Evolutionary game theory believes that the sides in the game have the ability to learn and can guide their next strategy choice through imitative learning from past experience. Therefore, through this long-term imitation and improvement, all players have the opportunity to reach a stable state, that is, form an evolutionary stability strategy [17], [18].

We incorporated the government, farmers and consumers into a game system. All three stakeholders have the characteristics of bounded rationality and the abilities to learn and imitate. The profit and loss analysis of the stakeholders in different strategies is as follows:

### A. THE RELATED BENEFITS OF THE GOVERNMENT

Suppose the probability of the government taking safety supervision measures is $x(0 \leq x \leq 1)$, and the probability of not taking safety supervision measures is $(1-x)$. There are two situations: ① When the government supervises the pesticide application behavior of farmers, the supervision cost is $C_1$ [9]. The government certification cost of high-quality agricultural products is $C_2$ [19]. The government subsidies for farmers to apply green pesticide application is $S$ [20]. The government obtains the beneficial effects of farmers' green pesticide application is $W_1$. The government receives the fines from farmers' nongreen pesticide application is $M$. The impact of government supervision on social stability is $W_2$ [9]. ② When the government does not supervise the pesticide application behavior of farmers, the government obtains the beneficial effects of the green pesticide application behavior of farmers is $W_1$ [9]. The government bears the cost of adverse effects on farmers' nongreen pesticide application is $V_1$. The negative impact of government non-supervision regulation on social stability is $V_2$.

### B. THE RELATED BENEFITS OF THE FARMERS

Suppose the probability of farmers choosing green pesticide application behavior is $y(0 \leq y \leq 1)$, and the probability of nongreen pesticide application behavior is $(1-y)$. There are two situations: ① If farmers adopt green pesticide application behavior, the investment in purchasing green pesticides is $C_3$ [9]. The additional profit that farmers obtain from consumers buying high-quality agricultural products is $D_3$. After the government certifies high-quality agricultural products, the additional income that farmers obtain is $L_1$ [19], and farmers receive subsidies from the government is $S$ [20] ② If farmer adopts nongreen pesticide application behavior and does not obtain additional profit from consumers buying high-quality agricultural products, they obtain $D_3$. The government fines paid by farmers for nongreen pesticide application is $M$ [21].

### C. THE RELATED BENEFITS OF THE CONSUMERS

Suppose the probability of consumers buying high-quality agricultural products is $z(0 \leq z \leq 1)$, and the probability of consumers buying low-quality agricultural products is $(1 - z)$. ① When the government supervises the quality and safety of agricultural products, the government's supervision of agricultural products has a positive impact on consumers is $T_1$ [22], If consumers accept the purchase of high-quality agricultural products, the extra cost that consumers pay is $D_3 + L_1$, The beneficial effect of consumers eating high-quality agricultural products on their health is $W_3$ [23]; If consumers do not buy high-quality agricultural products, the additional cost savings is $D_3 + L_1$. The negative health effect of consumers eating low-quality agricultural products is $V_3$ [24]. ② When the government does not supervise the quality and safety of agricultural products, the government does not supervise the quality and safety of agricultural products, the negative effect to consumers is $T_2$ [9]. If the consumers accept the purchase of high-quality agricultural products, and the additional cost that consumers pay is $D_3$. The beneficial effect of consumers eating high-quality agricultural products on their health is $W_3$ [25]. If consumers do not buy high-quality agricultural products, the additional cost that consumers pay is $D_3$, The negative health effect of consumers eating low-quality agricultural products is $V_3$ [26].

According to the above content, the income matrix can be derived. The type of strategy combinations are based on whether the government implements safety monitoring measures, whether farmers adopt green pesticide application behavior, and whether consumers are willing to buy high-quality agricultural products. The specific content is shown in Table 1.

In the above relationship, according to a actual situation, the constraint conditions can be added as follows: The monitoring costs of the government monitoring the pesticide application behavior of farmers $C_1$ is greater the costs of government certification of high-quality agricultural products $C_2$, which means $C_1 > C_2$.

## III. GAME EQUILIBRIUM ANALYSES

(1) The expected profits of the government's supervision and nonsupervision decisions are $V_{1X}$ and $V_{2X}$ respectively, the average profit is $\overline{V_X}$:

$$\begin{aligned} V_{1X} &= yz(-C_1 + W_1 + S - C_2 + W_2) + y(1-z)(-C_1 \\ &\quad + W_1 + S - C_2 + W_2) + z(1-y)(-C_1 + W_2 - M) \\ &\quad + (1-y)(1-z)(-C_1 + W_2 - M) \\ &= -C_1 + W_2 - M + y(M + S - C_2 + W_1) \\ V_{2X} &= yz(W_1 - V_2) + y(1-z)(W_1 - V_2) - z(1-y)(V_1 + V_2) \\ &\quad - (1-y)(1-z)(V_1 + V_2) = -V_1 - V_2 + y(W_1 + V_1) \\ \overline{V_X} &= x \cdot V_{1X} + (1-x)V_{2X} \\ &= x[-C_1 + W_2 - M + y(M + S - C_2 + W_1)] \\ &\quad + (1-x)[-V_1 - V_2 + y(W_1 + V_1)] \end{aligned}$$

(2) The expected profits of the farmers' decisions on green application behavior and nongreen application behavior are $V_{1Y}$ and $V_{2Y}$ respectively, the average profit is $\overline{V_Y}$:

$$\begin{aligned} V_{1Y} &= xz(-C_2 + D_3 + L_1 + S) + x(1-z)(-C_2 + S) + z(1-x) \\ &\quad (-C_2 + D_3) + (1-x)(1-z)(-C_2) \\ &= L_1 xz + Sx + D_3 z - C_2 \\ V_{2Y} &= xz(C_2 - M) + x(1-z)(C_2 - M) = C_2 x - Mx \\ \overline{V_Y} &= y \cdot V_{1Y} + (1-y)V_{2Y} = y(L_1 xz + Sx + D_3 z - C_2) \\ &\quad + (1-y)(C_2 x - Mx) \end{aligned}$$

(3) The expected profits of consumers deciding to buy high-quality agricultural products and not buy high-quality agricultural products are $V_{1Z}$ and $V_{2Z}$ respectively, the average profit is $\overline{V_Z}$:

$$\begin{aligned} V_{1Z} &= xy(T_1 - D_3 - L_1 + W_3) + x(1-y)(T_1 - D_3 + W_3) \\ &\quad + y(1-x)(T_2 - D_3 + W_3) + (1-x) \\ &\quad \times (1-y)(T_2 - D_3 + W_3) \\ &= T_1 x - T_2 x - L_1 xy + T_2 - D_3 + W_3 \\ V_{2Z} &= xy(T_1 + D_3 + L_1 - V_3) + x(1-y) \\ &\quad \times (T_1 + D_3 + L_1 - V_3) \\ &\quad + y(1-x)(T_2 + D_3 - V_3) + (1-x) \\ &\quad \times (1-y)(T_2 + D_3 - V_3) \\ &= T_1 x - T_2 x + L_1 xy + T_2 - D_3 - V_3 \\ \overline{V_Z} &= xV_{1Z} + (1-x)V_{2Z} = x(T_1 x - T_2 y - L_1 xy + T_2 - D_3 \\ &\quad + W_3) + (1-x)(T_1 x - T_2 x + L_1 xy + T_2 + D_3 - V_3) \end{aligned}$$

### A. REPLICATOR DYNAMIC EQUATIONS OF GOVERNMENT SAFETY SUPERVISION BEHAVIOR

$$\begin{aligned} F(x) = \frac{dx}{dt} &= x(V_{1X} - \overline{V_X}) = x(1-x) \\ &\quad \times [-C_1 - M + W_2 + V_1 + V_2 + y(S - V_1 - C_2 + M)] \end{aligned} \tag{2-1}$$

(1) When $y = \frac{C_1+M-W_2-V_1-V_2}{S-V_1-C_2+M}$, we obtain $F(x) = 0$, which means that whether the government implements safety supervision is in a stable state.

(2) When $y \neq \frac{C_1+M-W_2-V_1-V_2}{S-V_1-C_2+M}$, let $F(x) = 0$, we obtain $x = 0$ and $x = 1$ may be the evolutionary stable point. It is

**TABLE 1.** Income combination of the three-party evolutionary game.

| Strategy portfolio | Government's profits | Farmer's profits | consumers' profits |
|---|---|---|---|
| (Supervision, Green application, Purchase) | $-C_1+S-C_2+W_1+W_2$ | $-C_2+D_3+L_1+S$ | $T_1-D_3-L_1+W_3$ |
| (Supervision, Green application, No Purchase) | $-C_1+S-C_2+W_1+W_2$ | $-C_2+S$ | $T_1+D_3+L_1-V_3$ |
| (Supervision, No green application, Purchase) | $-C_1-M+W_2$ | $C_2-M$ | $T_1-D_3+W_3$ |
| (Supervision, No green application, No Purchase) | $-C_1-M+W_2$ | $C_2-M$ | $T_1+D_3-V_3$ |
| (No supervision, Green application, Purchase) | $W_1-V_2$ | $-C_2+D_3$ | $T_2-D_3+W_3$ |
| (No supervision, Green application, No Purchase) | $W_1-V_2$ | $-C_2$ | $T_2+D_3-V_3$ |
| (No supervision, No green application, Purchase) | $-V_1-V_2$ | 0 | $T_2-D_3+W_3$ |
| (No supervision, No green application, No Purchase) | $-V_1-V_2$ | 0 | $T_2+D_3-V_3$ |

known via the stability theorem of the replication dynamic equation that $x$ as a stable strategy needs to conform to $F(x)=0$ and $F'(x)<0$.

The derivative with respect to $F(x)$, is:

$$F'(x) = (1-2x) \times [-C_1-M+W_2+V_1+V_2+y(S-V_1-C_2+M)] \quad (2\text{-}2)$$

① When $y < \frac{C_1+M-W_2-V_1-V_2}{S-V_1-C_2+M}$, $\frac{dF(x)}{dx}|_{x=0} < 0$, and $\frac{dF(x)}{dx}|_{x=1} > 0$. Therefore, $x=0$ is the point of evolutionary stability.

② When $y > \frac{C_1+M-W_2-V_1-V_2}{S-V_1-C_2+M}$, $\frac{dF(x)}{dx}|_{x=0} > 0$, and $\frac{dF(x)}{dx}|_{x=1} < 0$. Therefore, $x=1$ is the point of evolutionary stability.

### B. REPLICATOR DYNAMIC EQUATIONS OF FARMERS' GREEN APPLICATION BEHAVIOR

$$F(y) = \frac{dy}{dt} = y(V_{1Y} - \overline{V_Y}) = y(1-y)\,[x(L_1z+S+M-C_2)+D_3z-C_2] \quad (2\text{-}3)$$

(1) When $x = \frac{C_2-D_3z}{L_1z+S+M-C_2}$, we obtain $F(y)=0$, which means that whether farmers implement green pesticide application behavior is in a stable state.

(2) When $x \neq \frac{C_2-D_3z}{L_1z+S+M-C_2}$, let $F(y)=0$, we obtain $y=0$ and $y=1$ may be the evolutionary stable point. It is known via the stability theorem of the replication dynamic equation that $y$ as a stable strategy needs to conform to $F(y)=0$ and $F'(y)<0$.

The derivative with respect to $F(y)$, is:

$$F'(y) = \frac{dF(y)}{dy} = (1-2y)\,[x(L_1z+S+M-C_2)+D_3z-C_2] \quad (2\text{-}4)$$

① When $x < \frac{C_2-D_3z}{L_1z+S+M-C_2}$, $\frac{dF(y)}{dy}|_{y=0} < 0$, and $\frac{dF(y)}{dy}|_{y=1} > 0$. Therefore, $y=0$ is the point of evolutionary stability.

② When $x > \frac{C_2-D_3z}{L_1z+S+M-C_2}$, $\frac{dF(y)}{dy}|_{y=0} > 0$, and $\frac{dF(y)}{dy}|_{y=1} < 0$. Therefore, $y=1$ is the point of evolutionary stability.

### C. REPLICATOR DYNAMIC EQUATIONS OF CONSUMERS PURCHASING HIGH-QUALITY AGRICULTURAL PRODUCTS

$$F(z) = \frac{dz}{dt} = z\left(V_{1Z} - \overline{V_Z}\right) = z(1-z)(-2L_1xy+W_3+V_3-2D_3) \quad (2\text{-}5)$$

(1) When $y \neq \frac{W_3+V_3-2D_3}{2L_1x}$, we obtain $F(z)=0$, which means that whether consumers purchase high-quality agricultural products is in a stable state.

(2) When $y = \frac{W_3+V_3-2D_3}{2L_1x}$, let $F(z)=0$, we obtain $z=0$ and $z=1$ may be the evolutionary stable point. It is known via the stability theorem of the replication dynamic equation that $z$ as a stable strategy needs to conform to $F(z)=0$ and $F'(z)<0$.

The derivative with respect to $F(z)$, is:

$$F'(z) = (1-2z)(-2L_1xy+W_3+V_3-2D_3) \quad (2\text{-}6)$$

① When $y < \frac{W_3+V_3-2D_3}{2L_1x}$, $\frac{dF(y)}{dy}|_{y=0} < 0$, and $\frac{dF(y)}{dy}|_{y=1} > 0$. Therefore, $z=0$ is the point of evolutionary stability.

② When $y > \frac{W_3+V_3-2D_3}{2L_1x}$, $\frac{dF(y)}{dy}|_{y=0} > 0$, $\frac{dF(y)}{dy}|_{y=1} < 0$. Therefore, $z=1$ is the point of evolutionary stability.

### D. ANALYSIS OF THE EVOLUTION STABILITY OF GOVERNMENT FARMERS' AND CONSUMERS STRATEGY

From the formulas (2-1), (2-3) and (2-5) show that government's safety supervision decisions are related to farmers' decisions on green pesticide application behavior. Farmers' decisions on green pesticide application behavior are related to the government's safety supervision decisions and consumers' decisions to purchase high-quality agricultural products. Consumers' decisions to purchase high-quality agricultural products are related to the government's safety supervision decisions and farmers' decisions on green pesticide application behavior. Based on this, this study analyzes the strategy evolutionary stability of the three stakeholders of government, farmers and consumers step by step, This includes the evolutionary stability analysis of government and farmers, and the evolution stability analysis of farmers and consumers.

### 1) ANALYSIS ON THE EVOLUTIONARY STABILITY OF THE GOVERNMENT AND FARMERS

Equations (2-1) and (2-3) show that the dynamic game between the government and farmers contains 5 equilibrium points (0, 0), (0, 1), (1, 0), (1, 1), and ($x^* = \frac{C_2 - D_3 z}{L_1 z + S + M - C_2}, y^* = \frac{C_1 + M - W_2 - V_1 - V_2}{S - V_1 - C_2 + M}$), only when $0 \leq \frac{C_2 - D_3 z}{L_1 z + S + M - C_2} \leq 1, 0 \leq \frac{C_1 + M - W_2 - V_1 - V_2}{S - V_1 - C_2 + M} \leq 1$ is true. This gives the relevant content of the dynamic game's evolution.

Matrix $J_1$ determinant:

$$\begin{aligned} \det J_1 = {} & (1 - 2x)\,[-C_1 - M + W_2 + V_1 + V_2 \\ & + y(S - V_1 - C_2 + M)] \\ & (1 - 2\,y)\,[x(L_1 z + \mathrm{S} + M - \mathrm{C}_2) + D_3 z - \mathrm{C}_2] \\ & - x(1 - x)(L_1 z + S + M - C_2) y(1 - y) \\ & \times (S - V_1 - C_2 + M) \end{aligned}$$

The trace of matrix $J_1$ is:

$$\begin{aligned} trJ_1 = {} & (1 - 2x)\,[-C_1 - M + W_2 + V_1 + V_2 \\ & + y(S - V_1 - C_2 + M)] \\ & - (1 - 2y)\,[x(L_1 z + S + M - C_2) + D_3 z - C_2] \end{aligned}$$

Local stability analysis was performed based on the above 5 equilibrium points, and the results are shown in Table 2.

**TABLE 2.** **Analysis of the results of the evolutionary game stability of the government and farmers.**

| Equilibrium point | $detJ_1$ symbol | $trJ_1$ symbol | result | Stable condition |
|---|---|---|---|---|
| $x=0$, $y=0$ | + | - | *EES* | $W_2+V_1+V_2<C_1+M$ $D_3z<C_2$ |
| $x=0$, $y=1$ | + | - | *EES* | $W_2+S+V_2<C_1+C_2$ $D_3z>C_2$ |
| $x=1$, $y=0$ | + | - | *EES* | $W_2+V_1+V_2>C_1+M$ $L_1z+S+M+D_3z<2C_2$ |
| $x=1$, $y=1$ | + | - | *EES* | $W_2+S+V_2>C_1+C_2$ $L_1z+S+M+D_3z>2C_2$ |
| $x=x^*$, $y=y^*$ | 0 | 0 | Saddle point | Saddle point under any conditions |

Table 2 shows that if certain conditions are met during the dynamic evolution of the game between the government and farmers, a stable point can be formed:

① A stable point can be formed when the sum of the beneficial effects of the government supervising social stability and government's commitment to the negative effects of nongreen pesticide application by farmers is less than the sum of the government's regulatory costs of pesticide application behavior and fines paid by nongreen pesticide application farmers. In addition, the product of farmers' failure to obtain extra income from consumers buying high-quality agricultural products and the probability of consumers buying high-quality agricultural products is less than the costs of the government for certification of high-quality agricultural products, the result of the game between the government and farmers is a stable state $x = 0, y = 0$. That is, the government does not supervise safety, and farmers do not adopt green pesticide application behavior.

② A stable state can be formed when the sum of the beneficial effects of the government supervising social stability and government's subsidies to farmers for green pesticide application is less than the sum of the government's regulatory costs for farmers' pesticide application and the cost of government certification of high-quality agricultural products. In addition, when the product of farmers' failure to obtain extra income from consumers buying high-quality agricultural products and the probability of consumers buying high-quality agricultural products is less than the costs of the government for certification of high-quality agricultural products. The result of the game between government and farmers is a stable state $x = 0, y = 1$. That is, the government does not supervise safety, and farmers adopt green pesticide application behavior.

③ A stable state can be formed when the sum of the beneficial effects of the government supervising on social stability and government's commitment to the negative effects of nongreen pesticide application by farmers is more than the sum of the government's regulatory costs of farmers' pesticide application behavior and the government's fines paid by nongreen pesticide farmers. In addition, when the product of farmers' failure to obtain extra income from consumers buying high-quality agricultural products and the probability of consumers buying high-quality agricultural products is less than the costs of the government for certification of high-quality agricultural products, The result of the game between government and farmers is a stable state $x = 1, y = 0$. That is, government supervises safety, farmers do not adopt green pesticide application behavior.

④ A stable state can be formed when the sum of the beneficial effects of the government supervising on social stability and government's commitment to the negative effects of nongreen pesticide application by farmers is more than the sum of the government's regulatory cost of farmers' pesticide application behavior and the government fines paid by nongreen pesticide farmers. In addition, when the product of farmers' failure to obtain extra income from consumers buying high-quality agricultural products and the probability of consumers buying high-quality agricultural products is more than the costs of the government certification of high-quality agricultural products, The result of the game between government and farmers is a stable state $x = 1, y = 1$.

That is, government supervises safety, and farmers adopt green pesticide application behavior.

### 2) ANALYSIS OF THE EVOLUTIONARY STABILITY OF FARMERS AND CONSUMERS

Equations (2-3) and (2-5) show that the dynamic game between farmers and consumers contains 5 equilibrium points (0, 0), (0, 1), (1, 0), (1, 1), (1, 1), and ($y^{**} = \frac{W_3+V_3-2D_3}{2L_1x}$, $z^{**} = \frac{C_2-(L_1z+S+M-C_2)}{D_3}$), only when $0 \leq \frac{W_3+V_3-2D_3}{2L_1x} \leq 1$, $0 \leq \frac{C_2-(L_1z+S+M-C_2)}{D_3} \leq 1$ is true. This gives the relevant content of the dynamic game's evolution.

Matrix $J_2$ determinant:

$$\begin{aligned}\det J_2 = &(1-2y)\left[x(L_1z+S+M-C_2)+D_3z-C_2\right]\\ &\times(1-2z)(-2L_1xy+W_3+V_3-2D_3)\\ &-y(1-y)\left[x(L_1z+S+M-C_2)+D_3z-C_2\right]\\ &\times z(1-z)(-2L_1xy+W_3+V_3-2D_3)\end{aligned}$$

The trace of matrix $J_1$ is:

$$\begin{aligned}trJ_1 = &(1-2y)\left[x(L_1z+S+M-C_2)+D_3z-C_2\right]\\ &+(1-2z)(-2L_1xy+W_3+V_3-2D_3)\,xy\end{aligned}$$

Local stability analysis was performed based on the above 5 equilibrium points, and the results are shown in Table 3.

**TABLE 3. Analysis results of the stability of the game between farmers and consumers.**

| Equilibrium point | $detJ_1$ symbol | $trJ_1$ symbol | result | Stable condition |
|---|---|---|---|---|
| $y=0$, $z=0$ | + | - | *EES* | $2D_3 < W_3+V_3$ |
| $y=0$, $z=1$ | + | - | *EES* | $2D_3 > W_3+V_3$ <br> $C_2 < D_3$ |
| $y=1$, $z=0$ | + | + | Unstable | Unstable under any conditions |
| $y=1$, $z=1$ | + | - | *EES* | $2(L_1x+D_3)<W_3+V_3$ <br> $C_2 < D_3$ |
| $y=y^{**}$, $z=z^{**}$ | 0 | 0 | Saddle point | Saddle point under any conditions |

Table 3 shows that if certain conditions are met during the dynamic evolution of the game between farmers and consumers, a stable point can be formed:

① A stable point can be formed when the farmers obtain twice the extra income from when consumers buy high-quality agricultural products less than the sum of the positive health effects of consumers eating high-quality agricultural products and the negative health effects of consumers eating inferior agricultural products. The result of the game between farmers and consumers is a stable state $y = 0, z = 0$. That is, farmers do not adopt green pesticide application behavior, and consumers buy low-quality agricultural products.

② A stable point can be formed when the farmers obtain twice the extra income that consumers buy high-quality agricultural products at a rate greater than the sum of the positive health effects of consumers eating high-quality agricultural products and the negative health effects of consumers eating inferior agricultural products. In addition, the cost of the government certification of high-quality agricultural products is less than the additional profit that farmers obtain from consumers buying high-quality agricultural products. The result of the game between farmers and consumers is a stable state $y = 0, z = 1$ That is, farmers do not adopt green pesticide application behavior, and consumers buy high-quality agricultural products.

③ A stable point can be formed when the product of the extra income obtained by farmers after the certification of high-quality agricultural products and the probability that the governments take safety supervision measures is less than the health effects of consumers' consumption of high-quality agricultural products and the negative health effects of consumers' consumption of low-quality agricultural products. In addition, the cost of the government certification of high-quality agricultural products is less than the additional profits that farmers obtain from consumers buying high-quality agricultural products. The result of the game between farmers and consumers is a stable state $y = 0, z = 1$ That is, farmers adopt green pesticide application behavior, and consumers buy high-quality agricultural products.

## IV. NUMERICAL EXPERIMENT AND SIMULATION

### A. EFFECT OF DIFFERENT INITIAL PROPORTIONS ON THE EVOLUTIONARY RESULTS

The study starts from the idea of human-oriented management, and promotes the tripartite game of the government, farmers, and consumers to eventually evolve into the ideal decision-making state of government safety supervision, farmers' green pesticide application behavior, and consumers purchasing safe agricultural products ($x = 1, y = 1, z = 1$). According to constraint conditions and copied dynamic equations, the MATLAB simulation software is used to analyze the ideal state of the tripartite game among the government, farmers and consumers [27], [28]. To make a more intuitive understanding of the evolution process and results between the government, farmers and consumers in numerical experiments, we present experiments to simulate the evolution process when the initial proportions and related parameter changes. We obtain the data and preprocess the data through the three methods of publishing data in the National Statistical Yearbook [29], multi-subject questionnaire survey, and on-the-spot investigation, we set the basic parameter values are as follows: $C_1 = 20, C_2 = 15, C_3 = 30, S = 15, M = 30, W_1 = 30, W_2 = 40, W_3 = 20, V_1 = 15, V_2 = 30, V_3 = 10, D_3 = 10, L_1 = 20, T_1 = 40$, and $T_2 = 20$.

**(1)** The impact of government subsidies and punishments on farmers on the evolutionary process. Taking $x_0 = 0.4$, $y_0 = 0.6$, and $z_0 = 0.5$ as an example, leave the other

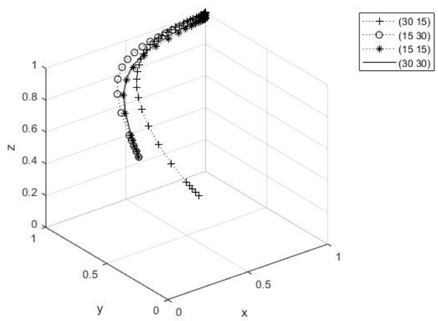


**FIGURE 1.** Spatial diagram of government rewards and punishments.

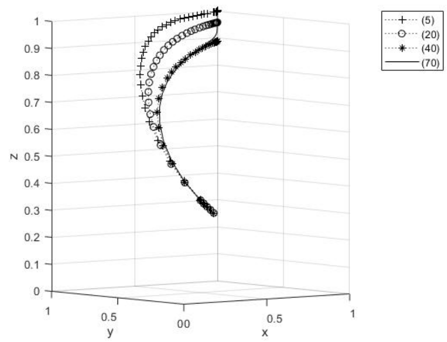


**FIGURE 2.** Spatial diagram of government certification.

parameters unchanged, the parameter values are $S_1 = 15$, $M = 15$; $S_1 = 15$, $M = 30$; $S_1 = 30$, $M = 15$; and $S_1 = 30$, $M = 30$. Figure 1 shows that when the government rewards and punishes farmers' green or nongreen pesticide application, the tripartite ideal state evolves. When the penalty is fixed, as the reward increases, the convergence speed of the tripartite evolutionary system is faster, and the time it takes to converge to an ideal state decreases. When the reward is fixed, as the penalty increases, the convergence speed of the tripartite evolutionary system decelerates, and the time it takes to converges to an ideal state increases. When the reward is less than the penalty, the convergence speed of the tripartite evolutionary system decelerates, and the time it takes to converge to an ideal state increases. When the reward is greater than the penalty, the convergence speed of the tripartite evolutionary system is faster, and the time it takes to converges to an ideal state decreases. From the above analysis, we can see that government adopts four types of the rewards and punishments, including, light rewards and light penalties, heavy penalties and light rewards, light penalties and heavy rewards, and heavy rewards and heavy penalties to gradually accelerate the convergence speed of tripartite evolutionary system, and the time required to converge to an ideal state gradually decreases.

**(2)** The effect of the extra income obtained by farmers after the government has certified high-quality agricultural products on the evolutionary process. Taking $x_0 = 0.4$, $y_0 = 0.6$ and $z_0 = 0.5$ as an example, leave the other parameters unchanged, the value of $L_1$ from small to large is 5, 20, 40, and 70. Figure 2 shows that when the government grants certifies of high-quality agricultural products, the additional income that farmers obtain increases, the convergence speed of the tripartite evolutionary system is faster, and the time it takes to converge to an ideal state decreases. From the above analysis, we can see that the government grants the certification of high-quality agricultural products is conducive to establish an ideal state among the three parties.

**(3)** The impact of changes in government supervision costs on the evolutionary process. Taking $x_0 = 0.4$, $y_0 = 0.6$ and $z_0 = 0.5$ as an example, leave the other parameters unchanged, the value of $C_1$ from small to large is 5, 20, 40, and 70. Figure 3 shows that when the cost of the government

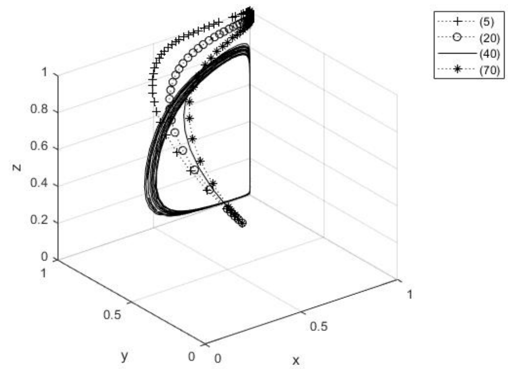


**FIGURE 3.** Spatial diagram of government investment.

supervision increases, the speed of the tripartite evolutionary system converges is faster, and the time it takes to converges to an ideal state decreases. From the above analysis, we can see that the increased cost of government supervision is conducive to establish an ideal state among the three parties.

**(4)** The impact of changes in the cost of farmers' green application behavior on the evolutionary process. Taking $x_0 = 0.4$, $y_0 = 0.6$ and $z_0 = 0.5$ as an example, leave the other parameters unchanged, the value of $C_3$ from small to large is 5, 20, 40, and 70. Figure 4 that when the cost of green application behavior of farmers gradually increases, the convergence speed of the tripartite evolutionary system decelerates, and the time it takes to converges to an ideal state increases. From the above analysis, we can see that the falling cost of farmers' green application behavior is conducive to establish an ideal state among the three parties.

**(5)** The impact of the extra cost of consumers buying high-quality agricultural products on the evolutionary process. Taking $x_0 = 0.4$, $y_0 = 0.6$ and $z_0 = 0.5$ as an example, leave the other parameters unchanged, the value of $D_3$ from small to large is 5, 20, 40, and 70. Figure 5 shows that when the extra cost for consumers to purchase high-quality agricultural products is too high or too low, the convergence speed of the tripartite evolutionary system decelerates, and the time it takes to be required to converge to an ideal state increases. When the extra costs for consumers to purchase high-quality agricultural products is within a moderate range,

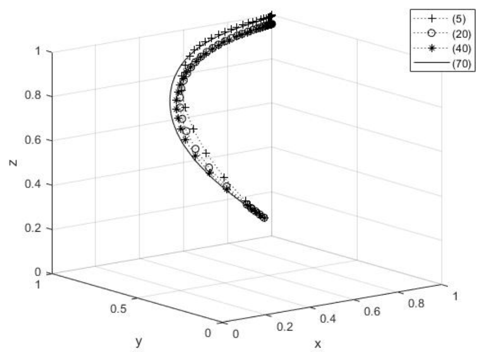


**FIGURE 4.** Spatial diagram of transformation investment.

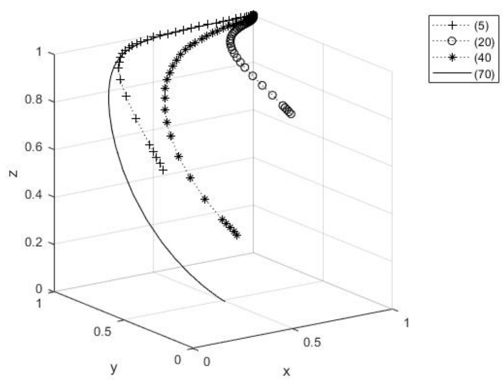


**FIGURE 5.** Spatial diagram of the extra cost of consumers.

as the extra costs for consumers to purchase high-quality agricultural products increases, the convergence speed of the tripartite evolutionary system is faster, and the time it takes to converges to an ideal state decreases, and the system finally evolves to an ideal state.

### B. DISCUSSION

Through the dynamic analysis of the decision-making replication among the three stakeholders in the safety management of the government, farmers, and consumers, the analysis of the evolutionary stability and the verification of the numerical simulation experiments, the following main conclusions are drawn:

(1) The decision replication dynamic equation shows that the proportion of government safety supervision decisions is related to the proportion of farmers' decisions on green pesticide application. The proportion of farmers' decisions on green pesticide application is related to the proportion of government safety supervision decisions and the proportion of consumers' decisions on purchasing high-quality agricultural products. The proportion of consumers' decisions on purchasing high-quality agricultural products is related to the proportion of government safety supervision decisions and the proportion of farmers' decisions on green pesticide application. Specifically, government decisions are directly affected by farmers' decisions, but not by consumers. Farmers' decisions are affected by both government and consumers decisions. Consumers' decisions are affected by government decisions and farmers' decisions. The link between the government, farmers and consumers in the tripartite decision-making process is farmers. In the process of safety production management process, it is necessary to clarify the relationships between the three parties.

(2) When the asymptotic stable point (1, 1, 1) is realized, the government does not take safety supervision measure, farmers adopt green pesticide application behavior, and consumers cannot buy high-quality agricultural products.. In this case, the decision-making behavior of government, farmers and consumers is the ideal state of trusteeship relationship. When the stability condition of the asymptotic stable point (1, 1, 1) is satisfied, through numerical simulation, we found that the proportion of stakeholders' strategy choices, the rewards and punishments of government, the government granting additional profits to farmers after the certification of high-quality agricultural products, the supervision cost of the government, the cost of farmers' green application behaviors, and the extra cost for consumers to purchase high-quality agricultural products affect the evolution of the three stakeholders to the ideal state. The increase in the proportion of stakeholders' strategy choice in either party or several parties makes the curve approach to (1, 1, 1) more quickly.

The numerical simulation results show that evolutionary process of the three parties to an ideal state is as follows: ① The government adopts four types of rewards and punishments, including, light rewards and light penalties, heavy penalties and light rewards, light penalties and heavy rewards, and heavy rewards and heavy penalties to gradually accelerate the convergence speed of the tripartite evolutionary system, and the time required to converge to an ideal state gradually decreases. ② When the government grants additional profit to farmers after the certification of high-quality agricultural products, the convergence speed of the tripartite evolutionary system increases, and the time required to converge to an ideal state decreases. ③ When the government's investment in supervision costs increases within a certain range, the convergence speed of a tripartite evolutionary system is accelerated, and the time required to converge to an ideal state is reduced. ④ When the cost of farmers' green application behaviors gradually increases, the convergence speed of the tripartite evolutionary system decelerates, and the time required to converge to an ideal state increases. ⑤ When the extra cost for consumers to purchase high-quality agricultural products is too high or too low, the convergence speed of the tripartite evolutionary system decelerates, and the time required to converge to an ideal state increases. When extra cost for consumers to purchase high-quality agricultural products increases within a moderate range, the time required for the tripartite evolutionary system to converge to an ideal state decreases.

## V. SUGGESTIONS AND COUTERMEASURES

Following the research idea of ''theoretical research-mathematical modeling-numerical simulation'', we reveal the decision-making game behavior and evolutionary law of the government, farmers and consumers. We draw the following conclusions:

(1) The government is a strong promoter of the safe production of agricultural products, can encourages the division of labor and collaboration among multiple departments, can implements comprehensive safety management, and can emphasizes the comprehensiveness and nature of safety management. The government can appropriately reduce the costs of safety supervision and increase penalties, provide agricultural economic support, and promote the transition from nongreen to green pesticide application behavior of farmers. At present, the deterrent effect of the government's supervision and punishment on farmers has decreased. The government should follow the management philosophy of guiding people's behavior, use various methods and measures to mobilize people's active behavioral management methods, formulate incentive-based management systems, and fully stimulate farmers' motivation for green pesticide application. The government should improve the certification mechanism for high-quality agricultural products, label high-quality agricultural products, and change the current chaotic situation in the high-quality agricultural product market.

(2) As the intermediary of tripartite game, farmers should actively respond to government decisions and actively learn laws and regulations issued by the government. They can change the ideology of agricultural product production and realized the transition from nongreen to green pesticide application. The government can introduce third-party certification agencies to establish long-term friendly cooperative relations with farmers and establish a credible certification mechanism for organic, green and pollution-free high-quality agricultural products. Farmers can develop a sale network of high-quality agricultural products, establish correct market price positioning, promote high-quality agricultural products at high prices, form their own brand effect, and effectively increase consumers trust.

(3) Consumers are purchasers of agricultural products, and the supply of high-quality agricultural products is closely related to the market demand. The information asymmetry between farmers and consumers, the lack of knowledge of high-quality agricultural products, and the relatively high prices of high-quality agricultural products have led to insufficient recognition and purchasing power of consumers. Consumers should improve their ability to identify high-quality agricultural products, and they should choose regular sales channels to purchase high-quality agricultural products, finally, while meeting their own needs, they should fully stimulate farmers' passion for producing high-quality agricultural products.

This research reveals the evolutionary path and evolutionary law of the behavior of the government, farmers, and consumers in safe production, and finds the equilibrium and stable conditions for the main body's decision to reach the ideal state. Numerical simulation verification is conducted to provide a theoretical reference and practical guidance for the government to make safe supervision decisions, farmers to choose green pesticide application behavior, and consumers to purchase high-quality agricultural products. The focus of future research is to collect actual research data and conduct further simulation research to make the research conclusions more objective and scientific.

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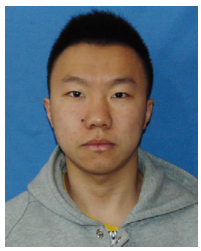

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