land

MDPI

Article

Research on Strategy Optimization of Green Agricultural Production Trusteeship to Promote Black Land Protection

Li Ma, Jiahao Lin, Chuangang Li and Yun Teng *

College of Engineering, Northeast Agricultural University, Harbin 150030, China; malimary@neau.edu.cn (L.M.); s230701006@neau.edu.cn (J.L.); s210701051@neau.edu.cn (C.L.)
* Correspondence: xlty@neau.edu.cn

Abstract: The whole trusteeship of green agricultural production plays an important role in promoting the protection of black land, and it is particularly crucial to clarify the behavioral characteristics and game relationships of agents involved in the whole trusteeship. This study uses the dynamic evolutionary game method to construct a tripartite evolutionary game model of governments, service organizations and farmers participating in the whole trusteeship of green agricultural production, aiming to come up with effective strategies to promote the widespread application of green agricultural production trusteeship and achieve agricultural green development. The results are as follows: (1) At present, the agricultural production model in Northeast China is dominated by traditional agricultural production and supplemented by green agricultural production. (2) Incentive and punitive measures will encourage agents to adopt positive strategies. (3) In areas with a poor awareness of green agricultural production trusteeship, the government's incentive and punishment measures for farmers and service organizations are imbalanced. (4) The relatively high cost of trusteeship leads to a lack of market competitiveness, which has a negative impact on service organizations promoting green agricultural production trusteeship. This study provides an effective reference for improving the overall implementation effect of black land protection in Northeast China.

Keywords: cultivated land protection; agricultural green development; agricultural production trusteeship; collaborative mechanism

check for updates

Citation: Ma, L.; Lin, J.; Li, C.; Teng, Y. Research on Strategy Optimization of Green Agricultural Production Trusteeship to Promote Black Land Protection. *Land* **2024**, *13*, 647. https://doi.org/10.3390/land13050647

Academic Editor: Volker Beckmann

Received: 23 January 2024
Revised: 5 May 2024
Accepted: 8 May 2024
Published: 9 May 2024

1. Introduction

The conservation tillage of black land has achieved phased results, and the sustainable promotion of black land protection is a long-term work. The grain production of black land in Northeast China accounts for 20% to 25% of the total national output [1]. Therefore, the sustainable agricultural production system is of great significance for black land in Northeast China to ensure national food security. However, due to the decline of the content (SOMs) caused by traditional agricultural production models, soil degradation and water loss has occurred [2–5]. Therefore, in recent years, the protection of black land has been considered a fundamental, coordinated and strategic issue, maintaining national ecological balance and food security [6]. The release of the "Action Plan for Conservation Tillage of Northeast Black Soil (2020–2025)" has promoted Lishu County to establish the demonstrative effect of the "Lishu Model", which implements green agricultural production technologies such as harvesting and straw mulching, soil loosening, no-tillage seeding and fertilization to comprehensively improve the production and ecological functions of black soil [7,8]. However, at present, the protection of black land in Northeast China is still faced with a series of problems such as whether the current farming methods can maintain the thickness of black soil layers [9]. Therefore, it is very important to continuously promote the protection of black land. The root cause of the problem of black land protection lies in the high-quality development of agriculture and the level of agricultural modernization. Agricultural green development is the only way to promote the realization of high-quality agricultural development and enhance agricultural modernization [10].

Agricultural green development is an important measure to continuously promote the protection of black land. Due to global climate change and ecological environmental degradation, green development has gradually become a topic of concern for international organizations [11–14]. “The Opinions on Innovating Systems and Mechanisms to Promote Green Agricultural Development” emphasize that governments, service organizations, farmers, consumers and other parties should be mobilized to actively participate in green development to achieve agricultural green development. Agricultural green development is an economic transformation process involving the adjustment of agricultural infrastructure and production models. In essence, it aims to reduce the depletion of natural resources and minimize the adverse impact on the environment in the process of agricultural production [15,16]. The core of agricultural green development is green agricultural production, which is a production model aimed at energy conservation and emission reduction adopting green agricultural production technologies to achieve sustainable development [17]. Shen et al. demonstrated that compared with conventional tillage, the use of subsoiling, no-tillage and other green agricultural production technologies [18] increased the aggregate associated organic carbon in the soil by 9.73%, effectively enhancing the carbon sequestration capacity of the soil [19]. Therefore, agricultural green development is an important support for consolidating the achievements of black land protection.

Comprehensively promoting the whole trusteeship of green agricultural production is an important guarantee for the realization of green agricultural development. According to the sixth national census, there are 210 million farming households with less than 10 mu (mu, a Chinese unit of land measurement that equals 1/15 of a hectare) of arable land. Therefore, effectively organizing and promoting the green transformation of farmers' production is the key and difficulty to realize agricultural green development [20]. Relying on service organizations to adopt agricultural production trusteeship is an important way to promote the precise connection between modern agricultural green development and green transformation for farmers [21,22]. Trusteeship refers to a socialized service model in which farmers entrust the partial or whole process of agricultural production, including planting, management and harvesting, to agricultural production service institutions without transferring land management rights [23]. Combined with the concept of agricultural green development, the whole trusteeship of green agricultural production is a model in which the service subjects use green production technology to complete the whole process of agricultural production entrusted by farmers and other subjects in a relatively low-cost manner. The whole trusteeship of green agricultural production is an important link for service organizations to promote agricultural green development and consolidate black land protection by popularizing green production behavior [24]. The model of the whole trusteeship of green agricultural production also provides an effective reference for solving the problems of the low willingness of farmers to participate in black land protection and the difficulty of governments to promote black land protection policies [25].

The trusteeship of green agricultural production under black land protection involves multi-agent behavioral decision making. “The Measures for the Management of Soil Environment of Agricultural Land” show that local governments are the regulatory agencies for black land protection, and farmers are the direct executors of black land protection. As rational people, it is difficult for farmers to give up the traditional agricultural production model. Green agricultural mechanization is an inevitable requirement for agricultural green development [26]. These agricultural machinery and equipment have a large input cost for farmers. However, some scholars demonstrate that scale effect (reducing the average cost of green production) is the key to promote farmers' green production. The whole trusteeship of green agricultural production can make farmers replace labor input with a lower machinery price through scale effect so as to realize green agricultural development [27,28]. Research has demonstrated that the agricultural socialized service market is a typical multi-agent game market [29]. However, the slow development of green agriculture in China stems from neglecting the conflicting interests of different participants in the process of green agricultural development [30]. The promotion of green agricultural production trusteeship is a complex behavioral game process that involves conflicts of interest between governments, service organizations, and farmers. It is necessary and important to coordinate the conflicts of interests among the tripartite agents involved. Therefore, it is necessary to use evolutionary game to simulate the strategic changes made by participants under the whole trusteeship of green agricultural production.

In summary, in the context of the continuous promotion of black land protection, this article carries out the following work: (1) We build a tripartite evolutionary game model between governments, service organizations and farmers. (2) We construct replication dynamic equations and analyze stable strategies for tripartite evolution. (3) Based on the obtained data, a numerical simulation is conducted on the tripartite evolutionary game model to determine effective strategy combinations and establish collaborative mechanisms to promote the widespread application of the whole trusteeship of green agricultural production, as shown in Figure 1. The remaining part of this study is structured as follows: (1) Section 2 is a literature review. (2) Section 3 is the theoretical basis and assumptions of the tripartite evolutionary game model. (3) Section 4 provides equilibrium and simulation analyses on the tripartite evolutionary game model. (4) Section 5 discusses the links between the findings of this study and relevant research on green agricultural production trusteeship. (6) Section 6 introduces the findings, recommendations and limitations of this study.

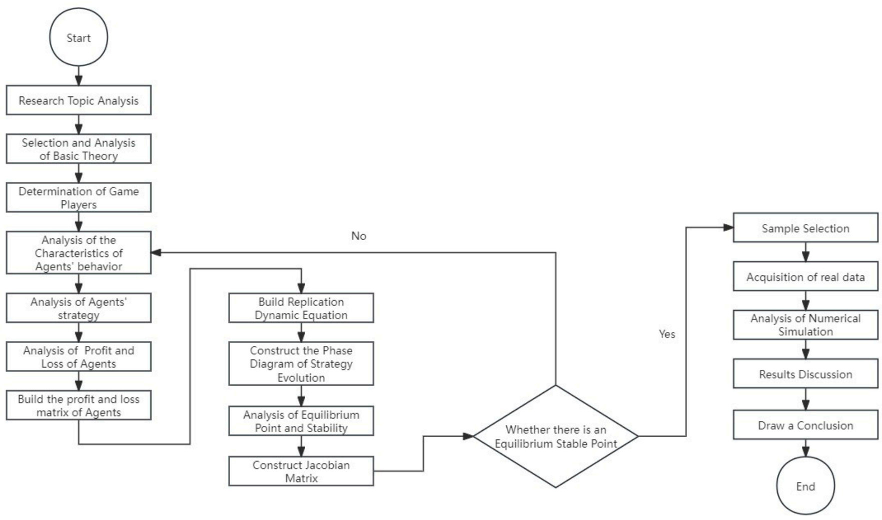


Figure 1. Specific technical route.

2. Literature Review

At present, research on the trusteeship of green agricultural production under the protection of black land is in the primary stage. This study reviews the literature from three aspects: green agricultural production, black land protection and the relationship between green agricultural production trusteeship and black land protection.

2.1. Research on Green Agricultural Production

The environmental challenges faced by natural resources are attributed to traditional agricultural production technology, and the key to prevent the degradation of natural resources is to realize green production technology. Fatemi et al. calculated the ecological indices such as the biocapacity and ecological footprint of rural areas of the Fars province of Iran and concluded that green technology is the main factor affecting the ecological index [31]. Green agricultural production technology plays an important role in sustainable environmental development. By establishing a comprehensive strategic framework based on SWOT, Ikram et al. concluded that the plans and programs for the promotion of green technology in the agricultural sector were considered the best strategy [32]. Xu et al. demonstrated that the ease of use and practicality of green agricultural production technology play an important role in the decision-making process of farmers [33]. Zeng and Shi proposed that the trusteeship model of green agricultural production is an important way to connect green production technology and agricultural green production [34]. Zhang and He certified that the model of green agricultural production trusteeship will drive farmers to engage in agricultural green production and promote the green development of agriculture [35]. These studies have proved that green agricultural production trusteeship is an important way to promote farmers to adopt green agricultural production technology and agricultural green development.

2.2. Research on Black Land Protection

Some scholars have studied the effectiveness of regulatory legislation in protecting agricultural land. Denver and Lenore demonstrated that the agricultural land reserve in British Columbia is relatively successful in protecting farmland [36]. On the contrary, research by Duguma and Tebarek showed that the legislation of farmland transformation greatly affects the livelihood assets of farmers [37]. Some scholars have analyzed the important factors of black land protection by establishing the index system of black land protection. Cynthia et al. showed that soil erosion is the main cause of land degradation and suggested that ecosystem services should be incorporated into future policies to prevent soil and water loss [38]. Based on the important factors of black land protection, some scholars put forward the relevant strategies of black land protection. Xu et al. took the black soil region of Northeast China as the research object. According to the landform and soil erosion characteristics, the black soil area in Northeast China was divided into rolling hills, low mountains, hills and gullies and agricultural and pastoral areas. The research team proposed the land use strategy of three lines of defense control mode, pyramid control mode and minimum development maximum protection control mode [39]. These studies mainly focus on the empirical research of black land protection.

2.3. Research on the Relationship between Black Land Protection and Green Agricultural Production Trusteeship

Based on the analysis of the influencing factors of black land protection, Qu et al. demonstrated that green agricultural production can promote black land conservation tillage [40]. The proposal of "Agricultural Production Trusteeship Service—Application of Green Production Technology—Agricultural Carbon Emission Reduction" mechanism can better analyze the internal interaction process between black land protection and green agricultural production trusteeship [41]. Research has proved that the enhancement of soil carbon sequestration capacity is an important indicator for the improvement of black soil quality [2]. Zhao et al. established a theoretical framework to analyze the impact of agricultural production trusteeship on carbon emissions from planting. The results showed that agricultural production trusteeship has a significant inhibitory effect on planting carbon emissions [42]. The trusteeship of green agricultural production not only ensures the improvement of black land quality but also improves the efficiency of food production. Based on the survey data of five major grain-producing provinces in China, Sun et al. used the propensity score matching method to study the promotion effect of agricultural production trusteeship on grain quality production. The empirical results showed that after farmers' participation in the trusteeship of green agricultural production, the high-quality grain yield increased by 0.292 percentage points [43].

At present, research studies on green agricultural production trusteeship and black land protection, which do not consider the impact of the decision-making changes made by participants on the promotion of the whole trusteeship of green agricultural production, basically focus on the factors analysis of farmers' willingness to adopt production trusteeship [44,45], the factors analysis to improve the efficiency of green agriculture production [46–48] and the increase in soil organic content [49,50]. There is little literature that combines the background of black land protection to study the behavioral decision making of governments, service organizations and farmers in the game of green agricultural production trusteeship. Therefore, it is important and necessary to explore the dynamic collaborative mechanism of the whole trusteeship of green agricultural production promotion.

To sum up, from the perspective of black land protection, this study constructs a tripartite evolutionary game model of governments, service organizations and farmers under the whole trusteeship of green agricultural production, analyzes the behavioral decision making characteristics and game relationship of the three stakeholders through a numerical simulation in Python 3.7.0 software and explores the optimal strategy combination for promoting the whole trusteeship of green agricultural production so as to provide reasonable suggestions for promoting the wide application of the whole trusteeship of green agricultural production.

3. Theoretical Basis and Hypothesis of Tripartite Evolutionary Game Model

Evolutionary game theory has been widely used in different disciplines. Based on the concept of bounded rationality, stakeholders show a tendency of iterative imitation and adaptation to enhance their strategies [51]. This theory is a valuable tool for studying the interaction between stakeholders. Its basic principles include evolutionary stability strategy and replication dynamics [52].

Many academic research studies have developed theoretical or empirical analysis frameworks based on game theory to study the interest differences among stakeholders. In the field of green agricultural production, some scholars have used the game theory method to build a game model between governments and farmers, studied the factors affecting the diffusion of green agricultural production technology and concluded that the policy effect and the cost of green agricultural production technology have a significant impact on the diffusion of green agricultural production technology [53–55]. With the deepening of research, multi-agent game theory has attracted much attention. Scholars have constructed a tripartite game model between government, farmers and consumers and concluded that enhancing the strength of policy tools can help farmers achieve green transformations [56]. In addition, some scholars have constructed a tripartite game model between the central government, local governments and farmers, proposing that governments should implement more complex dynamic subsidy strategies to encourage farmers to actively participate in farmland protection [57]. It is worth noting that current research has not considered the impact of green agricultural production trusteeship on black land protection and the green transformation of farmers.

Based on the research of scholars on green agricultural production, this article analyzes the game behavior of stakeholders in the process of promoting green agricultural production trusteeship in different contexts, determines effective strategy combinations and establishes collaborative mechanisms to promote the widespread application of the whole trusteeship of green agricultural production.

3.1. Agents Description

The promotion of the whole trusteeship of green agricultural production is a game process of multi-agent continuous interactions. It is necessary to understand the behavioral decision-making characteristics and dynamic interaction of governments, service organizations and farmers. Therefore, this study discusses the behavioral decision-making characteristics among the above subjects and elaborates on the interaction between the interest subjects. The organizational structure of governments, service organizations and farmers is shown in Figure 2.

Governments, service organizations and farmers have formed external and internal interactions. In terms of external interactions, the policies formulated by governments encourage and restrict farmers, and farmers consult with service organizations on production technology issues. This leads to the behavior of farmers being affected by governments and service organizations at the same time. In order to obtain a government subsidy for technological reform and special trusteeship, service organizations respond to governments' call to promote the whole trusteeship of green agricultural production to farmers.

The actual trusteeship demand of farmers has a feedback effect on service organizations, which leads to the behavior of service organizations being affected by governments and farmers at the same time. The external interaction of stakeholders leads to stakeholders' game in decision making, which constitutes an internal interaction. In terms of internal interactions, farmers choose to accept or reject green agricultural production trusteeship according to governments' reward and punishment policies and the trusteeship model of service organizations. Service organizations need to make decisions to promote the whole trusteeship of green agricultural production or traditional agricultural production according to governments' incentive policies and farmers' trusteeship requirements. According to the production behavior of farmers and the trusteeship model of service organizations, governments choose to actively promote the trusteeship of green agricultural production or passively promote the trusteeship of green agricultural production. According to the dynamic interaction and decision-making behavior among stakeholders, the following assumptions can be put forward.

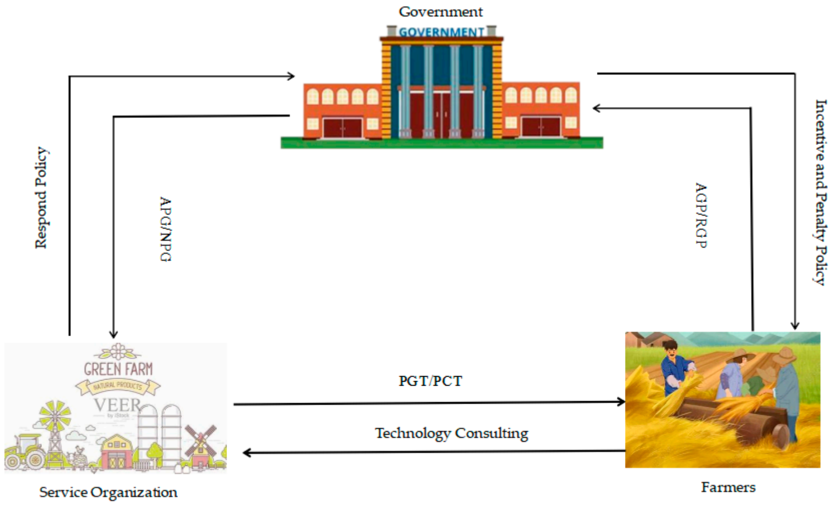


Figure 2. Relationship between governments, service organizations and farmers.

3.2. Model Assumptions

Hypothesis 1. *As the regulator of black land protection in Northeast China, governments are the protectors of ecological environments. Considering economic construction, ecological construction and government performance, governments' implementation of policies such as publicity and education [58], administrative penalties and production subsidies can promote the promotion of green agricultural production trusteeship. Considering the financial pressure, the difficulty of supervision and the contradiction between economic and efficient development and agricultural green development [59], governments have implemented fiscal tightening and other measures to passively promote the trusteeship of green agricultural production. Therefore, governments' behavior and decision making can be divided into the active promotion of green agricultural production trusteeship (APG) and the negative promotion of green agricultural production trusteeship (NPG).*

Hypothesis 2. *Service organizations are the promoters of popularizing green agricultural production trust. On the one hand, in order to seek long-term development, service organizations actively study technological reform and respond to government policies to promote green agricultural production trusteeship, popularize green agricultural production technology and improve farmers' awareness of green agricultural production trusteeship. On the other hand, service organizations seeking to maximize short-term interests give up their investment in technological innovation and continue to provide the whole trusteeship of traditional agricultural production rather than green agricultural production. Therefore, the behavioral decision making of service organizations can be divided into the promotion of the whole trusteeship of green agricultural production (PGT) and the promotion of traditional agricultural production (PCT).*

Hypothesis 3. *Farmers are the implementers of black land protection. On the one hand, considering the influence of factors such as green agricultural production trusteeship awareness, production subsidies, administrative penalties and long-term interests, farmers purchase green agricultural production trusteeship services from service organizations to develop green agriculture. On the other hand, in order to maximize short-term profits, conservative farmers still adopt the traditional agricultural production model over reclaiming black land and thus destroying the agricultural ecosystem. Therefore, the behavioral decision of farmers can be divided into accepting green agricultural production trusteeship (AGP) and rejecting green agricultural production trusteeship (RGP).*

3.3. Model Parameters

3.3.1. Relevant Benefits of Governments Are Assumed as Follows

① When governments choose APG, the technical reform and construction subsidy given to service organizations are R, the special subsidy for service organizations to promote the whole trusteeship of green agricultural production service is B_g (including straw, no-tillage seeding and subsoiling subsidies) and the subsidy given to farmers to participate in green agricultural production is I. When farmers reject the trusteeship of green agricultural production, the administrative penalty imposed by governments on farmers is B_F. The governance cost paid by governments due to the deterioration of agricultural ecosystem development is H_3. When farmers accept the trusteeship of green agricultural production because the agricultural ecosystem is protected for sustainable development, governments' tax revenue for green agricultural product processing is H_1 and governments' positive performance benefits from improving public trust are K_1.

② When governments choose NPG, technical reform and construction subsidy R is still provided to service organizations, but special subsidy B_g and subsidy I are respectively not issued to service organizations and farmers. When farmers reject the trusteeship of green agricultural production, the negative performance loss faced by governments due to the deterioration of agricultural ecosystems and the decline of public trust is K_2 and the non-green agricultural product processing tax received by governments is H_2.

3.3.2. Relevant Benefits of Service Organizations Are Assumed as Follows

① When service organizations adopt PGT (including straw returning, subsoiling, soil testing formula, no-tillage seeding, mechanized weeding and organic fertilizer), the special subsidy obtained by service organizations is B_g. The annual operating expenses obtained by service organizations are C_1. The cost of building a green agricultural production base by service organizations and the related publicity expenses are C_2. The production cost for service organizations to carry out the whole trusteeship of green agricultural production is C_g. The fee of the whole trusteeship of green agricultural production charged by service organizations to farmers is D_g. Due to the PGT, the reputation, social recognition and market share of service organizations are improved, and the potential benefits obtained by service organizations are N_1.

② When service organizations adopt PCT, the annual operating expenses of service organizations are C_3. The cost of building traditional agricultural production bases by service organizations and the related publicity expenses are C_4. The production cost of the whole trusteeship of traditional agricultural production carried out by service organizations is C_L. The fee of the whole trusteeship of traditional agricultural production charged by service organizations to farmers is D_L. When farmers choose the green agricultural production trusteeship, service organizations suffer negative potential loss N_2 due to the reduction in market share and social recognition.

3.3.3. Relevant Benefits of Farmers Are Assumed as Follows

① When farmers choose AGP and the strategic choices of farmers and service organizations are inconsistent, the self-planting cost of farmers adopting green agricultural production is A_1. When both farmers and service organizations choose green agricultural production, the fee that farmers pay service organizations for the whole trusteeship of green agricultural production is D_g. Farmers' income from green agricultural products is E_g. Due to the adoption of green agricultural production, the agricultural ecological environment is protected by sustainable development. The potential green environmental benefits for farmers are F_1 (including soil improvement, fertility enhancement, pesticide residue reduction, etc.) and the government rewards for farmers are I.

② When farmers choose RGP and the strategic choices of farmers and service organizations are inconsistent, the self-planting cost of farmers adopting traditional agricultural production is A_2. When both farmers and service organizations choose traditional agricultural production, the fee paid by farmers to service organizations for the whole trusteeship of traditional agricultural production is D_L. Farmers' income from non-green agricultural products is E_L. Due to the adoption of non-green agricultural production and the deterioration of the agricultural ecological environment, the potential losses suffered by farmers are F_2 (including soil hardening, water and soil loss, reduced fertility, increased pesticide residues, etc.), and the administrative penalty imposed by governments on farmers is B_F.

Based on the above assumptions, according to the interest assumption of the stakeholders, the tripartite game income matrix is constructed and the specific income corresponding to each strategy combination is obtained, as shown in Table 1.

Table 1. The tripartite game revenue matrix.

Strategies	Governments	Service Organizations	Farmers
(NPG, PCT, RGP)	$H_2 - R - K_2$	$R + D_L - C_3 - C_4 - C_L - N_2$	$E_L - D_L - F_2$
(NPG, PCT, AGP)	$H_1 - R$	$R - N_2 - C_3 - C_4$	$E_g - A_1 + F_1$
(NPG, PGT, RGP)	$H_2 - R - K_2$	$R + N_1 - C_1 - C_2$	$E_L - A_2 - F_2$
(NPG, PGT, AGP)	$H_1 - R$	$R + D_g + N_1 - C_1 - C_2 - C_g$	$E_g - D_g + F_1$
(APG, PCT, RGP)	$H_2 + K_1 - R - H_3 + B_F$	$R + D_L - C_3 - C_4 - C_L - N_2$	$E_L - D_L - F_2 - B_F$
(APG, PCT, AGP)	$H_1 + K_1 - R - I$	$R - C_3 - C_4 - N_2$	$I + E_g - A_1 + F_1$
(APG, PGT, RGP)	$H_2 + K_1 - R - H_3 + B_F - B_g$	$R + N_1 + B_g - C_1 - C_2$	$E_L - A_2 - F_2 - B_F$
(APG, PGT, AGP)	$H_1 + K_1 - R - I - B_g$	$B_g + D_g + R + N_1 - C_1 - C_2 - C_g$	$I + E_g - D_g + F_1$

4. Result

4.1. Equilibrium Analysis of Tripartite Evolutionary Game Model

Alos Ferrer and Ania proposed that individuals use different proportions of pure strategy combinations to represent mixed strategies in the game model [60]. This study assumes that the proportion of governments choosing APG is x and the proportion choosing NPG is $1 - x$; the proportion of service organizations adopting PGT is y and the proportion choosing PCT is $1 - y$; and the proportion of farmers choosing AGP is z and the proportion of farmers choosing RGP is $1 - z$.

4.1.1. Replication Dynamic Equation Analysis of Governments

The expected benefits of governments choosing APG and NPG are respectively U_x and U_{1-x}, and the average benefit is $\overline{U}_x$.

The expected benefits of governments' decisions are

$$U_x = H_2 + K_1 - R - H_3 + B_F + z(H_1 - I + H_3 - H_2 - B_F) - yB_g \tag{1}$$

$$U_{1-x} = H_2 - R - K_2 + z(K_2 + H_1 - H_2) \tag{2}$$

The average benefit of governments' decisions is

$$\overline{U}_x = xU_x + (1 - x)U_{1-x} \tag{3}$$

According to Malthusia's equation [61], the governments' replication dynamic equation RD is

$$F_1(x,y,z) = \frac{dx}{dt} = x(U_x - \overline{U}_x) = x(1-x)(U_x - U_{1-x}) = x(1-x)[K_1 + K_2 - H_3 + B_F - yB_g + z(H_3 - I - B_F - K_2)] \tag{4}$$

The first partial derivative of $F_1(x,y,z)$ with respect to x is

$$\frac{\partial F_1(x,y,z)}{\partial x} = (1-2x)[K_1 + K_2 - H_3 + B_F - yB_g + z(H_3 - I - B_F - K_2)] \tag{5}$$

According to Lyapunov's stability theorem [62], when $F_1(x,y,z) = 0$, $x = 0$, $x = 1$ and $y = \frac{K_1+K_2-H_3+B_F+z(H_3-I-B_F-K_2)}{B_g}$ are the three equilibrium strategies of governments' decision making in the evolutionary game system.

(1) When $y = \frac{K_1+K_2-H_3+B_F+z(H_3-I-B_F-K_2)}{B_g}$, this means that governments are in a balanced state regardless of whether they adopt the strategy of APG or NPG, but governments cannot form a stable strategy [63] due to $\frac{\partial F_1(x,y,z)}{\partial x} \mid_{x=0\ or\ x=1} = 0$.

(2) When $y \neq \frac{K_1+K_2-H_3+B_F+z(H_3-I-B_F-K_2)}{B_g}$, $x = 0$ or $x = 1$ may be an evolutionary stable strategy (ESS).

(3) When $y < \frac{K_1+K_2-H_3+B_F+z(H_3-I-B_F-K_2)}{B_g}$ and $\frac{\partial F_1(x,y,z)}{\partial x} \mid_{x=1} < 0$, $x = 1$ is the governments' ESS.

(4) When $y > \frac{K_1+K_2-H_3+B_F+z(H_3-I-B_F-K_2)}{B_g}$ and $\frac{\partial F_1(x,y,z)}{\partial x} \mid_{x=0} < 0$, $x = 0$ is the governments' ESS.

To draw the evolutionary trend map of the governments' strategies as shown in Figure 3, $y = \frac{K_1+K_2-H_3+B_F+z(H_3-I-B_F-K_2)}{B_g}$ divides the tripartite strategy combination into two spaces: G_1 and G_2. When the initial point of the game model is located at the bottom left of the split plane, the governments' strategies evolve towards $x = 1$ and governments eventually choose APG, as shown in b of Figure 3. When the initial point of the game model is located at the top right of the split plane, the governments' strategies evolve towards $x = 0$ and governments eventually choose NPG, as shown in c of Figure 3.

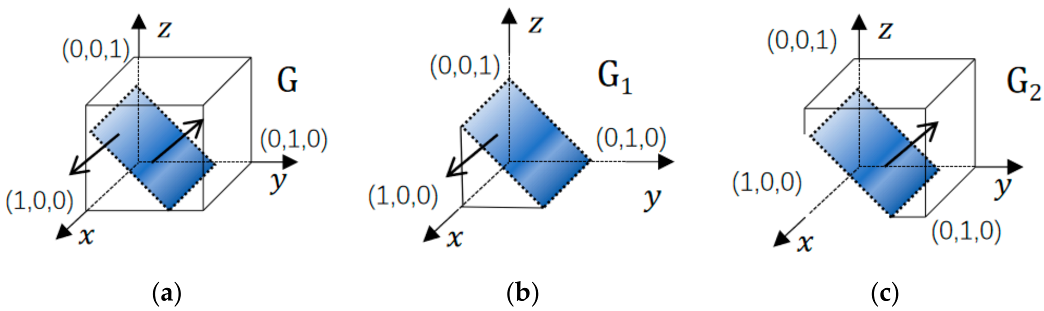


Figure 3. Evolution trend of governments' strategy. (**a**) Phase diagram of governments' dynamic evolution. (**b**) Evolution trend of governments' strategy APG. (**c**) Evolution trend of governments' strategy NPG.

Therefore, the probability that governments choose APG is $G_1 = \int_0^1 \int_0^1 \frac{K_1+K_2-H_3+B_F-z(H_3-I-B_F-K_2)}{B_g} dydx$, and the probability that governments choose NPG is $G_2 = 1 - G_1$.

4.1.2. Replication Dynamic Equation Analysis of Service Organizations

The expected benefits of service organizations choosing PGT and PCT are respectively U_y and U_{1-y}, and the average benefit is $\overline{U}_y$.

The expected benefits of service organizations' decision are

$$U_y = R + N_1 - C_1 - C_2 + z(D_g - C_g) + xB_g \tag{6}$$

$$U_{1-y} = R + D_L - C_3 - C_4 - C_L - N_2 + z(C_L - D_L) \tag{7}$$

The average benefit of service organizations' decisions is

$$\overline{U}_y = yU_y + (1-y)U_{1-y} \tag{8}$$

According to Malthusia's equation, the service organizations' replication dynamic equation RD is

$$F_2(x,y,z) = \frac{dy}{dt} = y(U_y - \overline{U}_y) = y(1-y)(U_y - U_{1-y}) = y(1-y)[N_1 + N_2 + C_3 + C_4 + C_L - C_1 - C_2 - D_L + xB_g + z(D_g + D_L - C_g - C_L)] \tag{9}$$

The first partial derivative of $F_2(x,y,z)$ with respect to y is

$$\frac{\partial F_2(x,y,z)}{\partial y} = (1-2y)[N_1 + N_2 + C_3 + C_4 + C_L - C_1 - C_2 - D_L + xB_g + z(D_g + D_L - C_g - C_L)] \tag{10}$$

According to Lyapunov's stability theorem, when $F_2(x,y,z) = 0$, $y = 0$, $y = 1$ and $z = \frac{N_1+N_2+C_3+C_4+C_L-C_1-C_2-D_L+xB_g}{C_L+C_g-D_L-D_g}$ are the three equilibrium strategies of service organizations' decision making in the evolutionary game system.

(1) When $z = \frac{N_1+N_2+C_3+C_4+C_L-C_1-C_2-D_L+xB_g}{C_L+C_g-D_L-D_g}$, this means that service organizations are in a balanced state regardless of whether it adopts the strategy of PGT or PCT, but service organizations cannot form a stable strategy due to $\frac{\partial F_2(x,y,z)}{\partial y} \mid_{y=0 \text{ or } y=1} = 0$.

(2) When $z \neq \frac{N_1+N_2+C_3+C_4+C_L-C_1-C_2-D_L+xB_g}{C_L+C_g-D_L-D_g}$, $y = 0$ or $y = 1$ may be the ESS.

(3) When $z < \frac{N_1+N_2+C_3+C_4+C_L-C_1-C_2-D_L+xB_g}{C_L+C_g-D_L-D_g}$ and $\frac{\partial F_2(x,y,z)}{\partial y} \mid_{y=1} < 0$, $y = 1$ is the service organizations' ESS.

(4) When $z > \frac{N_1+N_2+C_3+C_4+C_L-C_1-C_2-D_L+xB_g}{C_L+C_g-D_L-D_g}$ and $\frac{\partial F_2(x,y,z)}{\partial y} \mid_{y=0} < 0$, $y = 0$ is the service organizations' ESS.

To draw the evolutionary trend map of service organizations' strategies as shown in Figure 4, $z = \frac{N_1+N_2+C_3+C_4+C_L-C_1-C_2-D_L+xB_g}{C_L+C_g-D_L-D_g}$ divides the tripartite strategy combination into two spaces: S_1 and S_2. When the initial point of the game model is located in front of the split plane, service organizations' strategies evolve towards $y = 1$, and service organizations eventually choose PGT, as shown in b of Figure 4. When the initial point of the game model is located behind the split plane, the service organizations' strategies evolve towards $y = 0$, and service organizations eventually choose PCT, as shown in c of Figure 4.

Therefore, the probability that service organizations choose PGT is $S_1 = \int_0^1 \int_0^1 \frac{N_1+N_2+C_3+C_4+C_L-C_1-C_2-D_L+xB_g}{C_L+C_g-D_L-D_g} dzdx$, and the probability that service organizations choose PCT is $S_2 = 1 - S_1$.

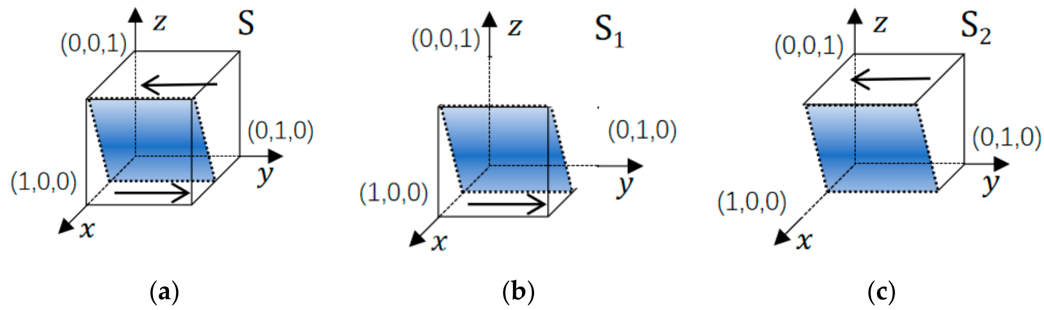


Figure 4. Evolution trend of service organizations' strategy. (**a**) Phase diagram of service organizations' dynamic evolution. (**b**) Evolution trend of service organizations' strategy PGT. (**c**) Evolution trend of service organizations' strategy PCT.

4.1.3. Replication Dynamic Equation Analysis of Farmers

The expected benefits of farmers choosing AGP and RGP are respectively U_z and U_{1-z}, and the average benefit is $\overline{U}_z$.

The expected benefits of farmers' decisions are

$$U_z = E_g - A_1 + F_1 + y(A_1 - D_g) + xI \tag{11}$$

$$U_{1-z} = E_L - D_L - F_2 - y(A_2 - D_L) \tag{12}$$

The average benefit of farmers' decisions is

$$\overline{U}_z = zU_z + (1-z)U_{1-z} \tag{13}$$

According to Malthusia's equation, the farmers' replication dynamic equation RD is

$$F_3(x,y,z) = \frac{dz}{dt} = z(U_z - \overline{U}_z) = z(1-z)(U_z - U_{1-z}) = z(1-z)E_g + F_1 + F_2 + D_L - E_L - A_1 + xI + y(A_1 + A_2 - D_g - D_L) \tag{14}$$

The first partial derivative of $F_3(x,y,z)$ with respect to z is

$$\frac{\partial F_3(x,y,z)}{\partial z} = (1-2z)[E_g + F_1 + F_2 + D_L - E_L - A_1 + xI + y(A_1 + A_2 - D_g - D_L)] \tag{15}$$

According to Lyapunov's stability theorem, when $F_3(x,y,z) = 0$, $z = 0$, $z = 1$ and $x = \frac{-E_g - F_1 - F_2 - D_L + A_1 + E_L - y(A_1 + A_2 - D_g - D_L)}{I}$ are the three equilibrium strategies of farmers' decision making in the evolutionary game system.

When $x = \frac{-E_g - F_1 - F_2 - D_L + A_1 + E_L - y(A_1 + A_2 - D_g - D_L)}{I}$, this means that farmers are in a balanced state regardless of whether they adopt the strategy of AGP or RGP, but farmers cannot form a stable strategy due to $\frac{\partial F_3(x,y,z)}{\partial z}\mid_{z=0 \text{ or } z=1} = 0$.

When $x \neq \frac{-E_g - F_1 - F_2 - D_L + A_1 + E_L - y(A_1 + A_2 - D_g - D_L)}{I}$, $z = 0$ or $z = 1$ may be the ESS.

When $x < \frac{-E_g - F_1 - F_2 - D_L + A_1 + E_L - y(A_1 + A_2 - D_g - D_L)}{I}$ and $\frac{\partial F_3(x,y,z)}{\partial z}\mid_{z=0} < 0$, $z = 0$ is the farmers' ESS.

When $x > \frac{-E_g - F_1 - F_2 - D_L + A_1 + E_L - y(A_1 + A_2 - D_g - D_L)}{I}$ and $\frac{\partial F_3(x,y,z)}{\partial z}\mid_{z=1} < 0$, $z = 1$ is the farmers' ESS.

To draw the evolutionary trend map of farmers' strategies as shown in Figure 5, $x = \frac{-E_g - F_1 - F_2 - D_L + A_1 + E_L - y(A_1 + A_2 - D_g - D_L)}{I}$ divides the tripartite strategy combination into two spaces: F_1 and F_2. When the initial point of the game model is located on the left of the split plane, farmers' strategies evolve towards $z = 0$ and farmers eventually choose AGP, as shown in b of Figure 5. When the initial point of the game model is located on the right of the split plane, farmers' strategies evolve towards $z = 1$ and farmers eventually choose NGP, as shown in c of Figure 5.

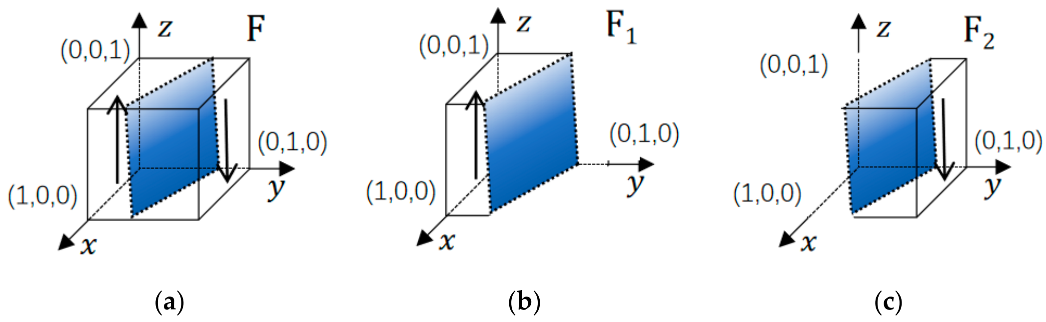


Figure 5. Evolution trend of farmers' strategy. (**a**) Phase diagram of farmers' dynamic evolution. (**b**) Evolution trend of farmers' strategy AGP. (**c**) Evolution trend of farmers' strategy NGP.

Therefore, the probability that farmers choose AGP is $F_1 = \int_0^1 \int_0^1 \frac{-E_g - F_1 - F_2 - D_L + A_1 + E_L - y(A_1 + A_2 - D_g - D_L)}{I} dzdy$, and the probability that farmers choose RGP is $F_2 = 1 - F_1$.

4.2. Stability Analysis of Evolutionary Equilibrium Point

A three-dimensional dynamic system (I) is composed of the replication dynamic equations of the three populations of governments, service organizations and farmers

:

$$\begin{cases} F_1(x,y,z) = x(1-x)[K_1 + K_2 - H_3 + B_F - yB_g + z(H_3 - I - B_F - K_2)] \\ F_2(x,y,z) = y(1-y)[N_1 + N_2 + C_3 + C_4 + C_L - C_1 - C_2 - D_L + xB_g + z(D_g + D_L - C_g - C_L)] \\ F_3(x,y,z) = z(1-z)[E_g + F_1 + F_2 + D_L - E_L - A_1 + xI + y(A_1 + A_2 - D_g - D_L)] \end{cases} \quad (16)$$

When $F_1(x,y,z) = 0$, $F_2(x,y,z) = 0$ and $F_3(x,y,z) = 0$, a three-dimensional dynamic system (I) exists that contains eight pure strategy equilibrium points, $E_1(0,0,0)$, $E_2(0,0,1)$, $E_3(0,1,0)$, $E_4(0,1,1)$, $E_5(1,0,0)$, $E_6(1,0,1)$, $E_7(1,1,0)$ and $E_8(1,1,1)$, and one mixed strategy equilibrium point, E_9.

$$E_9\left(\frac{-E_g - F_1 - F_2 - D_L + A_1 + E_L - y(A_1 + A_2 - D_g - D_L)}{I}, \frac{K_1 + K_2 - H_3 + B_F + z(H_3 - I - B_F - K_2)}{B_g}, \frac{N_1 + N_2 + C_3 + C_4 + C_L - C_1 - C_2 - D_L + xB_g}{C_L + C_g - D_L - D_g}\right) \quad (17)$$

Weibull pointed out that the equilibrium point of the mixed strategy does not strictly follow the Nash equilibrium [64]. Because the tripartite evolutionary game equilibrium is a strict Nash equilibrium, the pure strategy strictly follows the Nash equilibrium. Therefore, in the three-dimensional dynamic system (I) of the tripartite game, it is only necessary to discuss the asymptotic stability of the above eight pure strategy equilibrium points. The Jacobian matrix of system (I) is shown in Equation (18). According to evolutionary game theory and Lyapunov's stability theorem, when all eigenvalues are $\lambda < 0$ in the matrix, the equilibrium point is asymptotically stable in the sense of Lyapunov's stability theorem. When there is an eigenvalue $\lambda > 0$ in the matrix, the equilibrium point is unstable. When the eigenvalues of the matrix have both positive and negative λ, the equilibrium point is unstable and is called the saddle point. The corresponding eigenvalues of the eight pure strategy points of system (I) are shown in Table 2. Friedman proposed a method to judge the evolution equilibrium of the pure strategy and analyzed the stability of multivariate differential equations through the Jacobian matrix [65].

$$
\mathrm{J}(x,y,z)=\begin{bmatrix} \frac{\partial F_1(x,y,z)}{\partial x} & \frac{\partial F_1(x,y,z)}{\partial y} & \frac{\partial F_1(x,y,z)}{\partial z} \\ \frac{\partial F_2(x,y,z)}{\partial x} & \frac{\partial F_2(x,y,z)}{\partial y} & \frac{\partial F_2(x,y,z)}{\partial z} \\ \frac{\partial F_3(x,y,z)}{\partial x} & \frac{\partial F_3(x,y,z)}{\partial y} & \frac{\partial F_3(x,y,z)}{\partial z} \end{bmatrix}
$$

$$
\begin{cases} \frac{\partial F_1(x,y,z)}{\partial x} = (1-2x)[K_1+K_2-H_3+B_F+z(H_3-I-B_F-K_2)-yB_g] \\ \frac{\partial F_1(x,y,z)}{\partial y} = x(1-x)B_g \\ \frac{\partial F_1(x,y,z)}{\partial z} = x(1-x)(H_3-I-B_F-K_2) \\ \frac{\partial F_2(x,y,z)}{\partial x} = y(1-y)B_g \\ \frac{\partial F_2(x,y,z)}{\partial y} = (1-2y)[N_1+N_2+C_3+C_4+C_L-C_1-C_2-D_L+xB_g+z(-C_L-C_g+D_L+D_g)] \\ \frac{\partial F_2(x,y,z)}{\partial z} = y(1-y)(-C_L-C_g+D_L+D_g g) \\ \frac{\partial F_3(x,y,z)}{\partial x} = z(1-z)I \\ \frac{\partial F_3(x,y,z)}{\partial y} = z(1-z)(A_1+A_2-D_g-D_L) \\ \frac{\partial F_3(x,y,z)}{\partial z} = (1-2z)[E_g+F_1+F_2+D_L-A_1-E_L+y(A_1+A_2-D_g-D_L)+xI] \end{cases} \quad (18)
$$

Table 2. Characteristic value of pure strategy.

Strategy	Eigenvalue λ1	Eigenvalue λ2	Eigenvalue λ3
$E_1(0,0,0)$	$K_1+K_2-H_3+B_F$	$N_1+N_2+C_3+C_4+C_L-C_1-C_2-D_L$	$E_g+F_1+F_2+D_L-A_1-E_L$
$E_2(0,0,1)$	K_1-I	$N_1+N_2+C_3+C_4+D_g-C_g-C_1-C_2$	$-(E_g+F_1+F_2+D_L-A_1-E_L)$
$E_3(0,1,0)$	$K_1+K_2-H_3+B_F-B_g$	$-(N_1+N_2+C_3+C_4+C_L-C_1-C_2-D_L)$	$E_g+F_1+F_2+A_2-E_L-D_g$
$E_4(0,1,1)$	K_1-I-B_g	$-(N_1+N_2+C_3+C_4+D_g-C_g-C_1-C_2)$	$-(E_g+F_1+F_2+A_2-E_L-D_g)$
$E_5(1,0,0)$	$-(K_1+K_2-H_3+B_F)$	$N_1+N_2+C_3+C_4+C_L-C_1-C_2-D_L+B_g$	$E_g+F_1+F_2+D_L-A_1-E_L+I$
$E_6(1,0,1)$	$-(K_1-I)$	$N_1+N_2+C_3+C_4+B_g+D_g-C_g-C_1-C_2$	$-(E_g+F_1+F_2+D_L-A_1-E_L+I)$
$E_7(1,1,0)$	$-(K_1+K_2-H_3+B_F-B_g)$	$-(N_1+N_2+C_3+C_4+C_L-C_1-C_2-D_L+B_g)$	$E_g+F_1+F_2+A_2-E_L-D_g+I$
$E_8(1,1,1)$	$-(K_1-I-B_g)$	$-(N_1+N_2+C_3+C_4+B_g+D_g-C_g-C_1-C_2)$	$-(E_g+F_1+F_2+A_2-E_L-D_g+I)$

According to the eigenvalues given in Table 2, the stability of these eight equilibrium points is classified and discussed.

Case 1: When the eigenvalues $\lambda_1, \lambda_2, \lambda_3$ of equilibrium point E_1 meet this situation: $K_1+K_2+B_F<H_3, N_1+N_2+C_3+C_4+C_L<C_1+C_2+D_L, E_g+F_1+F_2+D_L<A_1+E_L$; equilibrium point E1 evolves into an ESS with the tripartite game in system (I). E_1 shows that governments adopt the strategy of NPG, service organizations adopt the strategy of PCT and farmers adopt the strategy of RGP. Governments do not implement such measures as financial subsidies and administrative penalties for the trusteeship of green agricultural production. Service organizations and farmers pursue the maximization of interests and adopt the model of traditional agricultural production, which exacerbates the deterioration of the agricultural ecological environment.

Case 2: When the eigenvalues λ_1, λ_2, λ_3 of equilibrium point E_2 meet this situation: $K_1<I, N_1+N_2+C_3+C_4+D_g<C_g+C_1+C_2, E_g+F_1+F_2+D_L>A_1+E_L$; equilibrium point E_2 evolves into an ESS with the tripartite game in system (I). E_2 shows that governments adopt the strategy of NPG, service organizations adopt the strategy of PCT and farmers adopt the strategy of AGP. Governments do not implement such measures as financial subsidies and administrative penalties for the trusteeship of green agricultural production. Relying on limited rationality, farmers spontaneously develop green agriculture, protect black land and give up pursuing the maximization of interests. Service organizations do not follow market feedback and adopt strategies that deviate from those of farmers.

Case 3: When the eigenvalues $\lambda_1, \lambda_2, \lambda_3$ of equilibrium point E_3 meet this situation: $K_1 + K_2 + B_F < H_3 + B_g, N_1 + N_2 + C_3 + C_4 + C_L > C_1 + C_2 + D_L, E_g + F_1 + F_2 + A_2 < E_L + D_g$; equilibrium point E_3 evolves into an ESS with the tripartite game in system (I). E_3 shows that governments adopt the strategy of NPG, service organizations adopt the strategy of PGT and farmers adopt the strategy of RGP. Governments do not implement such measures as financial subsidies and administrative penalties for the trusteeship of green agricultural production. Service organizations popularize green agricultural production to farmers and promote the whole trusteeship of green agricultural production. Farmers refuse the trusteeship of green agricultural production, pursue the maximization of grain production and excessively reclaim black land.

Case 4: When the eigenvalues $\lambda_1, \lambda_2, \lambda_3$ of equilibrium point E_4 meet this situation: $K_1 < I + B_g, N_1 + N_2 + C_3 + C_4 + D_g > C_g + C_1 + C_2, E_g + F_1 + F_2 + A_2 > E_L + D_g$; equilibrium point E_4 evolves into an ESS with the tripartite game in system (I). E_4 shows that governments adopt the strategy of NPG, service organizations adopt the strategy of PGT and farmers adopt the strategy of AGP. In the absence of governments' financial subsidies and administrative supervision, service organizations and farmers spontaneously abandon the traditional agricultural production model and adopt the green agricultural production model, relying on the role of market regulation. This stable state can be considered as a sub ideal state.

Case 5: When the eigenvalues $\lambda_1, \lambda_2, \lambda_3$ of equilibrium point E_5 meet this situation: $K_1 + K_2 + B_F > H_3, N_1 + N_2 + C_3 + C_4 + C_L + B_g < C_1 + C_2 + D_L, E_g + F_1 + F_2 + D_L + I < A_1 + E_L$; equilibrium point E_5 evolves into an ESS with the tripartite game in system (I). E_5 shows that governments adopt the strategy of APG, service organizations adopt the strategy of PCT and farmers adopt the strategy of RGP. Under the constraints and incentives of governments' administrative fines and financial subsidies, governments cannot promote farmers and service organizations to promote green agricultural production. Therefore, it is worth conducting in-depth research on the extent to which administrative penalties and financial subsidies can encourage farmers and service organizations to change their strategies.

Case 6: When the eigenvalues $\lambda_1, \lambda_2, \lambda_3$ of equilibrium point E_6 meet this situation: $K_1 > I, N_1 + N_2 + C_3 + C_4 + B_g + D_g < C_g + C_1 + C_2, E_g + F_1 + F_2 + D_L + I > A_1 + E_L$; equilibrium point E_6 evolves into an ESS with the tripartite game in system (I). E_6 shows that governments adopt the strategy of APG, service organizations adopt the strategy of PCT and farmers adopt the strategy of AGP. Under the government's financial subsidy incentives and administrative punishment constraints, farmers give up the traditional agricultural production model, respond to the governments' call to accept green agricultural production and purchase green agricultural production trusteeship. However, service organizations adopt the strategy of PCT which is contrary to the farmers.

Case 7: When the eigenvalues $\lambda_1, \lambda_2, \lambda_3$ of equilibrium point E_7 meet this situation: $K_1 + K_2 + B_F > H_3 + B_g, N_1 + N_2 + C_3 + C_4 + C_L + B_g > C_1 + C_2 + D_L, E_g + F_1 + F_2 + A_2 + I < E_L + D_g$; equilibrium point E_7 evolves into an ESS with the tripartite game in system (I). E_7 shows that governments adopt the strategy of APG, service organizations adopt the strategy of PGT and farmers adopt the strategy of RGP. Governments' financial subsidies and administrative penalties make service organizations and farmers take opposing strategies and service organizations do not adopt the same agricultural production model as farmers according to market feedback.

Case 8: When the eigenvalues $\lambda_1, \lambda_2, \lambda_3$ of equilibrium point E_8 meet this situation: $K_1 > I + B_g, N_1 + N_2 + C_3 + C_4 + B_g + D_g > C_g + C_1 + C_2, E_g + F_1 + F_2 + A_2 + I > E_L + D_g$; equilibrium point E_8 evolves into an ESS with the tripartite game in system (I). E_8 shows that governments adopt the strategy of APG, service organizations adopt the strategy of PGT and farmers adopt the strategy of AGP. The strategy combination of E_8 is idealized. Under the positive stimulus of governments' financial subsidies and the negative constraint of administrative punishment, farmers give up the traditional agricultural production model and seek a new agricultural production model to respond to and protect black land. Service organizations respond to market demand and promote green agricultural production trusteeship services with the support of government subsidies for technological reform.

4.3. Simulation Analysis

In the above theoretical analysis, this study determines the corresponding conditions for the evolution of pure strategic equilibrium points of stakeholders into stable points. In order to intuitively observe the evolution of the reality of green agricultural production trusteeship in Northeast China under the initial conditions and the influence of the parameters in the model on the stability of the system, this study uses Python 3.7.0 software for a numerical simulation based on the real data of Northeast China and analyzes the dynamic evolution trajectory of stakeholders' decisions. The data of parameters are mainly from the China Statistical Yearbook, the China Rural Statistical Yearbook, a rural field survey and an expert survey method, as shown in Table 3.

Table 3. Initial values of variable parameters based on real data.

Parameter	Date Resource	Date (CNY/mu)
A_1	Taking 250 million mu of black land protection area in Northeast China as the base, the cost of using organic fertilizer by farmers is 227 CNY/mu. The input of loosening soil for sowing and green pesticides is 85 CNY/mu and the cost of large-scale mechanization is about 258 CNY/mu. Total: 227 + 85 + 258 = 570 CNY/mu. (Data source: field survey in Lishu County).	570
A_2	Based on the protection area of 250 million mu of black land in Northeast China, the use of inorganic fertilizers by farmers is 133 CNY/mu, the cost of pesticides and small-scale mechanization is 278 CNY/mu and other costs such as pesticides are 69 CNY/mu. Total: 133 + 69 + 278 = 480 CNY/mu. (Data source: field survey in Lishu County).	480
C_2	This was obtained through field research in rural areas. (Data source: with the relevant service organizations in Lishu County).	60
C_3	With reference to the Agricultural Technology Extension Center of Fuyuan City and Yicheng District, the expenses for the daily work of the organizations are respectively 0.6031 million and 0.9873 million. According to the "Heilongjiang" 14th five year plan for agricultural science and technology development, there are 2528 service organizations. It is estimated that there are 7584 service organizations in the three provinces of Northeast China. Total: $[(0.6031 + 0.9873)/2] \times 7584/250 = 24.124$ CNY/mu. (Data source: Fuyuan Agriculture and Rural Bureau, Zhumadian Agricultural and Rural Bureau and Heilongjiang Provincial People's Government).	24.124
C_1	This refers to the notice of the implementation plan for the reform and construction of the grassroots agricultural technology extension system in Gaoan City in 2022, and the work funds and team building training funds are 0.625 million. Total: $[0.625 + (0.6031 + 0.9873)/2] \times 7584/250 = 42.48$ CNY/mu. (Data source: Gaoan Agricultural and Rural Bureau).	42.48
C_4	This was obtained field research in rural areas. (Data source: with the relevant service organizations in Lishu County).	12
D_L	Taking wheat planting in Lishu County, Heilongjiang Province, as a reference, compared with the farmers' self-planting, the service organization's traditional production trusteeship reduced the planting cost by 13–20%, the labor cost by 30–45% and the fertilizer application by 15–25%. The cost was estimated to be 340 CNY/mu. (Data source: Lishu County People's Government).	340

Table 3. *Cont.*

Parameter	Date Resource	Date (CNY/mu)
D_g	Taking wheat planting in Lanxi County, Heilongjiang Province, as a reference, compared with farmers' self-planting, the green production trusteeship of service organizations reduced the planting cost by 10–15%, the labor cost by 25–35% and the fertilizer application by 10–20%. The cost was estimated to be 440 CNY/mu. (Data source: LanXi County People's Government).	440
E_g	According to the China Statistical Yearbook in 2023, taking wheat planting as a reference, the average yield is 1100 kg/mu, the purchase price is 1.17 CNY/kg, the subsidy per mu is 58 and the land rent cost is 373. Total: $1100 \times 1.17 + 58 - 373 = 972$ CNY/mu. (Data source: China Statistical Yearbook 2023).	972
E_L	According to the China Statistical Yearbook in 2023, taking wheat planting as a reference, the yield of "predatory production" is 1300 kg/mu, the purchase price is 1.17 CNY/kg, the subsidy per mu is 58 and the land rent cost is 373. Total: $1300 \times 1.17 + 58-373 = 1206$ CNY/mu. (Data source: China Statistical Yearbook 2023).	1206
H_3	This takes the black land protection funds allocated by the finance bureaus of Inner Mongolia and prefecture-level cities as a reference, estimated by municipal units. Total: $80 \times 39/250 = 12.48$ CNY/mu. (Data source: Inner Mongolia Finance Bureau).	12.48
B_g	This is based on the funds of CNY 4.53772 million of the Sunwu County production trust project in 2022 and the funds of the Black Land Protection Project in Northeast China, estimated by county-level units. Total: $[4.5372 \times (60 + 67 + 100) + (800 + 620 + 540)]/250 = 11.956$ yuan/mu. (Data source: Sunwu County People's Government network, etc.).	11.956
I	Referring to the implementation plan of black land conservation tillage in 2022, 58 CNY/mu was used to subsidize farmers. Other subsidies, such as non-closed facility farming and organic fertilizer subsidies, were estimated to be 62 CNY/mu. Total: $58 + 62 = 120$ CNY/mu. (Data source: Chinese Government Website).	120
H_1	In 2022, the total output value of China's green agricultural product processing was about 2823.48 billion, with a tax rate of 17%, and the proportion of production in Northeast China was 25%. Total: (2823.48 billion $\times$ 0.17 $\times$ 0.25)/250 million mu = 480 CNY/mu. (Data source: Department of Rural Industry Development, Ministry of Agriculture and Rural Affairs of China).	480
H_2	In 2022, the total output value of non-green agricultural products processing in China was about 2352.94 billion, with a tax rate of 17%, and the proportion of non-green agricultural products in Northeast China was 25%. Total: (2352.94 billion $\times$ 0.17 $\times$ 0.25)/250 million mu = 400 CNY/mu. (Data source: Department of Rural Industry Development, Ministry of Agriculture and Rural Affairs of China).	400
C_L	The estimated cost is 295 CNY/mu based on the profit of about 45 CNY/mu achieved by the scientific operation of the service organization and in combination with the production trusteeship costs. Total: $340 - 45 = 295$ CNY/mu. (Data source: Ministry of Agriculture and Rural Affairs of China).	295
C_g	The estimated cost is 349 CNY/mu based on the profit of about 91 CNY/mu achieved by the scientific operation of the service organization and in combination with the production trusteeship costs. Total: $440 - 91 = 349$ CNY/mu. (Data source: Ministry of Agriculture and Rural Affairs of China).	349

Table 3. *Cont.*

Parameter	Date Resource	Date (CNY/mu)
F_1	Due to the adoption of green agricultural production trusteeship services and the optimization of black soil geology, the efficiency of wheat is 100 CNY/mu. (Data source: Ministry of Agriculture and Rural Affairs of China and expert survey estimate).	100
F_2	According to the statistics of the Ministry of Agriculture and Rural Areas, the annual loss of nitrogen, phosphorus, potassium and other minerals in the black soil area of Northeast China is about 4.5 million tons. According to 2800 yuan/ton of chemical fertilizer, it is estimated that 45 × 28 million = 12.6 billion, and the adverse and far-reaching impact is estimated by experts to be 20 billion. Total: (12.6 + 20) billion /250 million mu =130.4 CNY/mu. (Data source: Ministry of Agriculture and Rural Affairs of China).	130.4
B_F	Referring to the illegal sale of 250,000 m^3 of black land in Heilongjiang Province, the fine for black land is 3000 CNY/m^3. It is estimated that the penalty in Northeast China is 9 CNY/mu. (Data source: Heilongjiang Provincial People's Government).	9

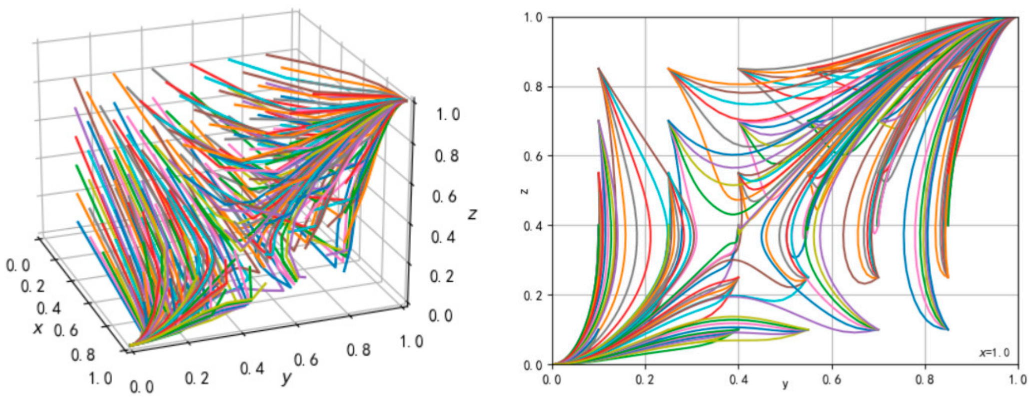
Combined with the actual data in Table 3, the specific characteristic values of each pure strategy point are shown in Table 4. Combined with the analysis of the above eight situations, it can be concluded that E_1, E_2, E_3, E_4, E_6 and E_7 are saddle points, but E_5 and E_8 are stability strategy points. With the evolution process of each participant's game, system (I) tends towards two stable points, E_5 and E_8.

Table 4. Real data eigenvalues of eight pure strategy equilibrium points.

Strategy	Eigenvalue λ_1	Eigenvalue λ_2	Eigenvalue λ_3
$E_1(0,0,0)$	446.32	−61.56	−233.6
$E_2(0,0,1)$	80	74.49	233.6
$E_3(0,1,0)$	434.36	61.56	36.4
$E_4(0,1,1)$	68.04	−74.49	−36.4
$E_5(1,0,0)$	−446.32	−49.60	−113.6
$E_6(1,0,1)$	−80	86.76	113.6
$E_7(1,1,0)$	−434.36	49.60	156.4
$E_8(1,1,1)$	−68.04	−86.76	−156.4

4.3.1. Evaluation of Implementation Effect of Initial Strategy

In order to evaluate the evolution and stability of green agricultural production trusteeship in Northeast China under black land protection under the initial conditions, we need to set different initial ratios for multiple evolutionary simulations to observe the evolution trajectory of the system. According to the setting method proposed by Chen and Gao, the probability of multi-agent initial decision making is set to 0.1 to 0.9, and the growth steps are 0.15, 0.1 and 0.05 [66]. However, because the step size is too small, the evolution trajectory would be too centralized and difficult to identify, so the growth step size of the initial decision probability is set to 0.15, and a total of 216 numerical simulations are simulated. It can be seen from Figure 6a that different initial strategy proportions in system (I) evolve towards (1,0,0) and (1,1,1) equilibrium points, respectively, and are in a stable state. The simulation effect of system (I) is consistent with the results shown in Table 4 above, which proves that the model of system (I) is correct.



(**a**) (**b**)

Figure 6. Evolution path of system (I) under real data. (**a**) The three-dimensional evolution path of system (I) with different initial strategies. (**b**) The evolution path of service organizations and farmers with different initial strategies. The lines in different color refer to the different initial strategies.

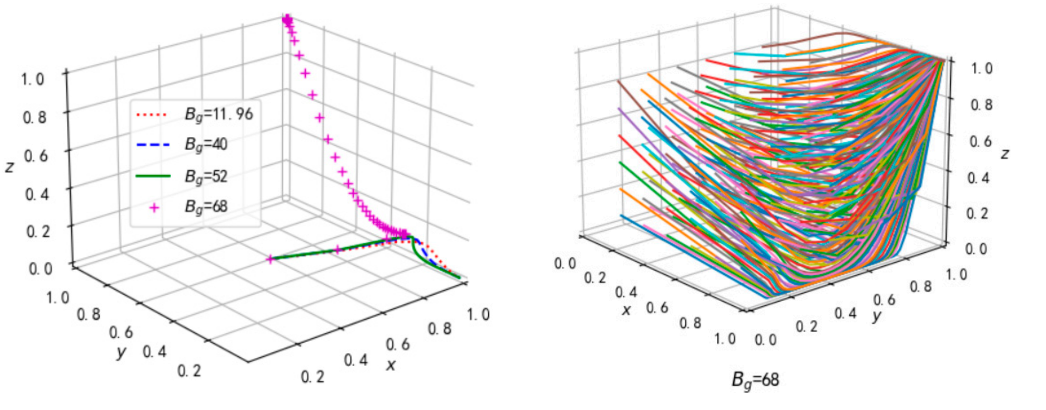
In view of the phenomenon that system (I) forms two equilibrium points, (1,0,0) and (1,1,1), the following analysis is made: ① As can be seen from Figure 6b, taking (0.4, 0.4) as the starting point, the horizontal and vertical jointly form a watershed. In the region with $y > 0.4$, service organizations that choose to promote green agricultural production trusteeships can guide farmers with different proportion strategies to choose green agricultural production trusteeships, making system (I) tend towards stable point (1,1,1). ② In the region with $y < 0.4$, with a low awareness of green agricultural production trusteeship and in the absence of government subsidy incentives and administrative punishment constraints, farmers should choose the traditional agricultural production trusteeship model in order to maximize their interests, so that the service organizations also choose to promote the traditional agricultural production trusteeship and rapidly occupy the market share, gradually eliminating the service organizations that choose to promote the green agricultural production trusteeship, making system (I) tend towards the stable point (1,0,0).

4.3.2. Sensitivity Analysis

This study assumes that the regions where the initial proportion strategies of the three parties are less than 0.5 are the regions with a low awareness of green agricultural production trusteeships and analyzes the influence of the changes in special subsidy B_g, farmer subsidy I, administrative penalty B_F, total cost of the whole trusteeship of green agricultural production C_g and the whole trusteeship of green agricultural production trusteeship fee D_g, etc., on the evolution trend of the tripartite game model.

Impact of Special Subsidy B_g

We set the initial point as E_I (0.3, 0.25, 0.25) and the unit of time t as year. Figure 7a shows that the increase in special subsidy B_g changes the evolution path of tripartite decision making. When special subsidy B_g is increased to 68 CNY/mu, the strategic stability point evolves from (1,0,0) to (1,1,1). For areas with a low awareness of green agricultural production trusteeship, increasing the financial subsidy allocated by governments to organizations is conducive to improving farmers' awareness of green agricultural production trusteeship. Figure 7b shows the following: ① When special subsidy B_g is increased to 68 CNY/mu, 216 simulations of system (I) will evolve towards (1,1,1). ② In areas where the awareness of green agricultural production trusteeship is extremely poor, the evolution path of the tripartite strategy combination shows that governments always take the lead in actively promoting green agricultural production trusteeship, and then the strategic ratio of service organizations and farmers shows exponential growth, tending to promote the whole trusteeship of green agricultural production and accepting the trusteeship of green agricultural production, respectively. This evolution path shows that governments are supervisors playing a guiding role in the popularization of green agricultural production trusteeship.



(**a**) (**b**)

Figure 7. Sensitivity of system (I) to changes in $\boldsymbol{B_g}$. (**a**) Evolution path of System (I) with $\boldsymbol{E_I}$ (0.3, 0.25, 0.25) under different $\boldsymbol{B_g}$ (**b**) The three-dimensional evolution path of system (I) with different initial strategies under $\boldsymbol{B_g}$ = 68. The lines in different color refer to the different initial strategies.

Figure 8 shows the following: ① Governments always actively promote the trusteeship of green agricultural production. ② The increase in special subsidies significantly increases the enthusiasm of service organizations to promote the whole trusteeship of green agricultural production. ③ Under the financial support of governments, with the continuous increase in special subsidy B_g, the game competition between the service organizations promoting PGT and the service organizations promoting PCT intensifies. When special subsidy B_g increases to 68 CNY/mu, the proportion of service organizations promoting PGT increases rapidly, and farmers experience the process of changing from the strategy of traditional agricultural production trusteeship to the strategy of green agricultural production trusteeship.

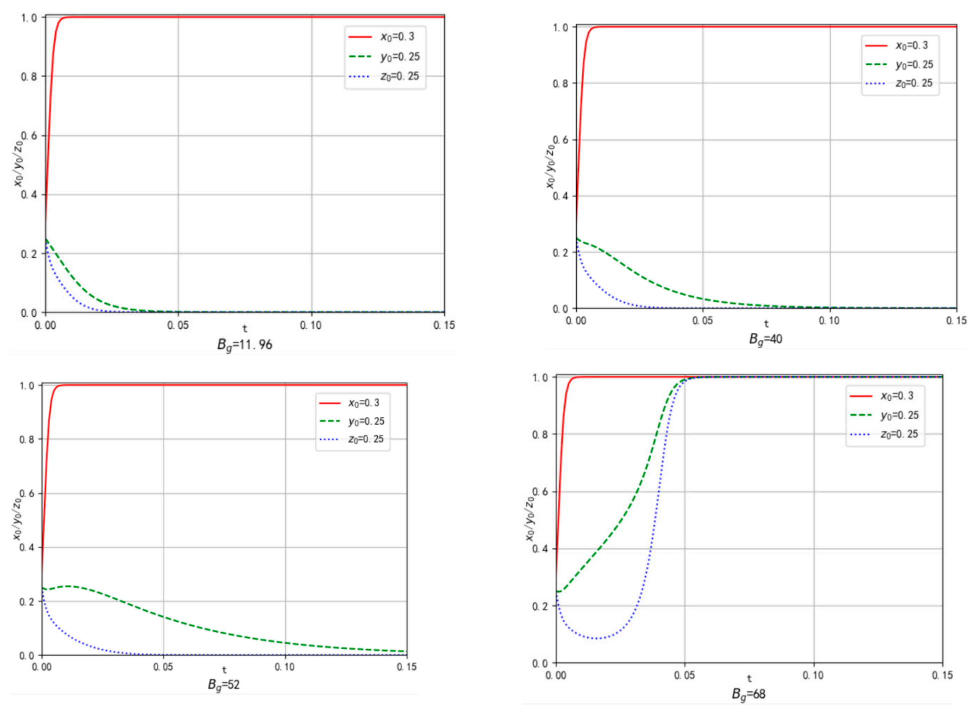
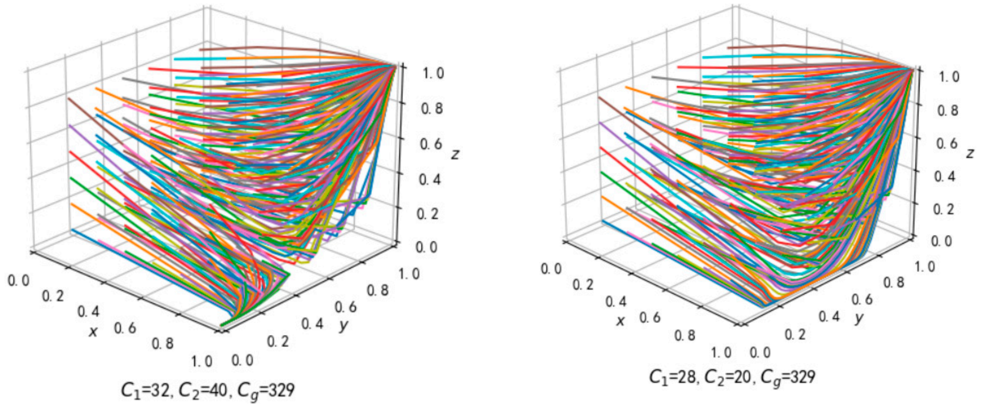


Figure 8. Evolution path of the tripartite agent under the influence of different $\boldsymbol{B_g}$.

Common Influence of the Total Cost of C_1, C_2 and C_g of Service Organizations

Figure 9a shows that reducing the total cost of the whole trusteeship of green agricultural production effectively reduces the evolution from the initial strategy point located in the weak area of green agricultural production trusteeship to the stable point (1,0,0). Figure 9b shows that when annual operating cost C_1 is reduced to 28 CNY/mu, the construction cost of green agricultural production base and related publicity cost C_2 is reduced to 20 CNY/mu and the cost, C_g, of the whole trusteeship of green agricultural production is reduced to 329 CNY/mu, meaning that service organizations gain higher profits. Because of their stronger competitiveness, the enthusiasm of service organizations to promote the whole trusteeship of green agricultural production services improves, which expands the scale of farmers adopting green agricultural production trusteeship strategies and finally makes all the initial strategy sets of system (I) evolve towards stable point (1,1,1).

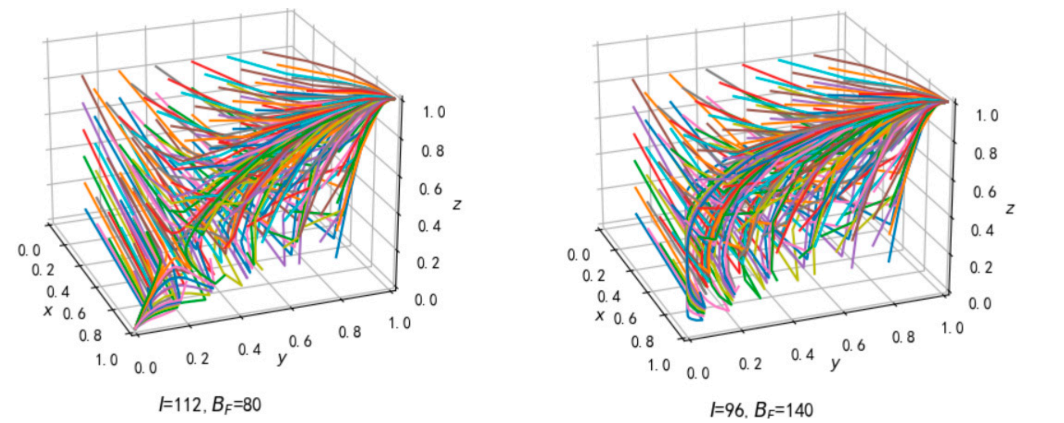


(**a**) (**b**)

Figure 9. Sensitivity performance of system (I) to common changes in $\boldsymbol{C_1}$, $\boldsymbol{C_2}$ and $\boldsymbol{C_g}$. (**a**) The three-dimensional evolution path of system (I) with different initial strategies under $\boldsymbol{C_1}$ = 32, $\boldsymbol{C_2}$ = 40, $\boldsymbol{C_g}$ = 329. (**b**) The three-dimensional evolution path of system (I) with different initial strategies under $\boldsymbol{C_1}$ = 28, $\boldsymbol{C_2}$ = 20, $\boldsymbol{C_g}$ = 329. The lines in different color refer to the different initial strategies.

Common Impact of Farmers' Subsidy I and Administrative Penalty B_F

Figure 10 shows the following: ① Reducing farmers' subsidy I and increasing administrative penalty B_F at the same time changes the evolution path of tripartite decision making. ② When I and B_F are 112 CNY/mu and 80 CNY/mu, respectively, the proportion of the tripartite strategies evolving to the stable point (1,0,0) in the area where green agricultural production trusteeship is weak in system (I) of Figure 10a is reduced by about 50% compared with system (I) of Figure 6a. ③ When I and B_F are 96 CNY/mu and 140 CNY/mu, respectively, the initial strategy points in system (I) in Figure 10b tend to evolve towards stable point (1,1,1). Reducing farmers' subsidy I and increasing administrative penalty B_F at the same time can effectively promote the whole trusteeship of green agricultural production. Reducing farmers' subsidy I can reduce the financial burden of governments, and increasing administrative penalty B_F can effectively restrain farmers from taking the whole trusteeship of traditional agricultural production excessively reclaiming black land and encourage farmers to choose green agricultural production trusteeship services, which improves farmers' willingness to accept the trusteeship of green agricultural production. Therefore, governments' subsidies for green farmers should not be excessive, and government administrative penalties for non-green farmers should be significantly increased.



(**a**) (**b**)

Figure 10. Sensitivity performance of system (I) to common changes in $\boldsymbol{I}$ and $\boldsymbol{B_F}$. (**a**) The three-dimensional evolution path of system (I) with different initial strategies under $\boldsymbol{I}$ = 112, $\boldsymbol{B_F}$ = 80. (**b**) The three-dimensional evolution path of system (I) with different initial strategies under $\boldsymbol{I}$ = 96, $\boldsymbol{B_F}$ = 140. The lines in different color refer to the different initial strategies.

We set the initial point as E_I (0.2, 0.2, 0.2) and the unit of time t as year. The slope of the tripartite evolution path in Figure 11 shows the following: ① farmers in areas with a poor awareness of green agricultural production trusteeship are sensitive to changes in production subsidy I and administrative penalty B_F and can quickly adjust their decision-making strategies. ② When B_F rises to 80 CNY/mu, the evolution path of farmers experiences a change entailing firstly a decline, then a small increase and finally a decline, indicating that when the B_F of administrative penalty reaches a certain critical value, farmers have a strategic "shake". After a period of game competition, farmers choose the traditional agricultural production trusteeship service if they find that the penalty does not offset the comprehensive benefits obtained from the traditional agricultural production trusteeship service too much. ③ When B_F continues to increase to 140 CNY/mu and I decreases to 96 CNY/mu, farmers quickly choose AGP due to the strong deterrent of a high penalty. With the feedback from the market, service organizations rapidly shift from PCT to PGT.

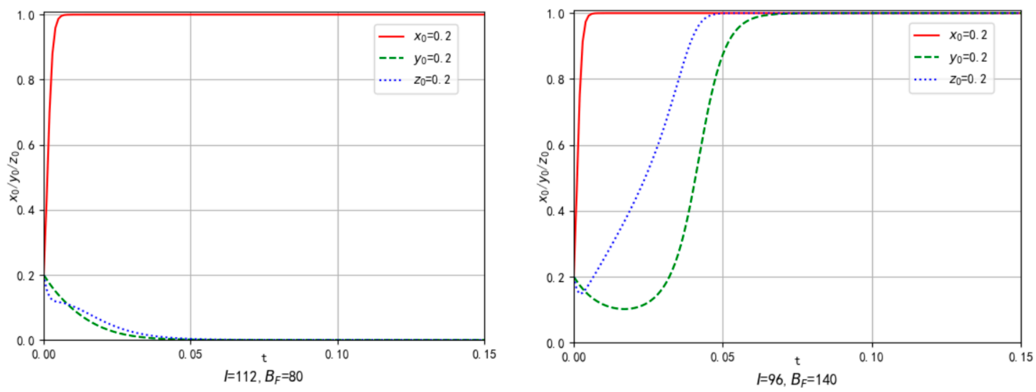


Figure 11. Evolution path of tripartite agent under the influence of different changes in $\boldsymbol{I}$ and $\boldsymbol{B_F}$.

The Cost of Self-Planting of Green Agriculture Production A_1, Farmers' Subsidy I and Administrative Penalty B_F

Compared with system (I) in Figure 6, Figure 12 shows the following: ① On the one hand, when the cost of A_1 is reduced from 570 CNY/mu to 550 CNY/mu and 490 CNY/mu, respectively, the initial strategies in the area with a poor awareness of green agricultural production trusteeship evolves towards the stable point (1,0,0) to a certain extent. ② On the other hand, the reduction in A_1 is the service of the partial or whole production trusteeship through service organizations and the use of green production technology to reduce the cost of mechanized operations and artificial pesticides. The reduction in A_1 is conducive to the popularization of the application of the whole trusteeship of green agricultural production.

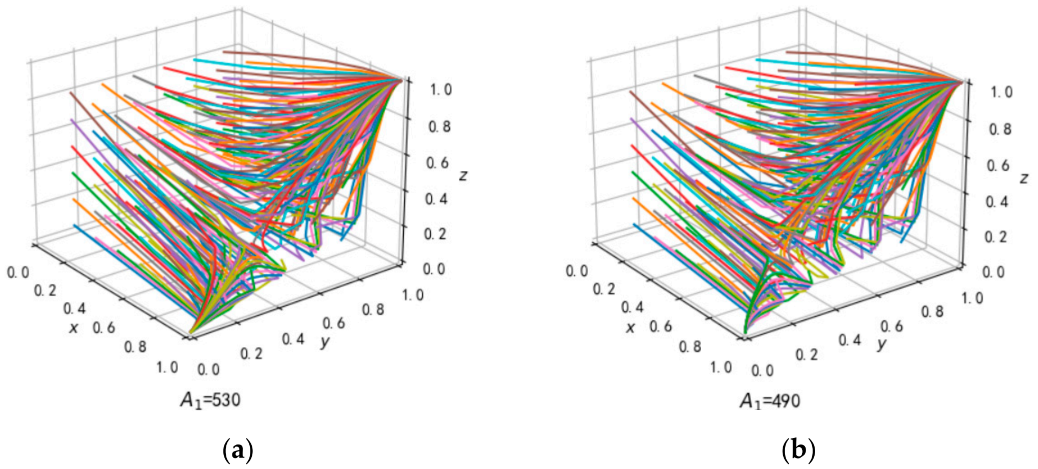
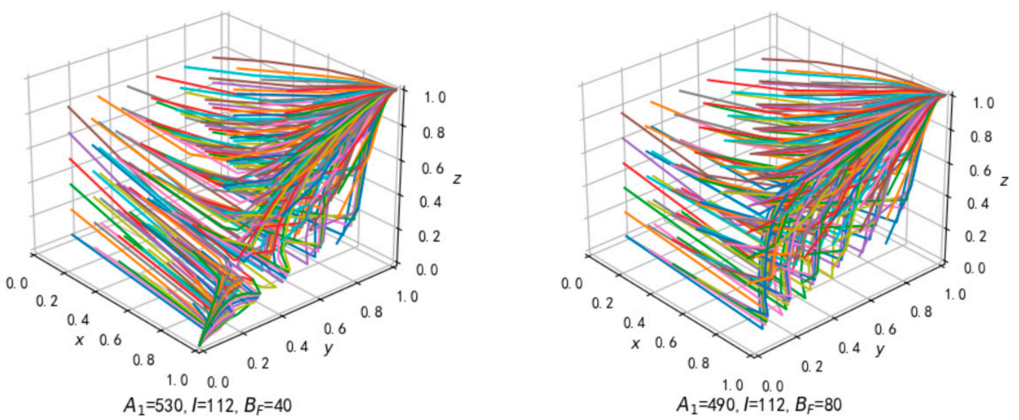


Figure 12. Sensitivity of system (I) to changes in A_1. (a) The three-dimensional evolution path of system (I) with different initial strategies under A_1 = 530. (b) The three-dimensional evolution path of system (I) with different initial strategies under A_1 = 490. The lines in different color refer to the different initial strategies.

From the above analysis, it can be seen that the reduction in A_1 cannot make the full initial strategies of system (I) evolve towards stable point (1,1,1). Therefore, it is necessary and important to analyze the impact on system (I) under the common changes in A_1, farmers' subsidy I and administrative penalty B_F. Figure 13a shows the following: ① when governments increase administrative penalty B_F, farmers adopt the green agricultural production model through the partial trusteeship with service organizations in order to find new agricultural production technologies to transform the model of agricultural production. In this case, the farmers' self-planting cost of green agricultural production A_1 decreases. Compared with system (I) in Figure 6, when A_1 = 530 CNY/mu, I = 112 CNY/mu, B_F = 40 CNY/mu, the proportion of the tripartite strategies evolving to the stable point (1,0,0) in the area with weak green agricultural production trusteeship in system (I) is reduced by about 45%. ② When governments continue to increase the administrative penalty B_F while maintaining the level of farmers' subsidy I, farmers independently carry out full trusteeship with service organizations to adopt green agricultural production, facing high illegal costs. In this case, cost A_1 continues to decline. Compared with system (I) in Figure 6, when A_1 decreases to 490 CNY/mu, I decreases to 112 CNY/mu and B_F increases to 80 CNY/mu, each initial strategy in system (I) tends to evolve towards stable point (1,1,1). The game model achieves the equilibrium state that service organizations and farmers jointly promote the wide application of the whole trusteeship of green agricultural production.

According to the simulation results, this study builds a multi-agent collaborative mechanism, which is shown in Figure 14. The mechanism to promote the wide application of the whole trusteeship of green agricultural production includes four sub mechanisms: 1. Multi-Agent Responsibility Mechanism with Responsibility as the Core. As the power source to promote the operation of the whole trusteeship of the green agricultural production mechanism, it can coordinate the relationship among governments, service organizations and farmers, clarify the responsibilities of each agent, ensure the normal operation of the whole trusteeship of the green agricultural production mechanism and improve the operation efficiency of each mechanism. 2. Reward and Punishment Mechanism with Policy System as the Core. With the goal of promoting the wide application of the whole trusteeship of green agricultural production, governments formulate regulatory, incentive and punishment policies to ensure that all agents implement in accordance with laws, regulations and the relevant policies, improve the green agricultural trusteeship service systems and guide service organizations and farmers to implement green agricultural production trusteeship. 3. Risk Sharing Mechanism with Financial Funds as the Core. The mechanism emphasizes the establishment of a mutual trust mechanism around governments, service organizations and farmers. Relying on financial funds, governments provide a solid financial source to help with the technical innovation risk of service organizations' promotion of the whole trusteeship of green agricultural production and the economic risk faced by farmers due to the transformation of farming methods. Service organizations rely on government financial funds to realize the innovation of green production technology, reduce the cost of the whole trusteeship of green agricultural production and provide green production technology returns for the investment risk of government financial funds. Farmers rely on government financial funds to realize the farming transformation of green agricultural production trusteeship and provide modern agricultural returns for the investment risk of government financial funds. 4. The Interest Distribution Mechanism with the Government's Overall Planning as the Core. Governments divide regions with a poor awareness of green agricultural production trusteeship and focus on supporting service organizations and farmers in regions with a poor awareness of green agricultural production trusteeship to promote the whole trusteeship of green agricultural production in accordance with the principles of openness, transparency, mutual benefit and win–win results. Governments need to strengthen the regional guidance of green agricultural production trusteeship, drive more regions to realize the transformation of green agricultural production and solidly promote the development of green agriculture. The four sub mechanisms are inseparable and contain each other. Only the four sub mechanisms working together can ensure the smooth operation of the mechanism to promote the wide application of the whole trusteeship of green agricultural production.



(**a**) (**b**)

Figure 13. Sensitivity performance of system (I) to common changes in $\boldsymbol{A_1}$, $\boldsymbol{B_F}$ and $\boldsymbol{I}$. (**a**) The three-dimensional evolution path of system (I) with different initial strategies under $\boldsymbol{A_1}$ = 530, $\boldsymbol{I}$ = 112, $\boldsymbol{B_F}$ = 40. (**b**) The three-dimensional evolution path of system (I) with different initial strategies under $\boldsymbol{A_1}$ = 490, $\boldsymbol{I}$ = 112, $\boldsymbol{B_F}$ = 80. The lines in different color refer to the different initial strategies.

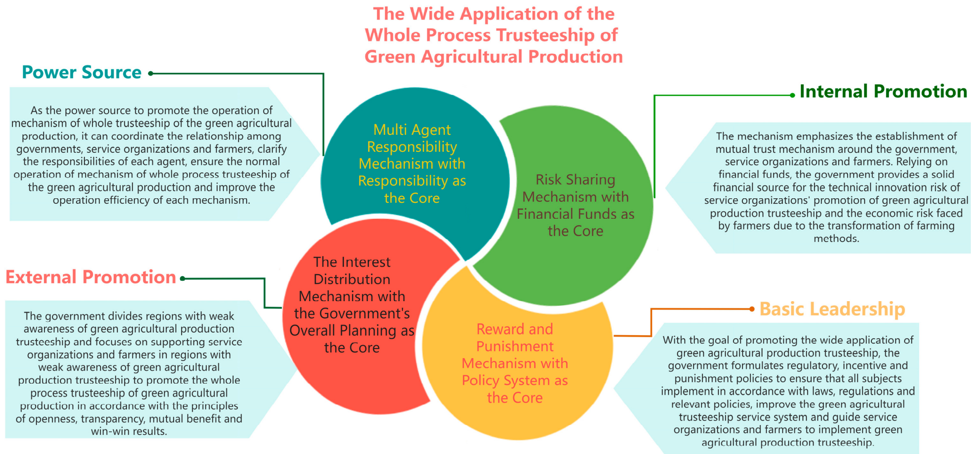


Figure 14. Multi-agent collaborative mechanism.

5. Discussion

Under the background of black land protection, green agricultural production trusteeship involves the decision-making behavior of relevant stakeholders. Therefore, this study proposes a tripartite evolutionary game model for promoting green agricultural production trusteeship. The results of this study are consistent with the relevant literature research and enrich the research content in the field of green agricultural production trusteeship.

The system simulation results under different initial ratios show that governments have always actively promoted the trusteeship of green agricultural production. "The Implementation Plan of the National Black Land Protection Project (2021–2025)" defines the goal of protecting 250 million mu of black land by 2030. Under the influence of policy effect, governments will vigorously and actively promote the trusteeship of green agricultural production, which is consistent with the research of Smith [67] and Ogle [68]. At present, China's policy tools for promoting green agricultural production can be divided into two categories, mainly including incentive measures and punitive measures. Incentive measures include subsidies for innovation [69], production trusteeship [70], and production [71]. Incentive and punishment measures mainly incentivize and constrain service organizations and farmers to transform traditional agricultural production models and achieve a green transformation through economic means. This study indicates that increasing the intensity of incentive measures can effectively promote service organizations to promote green agricultural production trusteeship. However, the incentive intensity for farmers should be maintained at a moderate level. The main form of government punishment is penalty. In fact, this study indicates that the effect of punishment is more pronounced than that of incentives. The punishment measures aim to limit the excessive farming behavior of non-green farmers. The incentive measures aim to promote green production behavior among service organizations and farmers, but this increases the financial burden on the government. Therefore, adjusting the subsidy and administrative penalty for farmers as well as service organizations is a key tool to promote green agricultural production trusteeship, which is consistent with the research of Lonester [72] and Kulkarni [73].

The production decisions of farmers and service organizations directly affects the promotion effect of green agricultural production trusteeship. Related studies have shown that farmers adopt traditional agricultural production models in pursuit of higher yields and higher farm returns [74,75]. However, more and more farmers are consciously adopting green agricultural production models [76]. This is consistent with the results of this study: there are two different states of agricultural production models in Northeast China at present, with traditional agricultural production methods and green agricultural production methods coexisting. Due to a lack of subjective responsibility and environmental friendliness [77], the proactive awareness of farmers to change traditional agricultural production models is not high [78]. Therefore, in addition to adjusting production subsidies and penalties for farmers, it is also necessary to focus on education and environmental publicity [79]. For example, measures such as legal publicity and guidance from resident experts can be taken to enhance the awareness of farmers towards green production transformation.

This study finds that the slow development of green agriculture is mainly due to the relatively high cost of green production trusteeship, which is consistent with the research of Ma [70]. Zhu et al. indicates that the adjustment effect of labor prices was the main factor in cost increases, but the effects of technological progress and efficiency improvement could effectively reduce the costs of production [80]. Therefore, in order to reduce the cost of production trusteeship, it is necessary to improve the level of mechanization and reduce the dependence on labor, such as accelerating the research and development of intelligent agricultural machinery. In addition, this study indicates that promoting farmers to reduce the costs of green agriculture production is beneficial for farmers to seek partial or whole trusteeship from service organizations [81], which is a key factor in promoting green agricultural development and is consistent with the research of Cui [54]. The action path is to reduce labor costs through mechanized partial trusteeship production and thereby increase the proportion of green agricultural production trusteeship.

In summary, this study provides a theoretical analysis for promoting green agricultural production trusteeship. In addition, from the perspectives of governments, service organizations and farmers, this study proposes the establishment of a multi-agent collaborative mechanism to incentivize and encourage relevant stakeholders to participate in the whole trusteeship of green agricultural production and consolidate the protection of black land.

6. Conclusions

6.1. Findings

Based on the background of consolidating the protection of black land, this study applies the dynamic evolutionary game method to include the governments, service organizations and farmers as interested agents in the promotion of green agricultural trusteeship. Through evolutionary game modeling and a numerical simulation, the impact of the relevant important parameters on strategy selection is analyzed. The following conclusions are drawn:

(1) From the theoretical analysis and numerical simulation, it can be seen that there are two different models of agricultural production in Northeast China at this stage: the coexistence of the traditional agricultural production model and green agricultural production. Under different initial strategies, on one hand, a part of the strategy sets with a low initial proportion eventually evolves into a non-ideal state in which governments actively promote the green agricultural production trusteeship to protect black land, and service organizations and farmers jointly choose the traditional agricultural production model to maximize profits. On the other hand, a part of the strategy sets with a high initial proportion eventually evolves into a state in which the tripartite agents jointly realize green agricultural production. Under the strategy sets of each initial proportion, governments always adopt the strategy of actively promoting green agricultural production trusteeship to protect black land. For regions with a poor awareness of green agricultural production trusteeship, governments need to balance fiscal expenditure and administrative punishment and strengthen the guidance for service organizations and farmers to promote the wide application of the whole trusteeship of green agricultural production.

(2) Through the simulation and analysis of key factors under different conditions, the following conclusions can be drawn: (1) In areas with a poor awareness of green agricultural production trusteeship, governments lack incentives for providing a special subsidy to service organizations and lack constraints on administrative penalties for farmers' excessive reclamation of black land. Therefore, in regions where the awareness of green agricultural production trusteeship is poor, the government subsidy for green farmers should be maintained at 112 CNY/mu, and administrative penalties for non-green farmers for the over-cultivation of black land should

be increased to a level above 80 CNY/mu. The increase in penalty is effective in promoting black land protection and raising farmers' awareness of green agricultural production trusteeship. (2) Due to the relatively high total cost of the whole trusteeship of green agricultural production, the green technology of service organizations lacks competitiveness. Reducing the total cost of trusteeships is the most direct and effective way for service organizations to promote green agricultural production trusteeship. Therefore, service organizations should control the production cost of trusteeships at 329 CNY/mu. (3) Governments need to strengthen their communication and cooperation with service organizations and increase the special subsidies given to service organizations, especially with regard to the introduction of green agricultural machinery from abroad and self-research. The special subsidy allocated by governments to service organizations should be maintained at 68 CNY/mu, which can effectively increase the incentive for service organizations to move into rural areas to carry out the promotion of the whole trusteeship of green agricultural production services, which promotes the awareness of green agricultural production trusteeship among farmers.

6.2. Recommendations

(1) Governments are the promoter of the promulgation and implementation of the green agricultural production trusteeship policy. (1) Governments should join the village committees together to establish green agricultural production trusteeship propaganda points in rural areas, organize regular lectures on the development of green agricultural production for farmers and help them to form a view of the harmonious development of human beings and nature. (2) Governments and village committees should jointly lead farmers to arrange reasonable field crop rotation according to different planting models and rotation fallow systems and order green agricultural production trusteeship services, forming a new green agricultural cultivation model of "low input, high output".

(2) Service organizations are important hubs between government policies to promote green agricultural development and farmers' implementation of green agricultural production trusteeship. In order to respond to the policy and promote the whole trusteeship of green agricultural production, service organizations should take the following measures: (1) regularly carry out green production technology forums to enhance the professionalism of the relevant technical personnel, which will help to rationally improve the green agricultural production process; (2) actively carry out work to promote the whole trusteeship of green agricultural production, take the initiative to open green agricultural production model publicity lectures and strengthen communication with farmers and form strategic partnerships; and (3) regularly inspect aging and dilapidated production facilities and replace them with new and advanced production facilities (such as green agricultural machinery and green HVAC equipment) in order to improve the efficiency of production and thus reduce the costs of production.

6.3. Limitations and Reflection

This study has the following limitations: (1) This study only examines the black land area in Northeast China, and future research should focus on the national cultivated land area to improve data sources. Moreover, this study also only examines governments, service organizations, and farmers, neglecting the role of village committees in achieving the transformation of green agriculture for farmers. (2) The return calculation process of evolutionary game theory is based on the objective return of expectation theory, which does not fully conform to the finite rationality hypothesis. Strategy selection is based on the perception of the value of strategy returns rather than the objective practical utility, so it is necessary to introduce prospect theory to make up for the shortcomings of evolutionary game theory.

Based on evolutionary game theory and prospect theory, future research can focus on agricultural production areas in the country, establish a four-way game model of governments, village committees, service organizations and farmers, analyze the influence of key factors on the behavior and decision making of four stakeholders, and put forward specific suggestions for the wide application of green agricultural production trusteeship.

Author Contributions: Conceptualization, L.M.; methodology, L.M.; software, J.L. and C.L.; validation, J.L. and C.L.; formal analysis, J.L.; investigation, L.M. and Y.T.; resources, J.L.; data curation, J.L. and C.L.; writing—original draft preparation, L.M., J.L.,Y.T. and C.L.; writing—review and editing, L.M., J.L. and Y.T.; visualization, J.L. and C.L.; supervision, L.M. and Y.T.; project administration, L.M. and Y.T.; funding acquisition, L.M. and Y.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Heilongjiang Province Philosophy and Social Science Planning Research Project, grant number (22JYB232).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Details regarding where data supporting the article can be found via the following websites: https://nync.ln.gov.cn/nync/index/tzgg/2023030109402763832/index.shtml (accessed on 2 January 2024); https://www.zhumadian.gov.cn/html/site_gov/articles/202203/151784.html; https://www.fgs.moa.gov.cn/flfg/202205/t20220511_6398873.html (accessed on 2 January 2024); https://www.hzjjs.moa.gov.cn/nyshhfw/201905/t20190521_6313322.html (accessed on 2 January 2024); http://www.hljfy.gov.cn/govinfo/upload/files/2023/3/2a2485050bba73d7.pdf (accessed on 4 January 2024); http://www.agri.jl.gov.cn/xdny/htdbh/202207/t20220707_8503681.html (accessed on 4 January 2024); https://www.mof.gov.cn/zhuantihuigu/cczqzyzfglbf/zxzyzf_7788/nyscfzzj/ (accessed on 5 January 2024); https://www.hlj.gov.cn/hlj/c108411/202201/c00_31182750.shtml (accessed on 5 January 2024); https://www.hlbe.gov.cn/News/show/836060.html (accessed on 5 January 2024).

Acknowledgments: The authors would like to thank the reviewers and the editor, whose suggestions greatly improved the manuscript.

Conflicts of 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.

References

1. Yu, S.; Zhang, X.; Wang, Y.; Shen, Y. Research review on the impacts of climate change on the staple grain crops in the Three Northeastern Provinces of China. *Chin. J. Eco-Agric.* **2024**, *32*, 1–16. [CrossRef]
2. Du, Z.; Gao, B.; Ou, C.; Du, Z.; Yang, J.; Batsaikhan, B.; Dorjgotov, B.; Yun, W.; Zhu, D. A Quantitative Analysis of Factors Influencing Organic Matter Concentration in the Topsoil of Black Soil in Northeast China Based on Spatial Heterogeneous Patterns. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 348. [CrossRef]
3. Cui, J.; Guo, L.; Xiong, S.; Yang, S.; Wang, Y.; Zhang, S.; Sun, H. Soil organic carbon induces a decrease in erodibility of black soil with loess parent materials in northeast China. *Quat. Res.* **2023**, 1–10. [CrossRef]
4. Zhao, G.; Deng, Z.; Liu, C. Assessment of the Coupling Degree between Agricultural Modernization and the Coordinated Development of Black Soil Protection and Utilization: A Case Study of Heilongjiang Province. *Land* **2024**, *13*, 288. [CrossRef]
5. Zhou, H.; Li, B.; Lu, Y. Micromorphological analysis of soil structure under no tillage management in the black soil zone of Northeast China. *J. Mt. Sci.* **2009**, *6*, 173–180. [CrossRef]
6. Zhao, R.; Li, J.; Wu, K.; Kang, L. Cultivated Land Use Zoning Based on Soil Function Evaluation from the Perspective of Black Soil Protection. *Land* **2021**, *10*, 605. [CrossRef]
7. Zhang, J.; Sun, B.; Zhu, J.; Wang, J.; Pan, X.; Gao, T. Black Soil Protection and Utilization Based on Harmonization of Mountain-River-Forest-Farmland-Lake-Grassland-Sandy Land Ecosystems and Strategic Construction of Ecological Barrier. *Bull. Chin. Acad. Sci.* **2021**, *36*, 1155–1164. [CrossRef]
8. Liao, Y.; Zhang, B.; Kong, X.; Wen, L.; Yao, D.; Dang, Y.; Chen, W. A Cooperative-Dominated Model of Conservation Tillage to Mitigate Soil Degradation on Cultivated Land and Its Effectiveness Evaluation. *Land* **2022**, *11*, 1223. [CrossRef]
9. Han, X.; Zou, W. Research Perspectives and Footprint of Utilization and Protection of Black Soil in Northeast China. *Acta Pedol. Sin.* **2021**, *58*, 1341–1358. [CrossRef]
10. Jiang, Q.; Li, J.; Si, H.; Su, Y. The Impact of the Digital Economy on Agricultural Green Development: Evidence from China. *Agriculture* **2022**, *12*, 1107. [CrossRef]

11. United Nations Statistics Division. *Global Indicator Framework for the Sustainable 374 Development Goals and Targets of the 2030 Agenda for Sustainable Development*; Report 375 No. A/RES/71/313; United Nations Statistics Division: New York, NY, USA, 2017.
12. Alejandro, N.; Linden, M. Agricultural intensification in Ghana: Evaluating the optimist's case for a Green Revolution. *Food Policy* **2014**, *48*, 153–167. [CrossRef]
13. Sethi, L.; Behera, B.; Sethi, N. Do green finance, green technology innovation, and institutional quality help achieve environmental sustainability? Evidence from the developing economies. *Sustain. Dev.* **2023**, 1–15. [CrossRef]
14. Bhandari, G.; Dhasmana, A.; Chaudhary, P.; Gupta, S.; Gangola, S.; Gupta, A.; Rustagi, S.; Shende, S.S.; Rajput, V.D.; Minkina, T.; et al. A Perspective Review on Green Nanotechnology in Agro-Ecosystems: Opportunities for Sustainable Agricultural Practices & Environmental Remediation. *Agriculture* **2023**, *13*, 668. [CrossRef]
15. Cheng, L.; Gao, Y.; Dai, X. Spatio-temporal comprehensive measurement of China's agricultural green development level and associated influencing factors. *PLoS ONE* **2023**, *18*, e0288599. [CrossRef] [PubMed]
16. Zhou, F.; Wen, C. Research on the Level of Agricultural Green Development, Regional Disparities, and Dynamic Distribution Evolution in China from the Perspective of Sustainable Development. *Agriculture* **2023**, *13*, 1441. [CrossRef]
17. Zang, D.; Yang, S.; Li, F. The Relationship between Land Transfer and Agricultural Green Production: A Collaborative Test Based on Theory and Data. *Agriculture* **2022**, *12*, 1824. [CrossRef]
18. Mao, H.; Zhou, L.; Ying, R.; Pan, D. Time Preferences and green agricultural technology adoption: Field evidence from rice farmers in China. *Land Use Policy* **2021**, *109*, 105627. [CrossRef]
19. Shen, Y.; Zhang, T.; Cui, J.; Chen, S.; Han, H.; Ning, T. Subsoiling increases aggregate-associated organic carbon, dry matter, and maize yield on the North China Plain. *PeerJ* **2021**, *9*, e11099. [CrossRef] [PubMed]
20. Li, Y.; Fan, Z.; Jiang, G.; Quan, Z. Addressing the Differences in Farmers' Willingness and Behavior Regarding Developing Green Agriculture—A Case Study in Xichuan County, China. *Land* **2021**, *10*, 316. [CrossRef]
21. Chen, S.; Zhong, Z.; Lu, H. Impact of agricultural production outsourcing service and land fragmentation on agricultural non-point source pollution in China: Evidence from Jiangxi Province. *Front. Environ. Sci.* **2023**, *10*, 1079709. [CrossRef]
22. Lu, H.; Chen, Y.J.; Hu, H.; Geng, X.H. Can agricultural productive services promote the adoption of environmentally friendly agricultural techniques by farmers. *J. Agrotech. Econ.* **2021**, *3*, 36–49. [CrossRef]
23. Hou, Y.; Chen, P. Research on the Relationship between Price Mechanism and Short-Term Behavior in Chinese Farmland Trusteeships. *Sustainability* **2019**, *11*, 5708. [CrossRef]
24. Li, Q.; Li, K. Impact of pest control trusteeship on technical efficiency: From the perspective of horizontal division efficiency and vertical coordination efficiency. *Resour. Sci.* **2022**, *44*, 1964–1979. [CrossRef]
25. Zhou, N.; Shu, S.; Xiao, L. Identification of the Key Factors Influencing Small Farmers' Participation in Modern Agricultural and Forestry. *J. Cent. South Univ. For. Technol.* **2022**, *42*, 196–208. [CrossRef]
26. Chi, Y.; Zhou, W.; Wang, Z.; Hu, Y.; Han, X. The Influence Paths of Agricultural Mechanization on Green Agricultural Development. *Sustainability* **2021**, *13*, 12984. [CrossRef]
27. Chen, Y.; Fan, Y. Effects of scale agriculture on product quality and safety: A case study of Heilongjiang reclamation area. *Res. Agric. Mod.* **2016**, *37*, 1076–1083. [CrossRef]
28. Deng, X.; Luo, Y.; Dong, S.; Yang, X. Impact of resources and technology on farm production in northwestern China. *Agric. Syst.* **2005**, *84*, 155–169. [CrossRef]
29. Speelman, E.N.; García-Barrios, L.E.; Groot, J.C.J.; Tittonell, P. Gaming for smallholder participation in the design of more sustainable agricultural landscapes. *Agric. Syst.* **2014**, *126*, 62–75. [CrossRef]
30. Xie, H.; Cheng, L.; Lv, T. Factors Influencing Farmer Willingness to Fallow Winter Wheat and Ecological Compensation Standards in a Groundwater Funnel Area in Hengshui, Hebei Province, China. *Sustainability* **2017**, *9*, 839. [CrossRef]
31. Fatemi, M.; Rezaei-Moghaddam, K.; Karami, E.; Hayati, D.; Wackernagel, M. An integrated approach of Ecological Footprint (EF) and Analytical Hierarchy Process (AHP) in human ecology: A base for planning toward sustainability. *PLoS ONE* **2021**, *16*, e0250167. [CrossRef]
32. Ikram, M.; Sroufe, R.; Awan, U.; Abid, N. Enabling Progress in Developing Economies: A Novel Hybrid Decision-Making Model for Green Technology Planning. *Sustainability* **2022**, *14*, 258. [CrossRef]
33. Xu, Y.; Liu, H.; Lyu, J.; Xue, Y. What Influences Farmers' Adoption of Soil Testing and Formulated Fertilization Technology in Black Soil Areas? An Empirical Analysis Based on Logistic-ISM Model. *Int. J. Environ. Res. Public Health* **2022**, *19*, 15682. [CrossRef] [PubMed]
34. Zeng, F.; Shi, F. How does Agricultural Socialized Service Promote the Organic Connection between Small Farmers and Modern Agricultural: A Theoretical Analysis Framework. *J. Jishou Univ. (Soc. Sci.)* **2021**, *42*, 92–100. [CrossRef]
35. Zhang, J.; He, K. Current Situation, Misunderstandings and Prospects of Agricultural Low-carbon Development Under the Targets of Carbon Peak and Carbon Neutrality. *Issues Agric. Econ.* **2022**, *9*, 35–46. [CrossRef]
36. Denver, V.; Lenore, N. The efficacy and politics of farmland preservation through land use regulation: Changes in southwest British Columbia's Agricultural Land Reserve. *Land Use Policy* **2016**, *59*, 227–240. [CrossRef]
37. Duguma, E.; Tebarek, L. The effects of farmland conversion on livelihood assets in peri-urban areas of Addis Ababa Metropolitan city, the case of Akaki Kaliti sub-city, Central Ethiopia. *Land Use Policy* **2022**, *119*, 106197. [CrossRef]
38. Cynthia, C.; Erik, L.; Joris, D.; Carolina, B. The evolution of soil conservation policies targeting land abandonment and soil erosion in Spain: A review. *Land Use Policy* **2019**, *83*, 174–186. [CrossRef]

39. Xu, X.; Xu, Y.; Chen, S.; Xu, S.; Zhang, H. Soil loss and conservation in the black soil region of Northeast China: A retrospective study. *Environ. Sci. Policy* **2010**, *13*, 793–800. [CrossRef]
40. Qu, Y.; Pan, C.; Guo, H. Factors Affecting the Promotion of Conservation Tillage in Black Soil—The Case of Northeast China. *Sustainability* **2021**, *13*, 9563. [CrossRef]
41. Sun, X.; Guang, S.; Cao, J.; Zhu, F.; Liu, J.; Sriboonchitta, S. Effect of Agricultural Production Trusteeship on Agricultural Carbon Emission Reduction. *Agriculture* **2023**, *13*, 1457. [CrossRef]
42. Zhao, L.; Liu, Y.; Shi, J. The environmental performance of agricultural production trusteeship from the perspective of planting carbon emissions. *China Agric. Econ. Rev.* **2023**, *15*, 853–870. [CrossRef]
43. Sun, X.; Wang, Y.; Zhu, F.; Liu, X.; Liu, J.; Sriboonchitta, S. Promotion Effect of Agricultural Production Trusteeship on High-Quality Production of Grain—Evidence from the Perspective of Farm Households. *Agronomy* **2023**, *13*, 2024. [CrossRef]
44. Zhang, X.; Zhang, L.; Nie, T. Study on the Impact of Social Capital on Farmers' Decision-Making Behavior of Adopting Trusteeship Services. *Sustainability* **2023**, *15*, 5343. [CrossRef]
45. Xiao, J.; Song, Y.; You, H. Explaining Peasants' Intention and Behavior of Farmland Trusteeship in China: Implications for Sustainable Agricultural Production. *Sustainability* **2020**, *12*, 5748. [CrossRef]
46. Gong, S.; Sun, Z.; Wang, B.; Yu, Z. Could Digital Literacy Contribute to the Improvement of Green Production Efficiency in Agriculture? *Sage Open* **2024**, *14*, 21582440241232789. [CrossRef]
47. Deng, H.; Jing, X.; Shen, Z. Internet technology and green productivity in agriculture. *Environ. Sci. Pollut. Res.* **2022**, *29*, 81441–81451. [CrossRef] [PubMed]
48. Nanseki, T.; Li, D.; Chomei, Y. Impacts and Policy Implication of Smart Farming Technologies on Rice Production in Japan. *J. Fac. Agric. Kyushu Univ.* **2022**, *67*, 219–225. [CrossRef]
49. Lal, R. Soils and food sufficiency. A review. *Agron. Sustain. Dev.* **2009**, *29*, 113–133. [CrossRef]
50. Somasundaram, J.; Sinha, N.K.; Dalal, R.C.; Lal, R.; Mohanty, M.; Naorem, A.K.; Hati, K.M.; Chaudhary, R.S.; Biswas, A.K.; Patra, A.K.; et al. No-Till Farming and Conservation Agriculture in South Asia—Issues, Challenges, Prospects and Benefits. *Crit. Rev. Plant Sci.* **2020**, *39*, 236–279. [CrossRef]
51. Chen, W.; Hu, Z. Using evolutionary game theory to study governments and manufacturers'behavioral strategies under various carbon taxes and subsidies. *J. Clean. Prod.* **2018**, *201*, 123–141. [CrossRef]
52. Hofbauer, J.; Sigmund, K. The theory of evolution and dynamical systems. *Acta Appl. Math.* **1990**, *18*, 297–300. [CrossRef]
53. Du, J.; Zhou, Z.; Xu, L. Evolutionary Game Mechanism on Complex Networks of Green Agricultural Production under Intensive Management Pattern. *Complexity* **2020**, *2020*, 8541517. [CrossRef]
54. Cui, H.; Zhao, T.; Tao, P. Evolutionary Game Study on the Development of Green Agriculture in China Based on Ambidexterity Theory Perspective. *Pol. J. Environ. Stud.* **2019**, *28*, 1093–1104. [CrossRef] [PubMed]
55. Zheng, Y.; Mei, L. How to promote the adoption of intelligent spray technology in farmers' cooperatives?—Based on the perspective of evolutionary game. *HELIYON* **2023**, *9*, e19897. [CrossRef] [PubMed]
56. Tian, M.; Zheng, Y.; Sun, X.; Zheng, H. A research on promoting chemical fertiliser reduction for sustainable agriculture purposes: Evolutionary game analyses involving 'government, farmers, and consumers'. *Ecol. Indic.* **2022**, *144*, 109433. [CrossRef]
57. Xie, H.; Wang, W.; Zhang, X. Evolutionary game and simulation of management strategies of fallow cultivated land: A case study in Hunan province, China. *Land Use Policy* **2018**, *71*, 86–97. [CrossRef]
58. Peng, H.; Shen, N.; Ying, H.; Wang, Q. Factor analysis and policy simulation of domestic waste classification behavior based on a multiagent study-Taking Shanghai's garbage classification as an example. *Environ. Impact Assess* **2021**, *89*, 12. [CrossRef]
59. Li, Y.; Zhang, Q.; Liu, B.; McLellan, B.; Gao, Y.; Tang, Y. Substitution effect of New-Energy Vehicle Credit Program and Corporate Average Fuel Consumption Regulation for Green-car Subsidy. *Energy* **2018**, *152*, 223–236. [CrossRef]
60. Alos-Ferrer, C.; Ania, A. The evolutionary stability of perfectly competitive behavior. *Econ. Theory* **2005**, *26*, 497–516. [CrossRef]
61. Albano, G.; Giorno, V.; Román-Román, P.; Torres-Ruiz, F. Study of a general growth model. *Commun. Nonlinear Sci. Numer. Simul.* **2022**, *107*, 106100. [CrossRef]
62. Yang, C.; Sun, J.; Zhang, Q.; Ma, X. Lyapunov Stability and Strong Passivity Analysis for Nonlinear Descriptor Systems. In *IEEE Transactions on Circuits and Systems I: Regular Papers*; IEEE: Piscataway Township, NJ, USA, 2013; Volume 60, pp. 1003–1012. [CrossRef]
63. Tao, Y.; Wang, Z. Effect of Time Delay and Evolutionarily Stable Strategy. *J. Theor. Biol.* **1997**, *187*, 111–116. [CrossRef]
64. Weibull, J.W. *Evolutionary Game Theory*; MIT Press: Cambridge, MA, USA, 1997.
65. Friedman, D. Evolutionary Games in Economics. *Econometrica* **1991**, *59*, 637–666. [CrossRef]
66. Chen, L.; Gao, M. A new learning interaction rule for municipal household waste classification behavior based on multi-agent-based simulation. *J. Clean. Prod.* **2020**, *271*, 122654. [CrossRef]
67. Smith, A.C.; Tasnim, T.; Irfanullah, H.M.; Turner, B.; Chausson, A.; Seddon, N. Nature-based Solutions in Bangladesh: Evidence of Effectiveness for Addressing Climate Change and Other Sustainable Development Goals. *Front. Environ. Sci.* **2021**, *9*, 737659. [CrossRef]
68. Ogle, S.M.; Conant, R.T.; Fischer, B.; Haya, B.K.; Manning, D.T.; McCarl, B.A.; Zelikova, T.J. Policy challenges to enhance soil carbon sinks: The dirty part of making contributions to the Paris agreement by the United States. *Carbon Manag.* **2023**, *14*, 2268071. [CrossRef]

69. Chen, Y.; Wen, X.; Wang, B.; Nie, P. Agricultural pollution and regulation: How to subsidize agriculture? *J. Clean. Prod.* **2017**, *164*, 15. [CrossRef]
70. Ma, L.; Wang, Y.; Teng, Y. Evolutionary game analysis of stakeholders under the whole process trusteeship mode of agricultural production. *Kybernetes* **2022**, *51*, 2877–2901. [CrossRef]
71. Du, J.; Liu, H.; Yuan, Y. On the impacts of agricultural subsidies on agricultural carbon emissions in China: Empirical evidence from microdata of rice production. *Environ. Sci. Pollut. Res.* **2023**, *30*, 101151–101167. [CrossRef]
72. Lonester, S.; Alastair, B.; Sophia, D. The impact of farm input subsidies on maize marketing in Malawi. *Food Policy* **2017**, *69*, 190–206. [CrossRef]
73. Kulkarni, A.P.; Tripathi, M.P.; Gautam, D.; Koirala, K.B.; Kandel, M.; Regmi, D.; Sapkota, S.; Zaidi, P.H. Willingness to Pay (WTP) for Heat-Tolerant Maize Hybrids in the Mid-Western Terai Region of Nepal. *Sustainability* **2023**, *15*, 3068. [CrossRef]
74. Yang, M.; Zhao, X.; Meng, T. What are the driving factors of pesticide overuse in vegetable production? Evidence from Chinese farmers. *China Agric. Econ. Rev.* **2019**, *11*, 672–687. [CrossRef]
75. Zheng, W.; Luo, B.; Hu, X. The determinants of farmers' fertilizers and pesticides use behavior in China: An explanation based on label effect. *J. Clean. Prod.* **2020**, *272*, 123054. [CrossRef]
76. Lee, R.; Uyl, R.; Runhaar, H. Assessment of policy instruments for pesticide use reduction in Europe; Learning from a systematic literature review. *Crop Prot.* **2019**, *126*, 104929. [CrossRef]
77. Galan, M.; Peschard, D.; Boizard, H. ISO 14 001 at the farm level: Analysis of five methods for evaluating the environmental impact of agricultural practices. *J. Environ. Manag.* **2007**, *82*, 341–352. [CrossRef] [PubMed]
78. He, Y.; Fu, D.; Zhang, H.; Wang, X. Can Agricultural Production Services Influence Smallholders' Willingness to Adjust Their Agriculture Production Modes? Evidence from Rural China. *Agriculture* **2023**, *13*, 564. [CrossRef]
79. Zhu, H.; Ao, Y.; Xu, H.; Zhou, Z.; Wang, Y.; Yang, L. Determinants of Farmers' Intention of Straw Recycling: A Comparison Analysis Based on Different Pro-Environmental Publicity Modes. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11304. [CrossRef] [PubMed]
80. Zhu, X.; Li, C.; Zhou, H. Cost Changes and Technical Efficiency of Grain Production in China against a Background of Rising Factor Prices. *Sustainability* **2022**, *14*, 12852. [CrossRef]
81. Jiang, F.; Song, H.; Gao, M. Theoretical analysis of agricultural production trusteeship to ensure national grain security: From the perspective of generative logic. *Res. Agric. Mod.* **2022**, *43*, 11–19. [CrossRef]