Research on the Evolutionary Game Played by Key Stakeholders in the Renovation of Residential Historic Districts

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Abstract: The complex and diverse interests of various stakeholders involved in residential heritage sites pose major challenges for renovation work. Promoting the renovation of residential heritage districts and achieving cooperation and win-win outcomes among government, developers, and residents are essential for sustainable and high-quality development in these areas. To analyze this issue in depth, this study will establish an evolutionary game model and analyze the evolutionary game behavior and strategic choices from the perspectives of government, developers, and residents. This aims to fully consider the demands of core stakeholders in future updates of residential heritage districts and propose targeted strategies.

1. Introduction

The rapid development of our country's economy and urban expansion have marginalized old city areas, leading to the decline and loss of vitality in residential neighborhoods. To protect historical neighborhoods and continue the urban heritage, updating work is necessary[1]. However, the government faces challenges in generating fiscal revenue and experiences significant financial pressures, making it difficult to sustain the renovation efforts. Therefore, we advocate for a combination of unified planning and progressive updates. The involvement of multiple stakeholders in neighborhood revitalization brings new perspectives [2,3] but also gives rise to conflicts and issues of fairness[4]. Furthermore, drawbacks such as excessive development, overconsumption, and excessive management have also been exposed [5].In order to address these issues, an analysis based on the principles and methods of evolutionary game theory is needed to guide decision-making and explore a path for high-quality development in residential historical neighborhoods.

2. Model Construction and Analysis

2.1 Hypotheses of the Game Model

(1) Bounded rationality assumption. The government, developers and residents are all bounded rational and their goal is to maximize their own interests. The information between the game participants is incomplete, and the game participants will continuously improve their game strategies based on their own benefits during the game process.

(2) In this evolutionary game, each participating party has two strategies to choose from: the government's strategy selection set is {participation, non-participation}; the developer's strategy selection set is {high-level development, low-level development}; the resident's strategy selection set is {support, non-support}.

(3) The government chooses to participate in the development process, and the total cost of manpower and material resources invested is C_1. At this time, rewarding resident support with a bonus of M, and earning additional commodity tax revenue of R_t. If the developer chooses high-level development, the government gains a reputation benefit of R_d. If the government chooses not to participate, it does not invest in actual elements, but provides assistance to the developer, resulting in damage to the government's image of B_u.

(4) The developer's fixed income is R_f, and the cost of choosing high-level and low-level

development is C_2 and C_3, respectively, and $C_2 > C_3$. Under government participation, high-level development earns an additional income of R_e. Under government participation, low-level development by the developer reduces the government's favorability towards it, resulting in compensation of B_s to the government. In the case of resident support, low-level development by the developer reduces the favorability of residents towards it, resulting in compensation of B_c to the residents.

(5) The cost for residents to choose support is C_4, and they receive a reward of M from the government for their support. Under the condition of high-level development, the income generated from supporting development is R_s. When the developer chooses low-level development, the loss to the public is B_l.

(6) The probability of the government choosing the participation strategy is x, and the probability of choosing the non-participation strategy is $1-\mathrm{x}$. The probability of the developer choosing the high-level development strategy is y, and the probability of choosing the low-level development strategy is $1-\mathrm{y}$. The probability of residents choosing the support strategy is z, and the probability of choosing the non-support strategy is $1-\mathrm{z}$ $(0 \le \mathrm{x} \le 1, 0 \le \mathrm{y} \le 1, 0 \le \mathrm{z} \le 1)$.

2.2 Payoff Matrix of Game Model

Based on the assumptions mentioned above, there are eight different choices of game strategies among the three participating entities: {Participate a_1, High-level development b_1, Support c_1}; {Participate a_2, High-level development b_2, Not support c_2}; {Participate a_3, Low-level development b_3, Support c_3}; {Participate a_4, Low-level development b_4, Not support c_4}; {Not participate a_5, High-level development b_5, Support c_5}; {Not participate a_6, High-level development b_6, Not support c_6}; {Not participate a_7, Low-level development b_7, Support c_7}; {Not participate a_8, Low-level development b_8, Not support c_8}.Based on this, the payoff matrix for the government, developers, and residents can be obtained, with specific results shown in Table 1.

2.3 Tripartite Dynamic Evolutionary Model

2.3.1 Analysis of the Government's Replication Dynamic Equation

Let U_{x1} represent the expected payoff for the government's choice to participate in the development process, and let U_{x2} represent the expected payoff for the government's choice not to participate in the development process.

$$\begin{aligned} U_{x1} &= yz(R_t + R_d - C_1 - M) + y(1-z)(R_t + R_d - C_1) \\ &+ (1-y)z(R_t + B_s - C_1 - M) + (1-y)(1-z)(R_t + B_s - C_1) \end{aligned} \tag{1}$$

$$\begin{aligned} U_{x2} &= yz(-B_u - M) + y(1-z)(-B_u) \\ &+ (1-y)z(-B_u - M) + (1-y)(1-z)(-B_u) \end{aligned} \tag{2}$$

Table 1 : Tripartite Game Payoff Matrix for the Government, Developers, and Residents.

strategy combination	government's payoff	developer's payoff	residents' payoff
(a_1, b_1, c_1)	$R_t + R_d - C_1 - M$	$R_f + R_e - C_2$	$R_s - C_4 + M$
(a_2, b_2, c_2)	$R_t + R_d - C_1$	$R_f + R_e - C_2$	0
(a_3, b_3, c_3)	$R_t + B_s - C_1 - M$	$R_f - C_3 - B_s - B_c$	$B_c + M - C_4 - B_l$
(a_4, b_4, c_4)	$R_t + B_s - C_1$	$R_f - C_3 - B_s$	$-B_l$
(a_5, b_5, c_5)	$-B_u - M$	$R_f - C_2$	$R_s - C_4 + M$
(a_6, b_6, c_6)	$-B_u$	$R_f - C_2$	0
(a_7, b_7, c_7)	$-B_u - M$	$R_f - C_3 - B_c$	$B_c + R_s - C_4 - B_l + M$
(a_8, b_8, c_8)	$-B_u$	$R_f - C_3$	$-B_l$

Based on equations (1)-(2) and the Malthusian equation, the dynamic replication equation for the government's strategy can be derived.

$$F(x) = x(1-x)(U_{x1} - U_{x2}) = x(1-x)[y(R_d - B_s) - 2zM + (R_t + B_s - C_1 - B_u)] \quad (3)$$

2.3.2 Analysis of the Developer's Replication Dynamic Equation

Let U_{y1} represent the expected payoff for the developer's choice of high-level development, and let U_{y2} represent the expected payoff for the developer's choice of low-level development.

$$U_{y1} = xz(R_f + R_e - C_2) + x(1-z)(R_f + R_e - C_2)$$
$$+(1-x)z(R_f - C_2) + (1-x)(1-z)(R_f - C_2) \quad (4)$$

$$U_{y2} = xz(R_f - C_3 - B_s - B_c) + x(1-z)(R_f - C_3 - B_s)$$
$$+(1-x)z(R_f - C_3 - B_c) + (1-x)(1-z)(R_f - C_3) \quad (5)$$

Based on equations (4)-(5) and the Malthusian equation, the dynamic replication equation for the developer's strategy can be derived:

$$F(y) = y(1-y)(U_{y1} - U_{y2}) = y(1-y)[(R_e + B_s)x + B_c z + (C_2 - C_3)] \quad (6)$$

2.3.3 Analysis of the Resident's Replication Dynamic Equation

Let U_{z1} represent the expected payoff for the resident's choice to support the development, and let U_{z2} represent the expected payoff for the resident's choice not to support the development:

$$U_{z1} = xy(R_s - C_4 + M) + x(1-y)(B_c + M - C_4 - B_l)$$
$$+(1-x)y(R_s - C_4 + M) + (1-x)(1-y)(B_c + R_s - C_4 - B_l + M) \quad (7)$$

$$U_{z2} = x(1-y)(-B_l) + (1-x)(1-y)(-B_l) \quad (8)$$

Based on equations (7)-(8) and the Malthusian equation, the dynamic replication equation for the resident's strategy can be derived:

$$F(z) = z(1-z)(U_{z1} - U_{z2})$$
$$= z(1-z)[xyR_s + xR_s + B_c y + (B_c + R_s + M - C_4)] \quad (9)$$

2.4 Analysis of Tripartite Strategy Evolution Stability

By taking partial derivatives of the government's, developer's, and resident's replication dynamic equations, the Jacobian matrix of the system can be obtained:

$$\begin{pmatrix} (1-2x)\begin{bmatrix} y(R_d - B_s) - 2zM \\ +(R_t + B_s - C_1 - B_u) \end{bmatrix} & x(1-x)(R_d - B_s) & -2x(1-x)M \\ y(1-y)(R_e + B_s) & (1-2y)\begin{bmatrix} (R_e + B_s)x + B_c z \\ +(C_2 - C_3) \end{bmatrix} & y(1-y)B_c \\ z(1-z)(yR_s + R_s) & z(1-z)(xR_s + B_c) & (1-2z)\begin{bmatrix} xyR_s + xR_s + B_c y \\ +(B_c + R_s + M - C_4) \end{bmatrix} \end{pmatrix}$$

Table 2 : Analysis of the Stability of System Equilibrium Points

Equilibrium points	Eigenvalues and Signs	Results	Stability conditions
$A_1(1,1,1)$	$2M + C_1 + B_u - R_d - R_t{}^{(s)}$, $-(R_e + B_c + B_s + C_2 - C_3)^{(-)}$, $C_4 - 3R_s - 2B_c - M^{(s)}$	Unstable	$R_d + R_t > 2M + C_1 + B_u$, $3R_s + 2B_c + M > C_4$
$A_2(1,1,0)$	$C_1 + B_u - R_d - R_t{}^{(s)}$, $-(R_e + B_s + C_2 - C_3)^{(-)}$, $3R_s + 2B_c + M - C_4{}^{(s)}$,	Unstable	$R_d + R_t > C_1 + B_u$, $C_4 > 3R_s + 2B_c + M^{(s)}$,
$A_3(1,0,1)$	$C_1 + B_u + 2M - R_d - R_t{}^{(s)}$, $R_e + B_c + B_s + C_2 - C_3{}^{(+)}, C_4 - 2R_s - B_c - M^{(s)}$	Unstable	
$A_4(1,0,0)$	$C_1 + B_u - R_t - B_s{}^{(s)}$, $R_e + B_s + C_2 - C_3{}^{(+)}$,	Unstable	

	$B_c + 2R_s + M - C_4{}^{(s)}$		
$A_5(0,1,1)$	$R_d + R_t - 2M - C_1 - B_u{}^{(s)}, -(B_c + C_2 - C_3)^{(-)},\ C_4 - 2B_c - R_s - M^{(s)}$	Unstable	$2M + C_1 + B_u > R_d + R_t,$ $2B_c + R_s + M > C_4$
$A_6(0,1,0)$	$R_d + R_t - C_1 - B_u{}^{(s)},\ C_3 - C_2{}^{(-)}, 2B_c + R_s + M - C_4{}^{(s)}$	Unstable	$R_d + R_t > C_1 + B_u,$ $2B_c + R_s + M > C_4$
$A_7(0,0,1)$	$R_d + R_t - 2M - C_1 - B_u{}^{(s)},\ B_c + C_2 - C_3{}^{(+)},$ $C_4 - B_c - 2R_s - M^{(s)}$	Unstable	
$A_8(0,0,0)$	$R_d + R_t - C_1 - B_u{}^{(s)},\ C_2 - C_3{}^{(+)},\ B_c + R_s + M - C_4{}^{(s)}$	Unstable	

Note: (+), (-), and (s) respectively represent positive, negative, and unknown signs of the eigenvalues.

Based on the first Lyapunov stability criterion, Table 2 provides the stability analysis of the eight equilibrium points and the positive/negative signs of the eigenvalues. The potential equilibrium points of the system are denoted as $A_1(1,1,1)$, $A_2(1,1,0)$, $A_5(0,1,1)$ and $A_6(0,1,0)$.

2.5 Result Analysis of Evolutionary Game

(1) Under the condition of $R_d + R_t > 2M + C_1 + B_u,\ 3R_s + 2B_c + M > C_4$, the cooperative relationship achieves maximum benefits for all parties involved. The government gains increased fiscal income and reputation, developers receive stable and additional returns, and residents enjoy government rewards and benefits brought by development. This mutually beneficial relationship leads to a stable state, and all parties have no motivation to change their strategic choices.

(2) Under the condition of $R_d + R_t > C_1 + B_u,\ C_4 > 3R_s + 2B_c + M$, The motivation and interests of the government and developers to participate in and develop at a high level are met, but residents may feel that the costs and risks outweigh the benefits. This unsupportive attitude results in residents choosing not to support the strategy and remaining unchanged, thus forming a stable state.

(3) Under the condition of $2M + C_1 + B_u > R_d + R_t,\ 2B_c + R_s + M > C_4$, The government may believe that not participating in development can reduce burdens and risks, while developers may gain more profits and reputation. At the same time, residents have a high level of support for the development process, perhaps because they have benefited from it in some way.

(4) Under the condition of $R_d + R_t > C_1 + B_u,\ C_4 > 3R_s + 2B_c + M$, The government may believe that not participating in development can reduce burdens and risks, while developers may gain more profits and reputation. However, residents may be skeptical about the government and developers' ability and willingness to protect their rights and interests in the development process.

3. Conclusion

The government, residents, and developers, as the core stakeholders of preservation work, directly affect the achievement of goals in residential historic districts. In renovation work, the interests and conflicts of all three should be balanced. The government should take a leading role, clarify the focus of the renovation work and adopt a phased updating strategy. Encouraging residents to be proactive, implement reasonable and standardized protection actions, and reduce the damage to historical and cultural heritage. Developers should take advantage of development investment institutions and adopt a moderate and reasonable market-oriented development mechanism based on the characteristics of key stakeholders. Attention should also be paid to underrepresented stakeholders and the role of social forces in the renovation and protection action should be emphasized.

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