



Research article

Effective guide for behaviour of farmers in the withdrawal of rural homesteads: An evolutionary game-based study

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Abstract: In this study, we determined how farmers can be effectively encouraged to withdraw from their idle homesteads, in addition to revitalising the rural construction land stock and realising the market-oriented allocation of land resources. We constructed an evolutionary game model under three scenarios: without penalty mechanism; with a static penalty mechanism; and with a dynamic penalty mechanism. Further, we explicitly describe the strategic behaviours and dynamic evolution processes of local governments and farmers during withdrawal from their rural homesteads. According to the results of the evolutionary stable strategy, under effect of the dynamic penalty mechanism, the strategy systems formed by local governments as well as farmers can gradually converge and stabilise after short-term shocks, compared with that under the no penalty and static penalty mechanisms. Overall, the penalty mechanism mitigates the instability in the game process during participants' incremental changes and strategy choices, while the dynamic mechanism is optimal. Both static and dynamic penalty mechanisms influence the binary equilibrium strategies of local governments as well as farmers, and farmers' strategies evolve towards this state of withdrawal from their homesteads with increasing penalty. When the model is dynamically improved, the probability of farmers' withdrawal of their homesteads increases with increasing penalty. Thus, clearly, the establishment of a penalty mechanism can promote stability of the participants' system; higher penalty implies higher motivation for farmers to withdraw their idle homesteads, enabling revitalisation of the rural stock of construction land and promotion of the optimal allocation of land resource elements.

Keywords: evolutionary game; construction land; penalty mechanism; idle homesteads; dynamic mechanism; allocation of land resource elements

1. Introduction

The allocation of construction land use rights under the strict construction land management system has long been characterised by urban–rural divisions, which has made it difficult to achieve optimal allocation of land across regions [1,2]. With rapid socio-economic development and increasing urbanisation, the cross-regional movement and migration of population are becoming increasingly frequent, because of which the shortcomings of the existing construction land management system are becoming increasingly prominent [3]. Moreover, with gradual expansion of the scale of industrialisation, the process of urbanisation is accelerating, and the total demand for construction land is showing an overall increase, which has resulted in a serious shortage of construction land quotas [4]. Furthermore, limited by factors such as human capital, the development of industries in rural areas is lacking, which has resulted in idle or inefficient utilisation of rural residential land. All these problems have restricted the optimal allocation of urban and rural land resources and hindered the sustainable development of China’s social economy [5,6]. Therefore, researchers are now focusing on encouraging farmers to withdraw their idle homesteads and tap the potential of rural construction land stock to enable efficient allocation of land resources.

Chongqing and Chengdu took the lead as pilot reform zones to introduce a production and trading mechanism for construction land quotas to achieve market-based allocation of urban and rural land resources [7]. Subsequently, Guangzhou and Zhengzhou also implemented a trading system of quotas to solve the problem of insufficient land quotas [8]. Similar to financial markets that aim to achieve the optimal allocation of capital across time, the trading of construction land quotas can achieve the optimal allocation of land resources across space, which will substantially increase the market value of idle construction land in remote areas, thus providing farmers in remote areas a new source to increase their income.

The current trading mechanism can effectively alleviate the dilemma faced by local governments in China; however, it has failed to meet expectations. The practice of withdrawal from rural homesteads (WRH) is led by the local governments in each region; farmers participating in WRH are unable to present their opinions on the compensation standard, and they only passively accept the price set by these local governments [9,10]. More importantly, in the process of trading of quotas, local governments and farmers have different sources of income. The local governments are interested in the land price obtained after the quotas are used, while the farmers are interested in the transaction price of the construction land quota. Owing to this significant difference between the two interests, farmers’ land rights and interests do not receive sufficient attention. According to Wang et al. [11], Chen et al. [12] and Kong et al. [13], local governments are more interested in inducing farmers to quickly withdraw from their idle homesteads. Farmers’ land rights are not effectively addressed and protected, which hampers their motivation to withdraw, decelerating the process of allocation optimisation of national land resources. In 2020, the State Council issued “The Opinions on Building a More Perfect Institutional Mechanism for Market-based Allocation of Factors”, which further emphasised the need to actively revitalise the stock of construction land, deepen the reform

pilot in each region, and provide land factor guarantee for rural revitalisation and integrated development of urban and rural areas. Clearly, governments should be able to more efficiently motivate farmers to voluntarily withdraw from their idle homesteads, enabling revitalisation of the rural stock of construction land and easing the pressure of construction land expansion on arable land protection.

2. Literature review

With an increasing focus of the country on the market-oriented allocation of land elements, an increasing number of studies have focused on farmers' withdrawal from homesteads and other related phases and aspects. First, several studies have presented a general overview of the mechanism of the WRH policy, including the modes of withdrawal from rural homesteads, motivation mechanisms, and connotation issues. Liang et al. [14] considered Jinjiang city as an example and emphasised that the operation mechanism and optimised countermeasures of the paid withdrawal model of homesteads are theoretical and practical problems that need to be solved for implementing the rural revitalisation strategy. Ouyang et al. [15] argued that the lack of a mechanism for WRH was the root cause of the current problems in the use of rural land in China; the authors proposed that the establishment of a mechanism for withdrawal from homesteads with incentives and constraints at the core is crucial for reforming and improving the management of the use of rural homesteads. Liu et al., [16] determined that economic structural change and village transformation are crucial for reforming the housing system in traditional farming areas; changes in the social and economic behavioural characteristics of second-generation farmers were considered the main driving force for reform of the housing system. Further, some studies have explored the compensation of homesteads' withdrawal, willingness to withdraw, and factors affecting withdrawal from homesteads in a particular period from the farmers' perspective. Liu et al. [17] argued that farmers' high-value expectations of rural homesteads and the large gap between their expected compensation and prices offered by local governments make promotion of WRH policies challenging. Yu [18] summarised the results of 33 pilot counties (cities and districts) and analysed three representative models in detail, namely "Pingluo experience", "Yujiang model", and "Yiwu wisdom". The author considered that although the pilot reform of homesteads' withdrawal had made significant progress, it had also encountered some difficulties such as farmers' low motivation. Zhao et al. [19] explored the effects of farmers' economic status, policy expectations, and perceived policy values on their satisfaction with homesteads' withdrawal policy through a questionnaire survey of 287 households in Jinhua County, Jiangsu Province, China. Using a unique survey data set from a pilot region in China, Fan et al. [20] investigated the main factors behind farmers' willingness to withdraw from rural homesteads and found that their personal attitudes and social norms played an important role in their decision-making. Third, several studies aimed to determine risks in the process of homesteads' withdrawal. Liu et al. [21] believed that local governments should consider the actual situation in their regions to ensure open and transparent WRH policy information to reduce information asymmetry between farmers and their willingness to withdraw from rural homesteads. Shui et al. [22] highlighted the possibility that farmers' lands might be reduced, lost, or may suffer losses due to change in ownership during the process of withdrawal. To address these issues, the central government should increase the compensation.

Existing literature shows that the willingness to withdraw from their homesteads, the factors affecting withdrawal, or the risks influencing the process of withdrawal have been studied from the farmers' perspective. However, a few studies have considered whether the strategic behaviours, such as central government rewards and penalty mechanisms, affect the behaviours of WRH. A few studies have described the role of static penalty mechanisms from a qualitative perspective; however, there have been fewer studies on dynamic penalty strategies. Moreover, no quantitative perspectives have been explored to determine the optimal penalty methods. Homesteads' withdrawal is a multiparty coordinated dynamic process, and evolutionary game theory can provide a good understanding of the dynamic process of group evolution and explain why and how the group will reach a steady state. Evolutionary game theory can make up for the deficiencies of traditional econometric models used for the evolution and interaction of systems [23]. Evolutionary game theory has been applied to various fields such as energy use regulation, environmental governance, and ecological compensation. More recently, this theory was introduced to land use and management. Xie et al. [24] examined the effects of different external factors on different subjects (namely central government, local government, and farmers) in arable land protection under different conditions. Pang et al. [25] explored the dynamics and stability of land revenue distribution in tourism development by using an evolutionary game model. Zhang et al. [26] analysed the logic and dilemma of land reserve strategies and illegal land reserve problems, along with the role of land inspectors from the perspective of game theory; they determined that under various conditions, participants face duplicate dynamic mechanisms and evolutionary stabilisation strategies. In general, although land use and management have been investigated in China via evolutionary game models, only a few studies have addressed how to achieve efficient withdrawal from homesteads. Studies on withdrawal of homesteads have mostly used static games or elaborate conclusions based on survey data from a specific period. Notably, homesteads' withdrawal is a dynamic process, and drawing definitive conclusions is complicated by factors such as information asymmetry. Thus, it is important to construct an evolutionary game to study efficient realisation of the withdrawal of rural homesteads and revitalise the stock of rural construction land.

This study has three main contributions. First, we simulated the dynamic evolution of homesteads' withdrawal strategies of stakeholders from a dynamic perspective and investigated evolutionary stabilisation strategies under three scenarios: no penalty, static penalty, and dynamic penalty mechanisms. Second, we conducted a multicycle visualisation and simulation analysis of the change process of participants' strategies in the process of WRH and explored the effects of different penalty methods on participants' strategic behaviours. Third, we determined how to quickly stabilise the cyclical fluctuation system by comparing the three penalty mechanisms. Finally, based on the model results, we propose suggestions for policy-makers to promote efficient withdrawal of homesteads.

3. Evolutionary game analysis of farmers and local governments

3.1. Model hypothesis

The process of WRH policy should focus on the strategic behaviours (i.e., the strategy choices and payoffs) of two stakeholders, namely local governments and farmers. The penalty mechanism of the central government may also affect the strategy selections and payoffs of the local governments

and farmers in the process of withdrawal from their homesteads. For instance, if the central government uses a strict penalty mechanism, it may promote compliance by local governments as well as farmers' motivation to withdraw from their homesteads. However, the probability of irregularities by local governments may also increase, which may decrease farmers' motivation to withdraw their idle homesteads, slowing down the revitalisation of the stock of construction land. Thus, we analysed the dynamic decision-making process between the local governments and farmers in three scenarios: no penalty, static penalty, and dynamic penalty. The pilot areas for homesteads' withdrawal are in an active development stage; herein, we investigated how farmers can be effectively encouraged to withdraw from their homesteads proactively, improving the efficiency of land allocation from the perspective of evolutionary game.

1) Local governments

There are two possible strategies, compliance and noncompliance, for local governments in the process of WRH. Let us assume that y denotes the probability that the local government selects the strategy of "Compliance", which means that the local government will actively follow the central government policy to implement homesteads' withdrawal. The costs incurred by local governments for publicity, homesteads' reclamation, and other costs are represented as C_2 , and the benefit for compliance is represented as Y_2 . If the local government adopts the strategy of "noncompliance", it will reap high benefits, represented as Y_1 , and subsequently high costs, represented as C_1 . Influenced by the central government's penalty mechanism, local governments spend other costs, represented as F , which include psychological and other costs, such as due to the fear of being discovered in the process of 'noncompliance' in the implementation of withdrawal policies.

2) Farmers

Farmers who own idle homesteads have two possible strategies (withdrawing and not withdrawing). Let us assume that x denotes the probability that farmers are willing to withdraw from their homesteads, and $1-x$ denotes the probability that farmers are not willing to withdraw. Because of the influence of the strategic behaviour of the local government, if the farmers are read to withdraw, that is, under the case of "compliance", the farmers can receive a subsidy for per square metre of homesteads, represented as S_1 (yuan/m²). If the local government fails to comply, the farmers can receive a subsidy of S_2 (yuan/m²) for withdrawing. When farmers refuse to withdraw, they lease the rural homestead to gain additional income; the profit from subleasing is represented as S_3 (yuan/m²), and the cost of human and material resources spent on leasing is represented as C_3 (yuan/m²). However, the law of the system related to the leasehold of homesteads, in the context of the Tripartite Entitlement System, is still unclear; therefore, the influence of the local government may lead to a cost loss, represented as f [27]. The area of farmers' homesteads is represented as A (m²). The notations of all variables used in the evolutionary game model are listed in Table 1.

Table 1. Notation.

Parameter	Description	Range
C_1	Costs that the local governments choose to “noncompliance”	$0 < C_2 < C_1$
C_2	Costs that the local governments choose to “compliance”	$0 < C_2 < C_1$
C_3	Costs incurred in renting out their homesteads	$C_3 > 0$
Y_1	Profits of the local governments in case of “noncompliance”	$Y_1 > Y_2 > 0$
Y_2	Profits of the local governments in case of “compliance”	$Y_1 > Y_2 > 0$
S_1	Subsidy received by farmers who withdraw in case of “compliance” by local governments	$S_1 > 0$
S_2	Subsidy received by farmers who withdraw in case of “noncompliance” by local governments	$S_2 > 0$
S_3	Profits of homesteads leased	$S_3 > 0$
A	Area of farmers’ homesteads	$A > 0$
F	Other costs incurred by the local governments fearing detection in the process of “noncompliance”	$F > 0$
f	Costs incurred due to leasing by farmers	$f > 0$
y	Probability that the local governments choose “compliance”	$0 \leq y \leq 1$
x	Probability that the farmers choose to “withdraw”	$0 \leq x \leq 1$

Table 2. Payoff matrix of stakeholders without central government’s penalty mechanism.

Subjects and strategies	Farmers		
	Withdrawal: x	Nonwithdrawal: $1 - x$	
Local governments	Compliance: y	$Y_2 - C_2, AS_1$	$-C_2, A(S_3 - C_3)$
	Noncompliance: $1 - y$	$Y_1 - C_1, AS_2$	$-C_1, A(S_3 - C_3) - f$

Table 3. Payoff matrix of stakeholders with central government’s static penalty mechanism.

Subjects and strategies	Farmers		
	Withdrawing: x	Withdrawing: $1 - x$	
Local governments	Compliance: y	$Y_2 - C_2, AS_1$	$-C_2, A(S_3 - C_3)$
	Noncompliance: $1 - y$	$Y_1 - C_1 - F, AS_2$	$-C_1, A(S_3 - C_3) - f$

Table 4. Payoff matrix of stakeholders with central government’s dynamic penalty mechanism.

Subjects and strategies	Farmers		
	Withdrawing: x	Withdrawing: $1 - x$	
Local governments	Compliance: y	$Y_2 - C_2, AS_1$	$-C_2, A(S_3 - C_3)$
	Noncompliance: $1 - y$	$Y_1 - C_1 - F(1 - y), AS_2$	$-C_1, A(S_3 - C_3) - f$

4. Model construction

4.1. Situation without penalty mechanism

First, the expected payoffs under different strategic behaviours of the local government and farmers are calculated. π_{p0}^x and π_{p0}^{1-x} represent the strategies of “withdrawal” and “nonwithdrawal” of farmers, respectively, and $\bar{\pi}_{p0}$ represents the average expected revenue. Thus, we obtain the following equations:

$$\pi_{p0}^x = y(AS_1) + (1-y)(AS_2)$$

$$\pi_{p0}^{1-x} = y(AS_3 - AC_3) + (1-y)(AS_3 - AC_3 - f)$$

$$\bar{\pi}_{p0} = x(1-x)(\pi_{p0}^x - \pi_{p0}^{1-x})$$

Therefore, the replication dynamic equation of the farmers’ choice of withdrawal strategy is represented as follows:

$$F_0(x) = \frac{dx}{dt} = x(1-x)(AS_2 - AS_3 + AC_3 + f - yAS_2 + yAS_1 - yf) \quad (1)$$

The variables π_{g0}^y and π_{g0}^{1-y} represent the expected payoffs of the local government for choosing the “compliance” and “noncompliance”, respectively, and the expected pay off of the local government is represented as $\bar{\pi}_{g0}$. Thus, we obtain the following equations:

$$\pi_{g0}^y = x(Y_2 - C_2) + (1-x)(-C_2)$$

$$\pi_{g0}^{1-y} = x(Y_1 - C_1) + (1-x)(-C_1)$$

$$\bar{\pi}_{g0} = y(1-y)(\pi_{g0}^y - \pi_{g0}^{1-y})$$

Hence, the replication dynamic equation of the local government’s choice of compliance strategy is represented as follows:

$$F_0(y) = \frac{dy}{dt} = y(1-y)(\pi_{g0}^y - \pi_{g0}^{1-y}) = y(1-y)(xY_2 - C_2 - xY_1 + C_1) \quad (2)$$

4.2. Situation with static penalty mechanism

First, π_{p1}^x and π_{p1}^{1-x} are the expected benefits for the local government derived from selecting the “withdrawal” and “nonwithdrawal” strategies, respectively, calculated using the following formulae:

$$\pi_{p1}^x = y(AS_1) + (1-y)(AS_2)$$

$$\pi_{p1}^{1-x} = y(AS_3 - AC_3) + (1-y)(AS_3 - AC_3 - f)$$

The average expected benefit of the mixed strategy adopted by the farmers is given as follows:

$$\bar{\pi}_{p1} = x(1-x)(\pi_{p1}^x - \pi_{p1}^{1-x})$$

The replication dynamic equation when farmers choose the withdrawal strategy is represented as follows:

$$F_1(x) = \frac{dx}{dt} = x(1-x)(AS_2 - AS_3 + AC_3 + f - yAS_2 + yAS_1 - yf) \quad (3)$$

π_{g1}^y and π_{g1}^{1-y} represent the expected benefits of the local government when it adopts the “compliance” and “noncompliance” strategies, respectively, and these are calculated as follows:

$$\pi_{g1}^y = x(Y_2 - C_2) + (1-x)(-C_2)$$

$$\pi_{g1}^{1-y} = x(Y_1 - C_1 - F) + (1-x)(-C_1 - F)$$

The average expected return of the mixed strategy adopted by the government is given as follows:

$$\bar{\pi}_{g1} = y(1-y)(\pi_{g1}^y - \pi_{g1}^{1-y})$$

The replication dynamics equation when local government chooses the compliance strategy is given as follows:

$$F_1(y) = \frac{dy}{dt} = y(1-y)(\pi_{g1}^y - \pi_{g1}^{1-y}) = y(1-y)(xY_2 - C_2 - xY_1 + C_1 + F) \quad (4)$$

4.3. Situation with dynamic penalty mechanism

The expected benefit of “withdrawal” strategy applied by the farmers is represented as follows:

$$\pi_{p2}^x = y(AS_1) + (1-y)(AS_2)$$

The expected benefit of “nonwithdrawal” strategy applied by the farmers is represented as follows:

$$\pi_{p2}^{1-x} = y(AS_3 - AC_3) + (1-y)(AS_3 - AC_3 - f)$$

The average profit of the farmers is represented as follows:

$$\bar{\pi}_{p2} = x(1-x)(\pi_{p2}^x - \pi_{p2}^{1-x})$$

Then, the replication dynamics equation of farmers’ withdrawing is calculated using Eq (5).

$$F_2(x) = \frac{dx}{dt} = x(1-x)(AS_2 - AS_3 + AC_3 + f - yAS_2 + yAS_1 - yf) \quad (5)$$

Similarly, the expected profits π_{g2}^y and π_{g2}^{1-y} and the average profit $\bar{\pi}_{g2}$ are given as follows:

$$\pi_{g2}^y = x(Y_2 - C_2) + (1-x)(-C_2)$$

$$\pi_{g2}^{1-y} = x[Y_1 - C_1 - F(1-y)] + (1-x)[-C_1 - F(1-y)]$$

$$\bar{\pi}_{g2} = y(1-y)(\pi_{g2}^y - \pi_{g2}^{1-y})$$

The replication dynamics equation of local government’s compliance strategy is obtained as follows:

$$F_2(y) = \frac{dy}{dt} = y(1-y)[xY_2 - C_2 - xY_1 + C_1 + F(1-y)] \quad (6)$$

4.4. Equilibrium point analysis

Based on the replicated dynamic functions obtained in Eqs (1)–(6), the equilibrium points $(x, y) \in [0, 1] \times [0, 1]$ are obtained; these satisfy the requirement that the replicated dynamic function should be equal to zero under the evolutionary game theory [28]. Therefore, we determined that the five equilibrium points of the evolutionary game are: $(1, 1)$, $(0, 0)$, $(0, 1)$, $(1, 0)$ and (x_*, y_*) , where $0 \leq x_* \leq 1$ and $0 \leq y_* \leq 1$, $*=0, 1, 2$.

According to the local stability analysis method for testing the properties of equilibrium points proposed by Fredman [29], the stability of equilibrium points is obtained from the local stability analysis of the system’s Jacobian matrix.

If the determinant of the equilibrium Jacobian matrix $Det(J_*) > 0$, and $Tr(J_*) < 0$, then the corresponding equilibrium point is considered to have the property of gradual stability, which is

called ESS (Evolutionary Stable Strategy). Therefore, the Jacobian matrix of the evolution system is given as follows:

$$\begin{aligned}
 J_0 &= \begin{bmatrix} \frac{\partial F_0(x)}{\partial x} & \frac{\partial F_0(x)}{\partial y} \\ \frac{\partial F_0(y)}{\partial x} & \frac{\partial F_0(y)}{\partial y} \end{bmatrix} \\
 &= \begin{bmatrix} (1-2x)(AS_2 - AS_3 + AC_3 + f - yAS_2 + yAS_1 - yf) & x(1-x)(-AS_2 + AS_1 - f) \\ y(1-y)(Y_2 - Y_1) & (1-2y)(xY_2 - C_2 - xY_1 + C_1) \end{bmatrix} \\
 J_1 &= \begin{bmatrix} \frac{\partial F_1(x)}{\partial x} & \frac{\partial F_1(x)}{\partial y} \\ \frac{\partial F_1(y)}{\partial x} & \frac{\partial F_1(y)}{\partial y} \end{bmatrix} \\
 &= \begin{bmatrix} (1-2x)(AS_2 - AS_3 + AC_3 + f - yAS_2 + yAS_1 - yf) & x(1-x)(-AS_2 + AS_1 - f) \\ y(1-y)(Y_2 - Y_1) & (1-2y)(xY_2 - C_2 - xY_1 + C_1 + F) \end{bmatrix} \\
 J_2 &= \begin{bmatrix} \frac{\partial F_2(x)}{\partial x} & \frac{\partial F_2(x)}{\partial y} \\ \frac{\partial F_2(y)}{\partial x} & \frac{\partial F_2(y)}{\partial y} \end{bmatrix} \\
 &= \begin{bmatrix} (1-2x)(AS_2 - AS_3 + AC_3 + f - yAS_2 + yAS_1 - yf) & x(1-x)(-AS_2 + AS_1 - f) \\ y(1-y)[Y_2 - Y_1] & (1-2y)[xY_2 - C_2 - Fy - xY_1 + C_1 + F] + Fy(y-1) \end{bmatrix}
 \end{aligned}$$

Furthermore, the expressions of the Jacobian matrix $Det(J_*) > 0$, and $Tr(J_*) < 0$, $*=0,1,2$, of each equilibrium point are shown in Table 5. Finally, the local stability of each equilibrium point under the initial state of different parameters is obtained according to the discrimination method.

Under the three punishment approaches, there are four systematic cases of strategy choice for the local government and the farmers, which are represented as follows:

System I: The equilibrium point $(1,0)$ is an ESS if $AS_2 - AS_3 + AC_3 + f > 0$ and $AS_1 - AS_3 + AC_3 > 0$.

System II: The equilibrium points $(0,1)$ and $(1,0)$ are ESS if $AS_2 - AS_3 + AC_3 + f > 0$ and $AS_1 - AS_3 + AC_3 < 0$.

System III: The equilibrium point (x_*, y_*) , $*=0,1,2$, is not a stable equilibrium point if $AS_2 - AS_3 + AC_3 + f < 0$ and $AS_1 - AS_3 + AC_3 > 0$.

System IV: The equilibrium point $(1,0)$ is an ESS if $AS_2 - AS_3 + AC_3 + f < 0$ and $AS_1 - AS_3 + AC_3 < 0$.

Table 5. Stability analysis of equilibrium points under different punishment situations (conditions 1–4).

Condition 1	Equilibrium points	$Tr(J_0)$	$Det(J_0)$	Stability
$AS_2 - AS_3 + AC_3 + f > 0$;	(0,0)	+	+	Unstable point
$AS_1 - AS_3 + AC_3 > 0$	(0,1)	?	-	Saddle point
	(1,1)	?	-	Saddle point
	(1,0)	-	+	ESS
Condition 2	Equilibrium points	$Tr(J_0)$	$Det(J_0)$	Stability
$AS_2 - AS_3 + AC_3 + f > 0$;	(0,0)	+	+	Unstable point
$AS_1 - AS_3 + AC_3 < 0$	(0,1)	-	+	ESS
	(1,1)	+	+	Unstable point
	(1,0)	-	+	ESS
Condition 3	Equilibrium points	$Tr(J_0)$	$Det(J_0)$	Stability
$AS_2 - AS_3 + AC_3 + f < 0$;	(0,0)	?	-	Saddle point
$AS_1 - AS_3 + AC_3 > 0$	(0,1)	?	-	Saddle point
	(1,1)	?	-	Saddle point
	(1,0)	?	-	Saddle point
Condition 4	Equilibrium points	$Tr(J_0)$	$Det(J_0)$	Stability
$AS_2 - AS_3 + AC_3 + f < 0$;	(0,0)	?	-	Saddle point
$AS_1 - AS_3 + AC_3 < 0$	(0,1)	-	+	ESS
	(1,1)	+	+	Unstable point
	(1,0)	?	-	Saddle point

We list another equilibrium point (x_*, y_*) , $*$ =0,1,2, in the three forms of central government, without penalty, static penalty, or dynamic penalty [30], and solve Eqs (7)–(9), given as follows:

$$\begin{cases} AS_2 - AS_3 + AC_3 + f - y_0 AS_2 + y_0 AS_1 - y_0 f = 0 \\ x_0 Y_2 - C_2 - x_0 Y_1 + C_1 = 0 \end{cases} \quad (7)$$

$$\begin{cases} AS_2 - AS_3 + AC_3 + f - y_1 AS_2 + y_1 AS_1 - y_1 f = 0 \\ x_1 Y_2 - C_2 - x_1 Y_1 + C_1 + F = 0 \end{cases} \quad (8)$$

$$\begin{cases} AS_2 - AS_3 + AC_3 + f - y_2 AS_2 + y_2 AS_1 - y_2 f = 0 \\ x_2 Y_2 - C_2 - x_2 Y_1 + C_1 + F - F y_2 = 0 \end{cases} \quad (9)$$

In cases of no, static, and dynamic central government penalty, solutions specified in Eqs (10)–(12), respectively, are obtained:

$$(x_0, y_0) = \left(\frac{C_2 - C_1}{Y_2 - Y_1}, \frac{AS_3 - AS_2 - AC_3 - f}{AS_1 - AS_2 - f} \right) \quad (10)$$

$$(x_1, y_1) = \left(\frac{C_2 - C_1 - F}{Y_2 - Y_1}, \frac{AS_3 - AS_2 - AC_3 - f}{AS_1 - AS_2 - f} \right) \quad (11)$$

$$(x_2, y_2) = \left(\frac{F(AS_3 - AC_3 - AS_1) + (C_2 - C_1)(AS_1 - AS_2 - f)}{(AS_1 - AS_2 - f)(Y_2 - Y_1)}, \frac{AS_3 - AS_2 - AC_3 - f}{AS_1 - AS_2 - f} \right) \quad (12)$$

Moreover, the conditions $0 \leq x_* \leq 1$ and $0 \leq y_* \leq 1$, $*$ =0,1,2, should be satisfied to ensure $(x, y) \in [0, 1] \times [0, 1]$.

5. Numerical simulation

In the practice of homesteads' withdrawal in Chongqing, if farmers voluntarily and actively withdrew from rural homesteads, the local governments compensated the farmers according to the size of the area, in accordance with the "Interim Measures for the Administration of Rural Land Exchange". If farmers did not withdraw from their homesteads, the idle homesteads were leased. Contemporary laws related to the lease or shareholding of homesteads are still vague to some extent; therefore, local governments are more reluctant towards using this method as it may influence the performance and may lead to noncompliance methods influencing farmers' choices. To more intuitively reflect the evolutionary game process and evolutionary stable equilibrium strategy between local governments and farmers under different penalty mechanisms, based on the WRH policy in Chongqing, MATLAB was used to simulate and analyse the stable strategy results of two stakeholders under different parameters.

The benefits obtained by the local governments during the implementation of WRH policy are given as $Y_i \in [50, 90]$, where $i = 1, 2$; the various costs incurred thereby such as publicity and land reclamation projects are given as $C_i \in [2, 6]$, where $i = 1, 2$. If the local government chooses "noncompliance" to implement WRH policies, there are costs such as psychological costs and central fines, represented as $F = 30$. Farmers' gain, if any, in the process of WRH policy is represented as $S_i \in [12, 19]$, $i = 1, 2$. If farmers choose to dispose unused homesteads only through leasing, there are costs as the relevant laws may not be perfect, in addition to costs such as leasing $f = 1$ and $C_3 = 1$. For the convenience of calculation, in this study, the area of farmers' homestead is considered to be 1 m², that is, $A = 1$.

5.1. Effect of F on the equilibrium strategy of both parties in system II

The strategy that will eventually evolve in system II is determined by the areas of the regions $OACD$ and $OABD$ (as shown in Figure 1), denoted by S_{OACD}^* and S_{OABD}^* , respectively, where $*$ = 0,1,2. $S_{OACD}^* > S_{OABD}^*$ indicates that the probability of the evolutionary stable strategy of system II being (1,0) is greater than the probability of the evolutionary strategy of system II being (0,1). Conversely, $S_{OACD}^* < S_{OABD}^*$ indicates that the probability of the evolutionary stable strategy of system II being (1,0) is less than the probability of the evolutionary stable strategy of system II being (0,1).

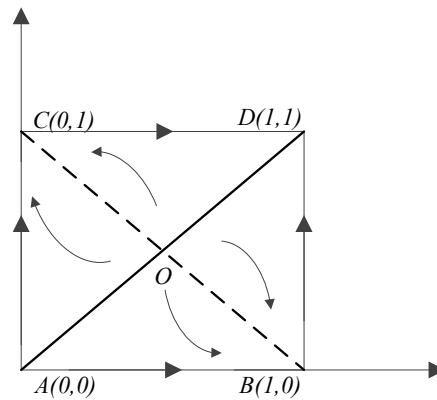


Figure 1. Replicated dynamic phase diagram of system II.

Taking the analysis S_{OACD}^* as an example, the probability of the system evolving a stable strategy (1,0) with different penalties can be calculated as follows:

$$S_{OACD}^0 = \frac{1}{2}(x_* + 1 - y_*) = \frac{C_2 - C_1}{(2Y_2 - 2Y_1)} - \frac{AC_3 - AS_3 + 1 + AS_2}{(2AS_2 - 2AS_1 + 2)} + \frac{1}{2};$$

$$S_{OACD}^1 = \frac{1}{2}(x_* + 1 - y_*) = \frac{C_2 - C_1 - F}{2(Y_2 - Y_1)} - \frac{AC_3 - AS_3 + 1 + AS_2}{(2AS_2 - 2AS_1 + 2)} + \frac{1}{2};$$

$$S_{OACD}^2 = \frac{1}{2}(x_* + 1 - y_*) = \frac{(C_2 - C_1)(AS_1 - AS_2 - 1) + F(AS_3 - AC_3 - AS_1)}{2(AS_1 - AS_2 - 1)(Y_2 - Y_1)} - \frac{AC_3 - AS_3 + 1 + AS_2}{(2AS_2 - 2AS_1 + 2)} + \frac{1}{2}$$

The aforementioned equations (S_{OACD}^0 , S_{OACD}^1 , S_{OACD}^2) show that various factors affect the evolutionary stable strategy. To simplify the analysis, we consider only the impact on the system evolution results, that is, assuming the penalty intensity. With other parameters set as follows, $A=1$, $S_1=12$, $S_2=15$, $S_3=16$, $C_3=2$, $f=1$, $Y_1=84$, $Y_2=64$, $C_1=4$, $C_2=3$, the results are presented in Figure 2.

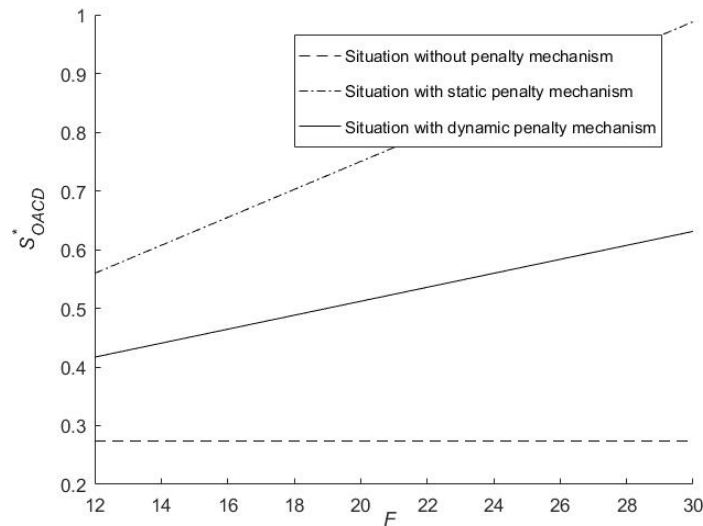


Figure 2. Influence of F on S_{OACD}^* .

Figure 2 shows that the same penalty intensity leads to different results of S_{OACD}^* , $*$ = 0,1,2 under different penalty mechanisms; the difference in penalty intensity under the same penalty mechanism (a static or a dynamic penalty mechanism) also leads to different results of S_{OACD}^* . If the central government uses a static or dynamic penalty mechanism, S_{OACD}^* increases with an increase in the penalty intensity; if the central government adopts a no penalty mechanism, S_{OACD}^* is fixed. That is, if there is a strict supervision by the central government, the system evolves more towards $(1,0)$, that is, if there is a strong external supervision, farmers think that the state can better protect their land rights and interests in the process of WRH policy; hence, they will actively cooperate with the local governments in withdrawing. Obviously, the central government is bound to consolidate the penalty mechanism for WRH and introduce specific supervision, compensation, and related guidelines, which can better promote farmers' motivation to voluntary withdraw from their homesteads.

Figure 2 also shows that S_{OACD}^* , $*$ = 0,1,2 under the static penalty mechanism of the central government is larger than S_{OACD}^* under the dynamic penalty mechanism, with all other parameters being equal. This implies that the system tends to evolve to be in the state of $(1,0)$, if there is a static

penalty mechanism of the central government, that is, farmers are more motivated to withdraw in this scenario and are better able to promote revitalisation of the stock of construction land.

5.2. Evolutionary trajectory diagram in system III

5.2.1. Evolutionary path of system III

Figures 3(a0) and 4(a1) show that the probability of farmers' withdrawal from their rural homesteads and the probability that the local governments choose to comply show a cyclical oscillation, and the system will not have a stable central point. In other words, local governments may still have illegal behaviors in this process, and static punishment or no punishment mechanism cannot restrain local governments' illegal strategies. In reality, such as the medical protective equipment market [31], internet financial platform [32], corporate environmental behavior in environmental regulation [33] and other situations also reveal that situation without penalty mechanism and situation with static mechanism still cannot truly constrain behavioral strategies.

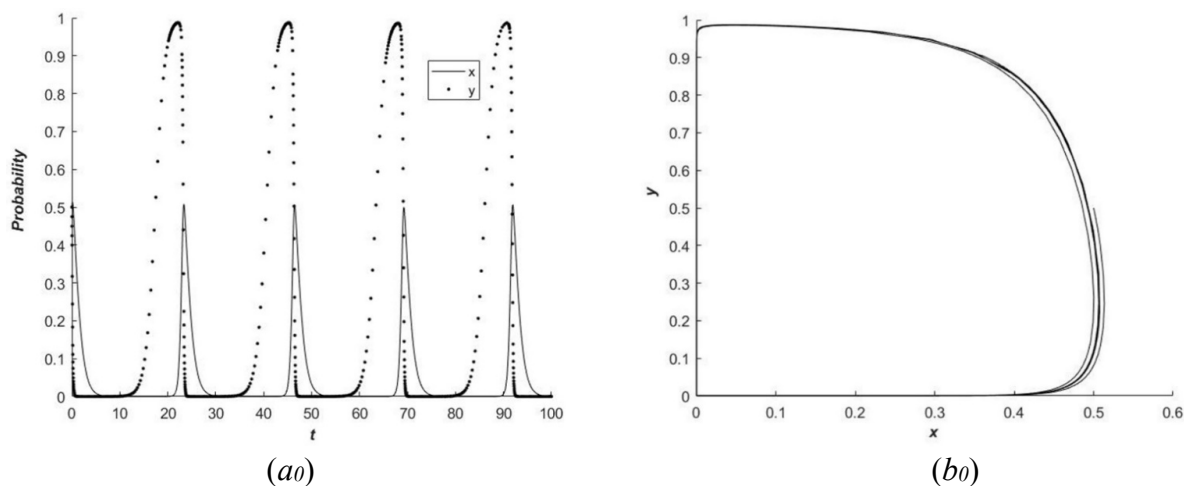


Figure 3. Dynamic evolution trajectories in system III without penalty mechanism.

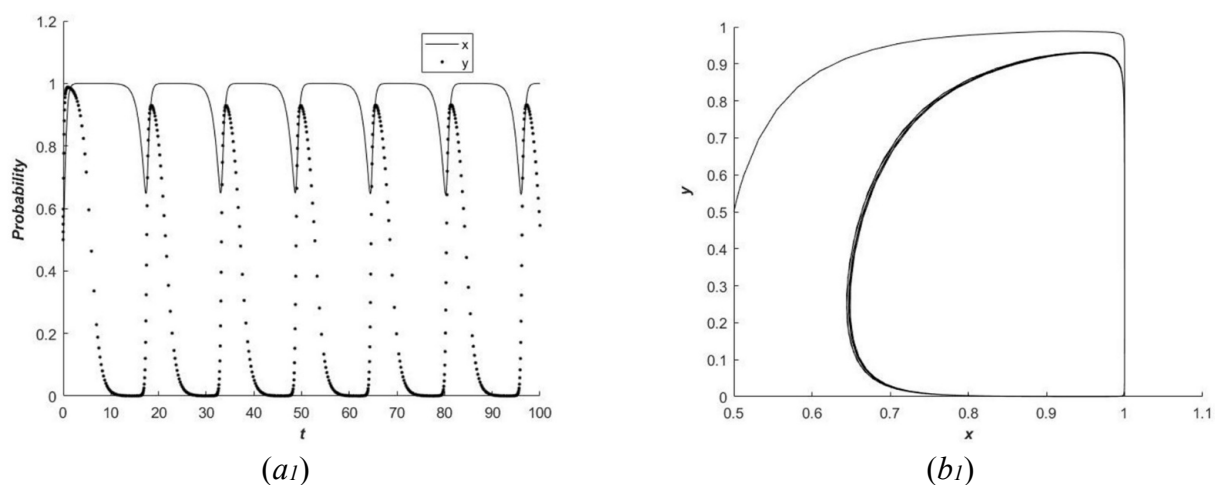


Figure 4. Dynamic evolution trajectories in system III with static penalty mechanism.

Figure 5(a₂) demonstrates that both the probabilities that farmers withdraw their homesteads and that local governments choose to comply converge gradually and stabilise after briefly oscillating. Clearly, the central government's dynamic penalty mechanism is better as it can effectively reduce the instability of the system. This finding is consistent with the conclusions drawn by Wang and Shi [34]. The results show that under the dynamic punishment mechanism (DPM), the evolution path between governments and enterprises tends to converge to a stable value. Thus, the DPM is more conducive than the SPM for industrial pollution control.

A comparison between Figure 3(b₀), Figure 4(b₁) and Figure 5(b₂) shows that if the central government adopts a static or no penalty mechanism, the evolutionary game process shows a closed orbital cycle without equilibrium point, that is, a cyclical behaviour pattern between local governments and farmers. However, if the central government adopts a dynamic penalty mechanism, the oscillations in the replicated dynamic system are lower and stabilise gradually. Thus, the central government's adoption of the dynamic penalty mechanism can better constrain the behaviours of both parties and lead to a stable state.

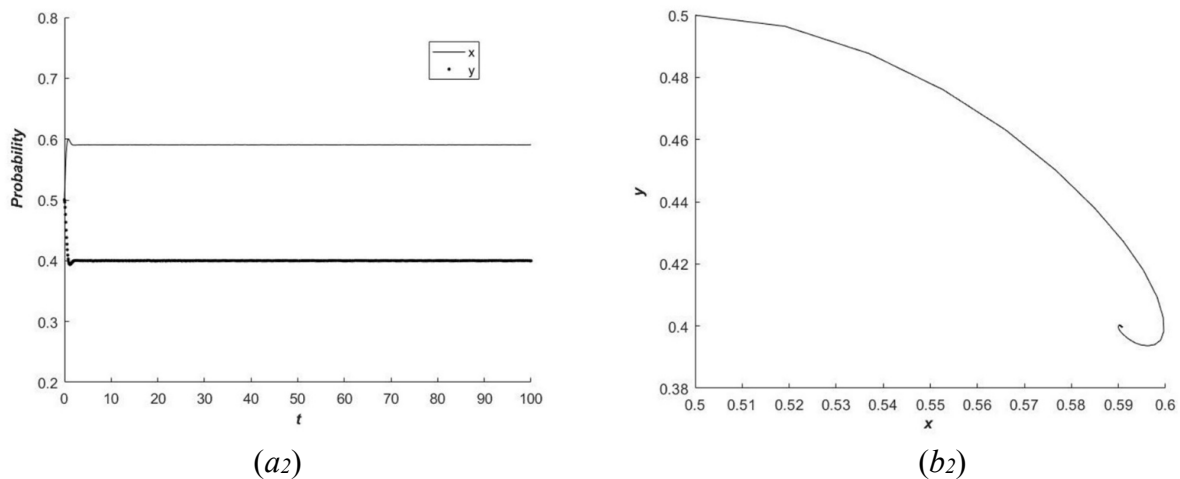


Figure 5. Dynamic evolution trajectories in system III with dynamic penalty mechanism.

5.2.2. Effect of F on the choice of strategy in system III

Figure 6 shows that the probability that farmers choose to withdraw and the probability that the local governments choose to comply stabilise gradually after a short-term shock as the central government's penalty, F , increases, with other parameters being constant. These figures also show that the probability of farmers' withdrawal, x , increases with an increase in penalty, while the probability of the local government choosing compliance, y , remains almost unchanged, with other parameters being constant. Thus, the increase in the central government's penalty increases the farmers' motivation to withdraw, realising revitalisation of the rural construction land stock. Moreover, considering that the probability of compliance remains unchanged, the central government can appropriately provide certain government subsidies or other similar benefits to promote the effectiveness and compliance of local government policy implementation.

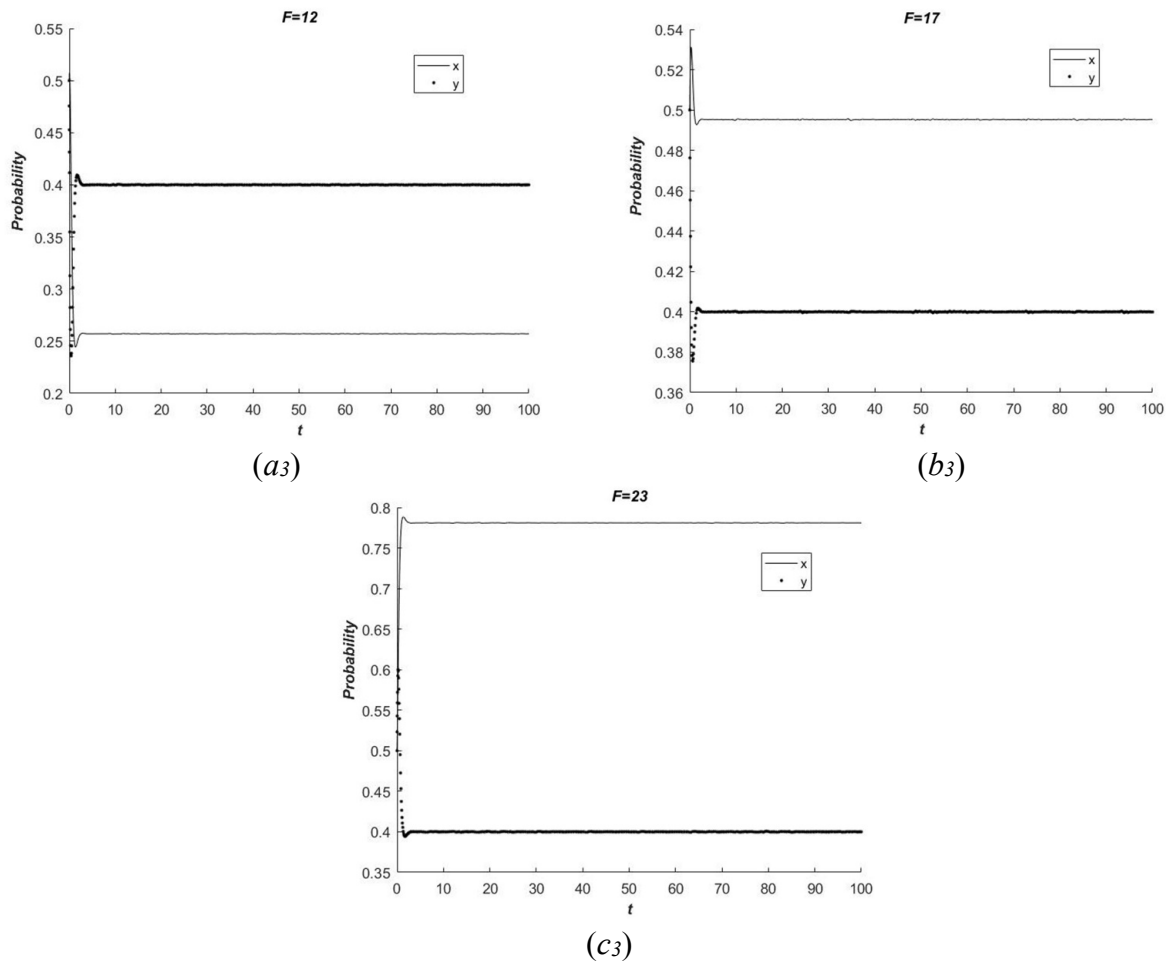


Figure 6. Effect of different penalty strengths on the probabilities of participants.

6. Conclusions and policy implications

6.1. Conclusions

Based on the evolutionary game analysis between the local government and farmers, this study simulated the evolutionary process of strategies of all participants in the process of WRH. By considering different penalty methods and scenarios, we analyse the game process between the two sides and present suggestions for coordinating the game relationship, providing insights for practical policy decision-making for WRH.

Both static and dynamic penalty mechanisms impact the binary equilibrium strategies of the participants; in this case, system II comprising farmers and local governments will evolve towards the state of (withdrawal, noncompliance) with increasing penalty. Overall, the establishment of the penalty mechanism promotes the stability of the participants' system, and higher penalty intensity implies higher motivation of farmers to withdraw.

Furthermore, under the no penalty or static penalty mechanism, the system comprising local governments and farmers is always in cyclical oscillations with no central point of stability. However, the penalty mechanism can alleviate the instability in the game process because the participants' choices and strategies vary. When a dynamic penalty mechanism is adopted, the

system gradually converges and stabilises after short-term shocks. The central government's penalty mechanism can effectively reduce the instability of the system, and the dynamic penalty approach is considered optimal.

When the model improves dynamically, the probability that farmers choose to withdraw increases with an increase in central government penalties; however, it does not affect the probability of local governments' compliance. Thus, the penalty mechanism does not reduce the probability that the local governments choose to be involved in illegal activities nor does it promote the effectiveness of policy implementation.

6.2. Policy implications

The central government should focus on the following aspects to better revitalise the rural construction land stock and promote efficient allocation of land resources.

First, the central government should adopt a dynamic penalty mechanism to stabilise strategic behaviours among local governments and farmers in the process of WRH. Second, it should increase penalty strength in the process of WRH to effectively constrain the behaviour norms of local governments and protect farmers' land rights. Third, the central government should consider measures to reduce the compliance cost of local governments, that is, the cost of policy propaganda and reclamation, and further reduce the local choice of noncompliance strategies.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

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