

Research Article

Study on the Multi-Governance of Public Rental Housing Exit in China Based on the Evolutionary Game Theory

Jing Tang ¹ and Shilong Li ^{1,2}

¹School of Management Science and Real Estate, Chongqing University, Chongqing 400044, China

²Center for Construction Economics and Management, Chongqing University, Chongqing 400044, China

Correspondence should be addressed to Shilong Li; lslcqu@126.com

Received 11 January 2022; Revised 17 February 2022; Accepted 20 April 2022; Published 23 May 2022

Academic Editor: Hassan Zargarzadeh

Copyright © 2022 Jing Tang and Shilong Li. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The COVID-19 pandemic has plunged the housing affordability and living sanitary conditions of China's low-income groups into a crisis. Public rental housing has made a significant contribution to alleviating this crisis, yet its exit problem has become more acute due to the impact of the epidemic. In order to explore how to effectively play the role of multi-governance in public rental housing exit, this paper adopts game theory to analyze the evolution of the behavioral strategies of government departments and public rental housing tenants in public rental housing exit by combining four influencing parameters: the epidemic severity, the epidemic influence coefficient, the public participation degree, and the public reporting fairness. In response to exploring the conditions for the effective functioning of the multi-governance model under the impact of the epidemic, the influences of parameter change on the stability of the system are analyzed. The results show that when the COVID-19 epidemic impact coefficient is high, government departments need to reduce their own supervision costs to achieve better multi-governance effects; when public reports are distorted, the government departments' own supervision capabilities determine the impact of public participation on governance effects.

1. Introduction

The sudden arrival of the COVID-19 epidemic has had an extremely negative impact on urban governance and public health in China. The most immediate impact has been reflected in the housing problem of low-income groups. On the one hand, the epidemic has directly led to a decline in the housing affordability of low-income groups [1]. Affected by the epidemic, urban housing costs [2] and unemployment rates have been continually on the rise. In 2020, China's new employment decreased by 4.7 million, and the loss rate of new employment reached 29.26% [3]. Due to the overlap with the Spring Festival, it is difficult for low-income groups to return to work, which makes the structural contradiction between the supply and demand of urban and rural labor more prominent, causing the unemployment of low-income groups to reach a new high [4]. The gradual increase in unemployment has brought a greater economic shock to

low-income groups, under which the budget for housing rents has exceeded their ability to pay. Housing affordability has become a major problem during the epidemic. On the other hand, the COVID-19 epidemic has threatened low-income groups' living sanitary conditions. During the epidemic, the majority of low-income groups were renting peasant-built houses in urban-rural areas. These dwellings have neither fixed property management services nor sufficient environmental health management. After the onset of the epidemic, low-income groups either fled the city and returned to their relatively safe rural home or lived in the city in fear, increasing the risk of public health. Poor housing affordability and living sanitary conditions caused by the epidemic have adversely affected the mental health of low-income groups [5]. Cheap and affordable housing with certain supporting facilities, public health services, and government supervision has received unprecedented attention and demand. The General Office of the State Council

also issued the “Opinions on Accelerating the Development of Affordable Rental Housing” in June 2021, emphasizing the expansion of the supply of affordable rental housing and the resolution to solve the prominent housing problems in big cities.

Public rental housing eases the housing and health pressure of China’s low-income groups during the COVID-19 epidemic [6]. On the one hand, the rent of public rental housing does not increase but falls, which greatly alleviates the economic pressure of low-income tenants. On the other hand, under the unified management of the government, public rental housing has basically guaranteed the tenants’ living sanitary conditions and public health management during the severe period of the epidemic. However, due to the imperfect review mechanism and exit mechanism, there is a phenomenon of “only enter but not exit” in public rental housing in many places of China. Especially under the negative impact of the COVID-19 epidemic, the problem of public rental housing exit has become more serious. Firstly, the epidemic has raised the cost of government supervision and enforcement so that the number of delay exit behaviors has increased. Furthermore, some tenants who should have quit public rental housing were affected by the epidemic, resulting in a decline in their housing affordability and choosing not to exit. As public rental housing has a social security function, if government departments fail to effectively address the problem of renegeing by some tenants, it is very likely that public rental housing will lose its fairness and fall into the “public housing” dilemma again.

When studying the issue of urban governance, most scholars emphasized the importance of subject participation to governance effects and proposed that the construction of a multiple collaborative co-governance mechanism should be accelerated to realize the transition from government “unified” supervision to social “diversified” governance. Wood et al. (1991) [7] elaborated on the theory of collaborative governance and proposed a governance model in which all stakeholders make joint decisions in the face of public affairs. The theory of collaborative governance has played an important role in the study of various governance issues. Guoxing Zhang proposed that a collaborative governance mechanism composed of government departments, enterprises, social organizations, and other subjects should be established to better protect the environment [8]. Junqing Li aimed to solve the problem of poverty in ethnic areas by building a multi-subject collaborative governance system in the field of poverty alleviation poverty issues [9]. Yulin Zhao pointed out that the multi-coordinated governance model should be led by the government, with the participation of relevant social entities, so as to achieve the effect of co-governance in Internet governance issues [10]. The multi-governance model is of great significance to flexible governance of COVID-19 epidemic [11]. Under the multi-governance model of collaborative governance, public participation is essential. It not only enables urban planners and policy makers to consider genuine public needs [12, 13], but also supports the sustainable development of urban communities [14]. By combining the organizational structure and mechanism of public rental housing exit from the

multi-governance model, it can be seen that the behavioral strategies of government departments and tenants influence each other, and there is a strong game relationship between them. At present, most scholars choose to adopt the evolutionary game method to explore effective measures to improve the governance effect when studying the regulatory issues of government departments. Different from the existing literature, we consider the roles of key stakeholders in the process of public rental housing exit, analyze the relationship between government and public rental housing tenants, explore the causes of the slow exit of tenants, and reveal the evolutionary mechanism of public rental housing exit. On the basis of theoretical analysis, the complexity scientific method is introduced and the evolutionary game model of public rental housing exit is established in order to study how to give full play to the best role of multi-governance in public rental housing exit governance. The innovation of this study mainly lies in two aspects: the first is to explore the effect of the COVID-19 epidemic and the public on public rental housing exit by considering two related parameters, the epidemic impact coefficient and the public reporting fairness; the second is to investigate the role of the government in the promotion of public rental housing exit through analyzing the dynamic decision-making process of both the government and tenants. Based on the research conclusions, this paper intends to provide reference for the government departments to give full play to the role of multi-governance in public rental housing exit. The framework of the study is shown in Figure 1.

2. Literature Review

2.1. Current Status of Public Rental Housing Exit Governance. The issue of public rental housing exit has existed for a long time in China’s urban governance. Scholars have done a lot of researches on related issues, which mainly focused on two aspects: tenant exit influencing factors and exit governance mechanisms.

The behavioral decisions of tenants to exit public rental housing are affected by many factors. A large body of literature showed that family income, education level, family size, and understanding of public rental housing policies are the main internal factors [15–17]. The probability of government departments’ effective review is the key external factor [18]. In addition, environmental health has gradually become an important factor influencing tenants’ decisions due to the COVID-19 epidemic [19]. However, few scholars have studied the impact of the epidemic on public rental housing exit.

Some scholars have conducted researches on typical models of public rental housing community governance in various countries, such as the American model [20], the Singapore HDB community management model, the Chongqing model [21], the Shanghai model [22] and the Ankang model [23], discussing the necessity for the establishment of dedicated agency, semiofficial people’s associations, and civil charity organizations to participate in public rental community governance. The polycentric and cooperative governance model is the common point of most

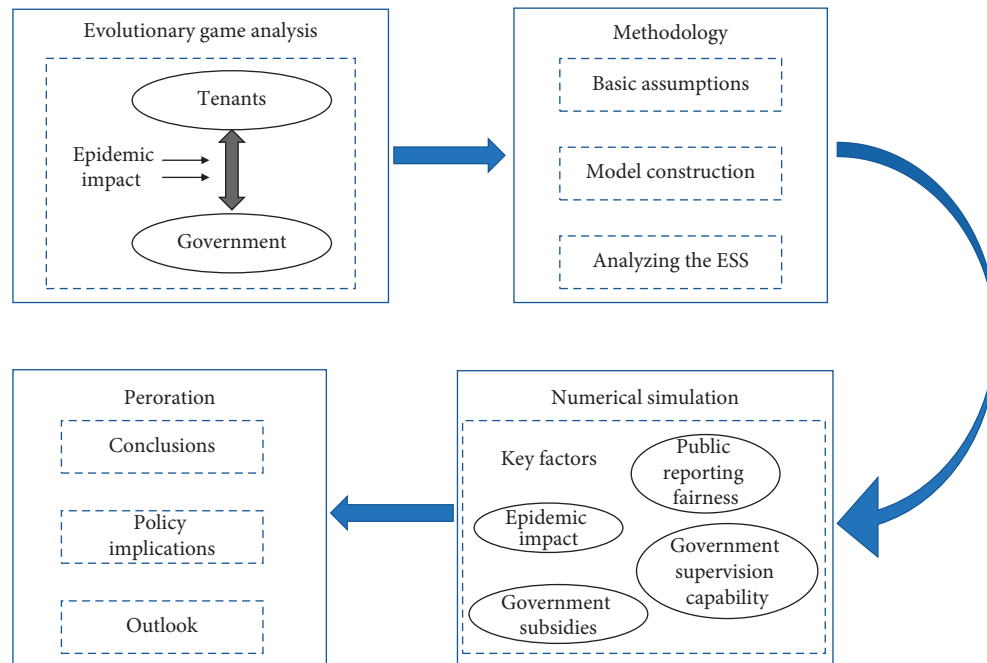


FIGURE 1: Framework of this research.

studies, arguing that the government should develop incentive mechanisms [24] and encourage residents to participate in the decision-making process of community management. It is generally accepted that the public participation in public rental housing exit is of great significance to exit governance. However, most studies focused on public participation in public rental housing construction [25] and ignored public's role in monitoring and reporting when tenants exit public rental housing.

2.2. Application of Evolutionary Game in Public Rental Housing Exit. Evolutionary game has considerable unrealized potential for modeling substantive economic issues. Smith (1986) [26] described the concepts of evolutionary game theory in the context of a simple game. Friedman (1998) [27] explicated the specification of evolutionary game models and classified the possible asymptotic behavior for one- and two-dimensional models. Evolutionary game theory is the application of population dynamical methods to game theory [28], which has strong modeling capabilities for explaining past evolution and predicting the future one [29]. As an analytical tool, evolutionary game theory has been applied to various fields of research studies to explain social phenomena [30–33], including construction and demolition waste supply chain [34], environmental governance [35, 36], and public health emergency management [37, 38]. In recent years, the application of the evolutionary game theory in the field of public rental housing exit has been increasing. For example, Baolong (2016) [39] pointed out the two key factors in exit mechanism of public rental housing by constructing game model of the public rental housing authorities and public rental housing tenants. Hui et al. (2017) [40] constructed an evolutionary game model between government departments and tenants based on

evolutionary game theory, determined the best time and proportion for government departments to sue delay exit tenants. Liu (2020) [41] provided effective suggestions for the establishment of the flexible exit mechanism of public rental housing in Urumqi through using logistic model to analyze the game evolution of the lessee's rent-seeking behavior.

As can be seen from the abovementioned literature review, the evolutionary game model has been applied to the study of public rental housing exit, but the related research mainly focused on the government supervision and paid less attention to the epidemic impact and public participation. Prior studies mainly considered the relationship between government and tenants. However, few scholars analyzed public rental housing exit from the perspective of multi-stakeholder relationship. It is difficult to see the full application of evolutionary game in public rental housing exit.

3. Model Construction and Analysis

3.1. Parameter Assumptions and Modeling. This paper models the issue of multi-governance for public rental housing exit under the impact of the COVID-19 epidemic, which involves two participants: government departments and the tenants who should have quit public rental housing but did not. During the epidemic period, the government's strategic actions include "positive supervision" and "negative supervision." The strategic behaviors of the tenants include "active exit" and "delay exit."

In order to clarify the relationship between the two participants in the game, this paper makes the following rational assumptions on the premise of fully integrating the public rental housing reality

- (1) In the process of multi-governance during the epidemic, the probability of government agencies adopting positive supervision is x ($0 < x \leq 1$). At this time, the government will spend a fixed supervision cost C_0 and incur additional supervision costs $P\omega/K$ caused by the epidemic; i.e., $C = C_0 + P\omega/K$. Simultaneously, the government can obtain benefits s , which means the improvement of the total social welfare and government credibility.
- (2) The probability that the government adopts negative supervision is $1 - x$. At this point, although the government does not have to pay supervision cost, it will suffer a loss qn if the tenants' irregularities are exposed, indicating the loss of credibility, suffered as a result of government inaction.
- (3) In the process of multi-governance, the probability of the tenants taking active exit strategy is y ($0 < y \leq 1$). At this point, the government will give a certain housing subsidy to alleviate the financial pressure of the tenants, while the active exit of the tenants will raise the total social welfare.
- (4) The tenants' delayed exit probability is $1 - y$. At this time, it will save a certain amount of housing cost but reduce the total social welfare. Moreover, when

government departments investigate and deal with delay exit tenants, they will be fined.

- (5) When the public perceives that the tenants have violated the regulations, they can report this to the government departments, at which point the probability that the tenants will be investigated and punished by the government is $\mu = \lambda + (1 - \lambda)q$. Nevertheless, considering that the information reported by the public may not be completely accurate, government departments will suffer losses $(1 - \alpha)qn$ and tenants will suffer losses $(1 - \alpha)q\phi$ when the public incorrectly reports tenants for violations.
- (6) The parameters of the game model: Under each game strategy combination, according to the cost, income, and loss of the government and tenants, the parameter settings are shown in Table 1.

3.2. Model Analysis. According to the model assumptions and the game parameters shown in Table 1, the benefits and payments of the two-party game subjects, the government and the tenant, are shown in Table 2.

Through the above game payment matrix, it can be concluded that the expected benefits of government departments under different behavior strategies are as follows:

$$\begin{aligned} F_x &= y(s - c - (1 - \alpha)qn + m - R_1) + (1 - y)(s - c - v) = s - c - v + y(1 - \alpha)qn + m - R_1 + v, \\ F_{1-x} &= y(-c - (1 - \alpha)qn + m - R_1) + (1 - y)(-v - qn) = -v - qn + y(qn\alpha + m - R_1 + v). \end{aligned} \quad (1)$$

The average expected revenue of the government is as follows:

$$\bar{F} = xF_x + (1 - x)F_{1-x}. \quad (2)$$

In the same way, the expected benefits of tenants under different behavior strategies are as follows:

$$\begin{aligned} G_y &= x(R_1 - (1 - \alpha)q\phi) + (1 - x)(R_1 - (1 - \alpha)q\phi) = R_1 - (1 - \alpha)q\phi, \\ G_{1-y} &= x(R_2 - \mu F) + (1 - x)(R_2 - qF) = R_2 - qF + x(R_1 - R_2 + qF - \mu F). \end{aligned} \quad (3)$$

The average expected revenue of the tenants is:

$$\bar{G} = yG_y + (1 - y)G_{1-y}. \quad (4)$$

It can be obtained that the dynamic equations of replication between government departments and tenants are as follows:

$$\begin{aligned} F(x, y) &= \frac{dx}{dt} = x(F_x - \bar{F}) = x(1 - x)(F_x - F_{1-x}) = x(1 - x)(s - c + qn - yqn), \\ G(x, y) &= \frac{dy}{dt} = y(G_y - \bar{G}) = y(1 - y)(G_y - G_{1-y}) = y(1 - y)(R_1 - R_2 - q\phi + q\alpha\phi + qF - xqF + \mu xF). \end{aligned} \quad (5)$$

Let $dx/dt = 0$ and $dy/dt = 0$; the five local equilibrium points of the evolutionary game system can be obtained as $(0, 0)$, $(0, 1)$, $(1, 0)$, $(1, 1)$, (x^*, y^*) .

TABLE 1: Related parameters and definition.

Parameter	Definition
x	Probability of positive supervision adopted by government, $0 \leq x \leq 1$
y	Probability of tenants actively exiting under the epidemic, $0 \leq y \leq 1$
p	Severity degree of the epidemic, $0 \leq p \leq 1$
ω	The impact coefficient of the epidemic, $0 \leq \omega \leq 1$
k	The government's ability to deal with the epidemic
q	Public participation degree, $0 \leq q \leq 1$
α	Fairness degree of public reporting, $0 \leq \alpha \leq 1$
ϕ	Loss to tenants due to public reporting distortion
n	The government losses caused by the public exposure to the illegal behavior of tenants
s	Government positive supervision benefits
C_0	Government supervision fixed costs
C	The total cost of government supervision
R_1	Subsidy for tenants exiting actively
R_2	Saved rent for tenants adopting delay exit
F	Penalties for tenants delaying exit when being investigated
m	Increased social benefits brought about by tenants' active exit
v	Declined social benefits caused by tenants' delay exit
μ	The probability that the government investigates the illegal behavior
λ	The government's own supervision capabilities

TABLE 2: Game payment matrix of government and tenants.

	Tenant strategy: y	Tenant strategy: $1-y$
Government strategy: x	$s - c - (1 - \alpha)qn + m - R_1, R_1 - (1 - \alpha)q\phi$	$s - c - v, R_2 - \mu F$
Government strategy: $1-x$	$-c - (1 - \alpha)qn + m - R_1, R_1 - (1 - \alpha)q\phi$	$-v - qn, R_2 - qF$

$$x^* = \frac{R_1 - R_2 - q\phi + q\alpha\phi + qF}{qF - \mu F},$$

$$y^* = \frac{s - c + qn}{qn}.$$
(6)

3.3. *Equilibrium and Stability Analysis.* In this paper, the local stability of the equilibrium point of the evolutionary game system is judged by the Jacobian matrix composed of the partial derivatives of the dynamic equations.

$$J = \begin{bmatrix} \frac{\partial F(x, y)}{\partial x} & \frac{\partial F(x, y)}{\partial y} \\ \frac{\partial G(x, y)}{\partial x} & \frac{\partial G(x, y)}{\partial y} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix},$$

$$a_{11} = \frac{\partial F(x, y)}{\partial x} = (1 - 2x)(s - c + qn - yqn),$$

$$a_{12} = \frac{\partial F(x, y)}{\partial y} = -x(1 - x)qn,$$

$$a_{21} = \frac{\partial G(x, y)}{\partial x} = y(1 - y)(\mu - q)F,$$

$$a_{22} = \frac{\partial G(x, y)}{\partial y} = (1 - 2y)(R_1 - R_2 - q\phi + q\alpha\phi + qF - xqF + \mu xF).$$
(7)

Through calculation, the value of the game system at the five local equilibrium points can be obtained, as shown in Table 3.

TABLE 3: Local equilibrium point value table.

Equilibrium point	\mathbf{a}_{11}	\mathbf{a}_{12}	\mathbf{a}_{21}	\mathbf{a}_{22}
(0, 0)	$s - c + qn$	0	0	$R_1 - R_2 - q\varphi + q\alpha\varphi + qF$
(0, 1)	$s - c$	0	0	$-(R_1 - R_2 - q\varphi + q\alpha\varphi + qF)$
(1, 0)	$-(s - c + qn)$	0	0	$R_1 - R_2 - q\varphi + q\alpha\varphi + \mu F$
(1, 1)	$c - s$	0	0	$-(R_1 - R_2 - q\varphi + q\alpha\varphi + \mu F)$
$(\mathbf{x}^*, \mathbf{y}^*)$	0	M	N	0

The meaning of the italic values in Table 3 are the values of \mathbf{a}_{11} and \mathbf{a}_{22} in different equilibrium points.

$$M = \frac{(R_1 - R_2 - q\varphi + q\alpha\varphi + qF)(R_1 - R_2 - q\varphi + q\alpha\varphi - \mu F)(s - c + qn)}{q(qF - \mu F)^2},$$

$$N = \frac{F(c - s)(s - c + qn)(\mu - q)}{(qn)^2}.$$
(8)

If the Jacobian matrix determinant value ($a_{11}a_{22} - a_{12}a_{21}$) is greater than zero and the determinant trace value ($a_{11} + a_{22}$) is less than zero, then the evolutionary game system has an evolutionary stability strategy (ESS). Since it is necessary to comprehensively consider the influence of the four parameters p , ω , q , and α on the stable evolution state of the system and it is difficult to determine the threshold space corresponding to each parameter, without affecting the purpose of this study, we select two reference values $s - c_0$ and R_2 as the judgment intermediary for analyzing the impact of parameter value range change on system stability, which can be divided into the following five situations:

- (1) When $\begin{cases} s - c_0 < (P\omega/K) + qn \\ R_2 > R_1 - q\varphi + q\alpha\varphi + qF \end{cases}$, the ESS is (0, 0). This means that after continuous selection and evolution, the system finally forms a stable state in which both the government's supervision probability and the tenant's exit probability tend to 0, which indicates that low subsidy and penalties are unfavorable for tenants to exit public rental housing.
- (2) When $\begin{cases} s - c_0 < (P\omega/K) \\ R_2 < R_1 - q\varphi + q\alpha\varphi + qF \end{cases}$, the ESS is (0, 1). It can be seen that after continuous selection and evolution, the system finally forms a stable state in which the government's supervision probability tends to 0 and the tenant's exit probability tends to 1, which indicates that high epidemic impact is unfavorable for the government to supervise.
- (3) When $\begin{cases} s - c_0 > (P\omega/K) + qn \\ R_2 > R_1 - q\varphi + q\alpha\varphi + (\lambda + (1 - \lambda)q)F \end{cases}$, the ESS is (1, 0). We can see that after continuous selection and evolution, the system finally forms a stable state in which the government's supervision probability tends to 1 and the tenant's exit probability tends to 0, which indicates that low epidemic impact and public participation are favorable for government to supervise.
- (4) When $\begin{cases} s - c_0 > (P\omega/K) \\ R_2 < R_1 - q\varphi + q\alpha\varphi + (\lambda + (1 - \lambda)q)F \end{cases}$, the ESS is (1, 1). This means that after continuous selection and evolution, the system finally forms a

stable state in which both the government's supervision probability and the tenant's exit probability tend to 1, which indicates that low epidemic impact and high penalties are favorable for tenants to exit public rental housing.

- (5) When $\begin{cases} (P\omega/K) < s - c_0 < (P\omega/K) + qn \\ R_1 - q\varphi + q\alpha\varphi + (\lambda + (1 - \lambda)q)F < R_2 < R_1 - q\varphi + q\alpha\varphi + (\lambda + (1 - \lambda)q)F \end{cases}$, there is no ESS.

3.4. Model Construction and Analysis. According to the above stability analysis, it is observed that the evolution of the stable state of the system depends on the relative magnitude relationship between the influence parameters and the reference values, where $s - c_0$ represents the difference between the benefits gained and the fixed cost required when the government adopts an positive supervision behavior strategy, i.e., the maximum benefits gained without considering the epidemic and public participation in the governance process; R_2 represents the additional benefits that the tenants can obtain if they adopt the delayed exit strategy, i.e., the opportunity benefits that can be obtained without considering the epidemic and public participation. From this, it can be seen that these two values are stable in the actual environment of public rental housing exit governance, independently of the epidemic and public participation. Therefore, the variation of the system stability equilibrium point within the range of different parameter values can be derived from a comprehensive analysis of the epidemic severity p , the epidemic impact coefficient ω , the public participation degree q , and the public reporting fairness a .

3.5. Special Case Analysis

Case 1: $\omega = 1$, $\alpha = 1$.

The epidemic impact coefficient $\omega = 1$ indicates that the epidemic has a great restriction on the supervision ability of the local government, causing a higher cost when the government adopts positive supervision strategy. The public reporting fairness $\alpha = 1$ indicates that the public has high

information recognition ability; that is, they can better identify whether the tenants delay exit so as to avoid additional losses to the government and tenants.

According to the calculation results of the model, in order to make the evolution state of the system toward (1, 1) stable, the relevant influencing parameters need to meet the following conditions:

$$s - c_0 > (p/K) \text{ and } R_2 < R_1 + (\lambda + (1 - \lambda)q)F; \text{ i.e., } p < k(s - c_0) \text{ and } q > (R_2 - R_1 - \lambda F / (1 - \lambda))F. \quad (9)$$

This shows that when the negative effect of the epidemic is great and the public reporting information is totally accurate, lowering epidemic severity and increasing public participation level can improve the effectiveness of the multi-governance model for public rental housing exit.

The epidemic impact coefficient $\omega = 0$ means that the epidemic will not affect the government's supervision costs. At this time, in order to make the evolution state of the system toward (1, 1) stable, the relevant influencing parameters need to meet the following conditions:

Case 2: $\omega = 0, \alpha = 1$.

$$s - c_0 > 0 \text{ and } R_2 < R_1 + (\lambda + (1 - \lambda)q)F; \text{ i.e., } 0 < s - c_0 \text{ and } q > R_2 - R_1 - \lambda F / (1 - \lambda)F. \quad (10)$$

This shows that when the negative effect of the epidemic is minimal, the severity of the epidemic has no impact on the effect of government governance. By comparing the parameter value range of Case 2 with that of Case 1, it can be found that the parameter value range of Case 2 is easier to meet in the context of the system evolution toward point (1, 1); i.e., in order to achieve better governance effect of multi-governance model for public rental housing exit, the parameter setting of Case 2 has more advantages. It shows that the government needs to reduce their own supervision cost to achieve better multi-governance effect when the epidemic has a great impact.

$\lambda F / F - \lambda F - \varphi$). At this time, $\lambda < (F - \varphi / F)$ means that the government's supervision ability is low and the parameter conditions for the system to evolve toward the point (1, 1) need to satisfy $q > (R_2 - R_1 - \lambda F / F - \lambda F - \varphi)$; i.e., in order to achieve better governance effect, it is essential to increase public participation enthusiasm.

Case 3: $\omega = 1, \alpha = 0$.

The public reporting fairness $\alpha = 0$ means that public's reporting information is distorted; i.e., the public will consider the active exit strategy adopted by the tenants as delayed exit strategy and report that to the government departments, which brings additional losses to government departments and tenants.

- (2) When $\lambda > (F - \varphi / F)$, the above conditions are converted to $p < k(s - c_0)$ and $q < (R_2 - R_1 - \lambda F / F - \lambda F - \varphi)$. At this time, $\lambda > (F - \varphi / F)$ means that the government's supervision ability is high and the parameter conditions for the system to evolve toward the point (1, 1) need to satisfy $q < (R_2 - R_1 - \lambda F / F - \lambda F - \varphi)$; i.e., in order to achieve better governance effect, it is essential to reduce public participation enthusiasm.

In order to make the evolution state of the system toward (1, 1) stable, the relevant influencing parameters need to meet the following conditions:

Through the above analysis, it is found that the difference in the government's own supervision capacity will affect the role of public participation in the governance process. In the case where public reporting is not completely impartial, government departments relying solely on public reporting information can hardly achieve the optimal effect of multi-governance, which indicates that the government's own supervision capacity plays a key role in strategy formulation and governance effectiveness.

$$\begin{aligned} s - c_0 &> (P/K), \\ R_2 &< R_1 - q\varphi + (\lambda + (1 - \lambda)q)F, \\ p &< k(s - c_0), \\ q(F - \lambda F - \varphi) &> R_2 - R_1 - \lambda F. \end{aligned} \quad (11)$$

In this case, the influence of public participation on the governance effect of government is not stable. Therefore, the discussion is divided into two different situations according to the government departments' own supervision ability.

By comparing the parameter value range of Case 3 with that of Case 1, it can be found that since $R_1 - q\varphi + (\lambda + (1 - \lambda)q)F < R_1 + (\lambda + (1 - \lambda)q)F$, in practice, in order to make the system evolve toward point (1, 1), the parameter value range of Case 1 is easier to meet, showing the key role of the public reporting fairness in the governance process.

Case 4: $\omega = 0, \alpha = 0$.

- (1) When $\lambda < (F - \varphi / F)$, the above conditions are converted to $p < k(s - c_0)$ and $q > (R_2 - R_1 -$

in order to make the evolution state of the system toward (1, 1) stable, the relevant influencing parameters need to meet the following conditions:

$$s - c_0 > 0 \text{ and } R_2 < R_1 - q\varphi + (\lambda + (1 - \lambda)q)F; \text{ i.e., } 0 < s - c_0 \text{ and } q(F - \lambda F - \varphi) > R_2 - R_1 - \lambda F. \quad (12)$$

In this case, the influence of public participation enthusiasm on the governance effect of government departments is also unstable, and it is affected by the government's own supervision ability as well. At this time, the influence of the government's own supervision ability on the enthusiasm of public participation is similar to that of Case 3.

By comparing and analyzing the parameter values of the system evolution toward the point (1, 1) under the four cases, we can clearly see that the government departments' multi-governance of public rental housing exit is influenced by many factors, among which the epidemic influence coefficient, the public reporting fairness, and the government's own supervision ability play a key role.

3.6. General Situation Analysis. In order to more clearly understand the impact of both the epidemic and the public related parameters on the effectiveness of governance, this paper analyzes the general condition for the evolution of the system toward the (1, 1) point, i.e., analyzes the situation when each parameter of the system satisfies the following condition:

$$\begin{cases} s - c_0 > \frac{P\omega}{K} \\ R_2 < R_1 - q\varphi + q\alpha\varphi + (\lambda + (1 - \lambda)q)F \end{cases}. \quad (13)$$

On the premise of not affecting the conclusion of the analysis, the following part will also take $s - c_0$ and R_2 as reference values to analyze how to set parameters to make the limitation more easily satisfied, i.e., by solving the system of (13) to discuss the effect of parameter changes on the function values, which leads to more general conclusions.

$$\begin{cases} \min F(p, \omega) > \frac{P\omega}{K} \\ \max M(q, \alpha) < R_1 - q\varphi + q\alpha\varphi + (\lambda + (1 - \lambda)q)F \end{cases}. \quad (14)$$

3.6.1. Analysis of Epidemic-Related Parameters. Analysis of the epidemic severity p .

Let the function $F(p, \omega)$ be derived with respect to the epidemic severity p .

$$\frac{\partial F(p, \omega)}{\partial p} = \frac{\omega}{K} > 0. \quad (15)$$

According to (15), it can be seen that the function $F(p, \omega)$ is an increasing function of the epidemic severity p ; i.e., alleviating the epidemic severity p reduces the value of the function $F(p, \omega)$. Therefore, to better satisfy the range of parameters for the evolution of the system toward the (1, 1) point, the epidemic spread needs to be suppressed.

Analysis of the epidemic impact coefficient ω .

Let the function $F(p, \omega)$ be derived with respect to the epidemic impact coefficient p .

$$\frac{\partial F(p, \omega)}{\partial p} = \frac{p}{K} > 0. \quad (16)$$

According to (16), it can be seen that the function $F(p, \omega)$ is an increasing function of the epidemic impact ω ; i.e., reducing the epidemic impact factor ω reduces the value of the function $F(p, \omega)$. Therefore, to better satisfy the range of parameters for the evolution of the system toward the (1, 1) point, it is necessary to reduce the impact of the epidemic on government surveillance capacity.

3.6.2. Analysis of Public-Related Parameter. Analysis of the public participation degree q .

Let the function $M(q, \alpha)$ derive from the level of public participation degree q .

$$\frac{\partial M(q, \alpha)}{\partial q} = -\varphi + \alpha\varphi + F - \lambda F. \quad (17)$$

According to (17), it can be seen that the plus or minus characteristic of the equation is unknown, and it is related to the government department's own supervision capacity. Therefore, this paper discusses two different cases according to the government department's own supervision capacity.

When $\lambda < (F - \varphi + \alpha\varphi/F)$, then $\partial M(q, \alpha)/\partial q > 0$. The function $M(q, \alpha)$ is positively correlated with the public participation degree q ; increasing the public participation degree q can make the function $M(q, \alpha)$ increase. Therefore, in order to better meet the range of parameters for the evolution of the system toward the point (1, 1), the public participation level needs to be increased.

When $\lambda > (F - \varphi + \alpha\varphi/F)$, then $\partial M(q, \alpha)/\partial q < 0$. The function $M(q, \alpha)$ is negatively correlated with the public participation degree q ; decreasing the public participation degree q can make the function $M(q, \alpha)$ increase. Therefore, in order to better meet the range of parameters for the evolution of the system toward the point (1, 1), the public participation level needs to be reduced.

Analysis of the fairness of public reporting α .

Let the function $M(q, \alpha)$ derive from the public reporting fairness α .

$$\frac{\partial M(q, \varphi)}{\partial \alpha} = q\varphi > 0 \quad (18)$$

According to (18), it can be seen that the function $M(q, \alpha)$ is an increasing function of the public reporting fairness α . Increasing the public reporting fairness α can make the function $M(q, \alpha)$ increase. Therefore, in order to better satisfy the range of parameters for the evolution of the system toward the (1, 1) point, the public reporting fairness needs to be increased.

4. Numerical Simulation

By solving and analyzing the model, we can see that the severity and impact coefficients of the epidemic, the level of public participation, and the degree of public report fairness

play a complex role in the stable evolutionary equilibrium of the game system. In order to explore the continuous trend of parameters on the evolution of the system toward the (1, 1) point, this section conducts numerical simulations of the outcome conditions of the parameters in the general case of the system and analyzes the impact trends of the parameters on the system by the simulation images.

4.1. Analysis of Strategic Options for Government Action. To investigate the effect of the epidemic severity p and the epidemic impact coefficient ω on the government strategy selection function $F(p, \omega)$, let $k=5$, while $p \in (0, 1)$ and $\omega \in (0, 1)$ are substituted into MATLAB software for numerical simulation; the resulting images are shown in Figure 2.

As can be seen from Figure 1, the function $F(p, \omega)$ that influences the choice of government strategy is an increasing function of the epidemic severity p and the impact coefficient ω . The result of simulation coincides with the conclusion that the COVID-19 epidemic expansion will increase homelessness and government costs [42]. Homelessness and the many vulnerabilities that inevitably accompany it are driving COVID-19 outbreaks in shelters and other congregate living situations. Public rental housing is an investment that will curb the spread of COVID-19 and help protect most of low-income groups from future pandemics. Therefore, in order for the system to evolve toward the (1, 1) point, the values of the epidemic severity p and the impact coefficient ω need to be reduced; i.e., in order to optimize the effect of multi-governance by government departments on public rental housing exit during the epidemic, government departments should strengthen their own supervision capacity to weaken the impact of the epidemic.

4.2. Analysis of the Behavioral Strategy Choices of Tenants. In order to investigate the effect of the public participation degree q and the reporting fairness α on the strategy selection function $M(q, \alpha)$, let $R_1 = 1$, $\varphi = 0.5$, $\lambda = 0.9$, and $F = 2$, while $q \in (0, 1)$ and $\alpha \in (0, 1)$ are substituted into MATLAB software for numerical simulation; the resulting images are shown in Figure 3.

From Figure 3, it can be seen that there are two cases that affect the tenant strategy selection function $M(q, \alpha)$. When the public reporting fairness α is low, the function $M(q, \alpha)$ is negatively correlated with the public participation degree q and the reporting fairness α ; when the public reporting fairness α is high, the function $M(q, \alpha)$ is positively correlated with the public participation degree q and the reporting fairness α . The result shows that the effect of multi-governance is not directly related to the amount of public participation. In fact, since public reporting is more based on interests than authenticity, the lack of authenticity of public reporting often becomes a major obstacle to cooperative governance [43]. Therefore, government departments should focus on the fairness of public reporting in public

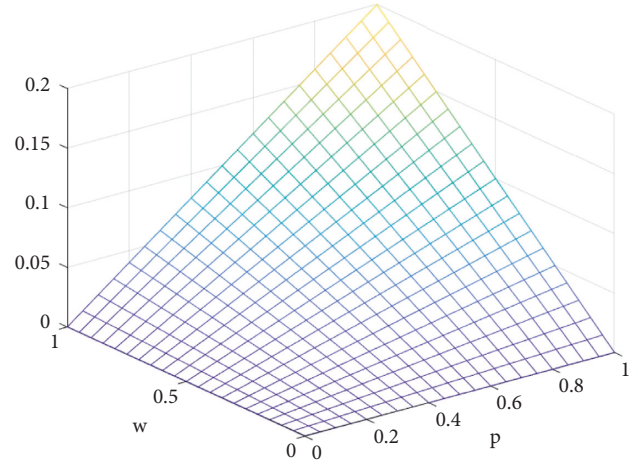


FIGURE 2: Government strategy selection simulation image.

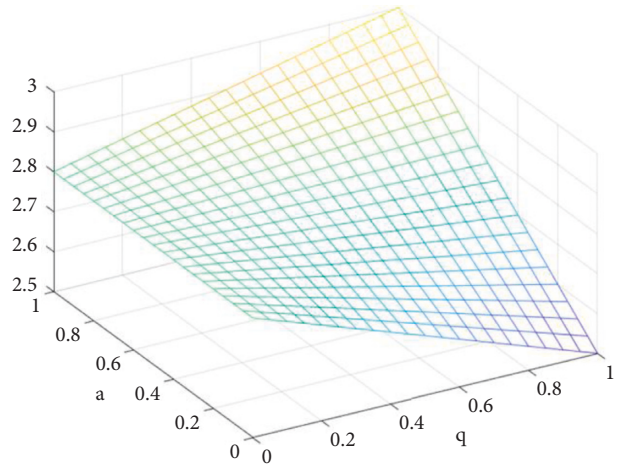


FIGURE 3: Tenant behavior selection system simulation images.

rental housing exit governance during the epidemic to achieve a better effect of multi-governance.

4.3. The Influence of Subsidy on Strategy Choices of Tenants. To derive the impact of the subsidy R_1 on evolutionary results, we fix other parameters and conduct experiments when $R_1 = 2, 3$, respectively. The dynamic evolutionary processes of the tenants in different situation are demonstrated in Figure 4.

From Figure 4, it can be seen that the subsidy can effectively promote the tenants to select the “active exit” strategy. Considering the maximization of the payoff, the willingness of tenants to choose active exit strategy would increase with the increase in the subsidy. However, the high subsidy brings a heavy burden on the local government, so the willingness of the government to adopt strict governance would decline with the increase in the subsidy [44]. Thus, appropriate subsidy is a key factor that the government should consider in the multi-governance of public rental housing exit during the epidemic.

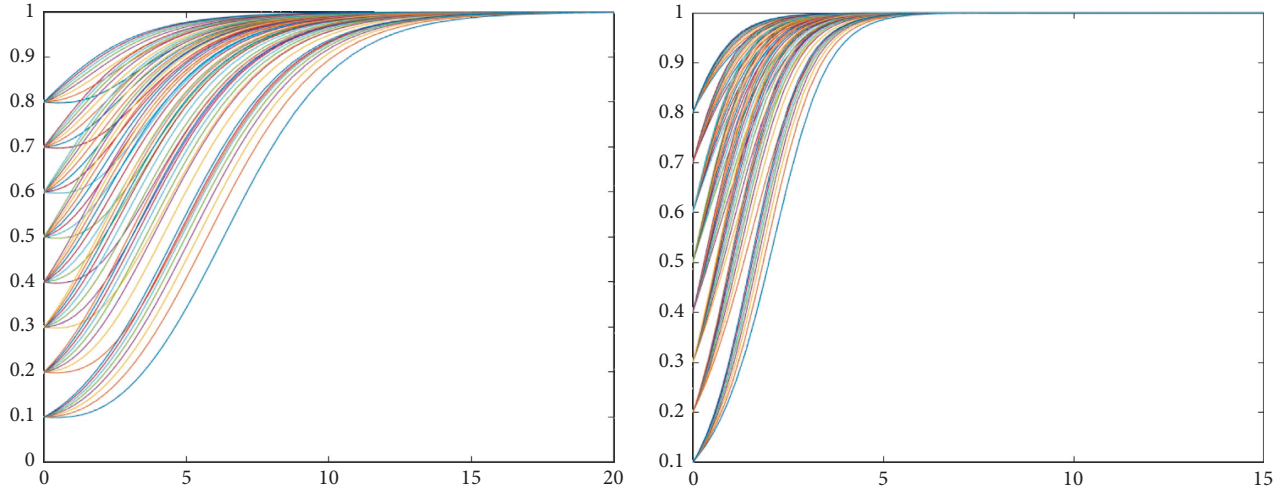


FIGURE 4: Tenant behavior selection system simulation images (left $R_1 = 2$, right $R_1 = 3$).

5. Conclusions

The government departments' implementation of multi-governance for public rental housing exit requires considering the participation of multiple factors, such as epidemic and public, in the governance process and exploring the conditions under which each acts effectively. This paper adopts game theory to construct an evolutionary game model of the multi-governance for public rental housing exit, analyzes the influence of the epidemic and public parameters on the stable evolutionary state of the game system, and explores the conditions for the effective performance of the multi-governance model. The results show the following:

- (1) The epidemic impact coefficient, the public reporting fairness, and the government supervision capacity are the critical factors affecting the multi-governance of public rental housing exit.
- (2) Reducing the impact of the epidemic, improving the public reporting fairness, and increasing the housing subsidy are the principal factors affecting tenants' adoption of active exit strategy.
- (3) The impact of the public participation degree on the effectiveness of governance is related to the level of the government departments' own supervision capacity, which decreases with the increase of supervision capacity and increases with the decrease of supervision capacity.

This study contributes to the present literature on collaborative governance theory in two areas. First, evolutionary game theory is utilized to study the multi-governance of public rental housing exit based on multiple stakeholders. This study compensates for the current lack of application of collaborative theory in public housing exit. Second, the effects of public participation on public rental housing exit are studied, which is of great value in the formulation and implementation of exit policies.

This study also has policy implications. First of all, government departments should pay full attention to the impact of the epidemic and try their best to suppress the epidemic transmission to promote tenants' active exit. Second, government departments need to enhance their supervision capability to reduce the losses caused by information misreported by the public. At last, the power of the public and other participating parties needs to be utilized in the multi-governance model in order to better maintain the healthy development of public rental housing in China.

However, this manuscript still has some limitations. In order to simplify the model, this manuscript assumes that the relationship between epidemic impact and government supervision cost is linear, but the actual situation may be more complicated. Moreover, we have only analyzed the general trend of the influence of each factor on the evolution results but not solved the critical value. Accordingly, the solution of critical value and inflection point and the validation of numerical theoretical models with real case data will be the main direction of future research.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This research was funded by the Fundamental Research Funds for the Central Universities, China (Project no. 2019CDJSK03XK20), and jointly supported by the Fundamental Research Funds for the Central Universities (Project nos. 2017CDJXY and 2020CDJSK03PT08).

References

- [1] C. Delclós and L. Vidal, "Beyond renovation: addressing Europe's long housing crisis in the wake of the COVID-19 pandemic," *European Urban and Regional Studies*, vol. 28, no. 4, pp. 333–337, 2021.
- [2] C. Mariana, "Arcaya, yael nidam, andrew binet, reann gibson, vedette gavin, rising home values and covid-19 case rates in Massachusetts," *Social Science & Medicine*, vol. 265, p. 113290, 2020.
- [3] X. Qu and J. Cheng, "Impacts of COVID-19 on the labor market and policy responses," *Journal of Hebei Normal University (Philosophy and Social Sciences Edition)*, vol. 43, no. 4, pp. 126–133, 2020.
- [4] R. Deng, "How Does the Relationship Resource in Social Capital Mobilization Affect the Employment Quality of Migrant Workers?" *Economic Perspectives*, vol. 1, pp. 52–68, 2013.
- [5] M. Bower, C. Buckle, E. Rugel et al., "'Trapped', 'anxious' and 'traumatised': COVID-19 intensified the impact of housing inequality on Australians' mental health," *International Journal of Housing Policy*, vol. 21, pp. 1–32, 2021.
- [6] T. Liang, *Economic development, public rental housing policy and residence quality of urban low-income families*, pp. 44–63, Lanzhou Academic Journal, 2021.
- [7] D. J. Wood and B. Gray, "Toward a comprehensive theory of collaboration," *The Journal of Applied Behavioral Science*, vol. 27, no. 2, pp. 139–162, 1991.
- [8] G. Zhang, J. Li, and X. Guan, "Evolution analysis of inter-ministerial cooperation based on energy-saving and emission-reduction policies," *Management Review*, vol. 31, no. 12, pp. 250–263, 2019.
- [9] J. Li and J. Xiang, *The Special Factors of Poverty in Ethnic Minority Areas and its Governance*, pp. 57–61, Chinese Public Administration, Zhongnanhai, China, 2018.
- [10] Y. Zhao, *Constructing Multi-Collaborative Model of China's Internet Governance: To Correct Four Chaos Made by ISPs*, pp. 16–20, Chinese Public Administration, Zhongnanhai, China, 2015.
- [11] V. Haldane, C. De Foo, S. M. Abdalla et al., "Health systems resilience in managing the COVID-19 pandemic: lessons from 28 countries," *Natura Med*, vol. 27, no. 6, pp. 964–980, 2021.
- [12] Z. Gao, S. Wang, and J. Gu, "Public participation in smart-city governance: a qualitative content analysis of public comments in urban China," *Sustainability*, vol. 12, no. 20, p. 8605, 2020.
- [13] Y. Huang, F. Aguilar, J. Yang, Y. Qin, and Y. Wen, "Predicting citizens' participatory behavior in urban green space governance: application of the extended theory of planned behavior," *Urban Forestry and Urban Greening*, vol. 61, Article ID 127110, 2021.
- [14] Y. Fu and W. Ma, "Sustainable urban community development: a case study from the perspective of self-governance and public participation," *Sustainability*, vol. 12, no. 2, p. 617, 2020.
- [15] J. Li, C. C. Wang, and J. Sun, "Empirical analysis of tenants' intention to exit public rental housing units based on the Theory of Planned Behavior-The case of Wuhan, China," *Habitat International*, vol. 69, pp. 27–36, 2017.
- [16] H. Zeng, X. Yu, and H. Wen, "What factors drive public rental housing fraud? Evidence from Hangzhou, China," *Habitat International*, vol. 66, pp. 57–64, 2017.
- [17] J. Li, M. Stehlik, and Y. Wang, "Assessment of barriers to public rental housing exits: evidence from tenants in Beijing, China," *Cities*, vol. 87, pp. 153–165, 2019.
- [18] S. Li and S. Liu, *Restraining the Illegal Sublease Phenomenon of Public Rental Housing in China: Based on Dynamic Evolutionary Game Theory*, American Society of Civil Engineers (ASCE), Banff, AB, Canada, 2019.
- [19] A. Amerio, A. Brambilla, A. Morganti et al., "COVID-19 lockdown: housing built environment's effects on mental health," *The European Journal of Public Health*, vol. 30, no. 5, p. 5793, 2020.
- [20] J. E. Wallace, "Financing affordable housing in the United States," *Housing Policy Debate*, vol. 6, no. 4, pp. 785–814, 1995.
- [21] X. Zheng, *Research on the Community Management Mode of Public-Rental Housing in Chongqing*, Chongqing University, Chongqing, China, 2013.
- [22] F. F. Luo, "Study on operation and management mode of public rental housing in China, taking Shanghai city and chongqing city for example," *American Journal of Sociological Research*, vol. 4, no. 3, pp. 102–107, 2014.
- [23] S. Mu, "Community building in social-mix public housing: participatory planning of Ankang redevelopment plan," *Procedia - Social and Behavioral Sciences*, vol. 222, pp. 755–762, 2016.
- [24] K. Li and L. Sheng, "On the legislative construction of the incentive mechanism for using and exiting of public rental housing in China," *Journal of Central China Normal University (Humanities and Social Sciences)*, vol. 60, no. 2, pp. 71–81, 2021.
- [25] J. Wang, *The Basic Experience and Insights of Public Rental Housing Construction in the UK*, pp. 88–92, Modern Economic Research, Cambridge, Massachusetts, 2014.
- [26] J. M. Smith, "Evolutionary game theory," *Physica D: Non-linear Phenomena*, vol. 22, no. 1-3, pp. 43–49, 1986.
- [27] D. Friedman, "On economic applications of evolutionary game theory," *Journal of Evolutionary Economics*, vol. 8, no. 1, pp. 15–43, 1998.
- [28] J. Hofbauer and K. Sigmund, "Evolutionary game dynamics," *Bulletin of the American Mathematical Society*, vol. 40, no. 4, pp. 479–519, 2003.
- [29] E. Altman, R. El-Azouzi, Y. Hayel, and H. Tembine, "The evolution of transport protocols: an evolutionary game perspective," *Computer Networks*, vol. 53, no. 10, pp. 1751–1759, 2009.
- [30] G. Cai and N. Kock, "An evolutionary game theoretic perspective on e-collaboration: the collaboration effort and media relateness," *European Journal of Operational Research*, vol. 194, no. 3, pp. 821–833, 2009.
- [31] D. Challet and Y.-C. Zhang, "Emergence of cooperation and organization in an evolutionary game," *Physica A: Statistical Mechanics and Its Applications*, vol. 246, no. 3–4, pp. 407–418, 1997.
- [32] Y. Liu and F. Dong, "What are the roles of consumers, automobile production enterprises, and the government in the process of banning gasoline vehicles? Evidence from a tripartite evolutionary game model," *Energy*, vol. 238, Article ID 122004, 2022.
- [33] S. Sun and L. Zhu, "Tripartite evolutionary simulation analysis of food supervision under public participation in the new media environment," *Management Review*, vol. 33, no. 3, pp. 315–326, 2021.
- [34] X. Li, R. Huang, J. Dai, J. Li, and Q. Shen, "Research on the evolutionary game of construction and demolition waste (CDW) recycling units' green behavior, considering remanufacturing capability," *International Journal of Environmental Research and Public Health*, vol. 18, no. 17, p. 9268, 2021.

- [35] W. Fan, S. Wang, X. Gu, Z. Zhou, Y. Zhao, and W. Huo, "Evolutionary game analysis on industrial pollution control of local government in China," *Journal of Environmental Management*, vol. 298, p. 113499, 2021.
- [36] K. Zhou, Q. Wang, and J. Tang, "Evolutionary game analysis of environmental pollution control under the government regulation," *Scientific Reports*, vol. 12, no. 1, 2022.
- [37] Y. Xiao, W. Xu, S. Zeng, and Q. Peng, "Online User Information Sharing and Government Pandemic Prevention and Control Strategies-Based on Evolutionary Game Model," *Frontiers in Public Health*, vol. 9, p. 747239, 2021.
- [38] Z. Yu and S. Abdul Rehman Khan, "Evolutionary game analysis of green agricultural product supply chain financing system: COVID-19 pandemic," *International Journal of Logistics Research and Applications*, vol. 31, pp. 1–21, 2021.
- [39] L. I. Baolong, "Research on the exit mechanism of public rental houses based on game theory," *Construction Economy*, vol. 37, no. 01, pp. 75–78, 2016.
- [40] H. Zeng and X. Yu, *The Problem of Delay-Exit in Public Rental House and its Solution to Lawsuit*, pp. 84–91, Urban Problems, China, 2017.
- [41] Y.-Z. Liu and H. Fang, "Study on the withdrawal issue of public rental housing in Urumqi: based on game theory," *Hubei Agricultural Sciences*, vol. 59, no. 13, pp. 195–198+204, 2020.
- [42] E. D. Riley, M. D. Hickey, E. Imbert, A. A. Clemenzi-Allen, and M. Gandhi, "Coronavirus disease 2019 (COVID-19) and HIV spotlight the United States imperative for permanent affordable housing," *Clinical Infectious Diseases*, vol. 72, no. 11, pp. 2042–2043, 2021.
- [43] X. Dang, *On the Requirement and Improvement of Government's Capability in Cooperative Governance*, pp. 46–52, Chinese Public Administration, Zhongnanhai china, 2017.
- [44] Z. Xu, Y. Cheng, and S. Yao, "Tripartite evolutionary game model for public health emergencies," *Discrete Dynamics in Nature and Society*, vol. 2021, Article ID 6693597, 14 pages, 2021.