Research Article

Evolutionary Game Mechanism on Complex Networks of Green Agricultural Production under Intensive Management Pattern

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The diffusion of green agricultural production under intensive management pattern is an interactive process of strategy comparison and learning on complex networks among traditional farmers and new agricultural operation entities. Based on the theory of evolutionary game and complex networks, we construct evolutionary game models on the scale-free networks to simulate the evolution process of green agricultural production under the market mechanism and the government guidance mechanism, respectively. The comparison analysis results in different scenarios show that the stable state of the green agricultural production network is determined by interactions among the subjects. Detailed experimental results indicate that the double-score system under government guidance mechanism has a significant effect on the diffusion of the green agricultural production, of which the extra reward or penalty obtained from government is crucial. Besides, the diffusion of the green agricultural production under the market mechanism is mostly affected by the net profit of green agricultural production. These results are of great significance for increasing efficiency of government’s incentive and promoting the initiatives of traditional farmers and new agricultural operation entities in the green agricultural production.

1. Introduction

Green agricultural production is a friendly environmental approach of farming and green agricultural technology that can not only promote sustainable ecology, agricultural productivity, and profitability but also reduce negative externalities and environmental pollution [1, 2]. Green agricultural production is closely related to environmental technology innovation and agricultural modernization [3], which can achieve environmentally friendly agriculture and provide healthy, ecological green agricultural products [4, 5]. Therefore, green agricultural production has become a consensus for developed countries who take more subsidies or tax incentives to encourage technological innovation and application of green agriculture [6]. Further, some developing countries have also gradually realized the importance of green agricultural production and support farmers to adopt green agricultural production by constraining the use of fertilizers and pesticides, as well as subsidies for organic fertilizer, green agricultural technologies, and consumption of green agricultural products [7, 8]. As an agricultural power and developing country, the Chinese government has also taken measures to adopt green agricultural production in recent years [9, 10].

Compared with developed countries with high levels of intensive management, mechanization, and modernization, many developing countries especially China and India’s agricultural production mode, which is mainly characterized by family-sized and small-scale peasant economy [11], has the weak ability in developing green agricultural production [12, 13]. It is confirmed that these have led to serious problems of agricultural nonpoint source pollution and the safety trouble of agricultural products in China [14, 15]. To solve the above problems, intensive management operated by producer organizations has been implemented, which could not only to lower agricultural products’ transaction costs but also to make it more effective for agricultural producer organizations attaining green agricultural
technology and advisory services from each other. Thus, it is beneficial to realize agricultural modernization, improve agricultural ecological environment, and increase green agricultural production [16–18]. For example, developed countries such as the United States, Canada, Japan, and France have realized agricultural intensive management in the process of agricultural modernization and thus solved the problem of agricultural nonpoint source pollution [19]. This can be mainly attributed to environmental protection awareness and extra benefits by the green agricultural production of intensive farmers who are also called new agricultural operation entities [20, 21]. However, traditional farmers and new agricultural operation entities will coexist for a long time in China because of the low level of agricultural modernization, mountainous land-resource features, and farmers’ dependence on land and other factors [22, 23]. Therefore, it is of great significance to identify the motivation, attitude, and behaviors about green agricultural production among traditional farmers and new agricultural operation entities and their interaction under this intensive management pattern.

Researchers have suggested that green agricultural production is attributed to the motivation and attitude of relevant subjects [24], which will clarify the decision-making rules and behaviors of traditional farmers and new agricultural operation entities, to provide a theoretical basis for policy design. Gong et al. [25] found that there was a big gap between farmers’ consciousness and behavior of green agricultural production, so it is necessary to convert farmers’ consciousness into practical behavior of green agricultural production to reduce rural ecological pollution. By analyzing the attitude and behaviors of 1,322 family farms in China, Cai et al. [26] proposed that the government should focus on encouraging them to take behaviors of resource-saving and environment-friendly agricultural production. Meanwhile, Sophia et al. [27] surveyed the impact of green schemes about agricultural production on the livelihood of communities in the Kavango Region, Namibia, and then they found that they should inculcate a change in attitude so as to encourage collaborative efforts between communities and the green scheme management which would impact on the livelihood of people positively. As for incentives to take actions of green agricultural production, Lapka et al. [28] found that subsidy was effective based on the survey data of farmers in the Czech Republic. Further, Li et al. [29] used Cournot model to find that the amount of green production investment increased with the green subsidy rate.

Although green agricultural production is dependent on the willingness and motivation of traditional farmers and new agricultural operation entities, it is also constrained by other stakeholders. Zhou and Li [30] constructed a game model of relevant stakeholders to analyze the government’s influence on the development of ecological agriculture. Bugri [31] used questionnaires to collect and analyze data from stakeholders in two selected districts which were characterized by poor agricultural production and environmental degradation in northeast Ghana. They revealed that women had little or no power and control over land use decision making and management under customary land tenure, which would have negative implications for tenure security and environmental sustainability in northeast Ghana, since most women were involved in food production. Bantilan and Reddy [32] addressed that there were expected gains in efficiency to enhance Indian groundnut sector’s international competitiveness and efficiency by capital subsidies to accelerate technological upgrading to shed inefficiency in the processing sectors. As for realizing the effective operation of green agricultural products market, Deng et al. [33] constructed a coordination mechanism of cooperation between producers, consumers, food safety inspection department, and e-commerce platform based on the cooperative game theory. At the same time, Cui and Zhao [34] found the solution to the diffusion problem of green agricultural technology based on an evolutionary game model between the government and farmers. However, most of the existing studies are based on the investigations and analysis of the linear relationship among subjects, which are insufficient to describe the mechanism and interaction relationship of individual to group behavior during the process of green agricultural production.

Therefore, the complex network based on description of the “individual-group” relationship is increasingly used to reveal the complex interactions and behaviors between subjects [35, 36]; especially in the process of green agricultural production, a series of new research studies have emerged. By analyzing the survey data of more than 1200 agricultural producers, Lubell and Fulton [37] pointed out that the diffusion network in the Sacramento River basin’s agricultural water quality management can help agricultural producers to actively participate in water quality management and positively implement sustainable agriculture. Further, Jussaume and Glenna [38] found that local social networks to gain information among wheat producers in Washington were conducive to promote new sustainable agricultural production methods. In fact, the agricultural innovation system can be regarded as a complete innovation network, Yao et al. [39] found that the network relationship, distribution characteristics, and interaction between subjects can boost water-saving agriculture. As for the effect of farmer’s social network structure on farmer’s innovation adoption, Zhu [40] found that it has a far-reaching influence of decision and agricultural innovation diffusion process.

Based on the complex system theory, it can be known that in China’s agricultural production system under the intensive management pattern, there are many complex relationships between traditional farmers and new agricultural operation entities, such as learning, competition, co-existence, and interest connection [41, 42], forming a complex network system composed of multiple interacting subsystems. This paper constructs a complex network model of green agricultural production based on scale-free networks as diffusion carriers and abstracts the single agent into node and the interrelationship between agents into edge. Then, computational experiments are carried out by MATLAB to analyze the emergence process of cooperative behaviors between traditional farmers and new agricultural operation entities on the green agricultural production network. The purpose of this paper is to clarify the
motivation, network diffusion process, and guidance mechanism of green agricultural production under the intensive management pattern to promote the positive diffusion and benign evolution of China’s green agricultural production network.

2. Model Construction

2.1. Basic Hypotheses. The green agricultural production network constructed in this paper is based on the scale-free networks, and the nodes in the network represent the subjects of the network who are traditional farmers and new agricultural operation entities. The connection of this network is regarded as the interactive game relationship between subjects [43], which is embodied in the relationship of relatives, friends, or neighbors among traditional farmers, cooperative partnership among new agricultural operation entities, and strategic learning relationship between traditional farmers and new agricultural operation entities. In the evolution process of this network, each subject carries out repetitive game based on the game model and updates its strategy according to the rules until its strategy achieves stability. In addition, other assumptions are as follows:

1. Once the node in this network is connected with the other node, their effects are mutual [44], all connected edges in the green agricultural production network are undirected, and one connected edge exists at most between two nodes.

2. In a certain period, the size of this network is fixed and the connection relationship between nodes will not change due to the result of strategy selection [33]. In other words, the number of traditional farmers and the number of new agricultural operation entities in a region during a certain period are all fixed values.

3. The game parameters in the green agricultural production network are all in the unit.

2.2. Game Model. Considering the role of market and government in China’s green agricultural production, this paper constructs two types of mechanism to clarify the evolution process of green agricultural production diffusion among traditional farmers and new agricultural operation entities on scale-free networks.

2.2.1. Evolutionary Game Model of Market Mechanism. The market mechanism has been widely used in environmental governance, which is based on the hypothesis of “self-interest of human nature.” It is embodied by the economic signal on the market to help economic subjects make decisions of their production or consumption behavior; that is, there are environmental impact of green economy to promote green consumption and improve environmental quality [45].

Under the market mechanism, traditional farmers and new agricultural operation entities play pairwise games between nodes according to the game rules proposed in Section 2.1. Among them, $S_n$ and $S_h$, respectively, reflect the revenue of traditional farmers and new agricultural operation entities which are obtained by nongreen agricultural production; $D_e$ and $D_h$ are denoted as damage of water and land pollution brought by the nongreen agricultural production. If a new agricultural operation entity adopts nongreen agricultural production, the damage to its neighbors of other new agricultural operation entities and traditional farmers is expressed by $D_{ne}$ and $D_{nh}$, and accordingly the damage to their neighbors of other traditional farmers and new agricultural operation entities caused by the pollution of one traditional farmer’s adopting non-green agricultural production are expressed by $D_{he}$ and $D_{he}$. When adopting the strategy of nongreen agricultural production, a new agricultural operation entity may give compensation to its neighbors who have adopted green agricultural production to make up for their losses caused the pollution spillover, and the compensation to neighbors of new agricultural operation entities and traditional farmers is expressed as $R_{ne}$ and $R_{nh}$, respectively.

If new agricultural operation entities and traditional farmers adopt strategy of green agricultural production, they need to pay extra costs to learn green agricultural production technologies or buy organic fertilizers, which are denoted as $C_e$ and $C_h$, and the excess returns of green agricultural products obtained by their green agricultural production under the market mechanism are $\Delta S_n$ and $\Delta S_h$. In addition, the adoption of green technologies by a new agricultural operation entity to carry out green agricultural production will have a technological spillover effect on its neighbors of new agricultural operation entities and traditional farmers, which are assumed as $T_{ne}$ and $T_{nh}$, while the technological spillover effect by a traditional farmer’s adoption of green agricultural technologies is only on its neighbors of traditional farmers due to its limitations of funds, technologies, and production scale, which is assumed as $T_{he}$. Therefore, the payment matrix between subjects can be seen in Tables 1–3.

As can be seen, for example, in Table 1 when both of new agricultural operation entities and traditional farmers adopt the strategy of green agricultural production, hereby their payoff is, respectively, $(S_e + \Delta S_e - C_e)$ and $(S_h + \Delta S_h - C_h + T_{eh})$. For new agricultural operation entities, their payoff is the sum of their basic revenue from nongreen agricultural production $S_e$ and the additional revenue from green agricultural production $\Delta S_e$, then minus the additional cost of green agricultural production $C_e$; and for traditional farmers, their payoff is the sum of their basic revenue of nongreen agricultural production $S_h$, the extra revenue obtained from green agricultural production $\Delta S_h$, and the technology spillover effect generated by new agricultural operation entities $T_{eh}$, then minus the extra cost of green agricultural production $C_h$. Similarly, their payoffs of other strategies in Tables 1–3 can also be explained as above.

2.2.2. Evolutionary Game Model of Government Guidance Mechanism. Agriculture is China’s primary industry and plays a fundamental role in the national economy. And in
the present process of developing green agricultural production, there are still existing problems such as lack of green awareness, regulation policies, advanced technology, and enough funds. Therefore, a series of government guidance mechanisms are needed to realize green agricultural production and ensure the sustainable development and fundamental position of agriculture.

Based on the green agricultural production process during the growing season of crops, this paper takes the sales volume of green agricultural products and the amount of chemical fertilizer used as the score evaluation index, and the government implements the green agricultural production guidance mechanisms under the double-score system. $S_w$ and $S_h$, respectively, represent the standard values of green agricultural product sales in one unit which is attained by new agricultural operation entities and traditional farmers under the double-score system. The actual sales volume of green agricultural products of new agricultural operation entities and traditional farmers with green agricultural production and nongreen agricultural production is, respectively, denoted as $R_{seg}$, $R_{sec}$, $R_{shg}$, and $R_{sh}$. When $R_{seg} \geq S_w$ or $R_{sec} \geq S_{he}$, a new agricultural operation entity would get a positive score, or else it would get a negative score. Similarly, when $R_{shg} \geq S_{sh}$ or $R_{sh} \geq S_{sh}$, a traditional farmer would get a positive score, or else it would get a negative score. $S_w$ and $S_{sh}$ represent the standard value of chemical fertilizer application in one unit for new agricultural operation entities and traditional farmers under the double-score system, respectively. The actual volume of chemical fertilizer application for new agricultural operation entities and traditional farmers with green agricultural production and nongreen agricultural production is, respectively, denoted as $R_{seg}$, $R_{sec}$, $R_{shg}$, and $R_{sh}$. When $R_{seg} \geq S_w$ or $R_{sec} \geq S_{he}$, a new agricultural operation entity would get a positive score, or else it would get a negative score. Similarly, when $R_{shg} \geq S_{sh}$ or $R_{sh} \geq S_{sh}$, a traditional farmer would get a positive score, or else it would get a negative score.

Table 1: The pairwise game matrix between traditional farmers and new agricultural operation entities under the market mechanism.

|       | Green agricultural production | Nongreen agricultural production |
|-------|-------------------------------|----------------------------------|
| New agricultural operation entities | $(e,h)$                         | $(e,h)$                          |
| Green agricultural production     | $(S_e + \Delta S_e - C_e, S_h + \Delta S_h - C_h)$ | $(S_e - R_{seg} - D_e, S_h + \Delta S_h - C_h + T_{eh})$ |
| Traditional farmers               | $(\pi,h)$                       | $(t,h)$                          |
| Nongreen agricultural production  | $(S_e + \Delta S_e - C_e - D_{he}, S_h - D_{he} + T_{eh})$ | $(S_e - D_{he} - D_e, S_h - D_{he} - D_h)$ |

Table 2: The pairwise game matrix among traditional farmers under the market mechanism.

|       | Green agricultural production | Nongreen agricultural production |
|-------|-------------------------------|----------------------------------|
| Traditional farmers | $(h,h)$                         | $(h,h)$                          |
| Green agricultural production     | $(S_h + \Delta S_h - C_h + T_{hh}, S_h + \Delta S_h - C_h - D_{hh})$ | $(S_h + T_{hh} - D_{hh}, S_h + \Delta S_h - C_h - D_{hh})$ |
| Traditional farmers               | $(h,h)$                          | $(h,h)$                          |
| Nongreen agricultural production  | $(S_h + \Delta S_h - C_h - D_{hh}, S_h + \Delta S_h - C_h - D_{hh})$ | $(S_h - D_{hh} - D_{hh}, S_h - D_{hh} - D_{hh})$ |

Table 3: The pairwise game matrix among new agricultural operation entities under the market mechanism.

|       | Green agricultural production | Nongreen agricultural production |
|-------|-------------------------------|----------------------------------|
| New agricultural operation entities | $(e,e)$                         | $(e,\pi)$                        |
| Green agricultural production     | $(S_e + \Delta S_e - C_e + T_{ee}, S_e + \Delta S_e - C_e + T_{ee})$ | $(S_e - D_e - R_{ee} + T_{ee}, S_e + \Delta S_e - C_e - D_{ee} + R_{ee})$ |
| Nongreen agricultural production  | $(S_e + \Delta S_e - C_e - D_{ee}, S_e - D_{ee} + T_{ee})$ | $(S_e - D_e - D_{ee}, S_e - D_{ee} - D_{ee})$ |
During the growing season of the crops, the scores of new agricultural operation entities and the traditional farmers would be accumulated. If the sum is positive, they would attain reward of \( \alpha \) in one unit; otherwise, the penalty would be paid by \( \beta \) in one unit. The extra reward or penalty obtained by new agricultural operation entities and the traditional farmers when they adopt nongreen agricultural production strategy and green agricultural production strategy can be denoted as \( W_c \), \( W_h \), \( W_{eg} \), and \( W_{hg} \), which can be expressed as follows:

\[
W_c = \frac{1}{2} \left[ a \left( d(R_{se} - S_{se} - R_{fe} + S_{fe}) \right) / (d(R_{se} - S_{se} - R_{fe} + S_{fe}) + 1) + \beta \left( d(R_{se} - S_{se} - R_{fe} + S_{fe}) \right) / (d(R_{se} - S_{se} - R_{fe} + S_{fe}) + 1) - 1 \right] \\
W_h = \frac{1}{2} \left[ a \left( d(R_{sh} - S_{sh} - R_{fh} + S_{fh}) \right) / (d(R_{sh} - S_{sh} - R_{fh} + S_{fh}) + 1) + \beta \left( d(R_{sh} - S_{sh} - R_{fh} + S_{fh}) \right) / (d(R_{sh} - S_{sh} - R_{fh} + S_{fh}) + 1) - 1 \right] \\
W_{eg} = \frac{1}{2} \left[ a \left( d(R_{seg} - S_{se} - R_{feg} + S_{feg}) \right) / (d(R_{seg} - S_{se} - R_{feg} + S_{feg}) + 1) + \beta \left( d(R_{seg} - S_{se} - R_{feg} + S_{feg}) \right) / (d(R_{seg} - S_{se} - R_{feg} + S_{feg}) + 1) - 1 \right] \\
W_{hg} = \frac{1}{2} \left[ a \left( d(R_{shg} - S_{sh} - R_{fhg} + S_{fhg}) \right) / (d(R_{shg} - S_{sh} - R_{fhg} + S_{fhg}) + 1) + \beta \left( d(R_{shg} - S_{sh} - R_{fhg} + S_{fhg}) \right) / (d(R_{shg} - S_{sh} - R_{fhg} + S_{fhg}) + 1) - 1 \right]
\]

(1)

2.3. Rules of Evolutionary Game on Complex Network. In each round of the game, all the nodes in the complex network play an evolutionary game with their connected neighbors and accumulate the payoffs. In the process of evolution, the Fermi function in statistical mechanics [27] is extended and used as the update rule:

\[
W(P_i \rightarrow P_j) = \frac{1}{1 + \exp\left(\frac{(U_i/b - U_j/d)}{k}\right)},
\]

where \( P_i \) and \( P_j \) represent the strategy of nodes \( i \) and \( j \) in one round of the game, respectively, \( U_i \) and \( U_j \) represent the cumulative payoffs of \( P_i \) and \( P_j \), respectively, and \( b \) and \( d \) are the number of neighbors of nodes \( i \) and \( j \). Parameter \( k \) (\( k > 0 \)) is the noise value, which represents the possibility of an irrational behavior. When \( k \) approaches 0, it denotes that the strategy selection of all nodes in the game process is completely rational. In other words, when the yield of \( P_i \) is higher than \( P_j \), \( P_j \) would imitate the strategy of \( P_j \) with a 100% probability. When \( k \) approaches infinity, it means that all information is drowned by noise, and the strategies of all nodes are updated randomly.

3. Simulation Experiment and Result Analysis

Those existing research studies on green agricultural production mainly focus on the influence of agricultural production subjects’ characteristics [46, 47] (e.g., their knowledge and willingness of green agricultural production and agricultural operation scale), government agricultural subsidies [17, 48, 49], network structure [29], and other factors on green agricultural production. It has been confirmed that diffusion network can boost the development of green agricultural production [23]. Based on those existing research studies, this paper constructs the simulation experiment of evolutionary game mechanism about green agricultural production on complex network, in order to clarify the effects of green agricultural production subjects’ payoffs, cost, technology spillovers, and environmental damage compensation on the evolution of green agricultural production network under the market mechanism and government guidance mechanism, respectively.

Assume the evolution time \( T = 100 \). The initial network is a scale-free network with 100 nodes; among them, 20 nodes are new agricultural operation entities, and the remaining 80 nodes are traditional farmers. The location and neighbors of subjects on the network are generated randomly. When \( T = 0 \), parameters are set; meanwhile, the strategies in the game process should be randomly assigned to the nodes on
When strategy is adopted; otherwise, the value would be set as 0. The value would be set as 1 if green agricultural production is adopted; otherwise, the value would be set as 0. 6 Complexity

Proposition 1. Extra revenue from green agricultural production is the core factor which affects the cooperative density of green agricultural production. By comparing Figures 1(a) and 1(b), it can be seen that when the extra revenue obtained from green agricultural production is greater than the extra cost of green agricultural production, either a new agricultural operation entity or a traditional farmer would prefer to make decisions of green agricultural production after a period of game and strategy learning. But if the costs outweigh the extra revenue, the cooperation of green agricultural production tends to collapse.

3.1. Comparative Analysis of Strategies and Results under Market Mechanism. The evolution process of green agricultural production on complex network is also the emergence of cooperative behaviors among new agricultural operation entities and traditional farmers in the green agricultural production network. Thus, to simulate the processes of cooperative density of green agricultural production in different scenarios and further analyze the efficiencies and effects of various sets of parameter values under market mechanism, this paper designs the following sets of parameter values for comparative experiments (Table 7).

According to the parameters of Table 7, the simulations in different scenarios of evolution trend are shown in Figures 1(a)–1(g).

### Table 4: The pairwise game matrix between traditional farmers and new agricultural operation entities under the government guidance mechanism.

| Traditional farmers | Green agricultural production | Nongreen agricultural production |
|---------------------|--------------------------------|---------------------------------|
|                      | (e, h)                         | (e, h)                          |
| Green agricultural production | \( S_e + \Delta S_e - C_e + W_{eg} \) | \( S_e + \Delta S_e - D_e + W_e \) |
|                      | \( S_h + \Delta S_h - C_h + T_{eh} + W_{hg} \) | \( S_h + \Delta S_h - D_h + R_{eh} + W_{hg} \) |

### Table 5: The pairwise game matrix among traditional farmers under the government guidance mechanism.

| Traditional farmers | Green agricultural production | Nongreen agricultural production |
|---------------------|--------------------------------|---------------------------------|
|                      | (h, h)                         | (h, h)                          |
| Green agricultural production | \( S_h + \Delta S_h - C_h + T_{hh} + W_{hg} \) | \( S_h + \Delta S_h - D_h + W_h \) |
|                      | \( S_h + \Delta S_h - C_h + T_{hh} + W_{hg} \) | \( S_h + \Delta S_h - D_h + R_{hh} + W_{hg} \) |

### Table 6: The pairwise game matrix among new agricultural operation entities under the government guidance mechanism.

| New agricultural operation entities | Green agricultural production | Nongreen agricultural production |
|-------------------------------------|--------------------------------|---------------------------------|
|                      | (e, e)                         | (e, e)                          |
| Green agricultural production      | \( S_e + \Delta S_e - C_e + T_{ee} + W_{eg} \) | \( S_e + \Delta S_e - R_{ee} + T_{ee} + W_{eg} \) |
|                      | \( S_e + \Delta S_e - C_e + T_{ee} + W_{eg} \) | \( S_e + \Delta S_e - D_e + R_{ee} + W_{eg} \) |
| Nongreen agricultural production  | \( S_e + \Delta S_e - C_e - D_{ee} + W_{eg} \) | \( S_e + \Delta S_e - D_e - W_{e} \) |
|                      | \( S_e + \Delta S_e - D_{ee} + R_{ee} + W_{eg} \) | \( S_e - D_e - D_{ee} + W_{e} \) |

the green agricultural production network, whose node value would be set as 1 if green agricultural production strategy is adopted; otherwise, the value would be set as 0. When \( T = 1 \), the first game is played, and comparisons of payoffs among the nodes and their neighbors are taken randomly. If their payoff is better than or equal to their neighbors, the strategy will not change in the next round of game; otherwise, they would update the learning strategy with probability of \( W(P_i \rightarrow P_j) \). When \( T = 2 \), the next round of the game is played until the end.
Scenario $a$ and $b$, respectively, simulate the situation when the extra revenue of green agricultural production is significantly higher and significantly lower than the extra cost which are shown in Figures 1(a) and 1(b). According to the comparison between Figures 1(a) and 1(b), cooperative density of green agricultural production would reach stable state when it is at the time of $T = 30$, i.e., after 30 times of game and strategy learning. However, the difference is that in Figure 1(a), both new agricultural operation entities and traditional farmers will be more inclined to adopt the strategy of green agricultural production, and the cooperative density of green agricultural production will reach the stable state of 1, while in Figure 1(b), both new agricultural operation entities and traditional farmers will be more willing to adopt the strategy of nongreen agricultural production. The main reason of this difference is that in scenario $b$, the profits of nongreen agricultural production are significantly higher than the benefits of green agricultural production, even if nongreen agricultural production may lead to environmental damage to themselves and their neighbors, and even though new agricultural operation entities also need to pay a certain environmental damage compensation, they would still attain more surplus profit by the nongreen agricultural production. Therefore, in scenario $b$, new agricultural operation entities and traditional farmers will gradually adopt the strategy of nongreen agricultural production after repeated comparison of profit and strategy learning with their neighbors, and thus the cooperation of green agricultural production will collapse.

**Proposition 2.** When the extra net profit of green agricultural production tends to be 0, the cooperative density of green agricultural production increases firstly and then decreases with the increasing environmental compensation fee paid by new agricultural operation entities for nongreen agricultural production (Figure 1(c)), while it increases with the increasing coefficient of green agricultural production technology spillover (Figure 1(d)) as well as the damage coefficient of nongreen agricultural production profit (Figure 1(e)).

In scenario $c$ in which the extra net profit in green agricultural production tends to be 0, new agricultural operation entities who have adopted the strategy of nongreen agricultural production should pay compensations for new agricultural operation entities who have adopted the strategy of green agricultural production. As it can be seen in Figure 1(c), with the increasing compensation, the cooperative density of green agricultural production shows a fluctuation trend and ends in an unstable state. Its fluctuation is characterized by an upward trend at the beginning, while a downward trend is observed after the time of $T = 35$. This may be mainly caused by the extra net profit of green agricultural production in scenario $c$ which tends to be 0. Because although other subjects who have adopted the strategy of green agricultural production may attain compensations paid by new agricultural operation entities who have adopted the strategy of nongreen agricultural production, they still suffer the loss of pollution spillover. Therefore, after a period of comparison between green and nongreen agricultural production strategies, the cooperation of green agricultural production finally collapses.

In scenario $d$ which is based on scenario $c$, the coefficient of green agricultural production technology spillover is increased. As it can be found in Figure 1(d), both new agricultural operation entities and traditional farmers will gradually prefer green agricultural production after repeated games and strategy studies, and the stable state is at the time of $T = 30$. When compared with traditional farmers, more new agricultural operation entities would be willing to adopt the strategy of green agricultural production in which their cooperative density will reach 1. This is because new agricultural operation entities are more significantly affected by technology spillover effect than traditional farmers, which is consistent with the reality that new agricultural operation entities have higher learning ability, technology adoption, and utilization degree than traditional farmers.

In scenario $e$ which is also based on scenario $c$, the potential negative impact of nongreen agricultural production on the profits of subjects is increased. It can be seen from Figure 1(e) that both new agricultural operation entities and traditional farmers will have the preference of green agricultural production when the nongreen agricultural production has a great potential damage to their profit. After about 50 games and learning strategy, they can reach the stable state of green agricultural production cooperative density of 1. This is mainly caused by the negative influence and increasing cost of nongreen agricultural production on agricultural ecological environment. Therefore, green agricultural production has become their stable strategy after multiple games.

**Proposition 3.** The updating strategy of new agricultural operation entities and traditional farmers is not only dependent on their own profit but also influenced by other subjects’ profit on the complex network of green agricultural production. Moreover, the influence of new agricultural production...
Figure 1: Continued.
operation entities on traditional farmers is significantly stronger than that of traditional farmers on new agricultural operation entities, which can be seen in Figures 1(f) and 1(g).

In scenario f, the extra net profit from green agricultural production of new agricultural operation entities is more than 0, while the extra net profit of traditional farmers is less than 0 (Figure 1(f)). On the contrary, in scenario g, the extra net profit from green agricultural production of new agricultural operation entities is less than 0, while the extra net profit of traditional farmers is more than 0 (Figure 1(g)). When comparing Figure 1(f) and Figure 1(a), it can be seen that although scenario f and scenario a are under the same conditions of which new agricultural operation entities meet the basic requirements that the cooperative density of green agricultural production tends to be 1, the final evolution trend of scenario f only shows an unstable state of green agricultural production, while comparing Figures 1(g) and 1(b), it can also be seen that the final evolution trend of scenario g shows a continuously fluctuating trend between state 0 and 1. Thus, it can be concluded that the updating strategy of new agricultural operation entities and traditional farmers is not only influenced by their own profit but also by their neighbors. The stable state of green agricultural production on complex network is the result of the joint action of new agricultural operation entities and traditional farmers.

Moreover, by comparing Figures 1(f) and 1(g), it can be seen that when the extra net profit of new agricultural operation entities by green agricultural production is more than 0, even if the extra net profit of traditional farmers by green agricultural production is less than 0, traditional farmers will gradually follow the new agricultural operation entities to adopt the strategy of green agricultural production. However, when the extra net profit of traditional farmers by green agricultural production is more than 0, but the extra net profit of new agricultural operation entities by green agricultural production is less than 0, the cooperative density would fluctuate between 0 and 1. Consequently, the effect of new agricultural operation entities on traditional farmers is significantly stronger than that of traditional farmers on new agricultural operation entities.

3.2. Comparative Analysis of Strategies and Results under Government Guidance Mechanism. The following two sets of parameter values in scenario h and i are designed (Table 8) for comparative experiments to simulate the evolution process of green agricultural production on complex network under the government guidance mechanism. The evolutionary trends of scenario h and i obtained are shown in Figures 2(a) and 2(b), respectively.

**Proposition 4.** Under the regulation of the government guidance mechanism, even if the extra net profit of green agricultural production is less than 0, new agricultural operation entities and traditional farmers are willing to adopt the strategy of green agricultural production after multiple games and strategy learning. Thus, it can be concluded that the government guidance mechanism has significant advantages over the market mechanism in the diffusion of green agricultural production on complex network which can be seen in Figure 2(a).

In scenario h which is based on scenario b, the evolution trend of green agricultural production on complex network under the regulation of government guidance mechanism is simulated. It can be seen from Figure 2(a), that as a result of nearly 60 times gaming and strategies learning, the complex network system will obviously tend to reach the stable state where the cooperative density of green agricultural production is 1. During the time of $T=0$ and $T=60$, the cooperation density of green agricultural production is in a state of greater volatility, which is caused by the negative net extra profit from green agricultural production. Thus, new agricultural operation entities and traditional farmers prefer nongreen agricultural production.
production, but they will pay a certain penalty for agricultural nonpoint pollution of nongreen agricultural production, while others will receive a certain amount of government rewards for their green agricultural production. Under the incentive and punishment of the government guidance mechanism, more and more new agricultural operation entities and traditional farmers are willing to adopt the strategy of green agricultural production after comparing profits, playing games, and learning strategies with their neighbors.

When comparing Figure 2(a) to Figures 1(a) and 1(b), it can be known that under the market mechanism, green agricultural production could be adopted only if the net profit of green agricultural production is greater than 0, while under the government guidance mechanism, it could be allowed less than 0. Therefore, it can be concluded that the government guidance mechanism has a significant advantage over the market mechanism in guiding the evolution of green agricultural production on complex network.

When comparing Figure 2(a) to Figures 1(a) and 1(b), it can be known that under the market mechanism, green agricultural production could be adopted only if the net profit of green agricultural production is greater than 0, while under the government guidance mechanism, it could be allowed less than 0. Therefore, it can be concluded that the government guidance mechanism has a significant advantage over the market mechanism in guiding the evolution of green agricultural production on complex network.

**Proposition 5.** Under the regulation of the government guidance mechanism, the level of government incentives and punishment will affect the stable evolution of green agricultural production on complex network.

Based on scenario $h$, scenario $i$ simulates the evolution trend of green agricultural production on complex network under the higher level of government incentives and punishments which refers to enhancing the value of $\alpha$ and $\beta$ as shown in Figure 2(b). When the value of $\alpha$ and $\beta$ is high, the system of green agricultural production on complex network will achieve a stable state of cooperative density of 1 after the time $T = 20$. By comparing Figure 2(a) and 2(b), it can be found that the duration of green agricultural production reaching the stable state of cooperative density 1 is significantly shortened. This is mainly due to the enhancing level of incentives and punishment under the regulation of the government guidance mechanism.

If the level of green agricultural production meets the scores required by green agricultural production guidance mechanisms, new agricultural operation entities and traditional farmers will get great awards which could cover their cost. However, if the level of nongreen agricultural production does not meet the scores, then the penalty will be relatively large in order to force them to prefer green agricultural production. Therefore, after several games and strategy learning, new agricultural operation entities and traditional farmers will prefer the strategy of green agricultural production in a relatively short time, and the green agricultural production system on complex network will quickly reach the stable state of cooperative density of 1.

### 4. Conclusions

Focusing on agricultural production strategies of new agricultural operation entities and traditional farmers under...
intensive management pattern, this paper constructs an evolution game model on complex network and simulates the processes of strategy evolution of new agricultural operation entities and traditional farmers in different scenarios. The proposed model can help to closely observe the dynamic process of strategy evolution from a microperspective between homogeneous subjects as well as a macroperspective between heterogeneous subjects on the complex network of green agricultural production.

As discussed in this paper, under the government guidance mechanism, more and more new agricultural operation entities and traditional farmers are willing to adopt strategy of green agricultural production after multiple games and strategy learning even if the extra net profit of green agricultural production is less than 0. This result indicates that the government guidance mechanism is better than the market mechanism in the diffusion of green agricultural production on complex network. This may be resulted by subsidies and punishments under the government guidance mechanism, which could play important roles in regulating subjects’ behaviors and strategy evolutions in the diffusion of green agricultural production on complex network. As such, in order to ensure the efficiency of the government guidance mechanism, the incentive and punishment system should be reasonably adopted for the production of green agricultural products and the application of chemical fertilizers. For example, certain subsidies of green fertilizers can be provided for green agricultural production, green agricultural production technology training can be used as technology subsidies, the farmland resource protection tax can be applied as environmental punishment, and so on.

The simulation results under the market mechanism show that the crucial factor affecting the evolution of green agricultural production network is the extra net profit of green agricultural production. If the extra net profit of green agricultural production is large enough, both new agricultural operation entities and traditional farmers will tend to adopt strategy of green agricultural production; otherwise, green agricultural production cooperation tends to collapse. While the extra net profit of green agricultural production approaches 0, the cooperative evolution result of green agricultural production network is negatively correlated with the environmental compensation but positively correlated with the spillover coefficient of green agricultural production technology as well as the damage coefficient of nongreen agricultural production profit. Therefore, application of green agricultural production technology and environmental compensation tax on nongreen producers should be used to encourage more new agricultural operation entities and traditional farmers to carry out green agricultural production.

It is also confirmed in this paper that the stable state of the green agricultural production on complex network is the result of the joint action of new agricultural operation entities and traditional farmers; furthermore, the influence of new agricultural operation entities on traditional farmers is more significant. This is because new agricultural operation entities have larger production scale and stronger green technology when compared with traditional farmers, so they have more pollution spillovers and green technology spillovers to traditional farmers. In addition, whether and how the local government conduct green agricultural production guidance will both greatly affect new agricultural operation entities and traditional farmers’ strategic choice of green agricultural production. Therefore, the local government should provide a series of guidance and training about green agricultural technologies, as well as encourage mutual learning among agricultural producers, in order to spread new ideas and technologies of green agricultural production faster and widely on complex network.

Based on the above results, there are still some important extension work that can be carried out in the future, which are neglected for the sake of clarity and simplicity in this paper. Firstly, the model assumes that the subjects have a consistent demand preference [32], without considering bounded rationality and social preference of the subjects. Secondly, the model does not consider that the network size is flexible and dynamic. Thirdly, consumer’s preference for green agricultural products and purchasing decision would also affect the diffusion of green agricultural production on complex network, which deserves further research in future.

Data Availability
The data used to support the findings of this study are available in this paper.

Conflicts of Interest
The authors declare that they have no conflicts of interest.

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