Opportunities and Challenges in Sustainability
https://www.acadlore.com/journals/OCS

Mitigating Farmland Abandonment in China Through the Separation of Three Rights: A Tripartite Evolutionary Game Analysis

Zaohong Zhou[1*], Jin Chen[2], Shimeng Xiao[3], Yanqing Huang[4], Yunbin Sun[1], Qiang Li[1]

[1] School of Information Management and Mathematics, Jiangxi University of Finance and Economics, 330013 Nanchang, China
[2] College of Architectural Engineering, GongQing Institute of Science and Technology, 332020 GongQing, China
[3] Office of International Cooperation and Exchange (OICE), Jiangxi University of Finance and Economics, 330013 Nanchang, China
[4] Business Operations Department, Digital Jiangxi Technology Co., Ltd, 330038 Nanchang, China

[*] Correspondence: Zaohong Zhou (zhouzaohong@jxufe.edu.cn)

Received: 01-25-2025 **Revised:** 03-15-2025 **Accepted:** 03-22-2025

Citation: Zhou, Z. H., Chen, J., Xiao, S. M., Huang, Y. Q., Sun, Y. B., & Li, Q. (2025). Mitigating farmland abandonment in China through the separation of three rights: A tripartite evolutionary game analysis. *Oppor Chall. Sustain.*, *4*(1), 41-55. https://doi.org/10.56578/ocs040104.

Abstract: The policy of "separation of three rights" in China, which distinguishes rural land ownership (collective), contract rights (farmers), and management rights (transferable), has been implemented to optimize resource allocation, advance agricultural modernization, and protect farmers' interests. To address the persistent issue of arable land abandonment, it is critical that the interactions among local governments, farmers, and agribusinesses be systematically understood. In this study, a tripartite evolutionary game model was developed to investigate the dynamic decision-making behaviors and stabilization strategies of the three primary stakeholders within the framework of three rights separation. The influence of variations in key parameters was quantitatively assessed. The results demonstrate that economic subsidies, cooperation costs, and loss of prestige significantly influence farmland utilization and transfer. It is emphasized that local governments must actively fulfill regulatory and facilitative roles during the pre-transfer phase of arable land, particularly by providing comprehensive economic and infrastructural support. Furthermore, the necessity of enhancing the construction of farmland mobility service systems is underscored, with the aim of reducing transaction barriers and enabling a more effective and sustainable separation of contracting and management rights. These findings offer theoretical and practical insights for strengthening farmland management systems, ensuring long-term farmland productivity, and supporting rural revitalization strategies in China.

Keywords: Farmland abandonment; Separation of three rights; Farmland transfer; Evolutionary game; China

1. Introduction

Land use change is a major component of sustainable development and seriously affects the global environment (Fu et al., 2017; Lambin & Meyfroidt, 2011; Qu & Long, 2018; Quintas-Soriano et al., 2016), especially in terms of ecosystem services and biodiversity (Liu et al., 2022a; Sun et al., 2021). Among them, arable land, as the largest land use type in the human landscape, is a fundamental resource for securing world food security (Deng et al., 2018). However, since the 1950s, arable land abandonment has gradually become one of the major land-use changes at the global scale (Jiménez-Olivencia et al., 2021; Levers et al., 2018). The occurrence of this phenomenon was initially observed in developed nations like Europe, the United States, and Japan (Lasanta et al., 2017; Postek et al., 2019), and it has subsequently been noted in developing nations including Latin America, Southeast Asia, China, and India, where the abandonment of arable land is becoming increasingly significant (Li & Li, 2017; Subedi et al., 2021). Arable land abandonment is the result of marginalization of arable land driven by multiple social, economic and environmental factors (Keenleyside et al., 2010; Leal Filho et al., 2016), which

not only threatens food production but also affects surface runoff, soil carbon stocks and biodiversity, and causes soil erosion (Knippenberg et al., 2020; Wang et al., 2022; Wei & Ying, 2019; Wertebach et al., 2017; Zhang et al., 2017). According to the World Health Organization Food and Nutrition Security Brief 2022, although 702-828 million people still face hunger globally as of 2021, moderate or severe food insecurity continues to increase globally, and the abandonment of arable land has not been effectively curbed.

The implementation of China's reform and opening-up policy in 1978 has led to accelerated urbanization and profound socioeconomic transformations (Liu et al., 2018). This period of rapid development has, however, introduced a multitude of challenges for the future advancement of rural areas in China (Long & Liu, 2016), with the abandonment of arable land being one of the most significant concerns (Shi et al., 2018). The average arable land area per household in China is about 0.38 ha (Wang et al., 2022), which is lower than the global level. The emergence of the COVID-19 epidemic has brought new uncertainties to agricultural trade and food security (Pu & Zhong, 2020). In response to the escalating challenges of food security and the critical issue of arable land abandonment, China has initiated a comprehensive exploration of land reform strategies. The "separation of three rights" policy represents an advanced framework for land property rights, delineating the distinct roles of farmland ownership, contracting, and management rights (Wang & Zhang, 2017). This policy is intended to foster the investment of essential agricultural production factors, namely land and capital, while ensuring the protection of farmers' interests (Gong et al., 2022). Its primary objectives are to revitalize underutilized rural assets and to catalyze the rejuvenation of the rural economy. However, rural land transfer has been restricted due to unclear property rights subjects, asymmetric information and an inadequate flow service system.

In recent years, China has been confronted with the challenge of farmland abandonment, a phenomenon closely linked to rural outmigration and economic transformation. In response, the Chinese government has implemented a land policy known as the "separation of three rights," which divides farmland property rights into collective ownership rights, contract rights, and operation rights. Historically, China's rural land ownership and operational rights were unified under collective ownership. Post-reform and opening up, a significant shift occurred with the separation of collective ownership of rural land and the contractual management rights of farmers. This implies that although land ownership remains collective, operational control is exercised through household-based contracts. Subsequently, the Chinese government further divided the land contract management rights into contract rights and operational rights, implementing the "separation of three rights," which marks another significant innovation in rural reform.

The policy's relevance to the issue of farmland abandonment lies in its potential to incentivize effective land use. By decoupling land rights, farmers are encouraged to make considered decisions about land management, leasing, or transfer based on their own economic circumstances and market demands. This flexibility is particularly critical in regions where farmland abandonment is prevalent, as it enables more efficient allocation of agricultural resources and supports the viability of rural communities.

In order to advance the reform of the "separation of three rights" in residential land, promote the transfer of residential land, and mitigate the issue of arable land abandonment, this study intends to identify the primary stakeholders in the residential land transfer process. A tripartite evolutionary game model was established for comprehensive analysis, aiming to investigate the evolutionary stabilization strategies of each stakeholder and the determinants affecting these strategies and conduct a sensitivity analysis on the pivotal factors. Conclusively, the study culminates in the formulation of targeted strategies to facilitate the reform process pertaining to the "three rights of ownership" in residential land sectors. The main contributions are as follows: First, the proposed tripartite evolutionary game model, incorporating the government, farmers, and operators, provides an effective framework for analyzing the factors influencing the behavioral strategies of these key stakeholders and the interaction mechanisms among them. Second, numerical simulations illustrate the effects of the main parameters, such as economic subsidies, cooperation costs, and loss of prestige, on the stakeholder groups. Third, in light of the current state of rural land reform in China, the study puts forward strategic recommendations to facilitate the advancement of the "separation of three rights."

2. Literature Review

2.1 Farmland Abandonment in China

With a large population, China is a large food-producing country. However, according to the third national land survey, China's arable land area was 1.918 billion mu. Compared with the second national land survey, the arable land area decreased by 113 million mu, and the arable land per capita was only 1.36 mu, which is far below the world average. In addition, the arable land area is still decreasing year by year (Liu et al., 2022b). There are many reasons for the decrease of arable land in China, among which the most critical factor is the abandonment of arable land, except for the effects of natural disasters and so on.

As China's cities grow faster, by 2021, nearly two-thirds of the country's population was living in urban areas. This has certainly been great for the economy and technological advancements. However, it has also caused an

exodus of rural population (Lin & Zhao, 2021; Xu et al., 2022), which exacerbates the problem of inefficient use and even abandonment of farmland (Bellout et al., 2020; Hou et al., 2021; Long et al., 2018). In addition to urbanization, factors such as aging rural population (Baek et al., 2022; He et al., 2020), remoteness (Chaudhary et al., 2020; Vinogradovs et al., 2018), altitude and slope (Chen & Shi, 2020; Su et al., 2018), fragmentation of arable land (Wang et al., 2022), and opportunity cost have also exacerbated the abandonment of arable land (Wang et al., 2020). In turn, arable land abandonment not only threatens food security in China but also affects the soil environment and biodiversity and weakens the fire protection capacity of mountainous landscapes, etc. (Sil et al., 2019). Therefore, the remediation of arable land abandonment is a part of China's agricultural modernization development process that cannot be ignored.

2.2 Separation of Three Rights

Land property rights and land policy are central issues in society and play a key role in the political economy (Li et al., 2018). As the basis for social progress, food production security is crucial. The main purpose of land reform is to improve agricultural productivity by refining property rights to arable land and promoting land transfer and large-scale operation (Alban Singirankabo & Willem Ertsen, 2020). Comparative analysis with other global land reform policies reveals that the "separation of three rights" shares some similarities with modernizing efforts in various countries, such as Russia's land reform, which lies in the reform of ownership rights, and initially involves the privatization of state-owned land, followed by a comprehensive push to enhance the liquidity of land. Vietnam has successfully implemented a policy that differentiates between the rights of land use, ownership, and management, ensuring a clear delineation of these entities. The Brazilian government has implemented the separation of land ownership, usage rights, and usufruct rights in rural areas.

However, the "separation of three rights" is uniquely tailored to the Chinese context, where collective ownership remains a cornerstone of rural society. To improve agricultural productivity, China has been continuously exploring land reform since 1978. In order to encourage land transfer and promote large-scale agricultural production, as early as 1990, several provinces and cities, including Zhejiang, Chongqing, Anhui, and Sichuan, issued local directives with the objective of facilitating land power transfer through the restructuring of the household registration system (Zhan, 2017). In 2013, China began to comprehensively register and issue certificates for rural land contract management rights, i.e., the "separation of three rights" reform, which is the premise and foundation of the reform. Later, China amended the Law of the People's Republic of China on Rural Land Contracts in 2018 to formally legalize the system of "separation of three rights" (Zhou et al., 2021).

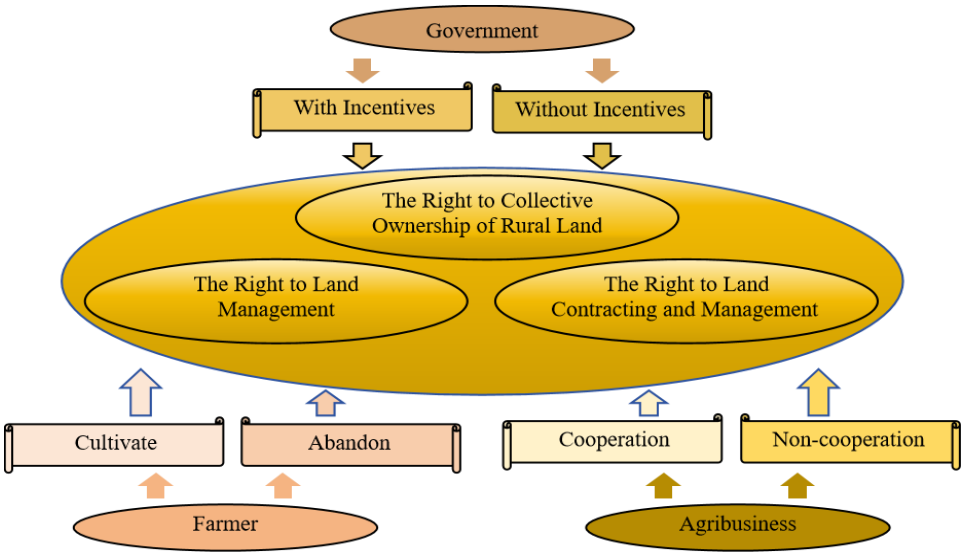

Figure 1. Framework of the “three rights”

As shown in Figure 1, the “three rights” framework consists of the right to collective ownership of rural land, the right to land contracting and management, and the right to land management (Zhou et al., 2020). The concept of “separation of three rights” signifies the distinct allocation of these rights among various civil entities, namely rural collectives, farmers, and operators. The new way of doing things, where farmland is owned by everyone, contracts are signed by folks in the community, and the actual farming is done by the growers, will make a big difference. It’ll use land better and help stop farmland from being wasted. However, there are some issues like who really owns what, not everyone having the same information, and services not being up to scratch, which is making it tough to move land around in rural areas. To really implement the “separation of three rights,” it is

necessary to make sure that everyone is on the same page and motivated to make it work.

The "separation of three rights" involves a triple nesting of the government and rural collectives, rural collectives and farmers, and farmers and land contract operators (Gong et al., 2022), which involves subjects, including the government, rural collectives, farmers and operators. In the process of implementing the "separation of three rights" reform, the key obstacles are the government's progress in carrying out the registration of contracted management rights and the degree of improvement of relevant laws and policies, as well as farmers' understanding and support of the policies. The operators may be reluctant to take over the operation of individual land due to unclear property rights and ambiguous land market prices (Moroni, 2018; Yan et al., 2021). In summary, it can be concluded that the key stakeholders in the implementation of "separation of three rights" are the government, farmers and operators. The evolutionary game model presented in this study focuses on the strategic decision-making processes of the government, farmers, and operators in various contexts pertaining to the implementation of the “separation of three rights” policy. Additionally, it examines the mechanisms through which key factors influence the actions of each entity involved.

3. Model Building

3.1 Model Assumptions

In this study, the government, farmers and operators are considered as participants in the game model.

Since the central government mainly assumes the role of regulator to local governments and has sufficient incentives to adopt active policies (Gao et al., 2018), the local government directly determines the local agricultural policy. When enacting the policy, it needs to consider the financial income and expenditure and weigh the pros and cons, directly affecting the implementation of the "separation of three rights" policy. Therefore, the government in this study refers to the local government by default. Existing studies have shown that the main reasons for farmers' abandonment include their unwillingness or inability to engage in agriculture and poor agricultural production conditions (Dolton-Thornton, 2021; Subedi et al., 2022), and the government can choose to remedy the abandonment of arable land, improve agricultural infrastructure construction, and provide financial support and subsidies to farmers and agricultural enterprises that are brought back to farming. The government can also choose to deal with it negatively to reduce financial expenditures, but this will bring potential threats such as personal reputation damage and fines to local government officials (Gao et al., 2020).

Considering the production and opportunity costs of operating agriculture (Shi et al., 2018; Xu et al., 2019), farmers may idle their land and choose to work outside the farm. Farming is chosen when farmers consider it profitable. Farmers traditionally farm on their own. Alternatively, through information gathering and legal advice, they may seek the cooperation of agribusinesses to transfer their business rights while they themselves engage in non-farm work. At this point, agribusinesses can match their needs with the land situation and choose whether to cooperate or not.

Based on the characteristics of the parties involved in the game, the following assumptions are given:

(a) The participants in the evolutionary game model have limited rationality and make independent decisions to maximize their own interests, and they can continuously adjust their own decisions according to the decisions of other participants.

(b) The government has two strategies: incentive and disincentive. "Incentive" means that the government takes measures to promote farmers to return to farming and actively introduce agribusiness to industrial production. In this case, if the land is returned to farming, the government can get a commendation from the central government and an implicit prestige accumulation. But at the same time, the government needs to spend money on agricultural infrastructure construction and give farmers and enterprises some financial subsidies. "Disincentive" means that the government treats the central government's supervision negatively. If the farmers themselves have no incentive to replant, the government may be punished by the higher level and lose its reputation.

(c) Farmers have two strategies: cultivation and idleness. "Farming" means that farmers make full use of the land they cultivate, and they can choose to cultivate it by themselves and bear some of the opportunity costs. Farmers can also outsource their land to agribusinesses and bear part of the cost of the partnership or simply leave it idle and engage in other work themselves, thereby earning some off-farm income.

(d) Agribusiness has two strategies: operating and not operating. When a farmer wants to make full use of the arable land, but is unwilling or unable to operate it himself, the agribusiness can cooperate with him or her to acquire the right to operate the land and profit from it. In this case, the agribusiness is required to pay a certain amount of rent to the farmer and bear a portion of the information costs required for cooperation.

(e) The probability that the government chooses to incentivize is x ($0 \le x \le 1$), the probability that the farmer chooses to farm is y ($0 \le y \le 1$), and the probability that the agribusiness chooses to operate is z ($0 \le z \le 1$).

Based on the above assumptions, a three-way government-farmer-agribusiness game payoff matrix can be established, as shown in Table 1. All the parameters in the payoff matrix and their descriptions are shown in Table 2 (Li et al., 2018; Yan et al., 2021).

Table 1. Profitability matrix of the government, farmers and agribusinesses

Farmer	Agribusiness	Government	
		With Incentives (*x*)	**Without Incentives (1-*x*)**
Cultivate (*y*)	Cooperation (*z*)	$G_1 - C_1 - C_2 - C$ $R + C_1 + W - F$ $E_1 - R + C_2 - F$	G_2 $R + W - F$ $E_2 - R - F$
	Non-cooperation (1-*z*)	$G_3 - C_1 - C$ $C_1 + I_1$ 0	G_4 I_2 0
Abandon (1-*y*)	Cooperation (*z*)	$-C$ W $-F$	$-P$ W $-F$
	Non-cooperation (1-*z*)	$-C$ W 0	$-P$ W 0

Table 2. Parameters and descriptions

Parameters	Descriptions
x	The probability that the government chooses to incentivize farming; the probability that it does not is 1-*x*, with $0 \le x \le 1$
y	The probability that the farmer chooses to cultivation; the probability that it does not is 1-*y*, with $0 \le y \le 1$
z	The probability that the agribusiness chooses to lease the farmer's field; the probability that it does not is 1-z, with $0 \le z \le 1$
G	The direct or indirect benefits of the rational use of arable land, which may vary according to the level of infrastructure development and industrialization, including G_1, G_2, G_3, and G_4, respectively, where $G_4 < G_3 < G_2 < G_1$
C	The costs incurred by the government for agricultural infrastructure development
C_1	The government subsidies for farmers who cultivate their fields
C_2	The government subsidies for agribusinesses that cultivate fields
P	The reputational damage caused by negative government replanting
R	The rent required to be paid by the agribusiness to operate the fields
I	The revenue generated by farmers engaged in farming, which may vary according to the status of agricultural infrastructure, including I_1 and I_2, respectively, where $I_2 < I_1$
E	The revenue generated by agricultural enterprises engaged in farming, which may vary according to the status of agricultural infrastructure, including E_1 and E_2, respectively, where $E_2 < E_1$
F	The costs of information collection, legal advice, etc. incurred by farmers and agribusinesses in order to establish cooperation
W	The farmers' earnings from non-farm work

3.2 Theoretical Model

Based on the payoff matrix, the expected payoffs U_x and U_{1-x} and the average expected payoff $\bar{U}_x$ for the government to make two choices were calculated, and its replication dynamic equation $F(x)$ was further obtained.

$$U_x = yz(G_1 - C_1 - C_2 - C) + (1-y)z(-C) + y(1-z)(G_3 - C_1 - C) + (1-y)(1-z)(-C) \quad (1)$$

$$U_{1-x} = yz(G_2) + (1-y)z(-P) + y(1-z)(G_4) + (1-y)(1-z)(-P) \quad (2)$$

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

$$F(x) = \frac{d_x}{d_t} = x(x-1)(C + yC_1 + yzC_2 - yzG_1 + yzG_2 + yzG_3 - yG_3 - yzG_4 + yG_4 + yP - P) \quad (4)$$

Similarly, the replication dynamics equations $F(y)$ and $F(z)$ for farmers and agribusinesses were obtained.

$$F(y) = \frac{d_y}{d_t} = y(y-1)(-xC_1 + zF + xzI_1 - xI_1 - xzI_2 + xI_2 + zI_2 - I_2 - zR - zW + W) \quad (5)$$

$$F(z) = \frac{d_z}{d_t} = z(z-1)(xyE_2 + F + yR - xyC_2 - xyE_1 - yE_2) \quad (6)$$

According to Eqs. (3), (5), and (6), a three-dimensional dynamic system of equations for the evolutionary model was obtained as follows:

$$\begin{cases} F(x) = x(x-1)(C + yC_1 + yzC_2 - yzG_1 + yzG_2 + yzG_3 - yG_3 - yzG_4 + yG_4 + yP - P) \\ F(y) = y(y-1)(-xC_1 + zF + xzI_1 - xI_1 - xzI_2 + xI_2 + zI_2 - I_2 - zR - zW + W) \\ F(z) = z(z-1)(xyE_2 + F + yR - xyC_2 - xyE_1 - yE_2) \end{cases} \quad (7)$$

When $F(x) = 0$, $F(y) = 0$, and $F(z) = 0$, eight pure strategy equilibria were obtained, namely e_1 (0, 0, 0), e_2 (1, 0, 0), e_3 (0, 1, 0), e_4 (0, 0, 1), e_5 (1, 1, 0), e_6 (1, 0, 1), e_7 (0, 1, 1), and e_8 (1, 1, 1). In addition, there may exist a mixed-strategy equilibrium point e^* (x^*, y^*, z^*) exactly such that the three replicated dynamic equations are equal to 0. However, an equilibrium point can be an asymptotically stable equilibrium point only when it satisfies the pure-strategy Nash equilibrium (Lyapunov, 1992; Wainwright, 1989). Therefore, in this study, only eight pure-strategy equilibrium points were considered when judging the evolutionary equilibrium point *ESS*.

According to Friedman's theory, the Jacobi matrix J of the three-dimensional dynamic system of equations was obtained (Friedman, 1991).

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix} = \begin{bmatrix} J_{11} & J_{12} & J_{13} \\ J_{21} & J_{22} & J_{23} \\ J_{31} & J_{32} & J_{33} \end{bmatrix} \quad (8)$$

where,

$$J_{11} = (2x-1)[C + y(C_1 - G_3 + G_4 + P) + yz(C_2 - G_1 + G_2 + G_3 - G_4) - P] \quad (9)$$

$$J_{12} = x(x-1)[C_1 + z(C_2 - G_1 + G_2 + G_3 - G_4) - G_3 + G_4 + P] \quad (10)$$

$$J_{13} = xy(x-1)(C_2 - G_1 + G_2 + G_3 - G_4) \quad (11)$$

$$J_{21} = y(y-1)(-C_1 + zI_1 - I_1 - zI_2 + I_2) \quad (12)$$

$$J_{22} = (2y-1)(-xC_1 + zF + xzI_1 - xI_1 - xzI_2 + xI_2 + zI_2 - I_2 - zR - zW + W) \quad (13)$$

$$J_{23} = y(y-1)(F + xI_1 - xI_2 + I_2 - R - W) \quad (14)$$

$$J_{31} = -yz(z-1)(C_2 + E_1 - E_2) \quad (15)$$

$$J_{32} = -z(z-1)(xC_2 + xE_1 - xE_2 + E_2 - R) \quad (16)$$

$$J_{33} = -(2z-1)(xyC_2 + xyE_1 - xyE_2 + yE_2 - F - yR) \quad (17)$$

The eigenvalues and stability conditions of each equilibrium point were obtained by substituting the eight pure strategy stable equilibrium points into the Jacobi matrix, as shown in Table 3.

For the sake of clarity, the implementation process of the “separation of three rights” policy is categorized into three distinct phases: the initial implementation phase, the developmental phase, and the phase of full maturity.

Taking Huzhou City, Zhejiang Province, as an example, from 2016 to 2020, through a three-stage subsidy reduction policy (from 50% at the beginning to 10% in the mature period), the transfer rate of land increased from 18% to 65%, and the coverage rate of market-oriented services gradually reached 80% by 2020. In this process, the enthusiasm of the government, farmers, and agricultural enterprises for the land transfer policy can be roughly divided into three stages, namely the initial stage of government promotion (1, 0, 0), the development stage with the government's leading role and the participation of all parties (1, 1, 1), and the mature stage of marketization (0, 1, 1).

In the initial stage, the government was faced with the food security problem caused by the abandonment of arable land, affecting the reputation and performance of local officials. Therefore, it had sufficient incentive to implement relevant policies to encourage replanting. In the initial stage of the implementation of the "separation of three rights," corresponding to the equilibrium point e_5 (1, 0, 0), three inequalities need to be satisfied at the same time, as shown in Table 3.

Table 3. Evolutionary stability points and their corresponding eigenvalues

ESS	Eigenvalues		
	λ_1	λ_2	λ_3
(0, 0, 0)	$-C+P$	I_2-W	$-F$
(0, 0, 1)	$-C+P$	$-F+R$	F
(0, 1, 0)	$-C-C_1+G_3-G_4$	$-I_2+W$	E_2-F-R
(0, 1, 1)	$-C-C_1-C_2+G_1-G_2$	$F-R$	$-E_2+F+R$
(1, 0, 0)	$C-P$	C_1+I_1-W	$-F$
(1, 0, 1)	$C-P$	C_1-F+R	F
(1, 1, 0)	$C+C_1-G_3+G_4$	$-C_1-I_1+W$	C_2+E_1-F-R
(1, 1, 1)	$C+C_1+C_2-G_1+G_2$	$-C_1+F-R$	$-C_2-E_1+F+R$

With the continuous improvement of agricultural infrastructure and the implementation of various subsidy policies, farmers responded positively to the resumption of farming when the returns from agricultural production were higher than those from non-farm production. Agricultural enterprises actively sought cooperation to lease land for industrial production when it was profitable, and the form of "separation of three rights" was gradually formed. Thus, the system gradually reached the equilibrium point e_8 (1, 1, 1), which requires the satisfaction of three inequalities, as shown in Table 3.

When the agricultural infrastructure was built maturely and the arable land was basically planned and applied rationally, the marginal return of government investment in farmland re-cultivation declined significantly. The government gradually stopped intervening, and farmers and agricultural enterprises became the main market entities. At this point, contracting and management rights were separated and the whole system evolved to the equilibrium point e_4 (0, 1, 1), at which time three inequalities need to be satisfied, as shown in Table 3.

4. Numerical Simulation

To address the gap between model parameters and real-world data, this study incorporates empirical data from Huzhou City, Zhejiang Province, a pilot region for China's "separation of three rights" reform. Huzhou was selected due to its well-documented policy implementation trajectory and publicly available agricultural statistics. Data were collected from multiple sources as follows:

(a) Huzhou Bureau of Agriculture and Rural Affairs: Annual reports (2016–2020) provide metrics on farmland abandonment rates, land transfer volumes, government subsidies (C_1 and C_2), and infrastructure investment costs (C).

(b) Household surveys: A total of 320 farmer households and 50 agribusinesses were surveyed in 2020 to quantify cooperation costs (F), non-farm income (W), and agricultural revenue (I_1, I_2, E_1, and E_2).

(c) Policy documents: Local government notices detail subsidy gradients (e.g., 50% initial subsidies reducing to 10% in maturity) and regulatory penalties (P) for farmland abandonment.

Key empirical parameters are summarized in Table 4, aligning with the model's three-stage framework.

Table 4. Some key parameters of Huzhou City, Zhejiang Province in different periods

Parameter	Initial Stage (2016)	Development Stage (2018)	Mature Stage (2020)
C_1 (RMB)	500	1500	2000
C_2 (RMB)	800	1800	2200
F (RMB)	300	150	50
P (reputation loss index)	30	30	30

Since there are no official statistical data for the quantification of some parameters, and in order to intuitively demonstrate the strategic choices of participants in different stages of the game, three sets of parameter values were simulated, as shown in Table 5. Each parameter set was designed to reflect the relative magnitudes of key parameters among agents under distinct phases of the interaction process.

(a) Dynamic evolution of stakeholders in the initial stage

The values of each parameter corresponding to the initial stage in Table 4 satisfy the stability conditions, i.e., $C < P$, $C_1 + I_1 < W$ and $F > 0$. MATLAB was used to uniformly generate 125 different sets of initial strategy points for x, y and z, and they all converged to e_5 (1, 0, 0) after iteration, as shown in Figure 2. That is, in the initial stage, local governments acted as advocates to promote arable land use for the sake of performance and reputation. However, at this time, farmers and agribusinesses did not adopt active strategies probably due to factors such as incomplete infrastructure establishment.

Table 5. Parameter values for each stage in the evolutionary game model

Parameters	G_1	G_2	G_3	G_4	C	C_1	C_2	P	R	I_1	I_2	E_1	E_2	F	W
Initial stage	80	20	20	10	5	5	5	30	10	30	20	40	30	30	40
Development stage	80	20	20	10	5	20	20	30	10	30	20	40	30	15	40
Mature stage	40	20	20	10	5	20	20	30	10	30	20	40	30	5	40

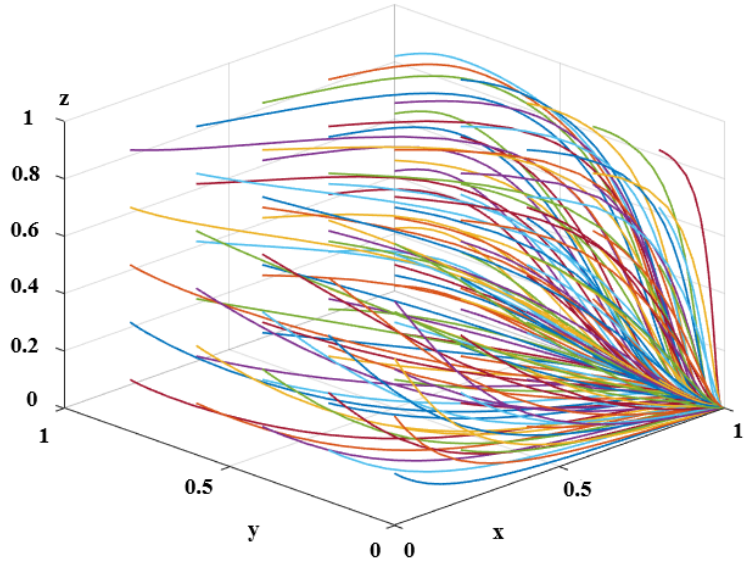

Figure 2. Evolution process of the system in the initial stage

(b) Dynamic evolution of stakeholders in the development stage

The values of each parameter corresponding to the development stage in Table 4 satisfy the stability conditions, i.e., $C + C_1 + C_2 < G_1 - G_2$, $F < R + C_1$ and $F + R < C_2 + E_1$. Similarly, 125 different sets of initial strategy points for x, y and z were generated, and after iteration, they all converged to e_8 (1, 1, 1), as shown in Figure 3. That is, in the development stage, with government incentives, farmers and agribusinesses were profitable and began to actively use arable land for agricultural production.

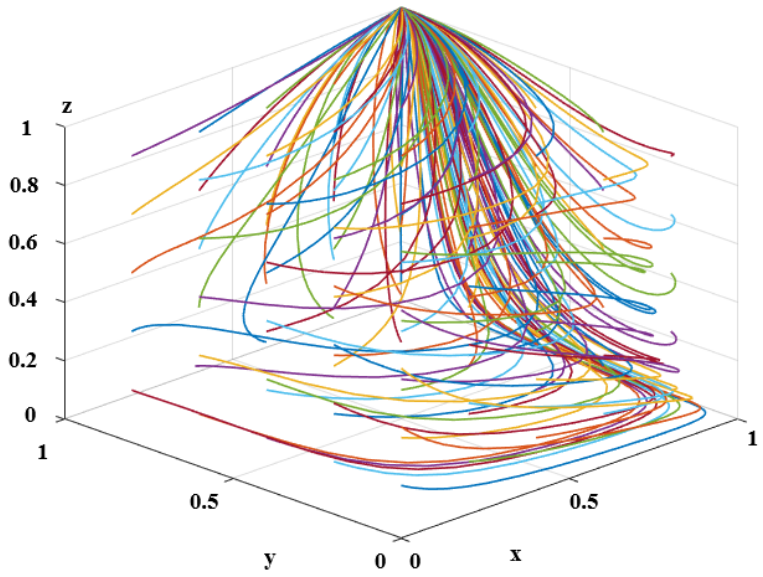

Figure 3. Evolution process of the system in the development stage

(c) Dynamic evolution of stakeholders in the mature stage

The values of each parameter corresponding to the maturity stage in Table 4 all satisfy the stability conditions, i.e., $C + C_1 + C_2 > G_1 - G_2$, $F < R$ and $F + R < E_2$. In a similar manner, 125 distinct sets of initial strategy coordinates

for variables x, y, and z were generated. Subsequent iterations led to their convergence at the point $e_4(0,1,1)$, as illustrated in Figure 4. That is, at the maturity stage, the agricultural facilities were basically well built and the cooperative relationship between farmers and agricultural enterprises was stabilized. As the marginal benefits of local governments' investment in agricultural infrastructure diminished significantly, it reached a point where the government ceased its market intervention and initiated a gradual withdrawal.

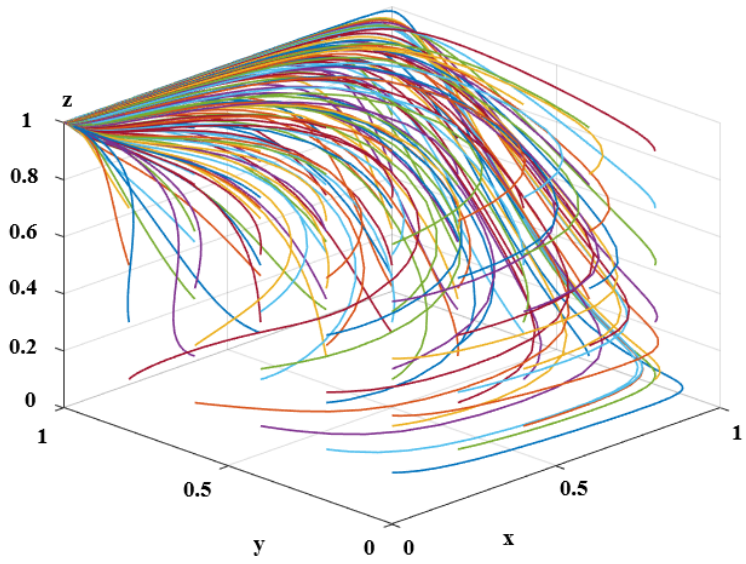

Figure 4. Evolution process of the system in the mature stage

5. Sensitivity Analysis

To clarify the specific impact of changes in each factor on the decisions of the three stakeholders, parameter adjustments were made as necessary. According to the actual situation, the parameters such as the cost of transferring farmland, the income from farmland, and the income from outside work cannot be directly regulated. Therefore, the impact of changes in parameters such as the cost of cooperation between farmers and enterprises, economic subsidies, and central government regulation were mainly considered.

(a) Costs of establishing cooperative relationships between farmers and agribusinesses

The cost of cooperation between the two parties was set to 5, 15 and 30. Based on the 3D dynamical system, the three values of F were simulated numerically, and the results are shown in Figure 5. When F was 15 and 30, both y and z decreased, indicating that the cooperation cost of both parties hindered their agricultural production initiatives. When F decreased to 5, both y and z gradually increased, indicating that the willingness of farmers and agribusinesses to produce increased when the benefits exceeded the costs required to reach cooperation.

(b) Financial subsidies

The economic subsidies promised by the government to farmers and agribusinesses were set to 5, 15 and 20, respectively, and the results were simulated numerically, as shown in Figure 6. When C_1 and C_2 were 5, both y and z decreased. At this time, farmers and agribusinesses had no strong intention to carry out agricultural production. As C_1 and C_2 gradually increased, a part of farmers and agribusinesses tried to cooperate in agricultural production, but the participation ratio always fluctuated repeatedly and could not form a stable state.

(c) Loss of reputation or regulatory penalty

The loss of reputation of the local government when the arable land is idle or its punishment by higher authorities was set to 0, 15 and 30, respectively, and the results were numerically simulated, as shown in Figure 7. When P was 15 and 30, the local government took active measures to promote the use of arable land. However, when it was not regulated by the central government, there was no sufficient incentive to invest financial support for agricultural construction.

(d) Economic subsidies and cooperation costs

When the system was still in the development stage, a part of the economic subsidy was withdrawn, i.e., the economic subsidy was set to 5, 15 and 20, respectively. The numerical simulation was executed, and the outcomes are presented in Figure 8. It can be found that the system eventually regressed back to the initial stage when C_1 and C_2 decreased.

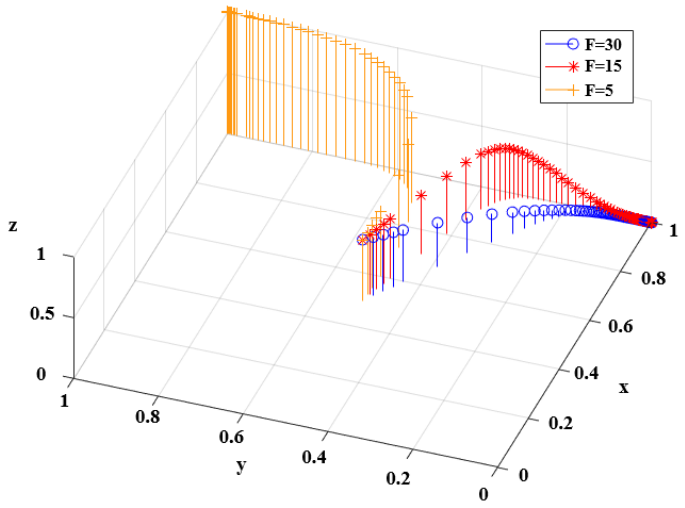

Figure 5. Impact of the cooperation cost

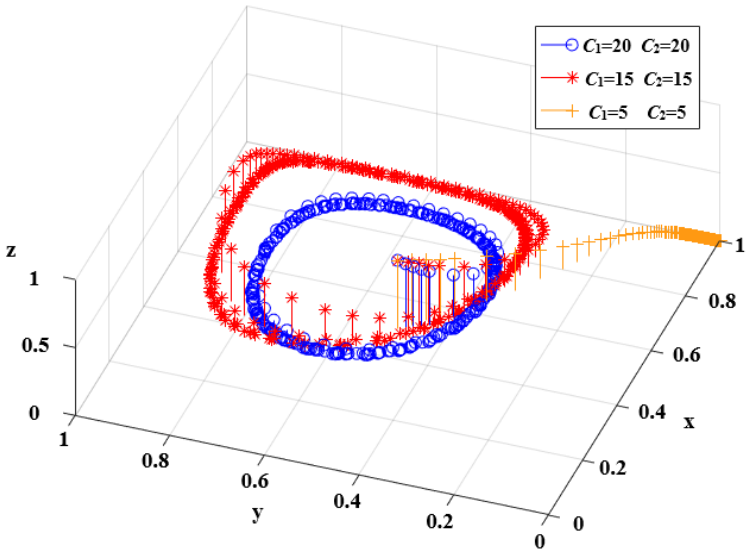

Figure 6. Impact of the subsidies

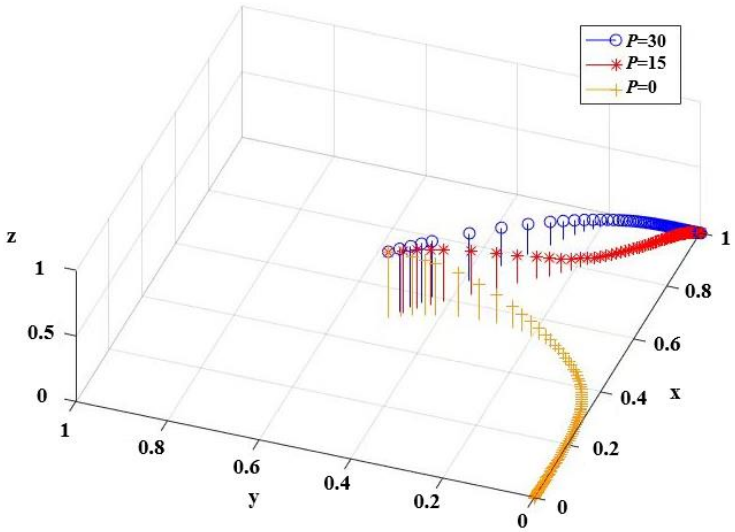

Figure 7. Impact of reputation loss or regulatory penalties

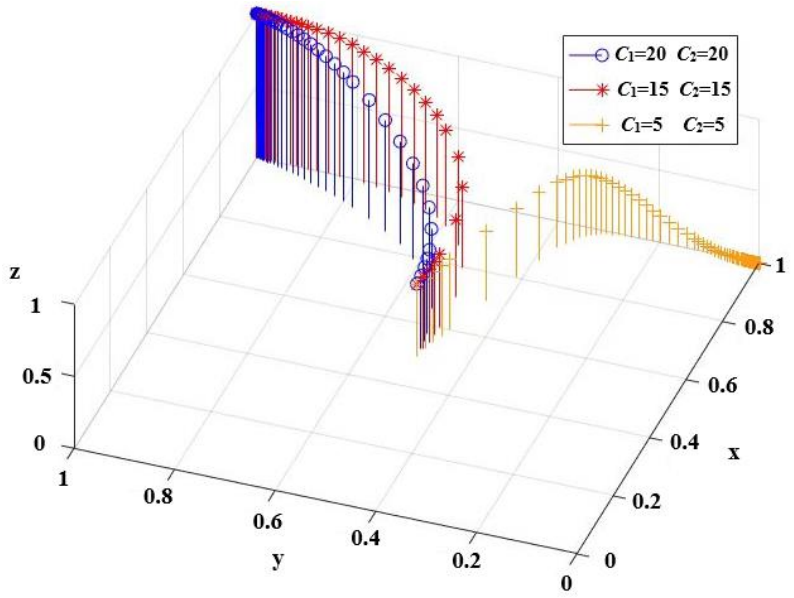

Figure 8. Impact of the subsidies in the development stage

6. Discussion

Based on the challenges encountered by stakeholders during the “separation of three rights” reform in China (Moroni, 2018; Yan et al., 2021), this study develops an evolutionary game theoretic model. Via the equilibrium point analysis and sensitivity analysis of the evolutionary game model, it can be understood that the local government chose to regulate the abandoned farmland, build agricultural infrastructure, encourage farmers to cultivate, and introduce agricultural enterprises for industrial production in order to improve production efficiency due to factors such as policy regulation by higher authorities and potential benefits of developing agriculture. In the early stage, local governments effectively promoted the utilization of farmland and the separation of contracting and management rights through economic subsidies. However, affected by information asymmetry, transaction costs and an inadequate mobility service system, farmers and agribusinesses were caught in a cyclical swing and were unable to cooperate in a long-term and in-depth manner. Moreover, even if the separation of contracting and management rights was achieved through economic subsidies, the system fell into a bad state again with the reduction of subsidies if a sound cooperation mechanism was not established between farmers and agribusinesses, which is unfavorable to the implementation of the “separation of three rights” in the long run.

To ensure the long-term and effective implementation of the “separation of three rights,” policy recommendations were derived from the simulation results below. In order to effectively separate contracting rights from management rights in the long run, local governments can improve agricultural infrastructure and grant subsidies upfront. However, the key is to improve the mobility service system, reduce the cost of transferring management rights, and eliminate the possible legal problems. Before farmers and agribusinesses establish effective, healthy and stable cooperative relationships, local governments should pay close attention to the utilization of farmland and ensure that farmers and agribusinesses receive adequate subsidies. The separation of contracting and management rights can be fully achieved when the mobility service system is established and mature, the problem of fragmentation of arable land is basically solved and economies of scale are formed (Wang et al., 2022). At this time, land transfer can form a market, and the government can gradually release its intervention. Combining the simulation analysis, the current situation of cultivated land in China, and historical policies, this study holds that the realization of land transfer and the improvement of cultivated land abandonment can be gradually advanced in three stages.

(a) Phase 1 (1-2 years for pilot exploration) involves establishing "one-stop land transfer service centers" in 30% of townships to integrate policy consultation, contract registration, and dispute mediation services, with 2-3 dedicated liaisons per township (modeled after Zhejiang’s "run at most once" reform), prioritizing infrastructure upgrades (e.g., "field network + road network + irrigation network" renovations, with an investment of 1,500 RMB/mu, 40% funded by the central government) in areas with farmland abandonment rates >15%, and conducting annual training for farmers (60% coverage on contract law and risk awareness) and agribusinesses (workshops on subsidy policies), aiming to increase land transfer rates in pilot areas by 10-15% and establish a subsidy efficiency evaluation system.

(b) Phase 2 (3-5 years for full-scale promotion) expands successful pilots provincially through a digital platform (e.g., Anhui’s "Wannongyun" model) integrating satellite land parcel data, enterprise credit ratings, and subsidy

application tracking to reduce cooperation costs F from 300 RMB/transaction to 100 RMB/transaction, implementing a three-year gradient subsidy reduction (from $C1$=1,200 RMB/mu and $C2$=1,500 RMB/mu in the third year to $C1$=500 RMB/mu and $C2$=600 RMB/mu in the fifth year), and establishing a "land transfer risk reserve fund" (60% government, 30% enterprises, 10% village collectives, with a scale ≥15% of annual transfer volume) to mitigate default and natural disaster risks, targeting a provincial land transfer rate of 50% and a 60% reduction in abandonment rates.

(c) Phase 3 (more than six years for long-term mechanism) transitions to market-driven governance by fostering third-party services (e.g., land trusteeship and contracted farming, with government purchase subsidies of 200 RMB/mu), launching "management right loans" for mortgage financing (referencing Anhui Jinzhai's pilot), and implementing region-specific policies (30% subsidy tilt for mountainous areas like Zhejiang Lishui, and an additional 500 RMB/mu chain industry subsidy for plains areas like Anhui Jianghuai Plain), supported by a tiered fiscal burden mechanism (central/provincial/county: 50%/40%/10-20%, exempting poor counties), a vice-governor-led interdepartmental task force coordinating agriculture, finance, and natural resources, and grassroots capacity building (one dedicated land broker per 10,000 residents, with 30% of salaries funded by provincial transfers), aiming for a sustainable system where market regulation accounts for 70% of land transactions and government intervention costs drop to 30% of peak levels. Rooted in real-world practices like Sichuan's "Sunshine Village Affairs" project and national standards (e.g., the *National High-Standard Farmland Construction Plan*), this roadmap provides actionable steps with clear responsibilities, timelines, and performance metrics, enhancing applicability for local governments to implement the "separation of three rights" policy effectively.

This research is subject to certain limitations. Owing to spatial constraints, the simulation analysis exclusively encompasses the three most indicative phases of the policy's implementation pertaining to the "separation of three rights." In fact, in the process of farmland transfer, there may also be transitional stages in which farmers or agricultural enterprises respond unilaterally to the policy, and their formation mechanisms and solutions are also important for the implementation of the three-rights splitting policy, which should be further improved in future studies.

7. Conclusion

The escalating phenomenon of arable land abandonment in China constitutes a significant threat to the nation's food security. The enforcement of the policy concerning the "separation of three rights" has the potential to substantially enhance the efficiency of arable land utilization, thereby fostering agricultural development. This study conducts an analysis of the strategic decisions made by pivotal entities—local governments, farmers, and agricultural enterprises—in the context of the "separation of three rights" across various scenarios through the application of evolutionary game theory. The results show that factors such as cooperation costs, subsidies, government reputation and regulatory penalties profoundly affect the utilization of arable land and the separation of contracting and management rights, among which it is crucial to reduce the transaction barriers existing in the process of arable land transfer.

From the previous simulation results and discussions, some policy suggestions can be made for the implementation of the "separation of three rights" policy in China. First, the central government should act as a regulator and monitor in real time to check whether local governments are effectively fulfilling their responsibilities and investing in local agricultural construction, like establishing a department responsible for overseeing the local government's investment and effectiveness in agricultural construction. Only when local governments pay full attention to food security can they promote land transfer at the source. Secondly, the government must prioritize the enhancement of agricultural infrastructure to align with the production requirements of the farming community. This action will augment the productivity of arable land, thereby enticing both farmers and agricultural enterprises to engage in agricultural activities. Thirdly, it is imperative for the government to allocate sufficient subsidies to guarantee the uninterrupted production on arable land and to facilitate the gradual involvement of agricultural enterprises in the early stages of policy implementation, such as direct subsidies, reward-based subsidies, loan interest subsidies, government purchasing services, and the quantification of asset stocks, which could support and guide individuals and agricultural production and operation organizations to assume responsibility for pertinent tasks or to provide financial support and active participation in the development of associated projects. Fourth, the government should strengthen the construction of the mobility service system and improve the relevant policies and laws, such as establishing a land transfer monitoring system to provide information release, policy consultation, and other services for both parties involved in the transfer. In addition, to innovate land transfer forms, the mutual rights and specific forms of realization among collective ownership, farmer contractual rights, and land management rights in land transfer could be explored. In addition, land transfer behaviors could be standardized to guarantee the clarity of the property right subjects, thereby reducing the barriers to the transfer of farmland and facilitating the sustained and consistent application of the policy concerning the "separation of three rights."

Funding

This study is funded by the National Social Science Fund of China (Grant No.: 20BJY144).

Data Availability

The datasets generated or analyzed during this study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

References

Alban Singirankabo, U. & Willem Ertsen, M. (2020). Relations between land tenure security and agricultural productivity: Exploring the effect of land registration. *Land*, *9*(5), 138. https://doi.org/10.3390/land9050138.

Baek, S., Yoon, H., & Hahm, Y. (2022). Assessment of spatial interactions in farmland abandonment: A case study of Gwangyang City, Jeollanam-do Province, South Korea. *Habitat Int.*, *129*, 102670. https://doi.org/10.1016/j.habitatint.2022.102670.

Bellout, A., Vaz, E., & Penfound, E. (2020). Rethinking agricultural land use in Algiers: A spatial analysis of the Eastern Mitidja Plain. *Habitat Int.*, *104*, 102239. https://doi.org/10.1016/j.habitatint.2020.102239.

Chaudhary, S., Wang, Y., Dixit, A. M., Khanal, N. R., Xu, P., Fu, B., Yan, K., Liu, Q., Lu, Y. F., & Li, M. (2020). A synopsis of farmland abandonment and its driving factors in Nepal. *Land*, *9*(3), 84. https://doi.org/10.3390/land9030084.

Chen, Z. & Shi, D. (2020). Spatial structure characteristics of slope farmland quality in Plateau Mountain area: A case study of Yunnan Province, China. *Sustainability*, *12*(17), 7230. https://doi.org/10.3390/su12177230.

Deng, X., Xu, D., Zeng, M., & Qi, Y. (2018). Landslides and cropland abandonment in China's mountainous areas: Spatial distribution, empirical analysis and policy implications. *Sustainability*, *10*(11), 3909. https://doi.org/10.3390/su10113909.

Dolton-Thornton, N. (2021). Viewpoint: How should policy respond to land abandonment in Europe? *Land Use. Pol.*, *102*, 105269. https://doi.org/10.1016/j.landusepol.2020.105269.

Friedman, D. (1991). Evolutionary games in economics. *Econometrica: J. Econ. Soc.*, *59*(3), 637-666. https://doi.org/10.2307/2938222.

Fu, Q., Li, B., Hou, Y., Bi, X., & Zhang, X. (2017). Effects of land use and climate change on ecosystem services in Central Asia's arid regions: A case study in Altay Prefecture, China. *Sci. Total Environ.*, *607*, 633-646. https://doi.org/10.1016/j.scitotenv.2017.06.241.

Gao, S., Ling, S., & Liu, W. (2018). The role of social media in promoting information disclosure on environmental incidents: An evolutionary game theory perspective. *Sustainability*, *10*(12), 4372. https://doi.org/10.3390/su10124372.

Gao, S., Ling, S., Liu, X., Dou, X., & Wu, R. (2020). Understanding local government's information disclosure in China's environmental project construction from the dual-pressure perspective. *J. Clean. Prod.*, *263*, 121311. https://doi.org/10.1016/j.jclepro.2020.121311.

Gong, M., Li, H., & Elahi, E. (2022). Three Rights Separation reform and its impact over farm's productivity: A case study of China. *Land Use Pol.*, *122*, 106393. https://doi.org/10.1016/j.landusepol.2022.106393.

He, Y., Xie, H., & Peng, C. (2020). Analyzing the behavioural mechanism of farmland abandonment in the hilly mountainous areas in China from the perspective of farming household diversity. *Land Use Pol.*, *99*, 104826. https://doi.org/10.1016/j.landusepol.2020.104826.

Hou, D., Meng, F., & Prishchepov, A. V. (2021). How is urbanization shaping agricultural land-use? Unraveling the nexus between farmland abandonment and urbanization in China. *Landscape Urban Plan.*, *214*, 104170. https://doi.org/10.1016/j.landurbplan.2021.104170.

Jiménez-Olivencia, Y., Ibáñez-Jiménez, Á., Porcel-Rodríguez, L., & Zimmerer, K. (2021). Land use change dynamics in Euro-mediterranean mountain regions: Driving forces and consequences for the landscape. *Land Use Pol.*, *109*, 105721. https://doi.org/10.1016/j.landusepol.2021.105721.

Keenleyside, C., Tucker, G., & McConville, A. (2010). Farmland Abandonment in the EU: An Assessment of Trends and Prospects. Institute for European Environmental Policy, London. https://www.researchgate.net/profile/Clunie-Keenleyside/publication/258375179_Farmland_Abandonment_in_the_EU_An_Assessment_of_Trends_and_Prospects_Report_Prepared_for_WWF/links/5411b0c50cf264cee28b50cc/Farmland-Abandonment-in-the-EU-An-Assessment-of-Trends-and-Prospects-Report-Prepared-for-WWF.pdf

Knippenberg, E., Jolliffe, D., & Hoddinott, J. (2020). Land fragmentation and food insecurity in Ethiopia. *American J. Agri. Economics*, *102*(5), 1557-1577. https://doi.org/10.1002/ajae.12081.

Lambin, E. F., & Meyfroidt, P. (2011). Global land use change, economic globalization, and the looming land scarcity. *Proc. Natl Acad Sci.*, *108*(9), 3465-3472. https://doi.org/10.1073/pnas.1100480108.

Lasanta, T., Arnáez, J., Pascual, N., Ruiz-Flaño, P., Errea, M. P., & Lana-Renault, N. (2017). Space–time process and drivers of land abandonment in Europe. *Catena*, *149*, 810-823. https://doi.org/10.1016/j.catena.2016.02.024.

Leal Filho, W., Mandel, M., Al-Amin, A. Q., Feher, A., & Chiappetta Jabbour, C. J. (2016). An assessment of the causes and consequences of agricultural land abandonment in Europe. *Int J. Sustain Dev. World Ecol.*, *24*(6), 554-560. https://doi.org/10.1080/13504509.2016.1240113.

Levers, C., Schneider, M., Prishchepov, A. V., Estel, S., & Kuemmerle, T. (2018). Spatial variation in determinants of agricultural land abandonment in Europe. *Sci. Total Environ.*, *644*, 95-111. https://doi.org/10.1016/j.scitotenv.2018.06.326.

Li, A., Wu, J., Zhang, X., Xue, J., Liu, Z., Han, X., & Huang, J. (2018). China's new rural "separating three property rights" land reform results in grassland degradation: Evidence from Inner Mongolia. *Land Use Pol.*, *71*, 170-182.https://doi.org/10.1016/j.landusepol.2017.11.052.

Li, S. & Li, X. (2017). Global understanding of farmland abandonment: A review and prospects. *J. Geogr Sci.*, *27*, 1123-1150. https://doi.org/10.1007/s11442-017-1426-0.

Lin, B. & Zhao, H. (2021). Does off-farm work reduce energy poverty? Evidence from rural China. *Sustain Prod. Consum.*, *27*, 1822-1829. https://doi.org/10.1016/j.spc.2021.04.023.

Liu, B., Song, W., & Sun, Q. (2022a). Status, trend, and prospect of global farmland abandonment research: A bibliometric analysis. *Int. J. Environ Res. Public Health.*, *19*(23), 16007. https://doi.org/10.3390/ijerph192316007.

Liu, Y., Li, J., & Yang, Y. (2018). Strategic adjustment of land use policy under the economic transformation. *Land Use Pol.*, *74*, 5-14. https://doi.org/10.1016/j.landusepol.2017.07.005.

Liu, Y., Wu, K., Li, X., Li, X., & Cao, H. (2022b). Adaptive management of cultivated land use zoning based on land types classification: A case study of Henan Province. *Land*, *11*(3), 346. https://doi.org/10.3390/land11030346.

Long, H., Ge, D., Zhang, Y., Tu, S., Qu, Y., & Ma, L. (2018). Changing man-land interrelations in China's farming area under urbanization and its implications for food security. *J. Environ. Manage.*, *209*, 440-451. https://doi.org/10.1016/j.jenvman.2017.12.047.

Long, H. & Liu, Y. (2016). Rural restructuring in China. *J. Rural Stud.*, *47*, 387-391. https://doi.org/10.1016/j.jrurstud.2016.07.028.

Lyapunov, A. M. (1992). The general problem of the stability of motion. *Int. J. Control.*, *55*(3), 531-534. https://doi.org/10.1080/00207179208934253.

Moroni, S. (2018). Property as a human right and property as a special title. Rediscussing private ownership of land. *Land Use Pol.*, *70*, 273-280. https://doi.org/10.1016/j.landusepol.2017.10.037.

Postek, P., Leń, P., & Stręk, Ż. (2019). The proposed indicator of fragmentation of agricultural land. *Ecol. Indic.*, *103*, 581-588. https://doi.org/10.1016/j.ecolind.2019.04.023.

Pu, M. & Zhong, Y. (2020). Rising concerns over agricultural production as COVID-19 spreads: Lessons from China. *Glob. Food Secur.*, *26*, 100409. https://doi.org/10.1016/j.gfs.2020.100409.

Qu, Y. & Long, H. (2018). The economic and environmental effects of land use transitions under rapid urbanization and the implications for land use management. *Habitat Int.*, *82*, 113-121. https://doi.org/10.1016/j.habitatint.2018.10.009.

Quintas-Soriano, C., Castro, A. J., Castro, H., & García-Llorente, M. (2016). Impacts of land use change on ecosystem services and implications for human well-being in Spanish drylands. *Land Use Pol.*, *54*, 534-548. https://doi.org/10.1016/j.landusepol.2016.03.011.

Shi, T., Li, X., Xin, L., & Xu, X. (2018). The spatial distribution of farmland abandonment and its influential factors at the township level: A case study in the mountainous area of China. *Land Use Pol.*, *70*, 510-520. https://doi.org/10.1016/j.landusepol.2017.10.039.

Sil, Â., Fernandes, P. M., Rodrigues, A. P., Alonso, J. M., Honrado, J. P., Perera, A., & Azevedo, J. C. (2019). Farmland abandonment decreases the fire regulation capacity and the fire protection ecosystem service in mountain landscapes. *Ecosyst. Serv.*, *36*, 100908. https://doi.org/10.1016/j.ecoser.2019.100908.

Su, G., Okahashi, H., & Chen, L. (2018). Spatial pattern of farmland abandonment in Japan: Identification and determinants. *Sustainability*, *10*(10), 3676. https://doi.org/10.3390/su10103676.

Subedi, Y. R., Kristiansen, P., & Cacho, O. (2022). Drivers and consequences of agricultural land abandonment and its reutilisation pathways: A systematic review. *Environ. Dev.*, *42*, 100681. https://doi.org/10.1016/j.envdev.2021.100681.

Subedi, Y. R., Kristiansen, P., Cacho, O., & Ojha, R. B. (2021). Agricultural land abandonment in the hill agro-ecological region of Nepal: Analysis of extent, drivers and impact of change. *Environ. Manage.*, *67*, 1100-

1118. https://doi.org/10.1007/s00267-021-01461-2.
Sun, Q., Qi, W., & Yu, X. (2021). Impacts of land use change on ecosystem services in the intensive agricultural area of North China based on multi-scenario analysis. *Alex. Eng. J.*, *60*(1), 1703–1716. https://doi.org/10.1016/j.aej.2020.11.020.
Vinogradovs, I., Nikodemus, O., Elferts, D., & Brūmelis, G. (2018). Assessment of site-specific drivers of farmland abandonment in mosaic-type landscapes: A case study in Vidzeme, Latvia. *Agric. Ecosyst. Environ.*, *253*, 113-121. https://doi.org/10.1016/j.agee.2017.10.016.
Wainwright, J. (1989). A dynamical systems approach to Bianchi cosmologies: Orthogonal models of class A. *Class. Quantum Grav.*, *6*(10), 1409. https://doi.org/10.1088/0264-9381/6/10/011.
Wang, J., Yu, C., Fang, X., Li, G., & Cao, Y. (2022). Does land tenure fragmentation aggravate farmland abandonment? Evidence from big survey data in rural China. *J. Rural Stud.*, *91*, 126-135. https://doi.org/10.1016/j.jrurstud.2022.03.013.
Wang, Q. & Zhang, X. (2017). Three rights separation: China's proposed rural land rights reform and four types of local trials. *Land Use Pol.*, *63*, 111-121. https://doi.org/10.1016/j.landusepol.2017.01.027.
Wang, Y., Li, X., Xin, L., & Tan, M. (2020). Farmland marginalization and its drivers in mountainous areas of China. *Sci. Total Environ.*, *719*, 135132. https://doi.org/10.1016/j.scitotenv.2019.135132.
Wei, S. & Ying, Z. (2019). Farmland abandonment research progress: Influencing factors and simulation model. *J. Resour. Ecol.*, *10*(4), 345-352. https://doi.org/10.5814/j.issn.1674-764x.2019.04.001.
Wertebach, T. M., Hölzel, N., Kämpf, I., Yurtaev, A., Tupitsin, S., Kiehl, K., Kamp, J., & Kleinebecker, T. (2017). Soil carbon sequestration due to post-Soviet cropland abandonment: Estimates from a large-scale soil organic carbon field inventory. *Glob. Change Biol.*, *23*(9), 3729-3741. https://doi.org/10.1111/gcb.13650.
Xu, D., Deng, X., Guo, S., & Liu, S. (2019). Labor migration and farmland abandonment in rural China: Empirical results and policy implications. *J. Environ. Manage.*, *232*, 738-750. https://doi.org/10.1016/j.jenvman.2018.11.136.
Xu, Z., Shen, J., Gao, X., & Zhen, M. (2022). Migration and household arrangements of rural families in China: Evidence from a survey in Anhui Province. *Habitat Int.*, *119*, 102475. https://doi.org/10.1016/j.habitatint.2021.102475.
Yan, J., Yang, Y., & Xia, F. (2021). Subjective land ownership and the endowment effect in land markets: A case study of the farmland "three rights separation" reform in China. *Land Use Pol.*, *101*, 105137. https://doi.org/10.1016/j.landusepol.2020.105137.
Zhan, S. (2017). Hukou reform and land politics in China: Rise of a tripartite alliance. *Chin. J.*, *78*(1), 25-49. https://doi.org/10.1086/690622.
Zhang, Z., Li, Q., Liu, G., & Tuo, D. (2017). Soil resistance to concentrated flow and sediment yields following cropland abandonment on the Loess Plateau, China. *J Soils Sediments*, *17*, 1662-1671. https://doi.org/10.1007/s11368-017-1650-3.
Zhou, C., Liang, Y., & Fuller, A. (2021). Tracing agricultural land transfer in China: Some legal and policy issues. Land, *10*(1), 58. https://doi.org/10.3390/land10010058.
Zhou, Y., Li, X., & Liu, Y. (2020). Rural land system reforms in China: History, issues, measures and prospects. *Land Use Pol.*, *91*, 104330. https://doi.org/10.1016/j.landusepol.2019.104330.