

Article

Driving Collaborative Governance: Simulating the Dynamic Evolution of Multi-Stakeholder Strategies in Industrial Heritage Renewal Through Policy Levers

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Abstract

At the critical juncture where Chinese cities are transitioning toward intensive urban renewal and sustainable development, the revitalization and adaptive reuse of industrial heritage face a collective action dilemma stemming from the misaligned interests among three key stakeholders: the Local Government (LG), the Industrial Heritage Developer (IHD), and the Neighboring Complementary Merchants (NCMs). To address this challenge, this study constructs a tripartite evolutionary game model and innovatively proposes an analytical framework of a Multi-Dimensional Policy Lever System, which integrates spatial synergy (k, w, v), economic incentives (p_1, p_2, q), and behavioral regulation (m, n). Numerical simulations reveal that the successful regeneration of industrial heritage does not rely on any single policy but fundamentally depends on the systematic coordination and dynamic adaptation of these three-dimensional levers. The nonlinear coupling of spatial elements forms the foundation for value leapfrogging. The economic driving force requires a critical shift from government subsidies (p) towards a market-based value capture and recycling mechanism (q). Behavioral interventions provide the necessary cognitive and normative safeguards for cooperation. The research elucidates a three-phase evolutionary pattern of the system, transitioning from a stalemate to synergy, and emphasizes the need for an adaptive and sequential combination of policies. The theoretical contribution of this study lies in providing an integrative quantitative analytical framework. Its practical significance is to offer a scientific basis for decision-makers to construct a dynamic policy toolbox and promote the sustainable collaborative governance of industrial heritage.

Keywords: industrial heritage; evolutionary game theory; multi-dimensional policy lever system; collaborative governance; sustainable urban regeneration

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1. Introduction

Against the backdrop of a profound global shift in urban development paradigms from extensive expansion to intensive renewal, the adaptive reuse of industrial heritage has emerged as a core issue for achieving Sustainable Development Goal 11 (SDG 11) [1,2]. Its essence lies in steering urban development away from consumptive growth towards regenerative development that encompasses cultural, social, economic, and environmental dimensions [3,4]. This process necessitates moving beyond mere physical renovation to a systematic assessment of the intrinsic value of heritage and the coordination of multi-dimensional interests [5–7]. This transition is particularly urgent and complex within the Chinese context. The Guiding Opinions on Promoting Urban Renewal Actions in a Sustained Manner (The Guiding Opinions) issued by the General Office of the State Council of China explicitly outlines strategic requirements to prevent massive demolition and construction, to strengthen the protection and utilization of industrial heritage, and to establish a sustainable urban renewal model featuring government guidance, market operation, and public participation [8]. This provides a top-level policy framework for systematically addressing the common collective action dilemma in industrial heritage renewal. Industrial heritage not only carries unique historical context and collective memory but also represents a critical asset within the urban stock space—one that urgently requires activation and possesses the potential to catalyze the integrated regeneration of entire districts [9]. Transforming these areas from industrial rust belts into vibrant life belts that blend cultural identity, ecological resilience, community vitality, and economic innovation is not only an essential path for promoting high-quality urban development but also a key practice in implementing China's People-Centric City concept and achieving an inclusive, sustainable urban future [6,10].

However, realizing this vision often faces severe challenges from a collective action dilemma in practice [11,12]. Industrial heritage renewal is fundamentally a complex game involving multiple stakeholders, including the Local Government (LG), the Industrial Heritage Developer (IHD), and Neighboring Complementary Merchants (NCMs). The LG must balance multiple objectives—heritage conservation, public service provision, and economic development—under fiscal constraints [13]. The IHD confronts high conservation and renovation costs alongside long-term operational risks, resulting in uncertain investment returns [14]. While NCMs are motivated to benefit from the positive externalities generated by heritage revitalization, they generally lack incentives to actively participate in synergistic upgrading and tend to free-ride [11,15]. This profound misalignment of interests and absence of incentives often lead projects into a stalemate, characterized either by proactive government initiatives with insufficient market response or by the low-end lock-in of surrounding areas after the core site's revitalization. Consequently, it becomes difficult to establish a sustainable, synergistic, and symbiotic regional regeneration system [14].

Existing research provides multi-dimensional perspectives for understanding the collective action dilemma in industrial heritage renewal, spanning a broad spectrum from physical-spatial planning to governance mode analysis [16]. In recent years, applying evolutionary game theory to analyze the strategic interactions among multiple agents in renewal processes has emerged as a new direction. Studies have confirmed the crucial role of government intervention and incentives in promoting redevelopment led by original land users [17–19]. However, most existing game models are confined to a binary framework involving only the government and developers, or they examine policy tools in a singular and static manner [20]. Although research has highlighted the importance of policy combinations and the evolutionary mechanisms of cooperative behavior in multi-agent systems [21], a core question remains systematically unanswered: How can an integrated set of policy tools be designed to simultaneously coordinate key variables across

spatial, economic, and behavioral dimensions, thereby effectively guiding the strategies of the LG, IHD, and NCMs from a non-cooperative game towards a sustainable synergistic equilibrium?

To address this research gap, this paper innovatively constructs a tripartite evolutionary game model encompassing the LG, IHD, and NCMs, and proposes a theoretical framework of a Multi-Dimensional Policy Lever System designed to resolve the synergistic dilemma in industrial heritage renewal. This framework systematically integrates scattered policy tools into three core levers that precisely target different evolutionary drivers:

- (1) **The Spatial Synergy Lever:** Through the coupled design of Infrastructure Carrying Capacity (k), Heritage Spatial Activation Rate (w), and Degree of Functional Mix (v), this lever aims to systematically enhance the physical environmental resilience, cultural core attractiveness, and business format vitality of the area, laying the material foundation for value creation.
- (2) **The Economic Incentive Lever:** Through the mechanism design of development incentives (p_1), operational incentives (p_2), and Value Capture and Recycling (q), this lever aims to reconfigure sustainable models for benefit distribution and cost-sharing. It facilitates a smooth transition of the driving force from initial government fiscal subsidies to a later-stage market-based value closed loop.
- (3) **The Behavioral Regulation Lever:** Through the strategic design of Place Perception intervention (m) and Spatial Negative Externality control (n), this lever aims to employ behavioral economics and spatial governance tools to correct agents' myopic cognition, establish reasonable competition rules, and guide long-termism and cooperative behavior from both psychological and institutional perspectives.

This study aims, through the construction and simulation analysis of this tripartite game model, to delve into the following questions: How do the strategic choices of the three parties dynamically evolve under different parameter combinations of the three policy levers? What are the critical thresholds and marginal effects of each lever, and how do their interactive and synergistic mechanisms operate? Ultimately, the goal of this research is to provide quantitative theoretical foundations and decision-making support for policymakers to design a precise, synergistic, and adaptable policy tool portfolio. This aims to propel industrial heritage renewal from isolated project islands towards a sustainable synergistic ecosystem, contributing theoretical insights and practical solutions for the high-quality regeneration of urban stock space in China and similar cities globally.

2. Literature Review

The adaptive reuse of industrial heritage has become a central theme in sustainable urban renewal [22]. The research paradigm is shifting from the conservation of individual buildings towards a focus on multi-stakeholder synergy and systemic revitalization [23–25]. However, when deconstructing the synergistic mechanisms of the core triad—LG, IHD, and NCMs—the fragmentation of analytical tools and the limitations of theoretical frameworks have become increasingly apparent. This review aims to clarify research progress concerning the three dimensions of space, economy, and behavior, thereby laying the groundwork for constructing an integrated Multi-Dimensional Policy Lever System.

2.1. The Spatial Synergy Lever (k, w, v): From Isolated Elements to Systemic Coupling

TSpace serves as the foundation for value regeneration in industrial heritage. Early spot-renewal models often led to projects becoming disconnected from the urban fabric, creating cultural islands. Subsequent area-based ecological restoration and industrial implantation still frequently face challenges of fragmented governance [25,26]. This has prompted cutting-edge research to adopt a networked and systemic perspective [27].

Three core variables within this perspective constitute The Spatial Synergy Lever in this study: Infrastructure Carrying Capacity (k) is the physical cornerstone determining regional accessibility, investment environment, and spatial performance, with its improvement significantly boosting commercial vitality [28]; Heritage Spatial Activation Rate (w) emphasizes transforming physical remains into living cultural capital and multifunctional spaces through creativity and technology [25]; and Degree of Functional Mix (v) is a key catalyst for stimulating regional economic and social network vitality [25,28]. Recent studies indicate that the synergistic coupling of k , w , and v can generate nonlinear value-added effects surpassing simple summation. For instance, linking dispersed nodes through linear spaces like heritage corridors can form a powerful regional brand ecosystem with significant positive spillovers [27–29]. At the theoretical modeling level, research has also begun to explore the complex influence of spatial structure on the evolution of multi-agent cooperation [30,31]. However, existing studies predominantly remain at the level of qualitative description or single-dimensional assessment. There is a lack of systematic modeling analysis and simulation verification concerning the precise quantitative interactions among k , w , and v , and how their synergistic gain mechanisms transmit to and influence the micro-level decisions of multiple stakeholders, including the LG, IHD, and NCMs [25,32].

2.2. The Economic Incentive Lever (p_1, p_2, q): From Fiscal Dependence to a Value Loop

Benefit distribution lies at the core of synergistic renewal. Extensive research confirms that initial government subsidies and policy incentives (p_1, p_2) can effectively lower entry barriers and startup costs for market entities, serving as crucial tools for catalyzing project initiation [18,33]. However, their limitations are also widely recognized: over-reliance on fiscal subsidies is not only unsustainable but also inadequate for precisely capturing and feeding back the positive externalities generated by private investment [33,34]. Consequently, academic and policy focus is shifting towards constructing a self-sustaining endogenous cycle mechanism, namely Value Capture and Recycling (q). Its core lies in institutional designs, such as tax increment financing or business improvement districts, to partially recapture gains from land value appreciation and commercial spillovers generated by heritage revitalization and then channel them back to cover renewal costs and sustain operations [33,34]. Existing discussions predominantly concentrate on macro-level public value capture, paying insufficient attention to the micro-level, market-contract-based benefit recycling mechanism (q) between private sectors, particularly from NCMs to the IHD. The resulting benefit imbalance, stemming from free-riding behavior, constitutes the fundamental economic cause for the IHD's lack of long-term investment motivation and the low-end lock-in of NCMs' business formats [18,35–37]. Therefore, designing a complete incentive chain that connects initial government incentives (p) with a long-term market-based closed loop (q) is essential. However, existing game models lack refined simulation and empirical testing regarding the dynamic transition conditions, critical thresholds for the effectiveness of the value recycling mechanism (q), and how it systematically influences the strategic co-evolution of the LG, IHD, and NCMs [38,39].

2.3. The Behavioral Regulation Lever (m, n): Governing Cognition and Rules Beyond Economic Rationality

Decision-making is influenced not only by economic interests but also profoundly by psychological cognition and social norms. In industrial heritage renewal, the Place Perception Coefficient (m) plays a pivotal role. Behavioral economics and heritage studies indicate that stakeholders often exhibit myopia, leading to a systematic undervaluation ($m < 1$) of the long-term cultural and social value of heritage due to cognitive biases [40–45]. Correcting this bias requires interventions such as active narrative dissemination,

community engagement, and digital technologies like extended reality (XR) to enhance collective identity and convert cultural capital into sustainable investment willingness [41,46].

On the other hand, the Spatial Negative Externality Coefficient (n) deeply affects the efficiency of collective action. Low-end or incompatible commercial activities can create a tragedy of the commons, eroding the overall value of the area ($n < 1$) [47,48]. Moving beyond traditional administrative commands, frontier research explores rules-based soft governance tools, such as merchant credit ratings and business format covenants, and draws on club resource theory to design incentive-compatible spatial rules [49,50]. This approach, which transforms spatial governance into a rule-based game, aims to foster positive social norms and peer pressure, thereby incentivizing merchants to pursue symbiotic upgrading and offering a new pathway for constructing a healthy competitive environment [49].

2.4. Innovations of This Study

In summary, while existing research has provided multi-dimensional insights, notable limitations persist: firstly, a fragmentation of dimensions, where spatial, economic, and behavioral tools lack an integrated framework; secondly, a limited perspective, often neglecting the critical third-party role of NCMs; and thirdly, static analysis, lacking quantitative examination of the synergistic evolution mechanisms of dynamically combined levers.

This study aims to bridge these gaps. By constructing an LG-IHD-NCMs tripartite evolutionary game model and proposing an integrated Multi-Dimensional Policy Lever System, this research will not only verify the independent effects of the three lever categories—spatial (k, w, v), economic (p_1, p_2, q), and behavioral (m, n)—but will also focus on revealing their interaction mechanisms, critical thresholds, and combination strategies. This approach systematically addresses the question of how to guide the three parties from a game stalemate towards synergistic symbiosis, thereby providing a new quantitative analytical framework for the sustainable governance of industrial heritage.

Theoretically, this framework advances debates on collaborative governance by moving beyond normative advocacy to specify its micro-foundations. It integrates insights from institutional economics (e.g., designing self-enforcing contracts via q to resolve free-riding), spatial political economy (e.g., treating spatial variables k, w, v as capitalizable assets within a value production network), and governance theory (e.g., how behavioral levers m, n shape the cognitive and normative context for cooperation). Thus, the contribution lies in providing a testable, integrative theory of how multi-dimensional policy interventions can structurally alter stakeholder incentives to transition from a governance stalemate to a synergistic equilibrium.

3. Building and Analysis of Evolutionary Game Model

3.1. Assumptions and Key Variables

Game theory focuses on the analysis of Behavioral Strategies among multiple stakeholders. Accordingly, this paper constructs a tripartite evolutionary game model involving LG), IHD and NCMs. The Strategic Interactions among these agents are illustrated in Figure 1, and the definitions of all parameters are detailed in Table 1. To maintain a balance between theoretical breadth and logical focus, the model is structured hierarchically. The core analytical framework is centered on regulatory governance and economic redistribution (represented by the payoff matrix), which governs the fundamental strategic choices of the three stakeholders. In contrast, elements of spatial production and behavioral cognition are treated as “input variables” or “extensible modules” that modulate the

values of specific parameters (e.g., k and v), rather than independent structural layers. This approach prevents conceptual overfitting while ensuring the model's adaptability to various renewal contexts.

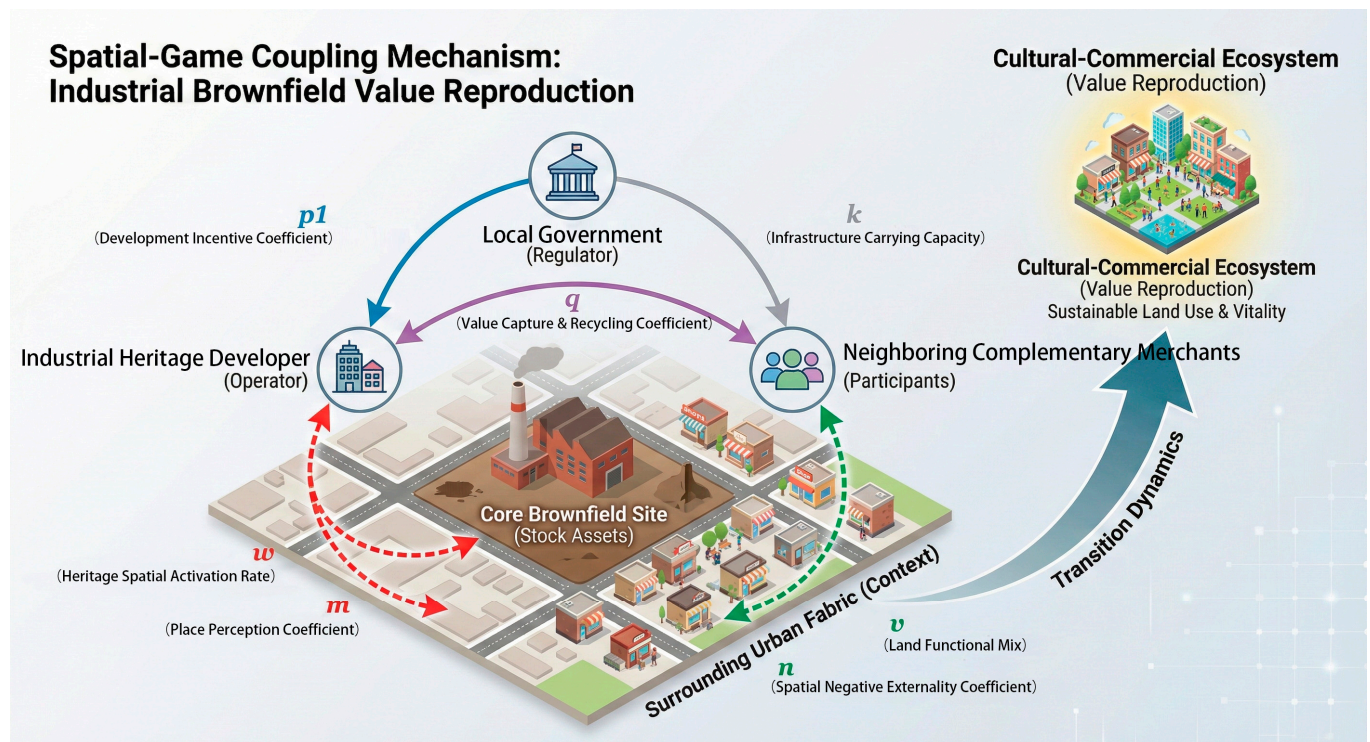


Figure 1. Strategic interaction mechanism among the Local Government, Industrial Heritage Developer, and Neighboring Merchants.

The model is predicated on the following assumptions:

Assumption 1. Bounded Rationality and Strategy Dynamics. All three parties are modeled as boundedly rational learners who refine their strategic choices via trial and error, learning from feedback, and imitating peers. Their respective strategy spaces are: LG (pro-active regulation, x ; status quo regulation, $1 - x$), IHD (adaptive reuse and revitalization, y ; low-value rent-seeking and idling, $1 - y$), and NCMs (symbiotic upgrading, z ; free-ride, $1 - z$), where $x, y, z \in [0,1]$ represent the proportion of each party adopting the proactive strategy.

Assumption 2. Synergy and Externalities in Payoffs. The payoff for each agent depends on the combination of its own strategy and the strategies of others, moderated by two key effects: (1) Synergy Effect: When two or all three parties adopt proactive strategies, they can generate supernormal payoffs through the coupling of elements; (2) Externality: The free-ride behavior of NCMs imposes a negative externality on the IHD, while their symbiotic upgrading behavior generates a positive externality.

Assumption 3. Multi-Dimensional Levers Embedded in the Payoff Functions. This study transforms the three major policy levers of space-economy-behavior into key parameters that directly adjust the costs or benefits of each party, embedding them into their respective payoff functions. This approach quantifies the micro-level pathways of policy intervention. Accordingly, the main variables and parameters of the model are defined as follows (key parameters are listed in Table 1), with their design closely corresponding to the three levers:

- (1) Spatial Synergy Lever Variables (Value Creation). This group of variables determines the ceiling and structure of value creation within the system.

Infrastructure Carrying Capacity (k): A government investment variable that enhances regional foundational support. Its investment cost exhibits increasing marginal costs ($C_{g2} \cdot l^k$). Concurrently, k enters the payoff functions of the IHD and NCMs as a synergy gain coefficient.

Heritage Spatial Activation Rate (w): An owner effort variable, measuring the degree of cultural heritage transformation. Its retrofitting cost exhibits increasing marginal costs ($C_{h2} \cdot j^w$). w is the core source of the area's cultural attractiveness.

Degree of Functional Mix (v): A collective action variable for merchants, reflecting the level of business format complexity. Its upgrading cost exhibits increasing marginal costs ($C_{p2} \cdot i^v$). v is key to stimulating network effects.

Synergy Gain Coefficients (s, d, u): Nonlinear combinations of the above three variables (e.g., $s = k \cdot a_1 + w \cdot a_2 + v \cdot a_3$), characterizing their multiplier effects on asset value (s), commercial spillover (d), and social benefit (u), respectively. They constitute the fundamental attraction driving systemic cooperation.

- (2) Economic Incentive Lever Variables (Value Distribution). This group of variables aims to regulate cost-sharing and benefit distribution, addressing the issue of incentive compatibility.

Government Subsidy Coefficients (p_1, p_2): Government policy variables that proportionally offset the IHD's revitalization cost ($p_1 \cdot C_{h2} \cdot j^w$) and the NCMs' upgrading cost ($p_2 \cdot C_{p2} \cdot i^v$), thereby lowering the initial action threshold.

Value Capture and Recycling Coefficient (q): A core contractual variable. When NCMs gain incremental benefits from systemic synergy, a certain proportion (q) of these benefits is recycled to compensate the IHD. This mechanism aims to internalize positive externalities, transforming free-riding into co-creation and benefit-sharing, thus serving as the economic link that sustains long-term cooperation.

- (3) Behavioral Regulation Lever Variables (Value Cognition). This group of variables characterizes the moderating effect of psychological cognition and interaction norms on decision-making.

Place Perception Coefficient (m): A cognitive bias variable ($m \geq 0$). The IHD's subjective evaluation of the long-term cultural and brand benefits generated by revitalization equals its objective value multiplied by m . An $m < 1$ indicates myopic undervaluation. Policy interventions (e.g., narrative building, participation) aim to increase m .

Spatial Negative Externality Coefficient (n): A behavioral constraint variable ($0 \leq n \leq 1$). When NCMs choose the "free-ride" strategy, their behavior reduces the IHD's base payoff by a multiplier n , simulating the damage caused by low-end business formats to the area's overall value. This creates market pressure that compels NCMs to regulate their behavior.

Table 1. Key Model Parameters and Definitions. (Note: An asterisk (*) denotes a parameter that can assume a value of either 0 or 1).

Parameter	Meaning	Remarks
k	Infrastructure Carrying Capacity coefficient, representing the level of improvement by the government in pipeline resilience, transportation micro-circulation, and public space around the plot.	$0 \leq k \leq 1$
w	Heritage Spatial Activation Rate, representing the degree of cultural retrofitting and developmental enhancement of the industrial heritage by the IHD.	$0 \leq w \leq 1$
v	Degree of Functional Mix, representing the extent to which NCMs upgrade from low-end to high-end business formats.	$0 \leq v \leq 1$

p_1	Industrial Heritage Development Subsidy coefficient, representing the proportion of the IHD's incremental cost subsidized by the government under proactive policies.	$0 \leq p_1 \leq 1$
p_2	Supporting Upgrade Subsidy coefficient, representing the proportion of the NCMs' incremental cost subsidized by the government under proactive policies.	$0 \leq p_2 \leq 1$
q	Value Capture and Recycling coefficient, representing the proportion of NCMs' incremental revenue shared with the IHD in states $(*, 1, 1)$.	$0 \leq q \leq 1$
m	Place Perception coefficient, quantifying the IHD's cognitive bias regarding the long-term cultural value (sentiment, memory) of the industrial heritage. An $m < 1$ indicates myopic undervaluation, while $m > 1$ signifies value discovery.	$m \geq 0$
n	Spatial Negative Externality coefficient, quantifying the crowding-out effect caused by spatial strategy conflicts. Its effect is state-dependent: (1) In state $(*, 0, 0)$ (both parties passive), the spatial uniqueness of the heritage gives the IHD a natural advantage over surrounding low-end merchants, so n only reduces NCMs' revenue. (2) In state $(*, 0, 1)$ (IHD passive, NCMs active), the quality upgrading of NCMs creates reverse competitive pressure on the core site, causing n to reduce the revenue of both parties (competitive dissipation).	$0 \leq n \leq 1$
r	Marginal Infrastructure Cost coefficient for the government's infrastructure improvement.	$r = l^k$
l	Infrastructure Cost Elasticity, regulating the sensitivity of the government's construction cost to capacity improvements (k).	$l > 0$
g	Marginal Heritage Retrofitting Cost coefficient for the IHD.	$g = j^w$
j	Heritage Retrofitting Cost Elasticity, regulating the sensitivity of the IHD's renovation cost to the activation rate (w).	$j > 0$
f	Marginal Functional Replacement Cost coefficient for NCMs' business format upgrading.	$f = i^v$
i	Commercial Upgrading Cost Elasticity, regulating the sensitivity of NCMs' upgrading cost to the functional mix (v).	$i > 0$
s	Differential Rent Synergy coefficient, representing the impact of the three parties' proactive behaviors on the IHD's revenue. In state $E_1(1,1,1)$, the coefficient is s_1 , and so on until s_8 in state $E_8(0,0,0)$.	$s_1 = k \cdot a_1 + w \cdot a_2 + v \cdot a_3;$ $s_2 = k \cdot a_1 + w \cdot a_2;$ $\dots$ $s_7 = v \cdot a_3;$ $s_8 = 0$
a_1	Contribution weight of infrastructure (k) to the Differential Rent Synergy (s).	$a_1 + a_2 + a_3 = 1$
a_2	Contribution weight of heritage activation (w) to the Differential Rent Synergy (s).	
a_3	Contribution weight of functional mix (v) to the Differential Rent Synergy (s).	
d	Spatial Positive Spillover coefficient, representing the impact of the three parties' proactive behaviors on NCMs' revenue. In state $E_1(1,1,1)$, the coefficient is d_1 , and so on until d_8 in state $E_8(0,0,0)$.	$d_1 = k \cdot b_1 + w \cdot b_2 + v \cdot b_3;$ $d_2 = k \cdot b_1 + w \cdot b_2;$ $\dots$ $d_7 = v \cdot b_3;$ $d_8 = 0$
b_1	Contribution weight of infrastructure (k) to the Spatial Positive Spillover (d).	$b_1 + b_2 + b_3 = 1$
b_2	Contribution weight of heritage activation (w) to the Spatial Positive Spillover (d).	
b_3	Contribution weight of functional mix (v) to the Spatial Positive Spillover (d).	
u	Socio-ecological Comprehensive Benefit coefficient, representing the impact of the three parties' proactive behaviors on the LG's urban operational revenue. In state $E_1(1,1,1)$, the coefficient is u_1 , and so on until u_8 in state $E_8(0,0,0)$.	$u_1 = k \cdot c_1 + w \cdot c_2 + v \cdot c_3;$ $u_2 = k \cdot c_1 + w \cdot c_2;$ $\dots$ $u_7 = v \cdot c_3;$ $u_8 = 0$
c_1	Contribution weight of infrastructure (k) to the Socio-ecological Comprehensive Benefit (u).	$c_1 + c_2 + c_3 = 1$

c ₂	Contribution weight of heritage activation (w) to the Socio-ecological Comprehensive Benefit (u).	
c ₃	Contribution weight of functional mix (v) to the Socio-ecological Comprehensive Benefit (u).	
B _{g1}	Base revenue for the LG's status quo regulation strategy.	
B _{g2}	Base incremental revenue for the LG's proactive intervention strategy.	
C _{g1}	Base cost for the LG's status quo regulation strategy.	
C _{g2}	Base incremental cost for the LG's proactive intervention strategy.	
R _{g1}	Subsidy provided by the LG to the IHD under proactive policies.	R _{g1} = p ₁ ·C _{h2} ·g
R _{g2}	Subsidy provided by the LG to NCMs for upgrading costs under proactive policies.	R _{g2} = p ₂ ·C _{p2} ·f
B _{h1}	Revenue for the IHD's low-value rent-seeking and idling strategy.	
B _{h2}	Base incremental revenue for the IHD's adaptive reuse and revitalization strategy.	
C _{h1}	Cost for the IHD's low-value rent-seeking and idling strategy.	
C _{h2}	Base incremental cost for the IHD's adaptive reuse and revitalization strategy.	
B _{p1}	Revenue for NCMs' status quo operation (free-ride) strategy.	
B _{p2}	Base incremental revenue for NCMs' symbiotic upgrading strategy.	
C _{p1}	Cost for NCMs' status quo operation (free-ride) strategy.	
C _{p2}	Base incremental cost for NCMs' symbiotic upgrading strategy.	
R _{p1}	Profit share transferred from NCMs to the IHD in state E _i (1,1,1).	R _{p1} = q·B _{p2} ·d ₁
R _{p2}	Profit share transferred from NCMs to the IHD in state E ₅ (0,1,1).	R _{p2} = q·B _{p2} ·d ₅

3.2. Establishing and Solving the Evolutionary Game Model

Based on the above assumptions and related variables, the pay-off matrix for the tripartite evolutionary game model is obtained Table 2.

Table 2. Pay-off Matrix for the Tripartite Evolutionary Game.

IHD	Adaptive Reuse and Revitalization (y)		Low-Value Rent-Seeking and Idling (1-y)		
NCMs	symbiotic Upgrading (z)	Status Quo Operation (1-z)	Symbiotic Upgrading (z)	Status Quo Op-eration (1-z)	
LG	proactive regeneration (x)	$E_1(1,1,1)$	$E_2(1,1,0)$	$E_3(1,0,1)$	$E_4(1,0,0)$
		$B_{g1} + B_{g2} \cdot u_1 - C_{g1} - C_{g2} \cdot r - R_{g1} - R_{g2}$	$B_{g1} + B_{g2} \cdot u_2 - C_{g1} - C_{g2} \cdot r - R_{g1}$	$B_{g1} + B_{g2} \cdot u_3 - C_{g1} - C_{g2} \cdot r - R_{g2}$	$B_{g1} + B_{g2} \cdot u_4 - C_{g1} - C_{g2} \cdot r$
		$m \cdot (B_{h1} + B_{h2} \cdot s_1) - C_{h1} - C_{h2} \cdot g + R_{g1} + R_{p1}$	$m \cdot (B_{h1} + B_{h2} \cdot s_2) - C_{h1} - C_{h2} \cdot g + R_{g1}$	$n \cdot B_{h1} \cdot (1 + s_3) - C_{h1}$	$B_{h1} \cdot (1 + s_4) - C_{h1}$
		$B_{p1} + B_{p2} \cdot d_1 - C_{p1} - C_{p2} \cdot f - R_{p1} + R_{g2}$	$B_{p1} \cdot (1 + d_2) - C_{p1}$	$n \cdot (B_{p1} + B_{p2} \cdot d_3) - C_{p1} - C_{p2} \cdot f + R_{g2}$	$n \cdot B_{p1} \cdot (1 + d_4) - C_{p1}$
	status quo regulation (1-x)	$E_5(0,1,1)$	$E_6(0,1,0)$	$E_7(0,0,1)$	$E_8(0,0,0)$
		$B_{g1} \cdot (1 + u_5) - C_{g1}$	$B_{g1} \cdot (1 + u_6) - C_{g1}$	$B_{g1} \cdot (1 + u_7) - C_{g1}$	$B_{g1} \cdot (1 + u_8) - C_{g1}$
		$m \cdot (B_{h1} + B_{h2} \cdot s_5) - C_{h1} - C_{h2} \cdot g + R_{p2}$	$m \cdot (B_{h1} + B_{h2} \cdot s_6) - C_{h1} - C_{h2} \cdot g$	$n \cdot B_{h1} \cdot (1 + s_7) - C_{h1}$	$B_{h1} \cdot (1 + s_8) - C_{h1}$
		$B_{p1} + B_{p2} \cdot d_5 - C_{p1} - C_{p2} \cdot f - R_{p2}$	$B_{p1} \cdot (1 + d_6) - C_{p1}$	$n \cdot (B_{p1} + B_{p2} \cdot d_7) - C_{p1} - C_{p2} \cdot f$	$n \cdot B_{p1} \cdot (1 + d_8) - C_{p1}$

Expected return of LG's proactive regeneration behavior (E_{g1}):

$$E_{g1} = y \cdot z \cdot (B_{g1} + B_{g2} \cdot u_1 - C_{g1} - C_{g2} \cdot r - R_{g1} - R_{g2}) + y \cdot (1-z) \cdot (B_{g1} + B_{g2} \cdot u_2 - C_{g1} - C_{g2} \cdot r - R_{g1}) + (1-y) \cdot z \cdot (B_{g1} + B_{g2} \cdot u_3 - C_{g1} - C_{g2} \cdot r - R_{g2}) + (1-y) \cdot (1-z) \cdot (B_{g1} + B_{g2} \cdot u_4 - C_{g1} - C_{g2} \cdot r) \quad (1)$$

Expected return of LG's regulatory behavior of maintaining the status quo (E_{g2}):

$$E_{g2} = y \cdot z \cdot (B_{g1} \cdot (1 + u_5) - C_{g1}) + y \cdot (1 - z) \cdot (B_{g1} \cdot (1 + u_6) - C_{g1}) + (1 - y) \cdot z \cdot (B_{g1} \cdot (1 + u_7) - C_{g1}) + (1 - y) \cdot (1 - z) \cdot (B_{g1} \cdot (1 + u_8) - C_{g1}) \quad (2)$$

Mean expected earnings for LG (E_{g3}):

$$E_{g3} = x \cdot E_{g1} + (1 - x) \cdot E_{g2} \quad (3)$$

Replicator dynamic equation for LG, $F(x) = x \cdot (E_{g1} - E_{g3})$, where

$$\begin{aligned} F(x) = & x \cdot (1 - x) \cdot ((y \cdot z \cdot (B_{g1} + B_{g2} \cdot (k \cdot c_1 + w \cdot c_2 + v \cdot c_3) - C_{g1} - C_{g2} \cdot (l^k) - p_1 \cdot C_{h2} \cdot (j^w) - p_2 \cdot C_{p2} \cdot (i^v)) \\ & + y \cdot (1 - z) \cdot (B_{g1} + B_{g2} \cdot (k \cdot c_1 + w \cdot c_2) - C_{g1} - C_{g2} \cdot (l^k) - p_1 \cdot C_{h2} \cdot (j^w)) \\ & + (1 - y) \cdot z \cdot (B_{g1} + B_{g2} \cdot (k \cdot c_1 + v \cdot c_3) - C_{g1} - C_{g2} \cdot (l^k) - p_2 \cdot C_{p2} \cdot (i^v)) \\ & + (1 - y) \cdot (1 - z) \cdot (B_{g1} + B_{g2} \cdot (k \cdot c_1) - C_{g1} - C_{g2} \cdot (l^k))) - (y \cdot z \cdot (B_{g1} \cdot (1 + (w \cdot c_2 + v \cdot c_3)) - C_{g1}) \\ & + y \cdot (1 - z) \cdot (B_{g1} \cdot (1 + (w \cdot c_2)) - C_{g1}) + (1 - y) \cdot z \cdot (B_{g1} \cdot (1 + (v \cdot c_3)) - C_{g1}) + (1 - y) \cdot (1 - z) \cdot (B_{g1} - C_{g1}))) \end{aligned} \quad (4)$$

Expected return of IHD's adaptive reuse and revitalization behavior (E_{h1}):

$$\begin{aligned} E_{h1} = & x \cdot z \cdot (m \cdot (B_{h1} + B_{h2} \cdot s_1) - C_{h1} - C_{h2} \cdot g + R_{g1} + R_{p1}) + (1 - x) \cdot z \cdot (m \cdot (B_{h1} + B_{h2} \cdot s_5) - C_{h1} - C_{h2} \cdot g + R_{p2}) \\ & + x \cdot (1 - z) \cdot (m \cdot (B_{h1} + B_{h2} \cdot s_2) - C_{h1} - C_{h2} \cdot g + R_{g1}) + (1 - x) \cdot (1 - z) \cdot (m \cdot (B_{h1} + B_{h2} \cdot s_6) - C_{h1} - C_{h2} \cdot g) \end{aligned} \quad (5)$$

Expected return of IHD's low-value rent-seeking and idling behavior (E_{h2}):

$$\begin{aligned} E_{h2} = & x \cdot z \cdot (n \cdot B_{h1} \cdot (1 + s_3) - C_{h1}) + (1 - x) \cdot z \cdot (n \cdot B_{h1} \cdot (1 + s_7) - C_{h1}) \\ & + x \cdot (1 - z) \cdot (B_{h1} \cdot (1 + s_4) - C_{h1}) + (1 - x) \cdot (1 - z) \cdot (B_{h1} \cdot (1 + s_8) - C_{h1}) \end{aligned} \quad (6)$$

Mean expected earnings for IHD (E_{h3}):

$$E_{h3} = y \cdot E_{h1} + (1 - y) \cdot E_{h2} \quad (7)$$

Replicator dynamic equation for IHD, $F(y) = y \cdot (E_{h1} - E_{h3})$, where

$$\begin{aligned} F(y) = & y \cdot (1 - y) \cdot ((x \cdot z \cdot (m \cdot (B_{h1} + B_{h2} \cdot (k \cdot a_1 + w \cdot a_2 + v \cdot a_3)) - C_{h1} - C_{h2} \cdot (j^w) + p_1 \cdot C_{h2} \cdot (j^w) \\ & + q \cdot B_{p2} \cdot (k \cdot b_1 + w \cdot b_2 + v \cdot b_3)) + (1 - x) \cdot z \cdot (m \cdot (B_{h1} + B_{h2} \cdot (w \cdot a_2 + v \cdot a_3)) - C_{h1} - C_{h2} \cdot (j^w) \\ & + q \cdot B_{p2} \cdot (w \cdot b_2 + v \cdot b_3)) + x \cdot (1 - z) \cdot (m \cdot (B_{h1} + B_{h2} \cdot (k \cdot a_1 + w \cdot a_2)) - C_{h1} - C_{h2} \cdot (j^w) + p_1 \cdot C_{h2} \cdot (j^w)) \\ & + (1 - x) \cdot (1 - z) \cdot (m \cdot (B_{h1} + B_{h2} \cdot (w \cdot a_2)) - C_{h1} - C_{h2} \cdot (j^w))) - (x \cdot z \cdot (n \cdot B_{h1} \cdot (1 + (k \cdot a_1 + v \cdot a_3)) \\ & - C_{h1}) + (1 - x) \cdot z \cdot (n \cdot B_{h1} \cdot (1 + (v \cdot a_3)) - C_{h1}) + x \cdot (1 - z) \cdot (B_{h1} \cdot (1 + (k \cdot a_1)) - C_{h1}) + (1 - x) \cdot (1 - z) \cdot (B_{h1} - C_{h1}))) \end{aligned} \quad (8)$$

Expected return of NCMs' symbiotic upgrading behavior (E_{p1}):

$$\begin{aligned} E_{p1} = & x \cdot y \cdot (B_{p1} + B_{p2} \cdot d_1 - C_{p1} - C_{p2} \cdot f - R_{p1} + R_{g2}) + (1 - x) \cdot y \cdot (B_{p1} + B_{p2} \cdot d_5 - C_{p1} - C_{p2} \cdot f - R_{p2}) \\ & + x \cdot (1 - y) \cdot (n \cdot (B_{p1} + B_{p2} \cdot d_3) - C_{p1} - C_{p2} \cdot f + R_{g2}) + (1 - x) \cdot (1 - y) \cdot (n \cdot (B_{p1} + B_{p2} \cdot d_7) - C_{p1} - C_{p2} \cdot f) \end{aligned} \quad (9)$$

Expected return of NCMs' status quo operation behavior (E_{p2}):

$$\begin{aligned} E_{p2} = & x \cdot y \cdot (B_{p1} \cdot (1 + d_2) - C_{p1}) + (1 - x) \cdot y \cdot (B_{p1} \cdot (1 + d_6) - C_{p1}) \\ & + x \cdot (1 - y) \cdot (n \cdot B_{p1} \cdot (1 + d_4) - C_{p1}) + (1 - x) \cdot (1 - y) \cdot (n \cdot B_{p1} \cdot (1 + d_8) - C_{p1}) \end{aligned} \quad (10)$$

Mean expected earnings for NCMs (E_{p3}):

$$E_{p3} = z \cdot E_{p1} + (1 - z) \cdot E_{p2} \quad (11)$$

Replicator dynamic equation for NCMs' responses $F(z) = z \cdot (E_{p1} - E_{p3})$, where

$$\begin{aligned} F(z) = & z \cdot (1 - z) \cdot ((x \cdot y \cdot (B_{p1} + B_{p2} \cdot (k \cdot b_1 + w \cdot b_2 + v \cdot b_3) - C_{p1} - C_{p2} \cdot (i^v) - q \cdot B_{p2} \cdot (k \cdot b_1 + w \cdot b_2 + v \cdot b_3) \\ & + p_2 \cdot C_{p2} \cdot (i^v)) + (1 - x) \cdot y \cdot (B_{p1} + B_{p2} \cdot (w \cdot b_2 + v \cdot b_3) - C_{p1} - C_{p2} \cdot (i^v) - q \cdot B_{p2} \cdot (w \cdot b_2 + v \cdot b_3)) \\ & + x \cdot (1 - y) \cdot (n \cdot (B_{p1} + B_{p2} \cdot (k \cdot b_1 + v \cdot b_3)) - C_{p1} - C_{p2} \cdot (i^v) + p_2 \cdot C_{p2} \cdot (i^v)) \\ & + (1 - x) \cdot (1 - y) \cdot (n \cdot (B_{p1} + B_{p2} \cdot (v \cdot b_3)) - C_{p1} - C_{p2} \cdot (i^v))) - (x \cdot y \cdot (B_{p1} \cdot (1 + (k \cdot b_1 + w \cdot b_2)) - C_{p1}) \\ & + (1 - x) \cdot y \cdot (B_{p1} \cdot (1 + (w \cdot b_2)) - C_{p1}) + x \cdot (1 - y) \cdot (n \cdot B_{p1} \cdot (1 + (k \cdot b_1)) - C_{p1}) + (1 - x) \cdot (1 - y) \cdot (n \cdot B_{p1} - C_{p1}))) \end{aligned} \quad (12)$$

3.3. Equilibrium Analysis of Evolutionarily Stable Strategies

The solution to the system of replicator dynamics equations ($F(x) = 0$, $F(y) = 0$, $F(z) = 0$) yields eight pure-strategy equilibrium points for the tripartite game: $E_1(1,1,1)$, $E_2(1,1,0)$, $E_3(1,0,1)$, $E_4(1,0,0)$, $E_5(0,1,1)$, $E_6(0,1,0)$, $E_7(0,0,1)$ and $E_8(0,0,0)$ [51–53].

The local stability of each equilibrium point within this system of differential equations is assessed by analyzing the eigenvalues of its associated Jacobian matrix. For the tripartite evolutionary game, the Jacobian matrix J is given by:

$$J = \begin{pmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{pmatrix} = \begin{pmatrix} (2x-1) \cdot g(1) & x \cdot (x-1) \cdot g(2) & x \cdot (x-1) \cdot g(3) \\ y \cdot (1-y) \cdot g(4) & (1-2y) \cdot g(5) & y \cdot (y-1) \cdot g(6) \\ z \cdot (1-z) \cdot g(7) & z \cdot (z-1) \cdot g(8) & (2z-1) \cdot g(9) \end{pmatrix} \quad (13)$$

where

$$g(1) = C_{g2} \cdot l^k - B_{g2} \cdot c_1 \cdot k + C_{p2} \cdot i^v \cdot p_2 \cdot z + C_{h2} \cdot j^w \cdot p_1 \cdot y + B_{g1} \cdot c_2 \cdot w \cdot y + B_{g1} \cdot c_3 \cdot v \cdot z - B_{g2} \cdot c_2 \cdot w \cdot y - B_{g2} \cdot c_3 \cdot v \cdot z$$

$$g(2) = C_{h2} \cdot j^w \cdot p_1 + B_{g1} \cdot c_2 \cdot w - B_{g2} \cdot c_2 \cdot w$$

$$g(3) = C_{p2} \cdot i^v \cdot p_2 + B_{g1} \cdot c_3 \cdot v - B_{g2} \cdot c_3 \cdot v$$

$$g(4) = C_{h2} \cdot j^w \cdot p_1 - B_{h1} \cdot a_1 \cdot k + B_{h2} \cdot a_1 \cdot k \cdot m + B_{h1} \cdot a_1 \cdot k \cdot z - B_{h1} \cdot a_1 \cdot k \cdot n \cdot z + B_{p2} \cdot b_1 \cdot k \cdot q \cdot z$$

$$g(5) = B_{h1} \cdot m - B_{h1} + B_{h1} \cdot z - C_{h2} \cdot j^w - B_{h1} \cdot n \cdot z + C_{h2} \cdot j^w \cdot p_1 \cdot x - B_{h1} \cdot a_1 \cdot k \cdot x + B_{h2} \cdot a_2 \cdot m \cdot w + B_{h2} \cdot a_1 \cdot k \cdot m \cdot x + B_{h1} \cdot a_1 \cdot k \cdot x \cdot z + B_{h2} \cdot a_3 \cdot m \cdot v \cdot z - B_{h1} \cdot a_3 \cdot n \cdot v \cdot z + B_{p2} \cdot b_3 \cdot q \cdot v \cdot z + B_{p2} \cdot b_2 \cdot q \cdot w \cdot z - B_{h1} \cdot a_1 \cdot k \cdot n \cdot x \cdot z + B_{p2} \cdot b_1 \cdot k \cdot q \cdot x \cdot z$$

$$g(6) = B_{h1} - B_{h1} \cdot n + B_{h1} \cdot a_1 \cdot k \cdot x + B_{h2} \cdot a_3 \cdot m \cdot v - B_{h1} \cdot a_3 \cdot n \cdot v + B_{p2} \cdot b_3 \cdot q \cdot v + B_{p2} \cdot b_2 \cdot q \cdot w - B_{h1} \cdot a_1 \cdot k \cdot n \cdot x + B_{p2} \cdot b_1 \cdot k \cdot q \cdot x$$

$$g(7) = C_{p2} \cdot i^v \cdot p_2 - B_{p1} \cdot b_1 \cdot k \cdot n + B_{p2} \cdot b_1 \cdot k \cdot n - B_{p1} \cdot b_1 \cdot k \cdot y + B_{p2} \cdot b_1 \cdot k \cdot y + B_{p1} \cdot b_1 \cdot k \cdot n \cdot y - B_{p2} \cdot b_1 \cdot k \cdot n \cdot y - B_{p2} \cdot b_1 \cdot k \cdot q \cdot y$$

$$g(8) = B_{p1} \cdot b_2 \cdot w - B_{p2} \cdot b_3 \cdot v - B_{p2} \cdot b_2 \cdot w + B_{p1} \cdot b_1 \cdot k \cdot x - B_{p2} \cdot b_1 \cdot k \cdot x + B_{p2} \cdot b_3 \cdot n \cdot v + B_{p2} \cdot b_3 \cdot q \cdot v + B_{p2} \cdot b_2 \cdot q \cdot w - B_{p1} \cdot b_1 \cdot k \cdot n \cdot x + B_{p2} \cdot b_1 \cdot k \cdot n \cdot x + B_{p2} \cdot b_1 \cdot k \cdot q \cdot x$$

$$g(9) = C_{p2} \cdot i^v - C_{p2} \cdot i^v \cdot p_2 \cdot x - B_{p2} \cdot b_3 \cdot n \cdot v - B_{p2} \cdot b_3 \cdot v \cdot y + B_{p1} \cdot b_2 \cdot w \cdot y - B_{p2} \cdot b_2 \cdot w \cdot y + B_{p1} \cdot b_1 \cdot k \cdot n \cdot x - B_{p2} \cdot b_1 \cdot k \cdot n \cdot x + B_{p1} \cdot b_1 \cdot k \cdot x \cdot y - B_{p2} \cdot b_1 \cdot k \cdot x \cdot y + B_{p2} \cdot b_3 \cdot n \cdot v \cdot y + B_{p2} \cdot b_3 \cdot q \cdot v \cdot y + B_{p2} \cdot b_2 \cdot q \cdot w \cdot y - B_{p1} \cdot b_1 \cdot k \cdot n \cdot x \cdot y + B_{p2} \cdot b_1 \cdot k \cdot n \cdot x \cdot y + B_{p2} \cdot b_1 \cdot k \cdot q \cdot x \cdot y$$

This study employs standard Jacobian eigenvalue analysis to evaluate the stability of the eight candidate equilibrium points in the tripartite replicator dynamics system. Following Lyapunov's direct method, an equilibrium is identified as an Evolutionarily Stable Strategy (ESS) only when all three associated eigenvalues possess negative real parts ($\lambda < 0$). Instability is concluded if any eigenvalue is positive ($\lambda > 0$). The calculated eigenvalues (λ) corresponding to each equilibrium point are summarized in Table 3.

Table 3. Calculated Eigenvalues and Stability Conditions for the Eight Pure-Strategy Equilibria (Local asymptotic stability requires all eigenvalues to have negative real parts).

ESS	λ_1	λ_2	λ_3
E_1 (1,1,1)	$B_{g1} \cdot (c_3 \cdot v + c_2 \cdot w + 1) - B_{g1} - B_{g2} \cdot (c_1 \cdot k + c_3 \cdot v + c_2 \cdot w) + C_{g2} \cdot l^k + C_{p2} \cdot i^v \cdot p_2 + C_{h2} \cdot j^w \cdot p_1$	$C_{h2} \cdot j^w - m \cdot (B_{h1} + B_{h2} \cdot (a_1 \cdot k + a_3 \cdot v + a_2 \cdot w)) - B_{p2} \cdot q \cdot (b_1 \cdot k + b_3 \cdot v + b_2 \cdot w) - C_{h2} \cdot j^w \cdot p_1 + B_{h1} \cdot n \cdot (a_1 \cdot k + a_3 \cdot v + 1)$	$B_{p1} \cdot (b_1 \cdot k + b_2 \cdot w + 1) - B_{p1} - B_{p2} \cdot (b_1 \cdot k + b_3 \cdot v + b_2 \cdot w) + C_{p2} \cdot i^v + B_{p2} \cdot q \cdot (b_1 \cdot k + b_3 \cdot v + b_2 \cdot w) - C_{p2} \cdot i^v \cdot p_2$
E_2 (1,1,0)	$B_{g1} \cdot (c_2 \cdot w + 1) - B_{g1} - B_{g2} \cdot (c_1 \cdot k + c_2 \cdot w) + C_{g2} \cdot l^k + C_{h2} \cdot j^w \cdot p_1$	$B_{h1} \cdot (a_1 \cdot k + 1) - m \cdot (B_{h1} + B_{h2} \cdot (a_1 \cdot k + a_2 \cdot w)) + C_{h2} \cdot j^w - C_{h2} \cdot j^w \cdot p_1$	$B_{p1} - B_{p1} \cdot (b_1 \cdot k + b_2 \cdot w + 1) + B_{p2} \cdot (b_1 \cdot k + b_3 \cdot v + b_2 \cdot w) - C_{p2} \cdot i^v - B_{p2} \cdot q \cdot (b_1 \cdot k + b_3 \cdot v + b_2 \cdot w) + C_{p2} \cdot i^v \cdot p_2$
E_3 (1,0,1)	$B_{g1} \cdot (c_3 \cdot v + 1) - B_{g1} - B_{g2} \cdot (c_1 \cdot k + c_3 \cdot v) + C_{g2} \cdot l^k + C_{p2} \cdot i^v \cdot p_2$	$m \cdot (B_{h1} + B_{h2} \cdot (a_1 \cdot k + a_3 \cdot v + a_2 \cdot w)) - C_{h2} \cdot j^w + B_{p2} \cdot q \cdot (b_1 \cdot k + b_3 \cdot v + b_2 \cdot w) + C_{h2} \cdot j^w \cdot p_1 - B_{h1} \cdot n \cdot (a_1 \cdot k + a_3 \cdot v + 1)$	$C_{p2} \cdot i^v - n \cdot (B_{p1} + B_{p2} \cdot (b_1 \cdot k + b_3 \cdot v)) - C_{p2} \cdot i^v \cdot p_2 + B_{p1} \cdot n \cdot (b_1 \cdot k + 1)$

E ₄ (1,0,0)	$C_{g2} \cdot l^k - B_{g2} \cdot c_1 \cdot k$	$m \cdot (B_{h1} + B_{h2} \cdot (a_1 \cdot k + a_2 \cdot w)) - B_{h1} \cdot (a_1 \cdot k + 1) - C_{h2} \cdot j^w + C_{h2} \cdot j^w \cdot p_1$	$n \cdot (B_{p1} + B_{p2} \cdot (b_1 \cdot k + b_3 \cdot v)) - C_{p2} \cdot i^v + C_{p2} \cdot i^v \cdot p_2 - B_{p1} \cdot n \cdot (b_1 \cdot k + 1)$
E ₅ (0,1,1)	$B_{g1} - B_{g1} \cdot (c_3 \cdot v + c_2 \cdot w + 1) + B_{g2} \cdot (c_1 \cdot k + c_3 \cdot v + c_2 \cdot w) - C_{g2} \cdot l^k - C_{p2} \cdot i^v \cdot p_2 - C_{h2} \cdot j^w \cdot p_1$	$C_{h2} \cdot j^w - m \cdot (B_{h1} + B_{h2} \cdot (a_3 \cdot v + a_2 \cdot w)) + B_{h1} \cdot n \cdot (a_3 \cdot v + 1) - B_{p2} \cdot q \cdot (b_3 \cdot v + b_2 \cdot w)$	$B_{p1} \cdot (b_2 \cdot w + 1) - B_{p1} - B_{p2} \cdot (b_3 \cdot v + b_2 \cdot w) + C_{p2} \cdot i^v + B_{p2} \cdot q \cdot (b_3 \cdot v + b_2 \cdot w)$
E ₆ (0,1,0)	$B_{g1} - B_{g1} \cdot (c_2 \cdot w + 1) + B_{g2} \cdot (c_1 \cdot k + c_2 \cdot w) - C_{g2} \cdot l^k - C_{h2} \cdot j^w \cdot p_1$	$B_{h1} + C_{h2} \cdot j^w - m \cdot (B_{h1} + B_{h2} \cdot a_2 \cdot w)$	$B_{p1} - B_{p1} \cdot (b_2 \cdot w + 1) + B_{p2} \cdot (b_3 \cdot v + b_2 \cdot w) - C_{p2} \cdot i^v - B_{p2} \cdot q \cdot (b_3 \cdot v + b_2 \cdot w)$
E ₇ (0,0,1)	$B_{g1} - B_{g1} \cdot (c_3 \cdot v + 1) + B_{g2} \cdot (c_1 \cdot k + c_3 \cdot v) - C_{g2} \cdot l^k - C_{p2} \cdot i^v \cdot p_2$	$m \cdot (B_{h1} + B_{h2} \cdot (a_3 \cdot v + a_2 \cdot w)) - C_{h2} \cdot j^w - B_{h1} \cdot n \cdot (a_3 \cdot v + 1) + B_{p2} \cdot q \cdot (b_3 \cdot v + b_2 \cdot w)$	$B_{p1} \cdot n + C_{p2} \cdot i^v - n \cdot (B_{p1} + B_{p2} \cdot b_3 \cdot v)$
E ₈ (0,0,0)	$B_{g2} \cdot c_1 \cdot k - C_{g2} \cdot l^k$	$m \cdot (B_{h1} + B_{h2} \cdot a_2 \cdot w) - C_{h2} \cdot j^w - B_{h1}$	$n \cdot (B_{p1} + B_{p2} \cdot b_3 \cdot v) - C_{p2} \cdot i^v - B_{p1} \cdot n$

Based on the analysis of equilibrium stability and practices in China, the construction of an industrial heritage “cultural–commercial ecosystem” can be divided into three stages, corresponding to different equilibria and revealing the evolutionary process of the policy lever system (the conceptual pathway is illustrated in Figure 2).

(1) Initiation Phase: Systemic Gridlock (Stable at E₈(0,0,0))

At this stage (Figure 2a), the entire policy lever system fails to function effectively. The Spatial Synergy Lever (w, v) is inefficient, unable to generate sufficient added value to cover costs; The Behavioral Regulation Lever is weak, characterized by insufficient value cognition (low m) and a lack of negative externality constraints (weak effect of n); The Economic Incentive Lever (p₁, p₂, q) is absent. The payoff of any proactive strategy falls below that of the status quo, locking the system into a collective action dilemma of mutual inaction. In terms of governance arrangements, this state corresponds to a “Market Failure” scenario where the absence of effective policy levers prevents any spontaneous renewal.

(2) Growth Phase: Heritage Activation (Stable at E₂(1,1,0))

At this stage (Figure 2b), the government achieves a single-point breakthrough through dominant intervention. Enhancing infrastructure (k) and providing subsidies (p₁) significantly improve the IHD’s payoff expectations, driving its active participation (y → 1). However, The Economic Incentive Lever remains incomplete due to the absence of the Value Capture and Recycling mechanism (q). Consequently, the free-ride strategy (z = 0) remains the dominant strategy for NCMs. The system stabilizes at an asymmetric equilibrium of government-led activation with merchant passivity. This reflects a typical “Government-Dominant Model” often seen in the early stages of Chinese urban renewal, characterized by high fiscal input but low market spillover.

(3) Maturation Phase: Synergistic Development (Stable at E₁(1,1,1))

This stage (Figure 2c) marks the achievement of synergistic optimization within the multi-dimensional lever system. The Spatial Synergy Lever (k, w, v) couples efficiently, creating a solid foundation for value-added growth. The Economic Incentive Lever completes its critical transformation, shifting from initial subsidies (p) to a mature, market-based Value Capture and Recycling mechanism (q), which institutionally resolves the free-riding dilemma and aligns the interests of the IHD and NCMs. Simultaneously, The Behavioral Regulation Lever (high m, effective n) provides cognitive and regulatory safeguards. Consequently, the mutually reinforcing proactive strategies adopted by all three parties establish a virtuous cycle, driving the system’s convergence to an optimal synergistic equilibrium. This state represents the ideal “Collaborative Governance” mode, where the interests of the LG, IHD and NCMs are aligned through institutionalized value loops.

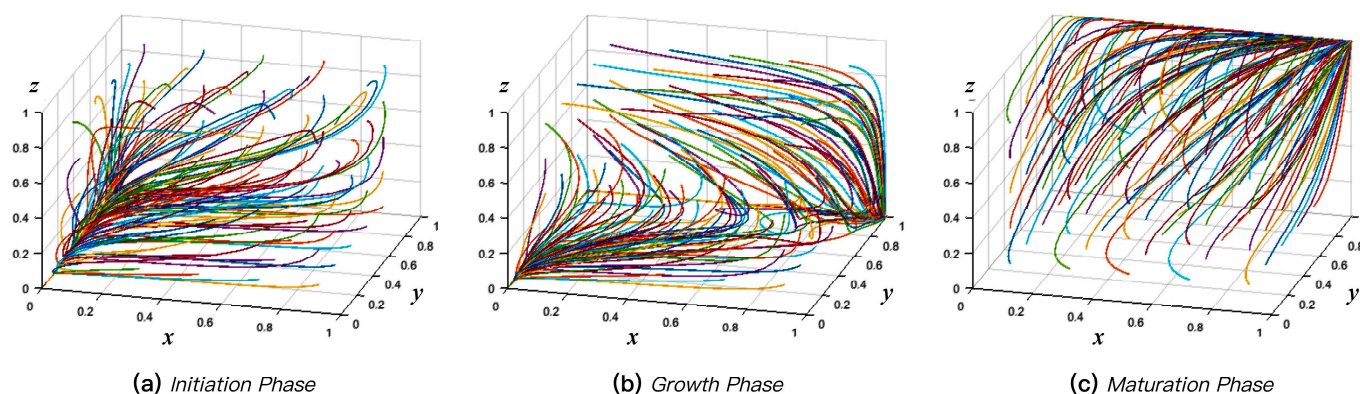


Figure 2. Evolutionary pathway diagrams derived from the tripartite game model, illustrating the (a) Initial, (b) Developmental, and (c) Consolidated phases of the system.

4. Simulation Results and Analysis

Promoting the effective synergistic development of Chinese industrial heritage sites and advancing them to the maturation phase is a crucial objective for urban renewal in many Chinese cities, as it also helps maximize the investment returns for all stakeholders. Therefore, this study selects the stable point $E_1(1,1,1)$ as the focal research state. We performed numerical simulations in MATLAB 2024 (b) to generate the strategy evolution paths for each player. This methodology graphically illustrates how key parameters within the replicator dynamics shape the evolutionary process and outcomes of the three-party game [54].

4.1. Calibration Framework and Parameterization Strategy

This section aims to establish rigorous parameter assignment criteria for the numerical simulation of the tripartite evolutionary game model. The goal is to ensure that the results effectively validate the theoretical mechanisms of the three major policy levers—spatial, economic, and behavioral—and reflect the realistic context of industrial heritage renewal in China. The setting of baseline values and ranges for all parameters is centrally focused on revealing the independent thresholds, interactive effects, and dynamic pathways of these levers.

The parameterization of The Spatial Synergy Lever (k, w, v) is calibrated not only against publicly available data from typical domestic projects (e.g., Beijing Shougang Park, Shanghai Yangpu Riverfront) [55–60] but is also deeply rooted in depicting the economic law of increasing marginal costs inherent in high-quality renewal. By setting cost elasticity coefficients greater than 1 ($l, j, i > 1$), improvements in Infrastructure Carrying Capacity (k), Heritage Spatial Activation Rate (w), and Degree of Functional Mix (v) correspond to exponentially rising costs. This reproduces resource constraints and nonlinear threshold effects within the model, aligning with the research framework for multi-criteria optimization decision-making in the adaptive reuse of industrial heritage [61].

The parameterization of The Economic Incentive Lever (p_1, p_2, q) simulates the transition of driving forces from external subsidies to an endogenous cycle. The value ranges for the Government Subsidy Coefficients (p_1, p_2) are informed by diverse fiscal support practices in urban renewal [58], and their dynamic adjustment effects draw on findings from related evolutionary game studies concerning the fine design of government incentive tools. The setting of the core parameter—the Value Capture and Recycling Coefficient (q)—focuses on investigating its critical threshold for triggering the internalization of pos-

itive externalities among private sectors. This is key to overcoming the free-riding dilemma and constructing a market-based closed loop, a mechanism akin to incentive conditions that foster cooperative equilibria in structured game populations [62].

The parameters for The Behavioral Regulation Lever (m , n) are grounded in behavioral science and spatial governance research. The baseline value of the Place Perception Coefficient (m) is set below 1 to quantify stakeholders' systematic myopic undervaluation of heritage cultural value. This aligns with research conclusions on enhancing heritage site satisfaction by increasing social impact and community engagement [25]. The Spatial Negative Externality Coefficient (n) measures the value degradation caused by low-end business formats on the area. Its intervention logic resonates with spatial governance studies that aim to shape compliant behavior and avoid the tragedy of the commons through rules and oversight [62]. All parameters underwent systematic iterative fine-tuning to ensure the model can robustly reproduce the complete evolutionary spectrum from a game stalemate to a synergistic equilibrium.

Ultimately, through systematic iterative refinement, all parameters were calibrated to ensure the model can stably replicate multiple potential equilibria from stalemate to synergy under baseline conditions, providing a robust foundation for subsequent sensitivity analysis and policy combination simulations. The baseline values for all parameters are detailed in Table 4.

Table 4. Assumptions of initial parameter values before simulation. (Note: The cost-related variables (l , j , i , f) are defined as base coefficients for the power functions within the replicator dynamic system to simulate the non-linear marginal costs associated with multi-stakeholder participation.).

Parameter Category	Parameter	Value	Parameter	Value	Parameter	Value
The Spatial Synergy Lever Parameters	k	0.4	w	0.6	v	0.3
The Economic Incentive Lever Parameters	p_1	0.2	p_2	0.1	q	0.2
The Behavioral Regulation Lever Parameters	m	0.8	n	0.6		
Nonlinear Cost Elasticity	l	6	j	7	i	5
Revenue Weight Coefficients	a_1	0.2	a_2	0.4	a_3	0.4
	b_1	0.2	b_2	0.5	b_3	0.3
	c_1	0.1	c_2	0.3	c_3	0.6
LG's Revenue & Cost Parameters	B_{g1}	3	B_{g2}	78		
	C_{g1}	5	C_{g2}	6		
IHD's Revenue & Cost Parameters	B_{h1}	1	B_{h2}	35		
	C_{h1}	5	C_{h2}	5		
NCMs' Revenue & Cost Parameters	B_{p1}	4	B_{p2}	80		
	C_{p1}	3	C_{p2}	10		

4.2. Nonlinear Sensitivity Results of Physical Spatial Elements

Infrastructure resilience (k), Heritage Spatial Activation Rate (w), and Degree of Functional Mix (v) constitute the three cornerstones of the synergistic “people-place-industry” system in industrial heritage. In Figures 3–5, the values of k , w , and v are sequentially set to 0.2, 0.4, 0.6, 0.8, and 1.0; 0.4, 0.5, 0.6, 0.7, and 0.8; and 0.1, 0.3, 0.5, 0.7, and 0.9, respectively. The tripartite simulation results reveal the diminishing marginal utility and threshold effects of physical spatial interventions.

First, Infrastructure Carrying Capacity (k) exhibits a strict threshold for fiscal sustainability. As shown in Figure 3, moderately increasing k (from 0.2 to 0.4) can effectively improve the investment environment and promote cooperation among the three parties.

However, once the investment becomes excessively high ($k \geq 0.8$), the exponentially rising marginal cost ($C_{g2} \cdot 1^k$) rapidly depletes fiscal surpluses, causing the government's strategy (x) to collapse toward a non-cooperative state. This quantitatively substantiates the necessity of preventing massive demolition and construction and pursuing moderate renewal.

Second, Heritage Spatial Activation Rate (w) and Degree of Functional Mix (v) demonstrate a more pronounced positive lock-in effect. As shown in Figures 4 and 5, when w and v are at low levels, the system remains in a stalemate. However, once they surpass the critical thresholds of $w > 0.6$ and $v > 0.5$, the synergy gain coefficients are significantly amplified, driving both the IHD and NCMs to rapidly converge towards the ideal state $E_1(1,1,1)$. This indicates that, compared to mere hardware renovation, value creation based on content implantation (w) and business format symbiosis (v) is the core endogenous driver for supporting the formation of a multi-layered value network and propelling the system's transition from government-led to synergistic symbiosis.

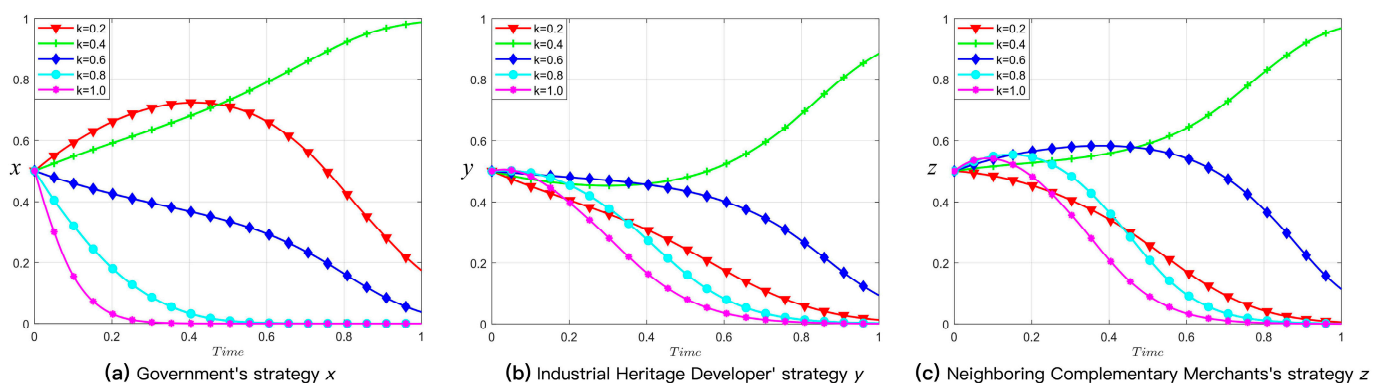


Figure 3. Evolutionary trajectories of strategies under different k . The specific values of k for each trajectory are 0.2, 0.4, 0.6, 0.8, and 1.0, as indicated in the legend. All simulations share a common initial strategy profile of $(x_0, y_0, z_0) = (0.5, 0.5, 0.5)$. Subplots (a–c) depict the strategic evolution of the Local Government (x), the Industrial Heritage Developer (y), and the Neighboring Complementary Merchants (z), respectively. The horizontal axis, labeled “Time (Simulation Steps)”, denotes the iteration count in the numerical simulation.

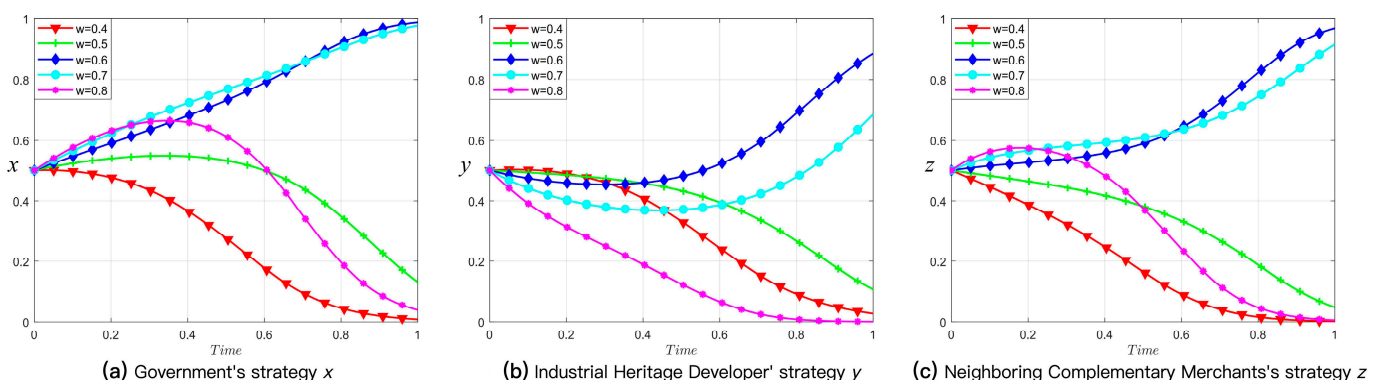


Figure 4. Evolutionary trajectories of strategies under different w . The specific values of w for each trajectory are 0.4, 0.5, 0.6, 0.7, and 0.8, as indicated in the legend. All simulations share a common initial strategy profile of $(x_0, y_0, z_0) = (0.5, 0.5, 0.5)$. Subplots (a–c) depict the strategic evolution of the Local Government (x), the Industrial Heritage Developer (y), and the Neighboring Complementary Merchants (z), respectively. The horizontal axis, labeled “Time (Simulation Steps)”, denotes the iteration count in the numerical simulation.

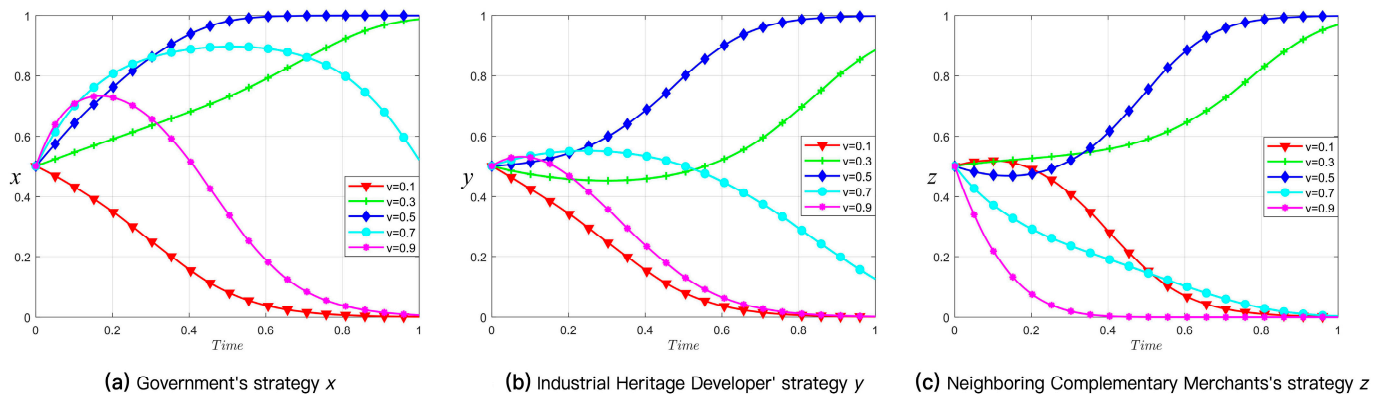


Figure 5. Evolutionary trajectories of strategies under different v . The specific values of v for Each trajectory are 0.1, 0.3, 0.5, 0.7, and 0.9, as indicated in the legend. All simulations share a common initial strategy profile of $(x_0, y_0, z_0) = (0.5, 0.5, 0.5)$. Subplots (a–c) depict the strategic evolution of the Local Government (x), the Industrial Heritage Developer (y), and the Neighboring Complementary Merchants (z), respectively. The horizontal axis, labeled “Time (Simulation Steps)”, denotes the iteration count in the numerical simulation.

4.3. Regulatory Effects of Policy Levers and Benefit Loops

Addressing the “collective action dilemma,” this section simulates the distinct mechanisms of external incentives (p_1, p_2) and the endogenous contract (q). In Figures 6–8, the values of p_1, p_2 , and q are sequentially set to 0.0, 0.2, 0.4, 0.6, and 0.8; 0.1, 0.3, 0.5, 0.7, and 0.9; and 0.0, 0.1, 0.2, 0.3, and 0.4, respectively. This aims to reveal how parameter design can resolve the collective action dilemma caused by free-riding. The simulation results validate the necessity of transitioning the driving mechanism from fiscal dependence to a value closed loop.

The results indicate that fiscal subsidies (p_1, p_2) exhibit a significant double-edged nature. As shown in Figures 6 and 7, during the initiation phase, moderately increasing the development subsidy (p_1 from 0.2 to 0.4) and the mixed-use subsidy (p_2) can effectively lower market entry barriers, driving the strategies of the IHD and NCMs from negative to positive. However, subsidies face a strict fiscal constraint boundary: when $p_1 > 0.6$, excessive fiscal expenditure leads to a sharp decline in the government’s expected payoff, forcing its strategy (x) to rapidly collapse toward 0, ultimately destabilizing the system. This provides a quantitative basis for the subsequent discussion’s proposal to establish a subsidy exit mechanism.

Secondly, the Value Capture and Recycling Coefficient (q) acts as the ballast for sustaining long-term synergy. As shown in Figure 8, when $q < 0.1$, the IHD lacks continuous revitalization motivation due to insufficient compensation for positive externalities. Only when q surpasses the critical threshold of approximately 0.2 can the benefit recycling achieved through contracts (e.g., revenue sharing) effectively internalize externalities, driving the three parties to robustly converge to the Pareto-optimal state $E_1(1,1,1)$. This result strongly supports the core argument in the Conclusion regarding the construction of a market-based beneficiary-pays benefit closed loop.

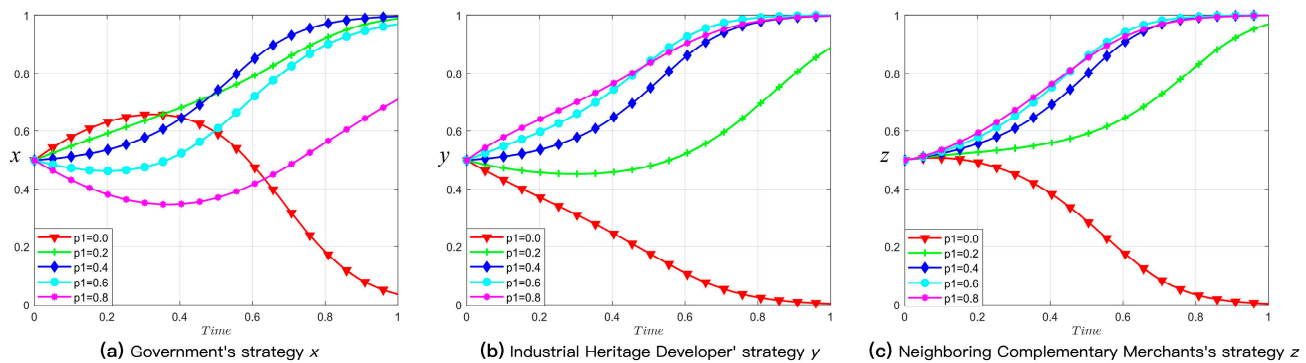


Figure 6. Evolutionary trajectories of strategies under different p_1 . The specific values of p_1 for each trajectory are 0.0, 0.2, 0.4, 0.6, and 0.8, as indicated in the legend. All simulations share a common initial strategy profile of $(x_0, y_0, z_0) = (0.5, 0.5, 0.5)$. Subplots (a–c) depict the strategic evolution of the Local Government (x), the Industrial Heritage Developer (y), and the Neighboring Complementary Merchants (z), respectively. The horizontal axis, labeled “Time (Simulation Steps)”, denotes the iteration count in the numerical simulation.

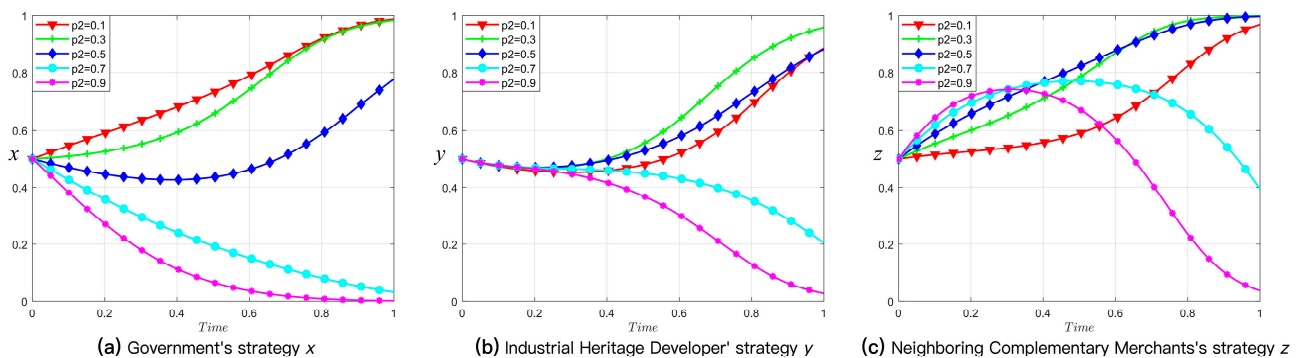


Figure 7. Evolutionary trajectories of strategies under different p_2 . The specific values of p_2 for each trajectory are 0.1, 0.3, 0.5, 0.7, and 0.9, as indicated in the legend. All simulations share a common initial strategy profile of $(x_0, y_0, z_0) = (0.5, 0.5, 0.5)$. Subplots (a–c) depict the strategic evolution of the Local Government (x), the Industrial Heritage Developer (y), and the Neighboring Complementary Merchants (z), respectively. The horizontal axis, labeled “Time (Simulation Steps)”, denotes the iteration count in the numerical simulation.

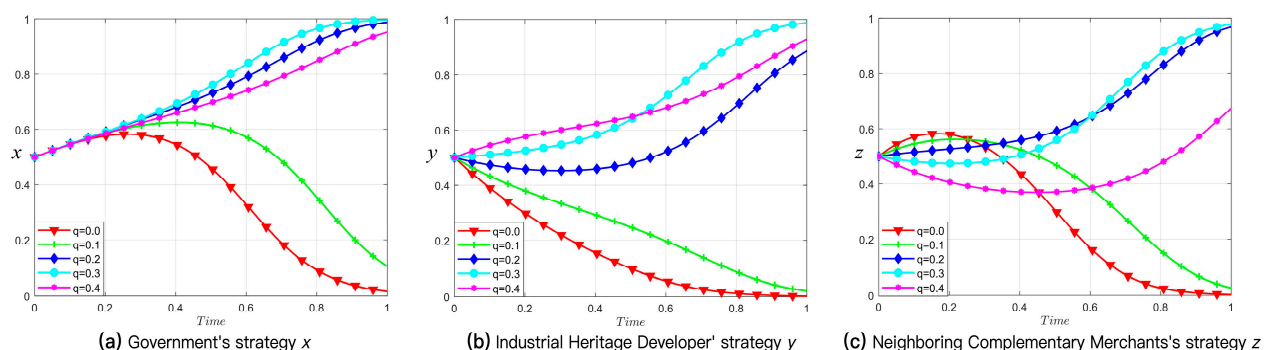


Figure 8. Evolutionary trajectories of strategies under different q . The specific values of q for Each trajectory are 0.0, 0.1, 0.2, 0.3, and 0.4, as indicated in the legend. All simulations share a common initial strategy profile of $(x_0, y_0, z_0) = (0.5, 0.5, 0.5)$. Subplots (a–c) depict the strategic evolution of the Local Government (x), the Industrial Heritage Developer (y), and the Neighboring Complementary Merchants (z), respectively. The horizontal axis, labeled “Time (Simulation Steps)”, denotes the iteration count in the numerical simulation.

4.4. Dual Regulation of Psychological Cognition and Spatial Competition

This study further introduces a behavioral economics perspective to explore the regulatory effects of micro-level psychology and spatial competition on macro-level evolution. In Figures 9 and 10, the values of m and n are sequentially set to 0.6, 0.8, 1.0, 1.2, and 1.4; and 0.2, 0.4, 0.6, 0.8, and 1.0, respectively. The tripartite simulation results reveal the dual governance logic of cognitive guidance and rule-based constraint.

First, the Place Perception Coefficient (m) plays a critical role as a value amplifier. As shown in Figure 9, when the IHD exhibits myopic bias ($m = 0.6$), the undervaluation of the heritage's long-tail brand premium leads to a rapid decline in cooperative willingness. Conversely, when m is elevated above 1.2 through cultural narratives and brand reinvention, the enhanced value identification can significantly offset initial cost pressures, driving an exponential acceleration in strategy evolution. This confirms the assertion in the Discussion that cognitive intervention can effectively correct agents' psychological discount rates.

Secondly, the Spatial Negative Externality Coefficient (n) validates a governance-forcing effect. As shown in Figure 10, in the absence of effective landscape control (low n), the broken windows effect of low-end business formats causes severe dissipation of regional value, forcing the IHD to withdraw ($y \rightarrow 0$). In contrast, implementing strict spatial access controls and negative list management (maintaining a high n value) not only protects the value of the core asset but also activates a Red Queen Effect within the system—the survival pressure of advance or regress compels NCMs to proactively choose symbiotic upgrading ($z \rightarrow 1$) to avoid market elimination. This indicates that hard spatial rules serve as the institutional foundation ensuring the fulfillment of soft economic contracts.

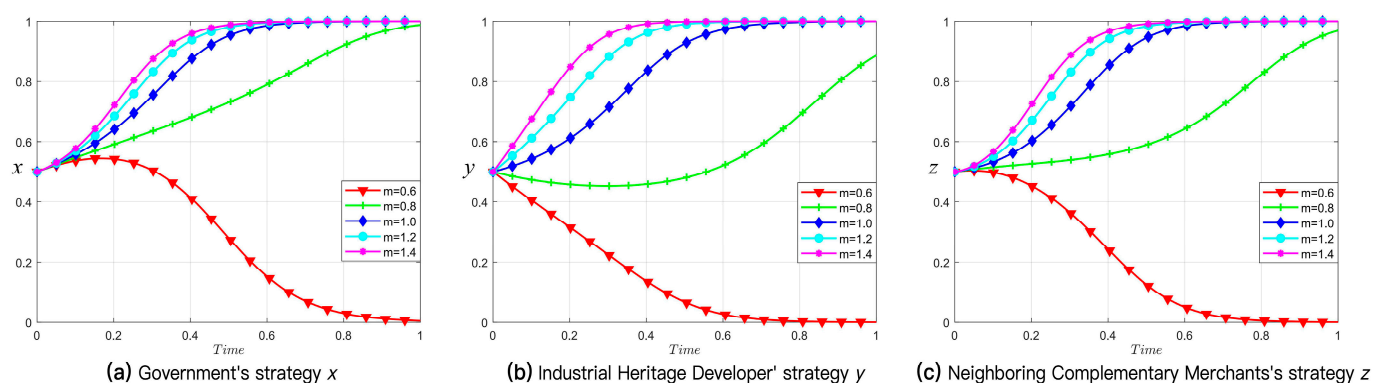


Figure 9. Evolutionary trajectories of strategies under different p_1 . The specific values of m for each trajectory are 0.6, 0.8, 1.0, 1.2, and 1.4, as indicated in the legend. All simulations share a common initial strategy profile of $(x_0, y_0, z_0) = (0.5, 0.5, 0.5)$. Subplots (a–c) depict the strategic evolution of the Local Government (x), the Industrial Heritage Developer (y), and the Neighboring Complementary Merchants (z), respectively. The horizontal axis, labeled “Time (Simulation Steps)”, denotes the iteration count in the numerical simulation.

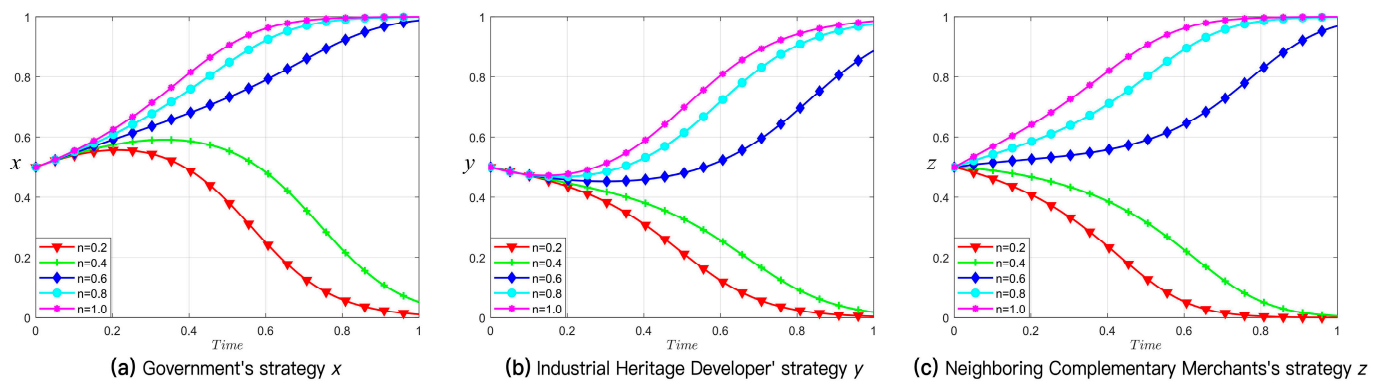


Figure 10. Evolutionary trajectories of strategies under different n . The specific values of n for each trajectory are 0.2, 0.4, 0.6, 0.8, and 1.0, as indicated in the legend. All simulations share a common initial strategy profile of $(x_0, y_0, z_0) = (0.5, 0.5, 0.5)$. Subplots (a–c) depict the strategic evolution of the Local Government (x), the Industrial Heritage Developer (y), and the Neighboring Complementary Merchants (z), respectively. The horizontal axis, labeled “Time (Simulation Steps)”, denotes the iteration count in the numerical simulation.

4.5. Stability Analysis of Synergistic Regeneration Paths

This section implements a cross-simulation analysis of the tripartite strategy evolution under controlled settings to investigate the interaction effects among the multi-dimensional policy levers and to assess the robustness of the system. By setting the Heritage Spatial Activation Rate (w) to 0.7 and the Degree of Functional Mix (v) to 0.5, and then sequentially assigning values of 0.2, 0.4, 0.6, 0.8, and 1.0 to the Infrastructure Carrying Capacity (k), behavioral evolutionary simulations are obtained that illustrate the impact of different land carrying capacity improvement coefficients on the three parties’ strategic evolution, as shown in Figure 11. Subfigure (a) shows the behavioral evolution simulation for the government, subfigure (b) for the industrial heritage developer, and subfigure (c) for the neighboring complementary merchants.

The simulation results reveal significant synergistic multiplier and risk-buffering effects. Compared to the stringent condition in Section 4.2’s single-factor analysis where cooperation was only stable around $k = 0.4$, Figure 11 shows that, with high-quality content empowerment (elevated w and v), the market entities (IHD, NCMs) maintain robust cooperative resilience across a broad range of $k \in [0.4, 0.8]$, rapidly converging to the ideal steady state E_1 . This indicates that high-quality cultural and business format content can effectively hedge against the uncertainty risks brought by fluctuations in infrastructure supply.

For the government (x), although the high investment at $k = 0.8$ brings initial fiscal pressure, the strategy ultimately returns to an active state. This is due to the exponential growth in comprehensive social benefit (u) triggered by the increases in w and v . This result strongly supports the theoretical judgment in Section 5 (Discussion) regarding achieving value leapfrogging and enhancing system fault tolerance through the nonlinear coupling of spatial elements.

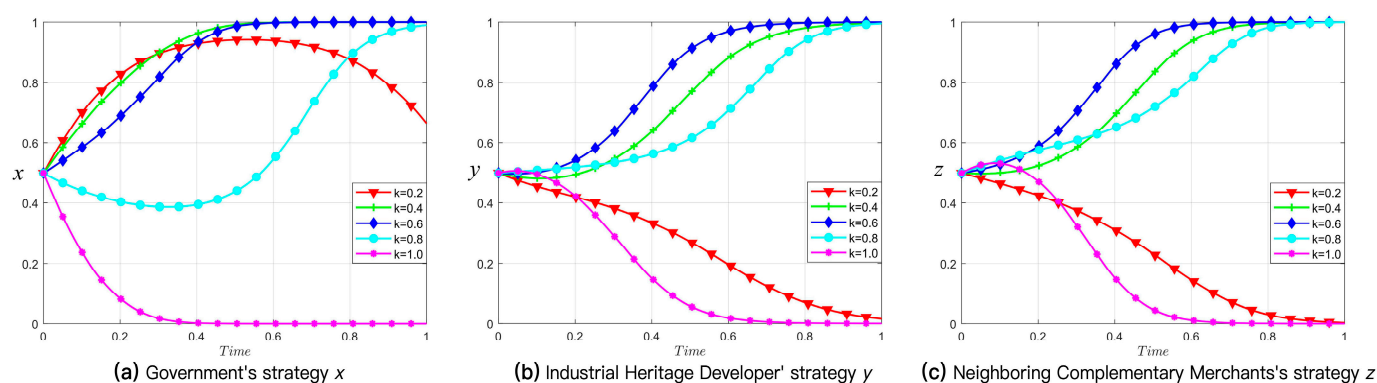


Figure 11. Simulated strategy evolution under a fixed setting ($w = 0.7$, $v = 0.5$) while varying the infrastructure coefficient ($k = 0.2, 0.4, 0.6, 0.8, 1.0$). All simulations share a common initial strategy profile of $(x_0, y_0, z_0) = (0.5, 0.5, 0.5)$. Subplots (a–c) depict the strategic evolution of the Local Government (x), the Industrial Heritage Developer (y), and the Neighboring Complementary Merchants (z), respectively. The horizontal axis, labeled “Time (Simulation Steps)”, denotes the iteration count in the numerical simulation.

5. Discussion

This section aims to elucidate the underlying mechanisms, interactive relationships, and dynamic evolutionary patterns of the three-dimensional policy levers. It further synthesizes these insights into a dynamic governance framework.

5.1. Key Findings and Micro-Level Mechanisms of the Levers

The simulation results first clearly delineate the unique micro-level operational pathways of the three levers. The core function of The Spatial Synergy Lever (k, w, v) is to construct a multi-layered value generation network. Within this, Infrastructure Carrying Capacity (k) forms the physical foundation network, Heritage Spatial Activation Rate (w) creates the cultural-significance network, and the Degree of Functional Mix (v) catalyzes the socio-economic network. Improving a single element has limited effect, but when the three synergistically surpass critical thresholds (e.g., $w > 0.6$, $v > 0.5$), they trigger strong network externalities, enabling a nonlinear leap in value [6,16]. Conversely, for the government, maintaining the infrastructure coefficient (k) below the fiscal safety threshold of 0.8 is essential to avoid budget depletion. This mechanistically explains why fragmented, single-building retrofits often reach an impasse, whereas systematic district-scale renewal possesses greater vitality, precisely aligning with the policy orientation of preventing massive demolition and construction and promoting mixed-use development. This theoretical mechanism is empirically illustrated by the transformation of Beijing Shougang Park. In the model’s terms, the project’s success in the “Growth Phase” relied heavily on the government’s massive investment in infrastructure carrying capacity (k) and the initial policy subsidies (p_1) associated with the 2022 Winter Olympics. These interventions broke the initial deadlock ($E_8 \rightarrow E_2$), creating the necessary threshold for the subsequent influx of high-end commercial and technological formats (v) to establish a sustainable value loop (E_1).

The Economic Incentive Lever (p_1, p_2, q) follows the logic of incentive compatibility in its institutional evolution. Initial government subsidies (p_1, p_2) serve as an exogenous, powerful intervention, primarily functioning to break the participation constraints of market entities and overcome high sunk costs in the startup phase [13,27]. However, sustainable momentum must arise from internal market-based benefit balance. The Value Capture and Recycling mechanism (q) addresses the long-term incentive compatibility constraint precisely by internalizing positive externalities through contractual design [12,25].

The critical value of q identified in the simulations (approximately 0.2) essentially marks the key juncture where the system's driving force successfully transitions from being government-led to market-operated. Moreover, the simulation defines a "golden window" for initial development subsidies (p_1 between 0.2 and 0.4) to catalyze the market, while simultaneously warning that exceeding the 0.6 fiscal risk line will lead to system destabilization.

The role of The Behavioral Regulation Lever (m, n) is more profound, reshaping the decision-making environment at cognitive and normative levels. Enhancing the Place Perception Coefficient (m) is akin to setting a value cognitive anchor, aiming to correct decision-makers' systematic undervaluation of long-term cultural and social worth due to myopia [14,18]. This requires realizing value through in-depth cultural excavation and fostering public participation. Regulating the Spatial Negative Externality Coefficient (n), conversely, is like establishing a behavioral normative anchor. It defines the cost of free-riding or low-end lock-in through clear rules such as business format access control and landscape management, thereby guiding collective action towards a benign order [17,24]. Together, they provide indispensable psychological stability and institutional guarantees for economic cooperation. Specifically, elevating m above 1.2 acts as a powerful "value discovery" signal, significantly accelerating the transition toward a synergistic equilibrium.

5.2. Lever Interactions and Dynamic Synergistic Evolution

More critically, this research reveals that these levers do not operate in isolation. Deep interactive effects exist among them, and the healthy development of the system demands that policy combinations dynamically adapt to the renewal stage.

Levers exhibit both strategic substitution relationships—for instance, robust spatial synergy (high w, v) can effectively reduce dependence on high fiscal subsidies (high p), offering a pathway for renewal under fiscal constraints. They also demonstrate reinforcing complementarity relationships—for example, effective behavioral regulation (high m, n) can significantly enhance the credibility and enforcement efficiency of market-based contracts (q). Governance failure often stems from a mismatch of levers; for instance, promoting benefit-sharing (q) alone may fail due to rampant free-riding in the absence of rules (low n).

The three-phase evolutionary path from stalemate (E_8) to activation (E_2) and then to synergy (E_1), as revealed by the simulations, corresponds exactly to the inherent requirement for adaptive sequential shifts in policy focus. During the initiation/breakthrough phase, the core is behavioral priming and economic backstopping (elevating m , providing p) to build trust, share risks, and motivate the IHD to take the lead. In the growth/activation phase, the focus must shift to spatial empowerment and rule-building (elevating k, w, v , and setting n) to solidify the overall regional value foundation, prevent disorder in surrounding areas, and break the project-island dilemma. In the maturation/steady-state phase, success hinges on completing the benefit loop and governance institutionalization (establishing q , solidifying m, n). This ensures the system's endogenous sustainability through market-based value-recycling linkages and long-term cognitive-behavioral norms. The premature or delayed application of any lever may lock the system into a non-ideal equilibrium state.

Intuitively, the simulation reveals that these critical thresholds act as "tipping points" for governance transition. They imply that policy efficacy is non-linear: only when specific levers (e.g., the value recycling rate q) cross these thresholds can the system transition from a subsidized project to a self-sustaining ecosystem.

Based on this mechanistic understanding, this study advocates for a shift in policy design from a static, isolated tool mentality to a dynamic, integrated toolbox thinking.

This implies that policymakers need to select and dynamically combine tools from an integrative toolbox based on the initial endowments of a specific project, such as its location and property rights structure. Concretely, abstract lever parameters can be translated into operational policy packages: a planning bundled package to ensure the synchronized provision of spatial elements (k , w , v); a subsidy conversion fund to facilitate a smooth transition of incentive methods from p to q ; and community credit and landscape covenants to integrate value recognition (m) with behavioral norms (n). This provides a quantifiable and adjustable implementation framework for constructing the sustainable urban renewal model—featuring government guidance, market operation, and public participation—advocated in the Guiding Opinions. Excellent governance lies in accurately diagnosing the system's current stage and core constraints, and then flexibly deploying multi-dimensional policy tools for coordinated intervention. This approach aims to maximize governance efficacy and achieve the ultimate goal of sustainable system development.

6. Conclusions

Confronting the prevalent challenge of multi-stakeholder collaboration dilemmas in industrial heritage renewal, this study constructs a tripartite evolutionary game model integrating the LG, IHD, and NCMs. It innovatively proposes and validates a space–economy–behavior multi-dimensional policy lever system as the core analytical framework. The research confirms that successfully transforming industrial heritage from an idle asset into a cultural–commercial ecosystem cannot rely on the forceful intervention of any single policy. It fundamentally depends on the systematic coordination and dynamic adaptation of the three categories of policy levers.

The main findings can be summarized as follows. First, spatial synergy forms the physical foundation for value leapfrogging. The nonlinear coupling of Infrastructure Carrying Capacity (k), Heritage Spatial Activation Rate (w), and Degree of Functional Mix (v) can trigger significant network and multiplier effects, serving as the prerequisite for attracting market participation and creating sustainable value-added benefits. Second, economic incentives must undergo a critical transition in driving forces. Policy effectiveness relies on a smooth shift from initial government fiscal subsidies (p) to a later-stage market-based Value Capture and Recycling mechanism (q). The latter is the core institutional arrangement for resolving the free-riding dilemma and building a long-term community of shared interests. Third, behavioral regulation provides deep-level governance safeguards. The Place Perception Coefficient (m) and Spatial Negative Externality control (n) jointly shape the cognitive expectations and social norms for cooperation, establishing the indispensable psychological and institutional foundation for the effective execution of economic contracts. Simulations reveal that the healthy evolution of the system follows a phased pattern of initiation–growth–maturation, necessitating policy interventions that follow a temporally precise, adaptive and sequential combination.

The theoretical contribution of this study lies in integrating the three often separately discussed dimensions of spatial synergy, economic incentive, and behavioral regulation into a unified, quantifiable evolutionary game framework of a policy lever system for the first time, offering a new theoretical lens for analyzing complex urban renewal governance. At the practical level, its core implication is the need for a shift in policymaking mentality—from enacting single policies to designing a dynamic policy toolbox. The key to decision-making is accurately diagnosing the development stage and core constraints of the renewal system, and then synergistically applying the three lever categories for combined intervention. This guides multiple stakeholders from gaming confrontation towards synergistic symbiosis, ultimately achieving sustainable development encompassing economic vitality, cultural continuity, and community well-being.

This study employs necessary simplifications regarding agent heterogeneity and macro-environmental fluctuations in its model. Future research could employ methods such as multi-agent simulation and case comparative analysis incorporating geographic information to validate and extend this framework at a finer granularity, further enhancing its explanatory power and generalizability.

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References

1. United Nations General Assembly. Transforming Our World: The 2030 Agenda for Sustainable Development (A/RES/70/1). 2015. Available online: <https://sdgs.un.org/2030agenda> (accessed on 1 December 2025).
2. Sun, M.; Chen, C. Renovation of industrial heritage sites and sustainable urban regeneration in post-industrial Shanghai. *J. Urban Aff.* **2023**, *45*, 729–752.
3. Calvo Juarez, M.; Real, M.; Dal Cin, G. From industrial neighbourhoods to regenerative territories: Blueprinting the practices of (emerging) distributed networks of fabrication. In Proceedings of the Fab 24 “Fabricating Equity” Research Papers (Fab24), Puebla, Mexico, 3–9 August 2024. <https://doi.org/10.5281/zenodo.13221335>.
4. Mukherjee, A.; Banerji, H.; Chattopadhyay, S. Enhancing Resilience Through Sustainable Management of Brownfield Industrial Heritage: A Case of Kolkata. In *Urban Planning and Design for Megacities in the Global South: Smart and Sustainable Development*; Springer Nature: Singapore, 2025; pp. 193–218.
5. Nocca, F.; Bosone, M.; Orabona, M. Multicriteria Evaluation Framework for Industrial Heritage Adaptive Reuse: The Role of the ‘Intrinsic Value’. *Land* **2024**, *13*, 1266.
6. Han, S.H.; Li, Y.; Yu, P. What makes a successful industrial heritage park?—China’s experience based on the ecosystem cultural services perspective. *Urban Resil. Sustain.* **2024**, *2*, 93–109.
7. Arcila-Garrido, M.; Ramírez-Guerrero, G.; García-Onetti, J.; Chica-Ruiz, J.A. Socio-ecosystem Services for Integrated Heritage Assessment (IHA): A new approach to valuing cultural heritage. *Boletín Asoc. Geógrafos Españoles* **2024**, *101*, 3497. <https://doi.org/10.21138/bage.3497>.
8. General Office of the Central Committee of the Communist Party of China; General Office of the State Council. Guiding Opinions on Promoting Urban Renewal Actions in a Sustained Manner. 2025. Available online: https://www.gov.cn/zhengce/202505/content_7023882.htm (accessed on 1 December 2025).
9. Zhong, D.; Huang, P.; Xiong, G.; Li, H. Renewal strategies of industrial heritage based on placeness theory: The case of Guangzhou, China. *Cities* **2024**, *155*, 105407.
10. Wu, Y.; Han, F. Reconfiguring abandoned urban landscapes: A multidimensional place-making approach towards sustainable transformation of industrial waterfronts. *Landsc. Ecol. Eng.* **2025**, *21*, 175–190.
11. Pomesano, L.; Falanga, R. Cartography of industrial heritage. Transformation and future of dismissed industries in the eastern zone of Lisbon. *Archit. Struct. Constr.* **2025**, *5*, 19.

12. Li, S. Don't Simply Equate the Renewal of Old Factory Areas with Creating Cultural and Creative Parks. 21st Century Business Herald. Available online: <https://baijiahao.baidu.com/s?id=1836720603216990258&wfr=spider&for=pc> (accessed on 1 December 2025). (In Chinese)
13. Wei, R. Heritage Construction in China: Negotiation and Contestation of Decision-Making and Heritage Discourses. Doctoral Dissertation, London School of Economics and Political Science, London, UK, 2024.
14. López, M.I.; Herrera, R.; Arriagada, C.; Morales, M.F.; Carmona, P. Agents of change, power, and resistance in the patterns of change of an industrial heritage district: The case of Bellavista, Chile (1970–2019). *Urban Morphol.* **2023**, *27*, 143–160.
15. Golbach, J.A.M. Heritage for People, Not for Profit: Ruins, Regeneration and the Right to the City in Contemporary Rome. Doctoral Dissertation, University College London, London, UK, 2024.
16. Zheng, S.; Zhang, Y.; Yao, Y.; Yan, H.; Hao, Z. Revitalizing the Industrial Heritages with Ecological Approaches: Implications from Cases. In *International Symposium on Advancement of Construction Management and Real Estate*; Springer Nature: Singapore, 2023; pp. 1893–1906.
17. He, F.; Yi, Y.; Si, Y. Evolution process of urban industrial land redevelopment in China: A perspective of original land users. *Land* **2024**, *13*, 548.
18. Zhong, J.; Li, B.; Shen, G.; Zhou, L. Ally, deterrence, or leverage in the tripartite game? The effects of indirect stakeholders in historic urban regeneration. *Cities* **2024**, *149*, 104931.
19. Yuan, D.; Li, J.; Li, Q.; Fu, Y. Tripartite Evolutionary Game and Policy Simulation: Strategic Governance in the Redevelopment of the Urban Village in Guangzhou. *Land* **2024**, *13*, 1867.
20. Li, L.I.; Qian, W.U.; Zhang, X. Evolutionary game analysis between governments and enterprises in the regeneration of old industrial buildings. *Oper. Res. Manag. Sci.* **2022**, *31*, 69.
21. Wang, J.; Xu, H.; Wang, M. Technology diffusion considering technological progress and multiple policy combinations based on evolutionary game theory. *Technol. Soc.* **2025**, *81*, 102799.
22. Zhang, Y.; Liu, C.; Hou, C. Driving mechanisms of green regeneration in old industrial areas under ecological security constraints: Evolutionary game theory oriented toward public satisfaction. *J. Urban Plan. Dev.* **2024**, *150*, 04024008.
23. Jin, W.; Jin, J. Assessing Industrial Heritage Through Collaborative Counter-Mapping: A Case Study of Salts Mill, UK. *Urban Planning* **2024**, *9*, 7976. <https://doi.org/10.17645/up.7976>
24. Ramos, M.A.; Boix, M.; Aussel, D.; Montastruc, L. Development of a multi-leader multi-follower game to design industrial symbioses. *Comput. Chem. Eng.* **2024**, *183*, 108598.
25. Xia, J.; Wang, S.; Cheng, A. Industrial heritage and urban renewal: A quantitative study and optimization strategies for Chengdu East Suburb Memory. *Front. Environ. Sci.* **2025**, *13*, 1537211.
26. Ravaz, B.; Bombenger, P.H.; Capezzali, M.; Meyer, T. Reviewing 20 years of redevelopment trajectories of industrial sites literature and highlighting new research perspectives. *Land Use Policy* **2024**, *146*, 107326.
27. Liang, C.; Chen, Y.B.; Sun, Y.Y. From Scattered Points to Network: Exploring a New Model for the Protection and Utilization of Industrial Heritage—A Case Study of the Chengdu East Suburb Memory Functional Area. In *Beautiful China, Co-Construction, Co-Governance and Sharing, Proceedings of the 2024 China Urban Planning Annual Conference (03 Urban Renewal)*, Hefei, China, 7 September 2024; China Urban Planning Society: Beijing, China, 2024; pp. 373–386. <https://doi.org/10.26914/c.cnkihy.2024.034933>. (In Chinese)
28. Zhang, C.J.; Lu, Q.S.; Gu, Y.; Jiang, X.N. Abandoned Railway Renovation in Urban Regeneration: Impact Analysis of 20 Years of Construction of the China-Russia Railway Park. *Civ. Eng.* **2025**, *14*, 1214–1220. <https://doi.org/10.12677/hjce.2025.145130>. (In Chinese)
29. Stanojev, J.; Gustafsson, C. Multidimensional Spillovers of Cultural Heritage Through Regional Development and Circular Economy. In *Adaptive Reuse of Cultural Heritage: Circular Business, Financial and Governance Models*; Springer International Publishing: Cham, Switzerland, 2024; pp. 321–347.
30. Shi, Q.; Xiao, S.; Dai, Q.; Li, H.; Yang, J. Spatial structure might impede cooperation in evolutionary games with reinforcement learning. *Int. J. Mod. Phys. C* **2022**, *33*, 2250168. <https://doi.org/10.1142/S0129183122501686>.
31. Ding, R.; Wang, X.; Zhao, J.; Gu, C.; Chen, W. Evolutionary dynamics in spatial public goods games with environmental feedbacks. *Chaos Interdiscip. J. Nonlinear Sci.* **2024**, *34*, 123138. <https://doi.org/10.1063/5.0242366>.
32. Han, Z.; Deng, X.; Li, Z.; Huang, X. Mechanism and simulation of intensive use of urban inefficient land based on evolutionary game theory. *J. Asian Econ.* **2024**, *95*, 101840.
33. Communities and Local Government Committee. *House of Commons Communities and Local Government Committee—Sixth Report Regeneration*; The Stationery Office: London, UK, 2011.

34. Vitalization, D.C. Community Improvement Plan. *Policy* **2014**, *8*, 123138.
35. Alan, P.; Rizzo, I. 8 The practice of public intervention. In *The Heritage Game: Economics, Policy, and Practice*; Oxford Academic: Oxford, UK, 2008. <https://doi.org/10.1093/acprof:oso/9780199213177.003.0008>.
36. Zhu, X.X.; Mu, Q.R.; Liang, W.Z. An innovative strategic choice for stakeholders in the Chinese traditional commercial street renewal using evolutionary game theory. *J. Innov. Knowl.* **2022**, *7*, 100225.
37. Fisher, B.; Leite, F.; Weber, R. Value creation, capture, and destruction: Hudson yards and the false promise of self-financing mega-projects. *J. Am. Plan. Assoc.* **2023**, *89*, 134–145.
38. Huang, W.; Wu, J.; Wang, Y. Analysis of the transformation mode of old industrial area based on game theory. In Proceedings of the 5th International Conference on Economic Management and Model Engineering, ICEMME 2023, Beijing, China, 17–19 November 2023.
39. Li, J.; Wang, L. *Multi-Dimensional Collaborative Governance of Urban Sharing Platforms*; Springer: Berlin/Heidelberg, Germany, 2023.
40. Procentese, F.; Gatti, F. Participatory Processes Supporting Heritage Communities: Valorizing Identity Elements and Social Spaces in San Giovanni A Teduccio (Naples). 2021. Available online: <https://www.iris.unina.it/handle/11588/988132> (accessed on 1 December 2025)
41. Antleij, K.; Cooke, S.; Kelly, M.; Kennedy, R.; Pikó, L.; Horan, B. Understanding the social value of Geelong’s design and manufacturing heritage for extended reality. *Heritage* **2023**, *6*, 3043–3062.
42. Magnoni, F.; Valette-Florence, P.; De Barnier, V. Modeling the effects of place heritage and place experience on residents’ behavioral intentions toward a city: A mediation analysis. *J. Bus. Res.* **2021**, *134*, 428–442.
43. Kahneman, D.; Tversky, A. Prospect theory: An analysis of decision under risk. In *Handbook of the Fundamentals of Financial Decision Making: Part I*; The Econometric Society: New Haven, CT, USA, 2013; pp. 99–127.
44. Barberis, N.C. Thirty years of prospect theory in economics: A review and assessment. *J. Econ. Perspect.* **2013**, *27*, 173–196.
45. Rogers, R.W. A protection motivation theory of fear appeals and attitude change1. *J. Psychol.* **1975**, *91*, 93–114.
46. Adriansen, E.R.; Lueg, K. Co-telling Urban Memories: A Case Study of Web-Mediated Narratives of a Danish City’s Industrial Past. In *A World Scientific Encyclopedia of Business Storytelling Set 2: Methodologies and Big Data Analysis of Business Storytelling Volume 3: Business Storytelling Communication*; Word Scientific: Singapore, 2024; pp. 209–232.
47. Wu, T.T.; Liang, X.W. Research on the Failure Mechanism of Industrial Heritage Conservation from the Perspective of Tragedy of the Commons Theory: A Case Study of Guangzhou. *Urban Dev. Stud.* **2025**, *32*, 77–83. (In Chinese)
48. Shoag, D.; Veuger, S. Shops and the city: Evidence on local externalities and local government policy from big-box bankruptcies. *Rev. Econ. Stat.* **2018**, *100*, 440–453.
49. Liu, Y.; Liu, Y.; Chen, X.; Lin, C.; Zhou, Z. Balancing spatial logic and governance objectives for street vending: An optimizing model for dynamic formalization zones. *Cities* **2025**, *160*, 105819.
50. Scotchmer, S.; Shannon, C. Verifiability and group formation in markets. *J. Econ. Theory* **2019**, *183*, 417–477.
51. Taylor, P.D.; Jonker, L.B. Evolutionary stable strategies and game dynamics. *Math. Biosci.* **1978**, *40*, 145–156.
52. Smith, J.M. Evolution and the Theory of Games. In *Did Darwin Get it Right? Essays on Games, Sex and Evolution*; Springer: Boston, MA, USA, 1982; pp. 202–215.
53. Hofbauer, J.; Sigmund, K. *Evolutionary Games and Population Dynamics*; Cambridge university press: Cambridge, UK, 1998.
54. Liu, Y.; Zuo, J.; Pan, M.; Ge, Q.; Chang, R.; Feng, X.; Fu, Y.; Dong, N. The incentive mechanism and decision-making behavior in the green building supply market: A tripartite evolutionary game analysis. *Build. Environ.* **2022**, *214*, 108903.
55. Bo, H.T. Industrial Heritage Regeneration: Approaches to Landscape Preservation and Reinforcement—A Case Study of Three Typical Projects in Beijing Shougang Park. *Archit. J.* **2023**, *4*, 87–93. <https://doi.org/10.19819/j.cnki.ISSN0529-1399.202304018>. (In Chinese)
56. Yu, Y.M. “Liugonghui” in Beijing Shougang Park: A model for urban industrial heritage renewal. *China Bus. J.* <https://doi.org/10.38300/n.cnki.nzgjy.2022.000542>. (In Chinese)
57. Yue, X.Y.; Cai, F.Q.; Zhao, M.C. Research on the Development Strategy of Industrial Heritage Tourism Based on Cultural Memory: A Case Study of Beijing Shougang Park. *Cult. Exch. Between China Foreign Ctries.* **2025**, *2*, 128–130. (In Chinese)
58. Shanghai Municipal Housing and Urban-Rural Development Management Commission. Yangpu Riverfront “Old Industrial Zone” Becomes a New Urban Landmark. Available online: <https://zjw.sh.gov.cn/gqdt/20240304/b759e6c87772400f8d0ee00d0da21c71.html> (accessed on 4 March 2024). (In Chinese)
59. Tang, X.Y. Research on the Renewal and Design of Shanghai Yangpu Riverfront. *Shanghai Arts Crafts* **2025**, *3*, 108–111. (In Chinese)

60. Guo, Y.H.; Wang, J. Research on the Protection and Reuse of Industrial Sites Based on Context Inheritance. In Proceedings of the 14th Annual Conference of the Chinese Society of Landscape Architecture, Nanjing, China, 8–11 July 2024; Chinese Society of Landscape Architecture: Shanghai, China, 2024; pp. 423–427. <https://doi.org/10.26914/c.cnkihy.2024.080114>. (In Chinese)
61. Vizzarri, C.; Sangiorgio, V.; Fatiguso, F.; Calderazzi, A. A holistic approach for the adaptive reuse project selection: The case of the former Enel power station in Bari. *Land Use Policy* **2021**, *111*, 105709.
62. da Silva Rocha, A.B.; Salomão, G.M. Environmental policy regulation and corporate compliance in evolutionary game models with well-mixed and structured populations. *Eur. J. Oper. Res.* **2019**, *279*, 486–501.

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