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Adaptive Reuse of Existing Urban Space for Community Elderly Care: A Tripartite Evolutionary Game of Policy-Dependent Activation and Post-Targeted Maintenance

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Abstract

Adaptive reuse of existing urban space offers a resource-efficient pathway for expanding community elderly-care provision, but physical reuse does not necessarily ensure accessible locations, capable operation, or sustained utilization. This study develops a tripartite evolutionary game involving the government, stock-space provider, and professional elderly-care operator. Effective utilization links spatial accessibility and integrated operation through stand-alone gains and a configuration-generated utilization return, while targeted regulation introduces eligibility screening and differentiated quality incentives. Shanghai provides the institutional context, with Pudong New Area used to construct a case-informed reference configuration rather than an estimated local equilibrium. Results show that quality-invariant basic support can sustain provision without necessarily removing marginal spatial or operational quality barriers. Activation and coordination are sensitive to policy architecture, actor-specific rewards, costs, and the interaction between utilization and policy synergy. Under the modeled separation between basic support and an additional targeted-performance layer, post-targeted maintenance instead depends on configuration-generated utilization returns relative to incremental spatial and operational costs. Here, maintenance denotes local strategic maintainability under a given demand and parameter environment rather than long-term demographic or neighborhood stability. Numerical tests further show that local maintainability does not imply automatic reachability. The findings identify a conditional catalytic-governance mechanism in which targeted intervention can facilitate entry into a maintainable coordinated S_1O_1 configuration without implying permanent targeted-policy dependence or global convergence.

Keywords: urban regeneration; spatial accessibility; utilization complementarity; targeted regulation; catalytic governance

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1. Introduction

Population aging is increasing demand for community-based elderly-care services while built-up cities face growing constraints on additional land, construction, and public-service space. Adaptive reuse offers a resource-efficient response by accommodating new functions within existing urban building stock rather than treating new construction as the

only supply pathway [1–3]. Recent adaptive-reuse research links this strategy to building-life extension, reduction of vacancy and underuse, social-infrastructure provision, and broader sustainable urban regeneration [4–6]. Systematic reviews further show that successful reuse is not defined by physical retention alone, but by a combination of functional, economic, management, socio-cultural, and environmental conditions [7]. This multidimensional perspective is particularly relevant to elderly care because demographic change can create a simultaneous mismatch between underused buildings and rising demand for community services. Recent architectural research has directly demonstrated the potential to transform underused public buildings into elderly-care environments when spatial, structural, circulation, and daylight conditions support long-term adaptability [8]. Shanghai also provides an established urban context in which adaptive reuse has been discussed as part of sustainable inner-city development [9].

For community elderly care, however, converting or supplying floor area does not necessarily ensure effective use. Evidence from China shows that facilities can remain underutilized even after physical coverage has expanded, indicating that provision and realized utilization are analytically distinct [10]. Facility-level research in Chinese cities further demonstrates that walking accessibility, surrounding built-environment conditions, service capacity, functional-space characteristics, and user evaluations are associated with actual use of elderly-care facilities [11–13]. Other studies of home- and community-based services similarly report gaps between service availability, need, and realized utilization, with economic accessibility, enabling resources, service configuration, and user characteristics affecting whether older adults actually use available care [14–16]. These findings suggest that the planning problem is not simply how many facilities are supplied, but whether spatial and operational conditions allow intended services to be repeatedly and effectively used.

Spatial accessibility is therefore important not only as a distributional or proximity measure but also as part of the economic feasibility of adaptive reuse. Recent 15-min-city and elderly-care studies provide a broader accessibility framework and document age-specific accessibility deficits as well as persistent spatial disparities in access to urban amenities and elderly-care resources across different contexts [17–21]. A well-located facility may increase utilization potential through proximity to older residents, public transport, healthcare, and everyday community services. For older adults, however, effective accessibility also depends on pedestrian-route conditions such as continuity, slope, obstacles, crossing safety, and the ease of reaching the facility from surrounding residential areas. At the same time, accessible urban locations often face competing uses and higher alternative-use values. Studies of commercial property in Chinese cities, including Shanghai, show that transit accessibility can be associated with property-value premiums, although the relationship is nonlinear and spatially heterogeneous [22,23]. This evidence does not imply that every more accessible elderly-care site necessarily has a higher rent. Rather, it supports a stylized planning trade-off: securing well-located existing space can improve service-use potential while increasing the opportunity cost borne by the actor controlling that space.

Operation creates a parallel trade-off. Integrated elderly-care models emphasize coordination across services, multidisciplinary delivery, and person-centred organization [24], but these arrangements require additional staffing, management, equipment, and coordination resources. Empirical evidence also cautions against assuming that integrated provision automatically produces uniformly higher utilization; use remains conditioned by accessibility, service capacity, user needs, and local implementation [11,15,16,24]. The relevant planning question is therefore configurational: whether accessible space and capable operation together generate sufficient utilization value to justify the additional burdens borne by different actors. This is especially important in adaptive-reuse projects because

the space provider and the professional operator may face different cost structures and may not benefit equally from the same improvement in service use.

These interdependent decisions make evolutionary game theory (EGT) useful for examining how strategies change when stakeholders are boundedly rational and respond to relative payoffs. Elderly-care EGT research has already developed a substantial literature on government subsidy design, quality supervision, private-sector participation, service formalization, and multi-agent governance [25–33]. Several studies explicitly compare static and dynamic subsidies, periodic subsidy programs, or dynamic combinations of rewards and penalties [25,27,28,34]. Related studies in sustainable urban regeneration and age-friendly renewal likewise use multi-population evolutionary games to examine how subsidies, regulatory costs, stakeholder cooperation, and incentive structures affect the emergence of desirable strategies [35,36]. More directly related work has applied tripartite evolutionary-game analysis to elderly-community retrofit and to the conversion of vacant buildings for integrated medical and elderly-care functions [37,38]. More recent built-environment studies go further by considering gradually declining subsidy mechanisms or recommending that public support weaken as cooperation or diffusion becomes established [39,40]. Accordingly, neither dynamic incentives nor the possibility of later policy reduction should be treated as novel in themselves.

Against this literature, three more specific gaps remain relevant to adaptive-reuse elderly care. First, accessibility is commonly evaluated from the user side through proximity, service coverage, or facility distribution, whereas its utilization value and the supply-side opportunity cost of securing well-located existing space are less often incorporated together as a strategic spatial trade-off. Second, recent facility-level research has begun to examine accessibility and service capacity jointly [11], so the novelty cannot rest on merely placing spatial and operational factors in the same analysis. What remains underdeveloped is their formalization as a configuration-generated utilization return while assigning the associated incremental spatial and operational costs to distinct actors. Third, existing EGT studies—including those with dynamic or declining incentives—primarily examine how policy mechanisms alter strategy adoption or guide systems toward desirable equilibria [25,27,28,35,37–40]. They give less analytical attention to whether the conditions required to activate coordinated quality are different from those required to maintain an already-established spatial–operational configuration after the additional targeted-performance layer is no longer present in the marginal supply-side comparison.

The third gap motivates the paper's central distinction. The conditions required to reach coordinated spatial–operational quality need not be identical to those required to maintain it. Targeted intervention may help actors cross first-mover or coordination barriers, whereas subsequent persistence may depend on whether the resulting configuration generates sufficient utilization returns relative to continuing incremental costs. Under the institutional separation modeled here—quality-invariant basic support combined with an additional targeted-performance layer—the central proposition is that policy architecture shapes how spatial–operational quality is activated and coordinated, whereas post-targeted maintenance depends on configuration-generated utilization returns relative to incremental spatial and operational costs. This proposition is conditional rather than universal: if quality-contingent transfers remained embedded in the basic-support regime, policy variables would also enter the maintenance conditions. Accordingly, the principal theoretical contribution does not lie in introducing dynamic incentives or declining government support per se, but in formally separating the threshold conditions for policy-sensitive activation and coordination from those for configuration-dependent post-targeted maintenance within the same evolutionary framework.

To examine this mechanism, the study develops a tripartite evolutionary game involving the government (G), stock-space provider (S), and professional elderly-care operator (O). Spatial and operational quality are connected through effective utilization. The parameter q captures the utilization gain associated with higher accessibility, h captures the gain associated with integrated operation, and λ represents the additional utilization complementarity generated when both coexist. A separate coefficient, κ, represents joint-performance policy synergy under targeted regulation. Shanghai provides the institutional context, with Pudong New Area serving as the principal evidence anchor for a case-informed reference configuration rather than an estimated local equilibrium.

The study addresses two research questions. RQ1: How do policy architecture, spatial opportunity costs, operational costs, and spatial–operational complementarity shape the activation and coordination of spatial and operational upgrading in elderly-care provision? RQ2: Under the modeled separation between basic and targeted support, under what utilization–cost conditions can coordinated spatial and operational quality remain locally maintainable after the targeted-performance layer recedes?

The paper makes one primary theoretical contribution and two related extensions. Its primary contribution is to formalize a conditional activation–maintenance distinction by deriving separate threshold conditions for policy-sensitive activation and coordination and for configuration-dependent post-targeted maintenance under the modeled institutional separation. Building on this distinction, the model integrates accessibility-related opportunity cost, integrated-operation cost, and spatial–operational utilization complementarity while assigning the associated incremental costs to distinct actors. This structure, in turn, supports a conditional catalytic-governance interpretation: targeted intervention can facilitate entry into a locally coordinated S_1O_1 configuration, but such maintenance depends on the resulting spatial–operational configuration and does not imply permanent targeted-policy dependence or automatic global reachability. Accordingly, the framework is intended primarily as a mechanism model for explaining project-level strategic interactions and threshold conditions, rather than as an empirically validated planning-support or decision-optimization tool.

2. Conceptual Framework and Core Model Specification

2.1. Actors, Strategies, and Spatial–Operational Conflicts

Adaptive reuse for community elderly care involves three interdependent decisions: public support, allocation of existing urban space, and service operation. The model therefore considers three functionally defined stakeholder populations: the government (G), stock-space provider (S), and professional elderly-care operator (O). These populations represent comparable project-level decision settings rather than mixed strategies within a single Shanghai project. The framework therefore operates at the project-level decision-setting scale. It does not model citywide facility-network configuration, service-gap allocation, spatial-equity optimization, or the allocation of public resources across multiple projects; these are meso- or city-scale planning questions beyond the present model. The overall conceptual structure of the model, including the three stakeholder strategies, the two interacting mechanisms, and the activation–maintenance relationship, is summarized in Figure 1.

The government chooses between universal/basic support G_0 and targeted performance regulation G_1. Both are forms of active public intervention. Under G_0, basic support is quality-invariant with respect to the modeled spatial and operational strategies; G_1 adds eligibility screening and differentiated quality incentives. Thus, the distinction concerns an additional targeted-performance layer, not government presence versus withdrawal. This modeling choice is consistent with elderly-care EGT studies in which government strategies

vary through subsidy, regulation, or supervision intensity rather than representing the literal disappearance of public involvement [25,28,29].

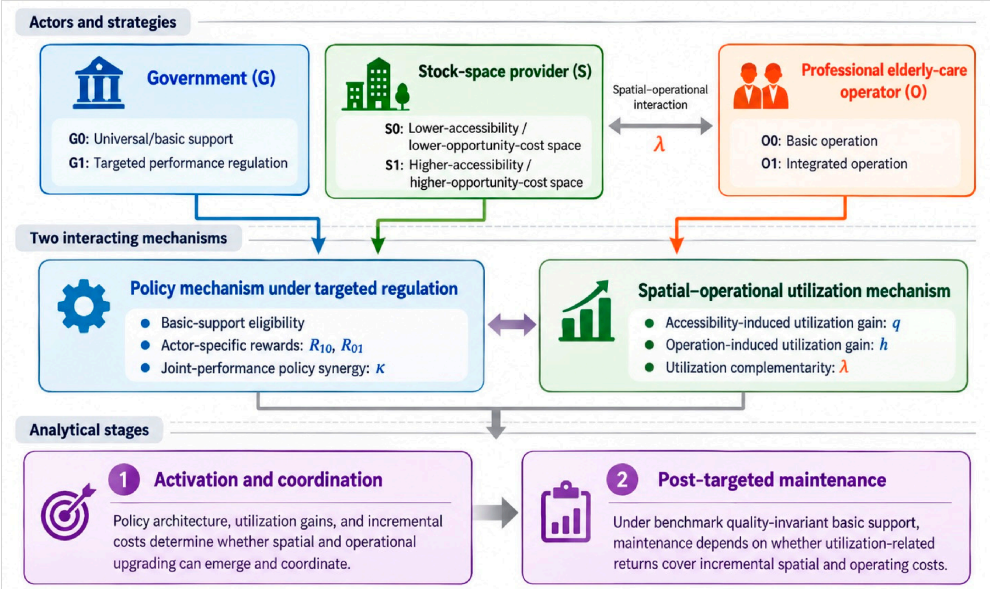


Figure 1. Simplified conceptual framework linking stakeholder strategies, spatial–operational utilization mechanisms, and the conditional activation–maintenance relationship.

The stock-space provider chooses between low-accessibility/low-opportunity-cost existing space S_0 and high-accessibility/high-opportunity-cost existing space S_1. In empirical application, S_0 and S_1 should be interpreted as relative spatial alternatives within a given planning context rather than as universal accessibility classes. Their distinction may be informed by context-specific indicators such as walking time to older residents, proximity to public transport, healthcare and daily services, pedestrian-network continuity, route slope, physical barriers, crossing safety, and other age-sensitive access conditions. The model does not prescribe a universal cutoff separating S_0 from S_1, because the relevant threshold is expected to vary across cities, neighborhoods, and elderly populations.

Facility-level evidence links spatial accessibility to actual elderly-care use [10,11], while Chinese commercial-property studies associate improved accessibility with higher alternative-use value [22,23]. The latter evidence is used only to motivate a stylized accessibility–alternative-value association, not to estimate an elderly-care rent premium. The model therefore represents a stylized project-level trade-off between the utilization potential of a more accessible location and the incremental opportunity cost of securing that location. C_S denotes the incremental opportunity cost of S_1 relative to S_0. This is a stylized positive association, not a deterministic empirical identity: ownership, property condition, regulation, lease arrangements, public-asset allocation, and local property-market conditions can weaken or reverse the relationship in individual projects.

The professional operator chooses between basic operation O_0 and high-quality integrated operation O_1. Here, "high-quality integrated operation" is a strategy label for the modeled operational upgrading represented by O_1; it does not constitute a direct empirical measure of overall care quality, user welfare, equity, or health outcomes. Integrated-care research emphasizes coordinated delivery, multidisciplinary collaboration, continuity, and person-centred organization [24]. In the model, adopting O_1 is represented as requiring additional staffing, equipment, management, and coordination, so C_O denotes the incremental operating cost of O_1 relative to O_0, rather than the total cost of operating an elderly-care facility. G and S are functionally, not necessarily legally, distinct: G represents

fiscal and regulatory authority, whereas S controls reusable urban assets. Neither S_0 nor O_0 denotes project withdrawal. The actors, strategies, and corresponding strategic conflicts are summarized in Table 1.

Table 1. Actors, strategies, and strategic conflicts.

Actor	Baseline Strategy	Target Strategy	Core Conflict
Government (G)	(G_0): universal/basic support	(G_1): targeted performance regulation	Broad provision versus differentiated quality incentives and regulatory cost
Stock-space provider (S)	(S_0): low-accessibility/low-opportunity-cost space	(S_1): high-accessibility/high-opportunity-cost space	Lower opportunity cost versus greater utilization potential
Professional operator (O)	(O_0): basic operation	(O_1): high-quality integrated operation	Lower incremental operating cost versus greater utilization potential

2.2. Core Model Notation and Evolutionary Interpretation

Table 2 summarizes the notation. Numerical reference values and their evidence status are introduced separately in Section 4.

Table 2. Core model notation and parameter domains.

Symbol	Definition	Domain/Status
x,y,z	Shares adopting G_1, S_1, O_1 across comparable settings	[0,1]
s,o	Spatial and operational strategy indicators	{0,1}
U_{ij}:$U_0 = U_{00}$	Realized utilization; baseline S_0O_0 reference utilization	$U_{ij} \geq 0$; $U_0 > 0$
q,h	Accessibility- and integrated-operation-induced relative utilization gains	≥0
λ	Spatial–operational utilization-synergy coefficient	≥0
$\delta(s,o)$; D	Relative utilization gain; coordinated gain	Derived
β_G,β_S,β_O	Utilization-payoff conversion coefficients	>0
C_G,C_S,C_O	Incremental regulation, spatial, and operating costs	≥0
B; θ	Basic support; share allocated to S	$B \geq 0$; $\theta \in [0,1]$
R_{10},R_{01}	Spatial- and operational-quality rewards	≥0
κ	Joint-performance policy-synergy coefficient	≥0
E_{OR}	Benchmark OR eligibility indicator	{0,1}
R_{10}^*, R_{01}^*; κ^*	Activation and coordination thresholds	Derived
$\lambda^*(q)$; q_0^*; q_c	Maintenance and regime-map thresholds	Derived
ρ	Share of basic support screened from S_0O_0 under G_1 in robustness analysis	[0,1]
η	Share of each actor's basic-support allocation remaining quality-contingent under G_0 in robustness analysis	[0,1]

The state variables x, y, and z are strategy shares across comparable decision environments, not probabilities that a single actor randomly switches strategy within one project. This follows the population logic of evolutionary-game and replicator-dynamic models, in which strategies with higher relative payoffs become more prevalent [41,42]. Accordingly, x, y, and z denote the prevalence of G_1, S_1, and O_1. Evolutionary time is dimensionless, not calendar time. The β coefficients are structural payoff-conversion scales rather than directly observed monetary returns.

For the stock-space provider, $\beta_S\delta$ represents a reduced-form utilization-related payoff rather than direct elderly-care service revenue. Depending on the contractual arrangement,

higher realized utilization may be transmitted to the space provider through occupancy- or performance-linked lease terms, revenue-sharing arrangements, reduced vacancy risk, or continuation value. The model abstracts from the specific contractual channel and captures these possible mechanisms through the structural conversion coefficient β_S.

2.3. Effective Utilization and Spatial–Operational Synergy

The model distinguishes physical provision from effective utilization, defined as realized use of the intended elderly-care services. Empirical evidence likewise distinguishes physical availability, accessibility, service capacity, and actual use [10,11,14–16]. Let U_{ij} denote realized utilization under S_iO_j, and let $U_0 = U_{00} > 0$ denote the low-quality reference state. The stand-alone relative gains from spatial and operational upgrading are

$$q = \frac{U_{10} - U_0}{U_0}, \quad h = \frac{U_{01} - U_0}{U_0}, \quad q, h \geq 0. \tag{1}$$

Both parameters are dimensionless. q is not a GIS accessibility index, travel-time threshold, or directly estimated causal coefficient; it represents the utilization gain associated with moving from S_0 to S_1 under otherwise basic operation. Accordingly, the model separates the measurement of accessibility from its modeled consequence. A GIS or network-based accessibility assessment could be used empirically to distinguish candidate S0 and S1 locations, whereas q represents the relative change in realized service utilization associated with that spatial improvement. This distinction avoids treating a spatial accessibility score itself as a payoff parameter and allows the same framework to accommodate different locally appropriate accessibility measures. Likewise, h represents the relative utilization gain associated with moving from O_0 to O_1 while the spatial strategy remains at S_0. These studies support mechanism relevance but do not identify the reference values of q and h.

For configuration (s,o), relative effective-utilization gain is

$$\delta(s,o) = qs + ho + \lambda qhso, \tag{2}$$

so coordinated S_1O_1 generates

$$D \equiv \delta(1,1) = q + h + \lambda qh. \tag{3}$$

The interaction λqh is termed the configuration-generated utilization return. $\lambda \geq 0$ is an exogenous scenario parameter representing spatial–operational complementarity, not an endogenous state variable, empirical estimate, or directly controlled government instrument. Existing evidence motivates complementarity as a plausible mechanism, while its magnitude remains scenario-dependent. Effective utilization is defined here only as the realized use of the intended elderly-care services. It is not a direct measure of overall care quality, satisfaction of population needs, affordability, inclusiveness, equity, health outcomes, or social welfare. High utilization may coexist with unmet needs among mobility-constrained or socially vulnerable older adults, and may also reflect concentrated demand or limited alternative service provision; these dimensions are not represented directly in the present payoff structure.

2.4. Benchmark Policy Architecture

The benchmark policy architecture separates quality-invariant basic support from an additional targeted-performance layer. Under G_0, support B is divided between S and O in shares θ and 1−θ, independently of the modeled spatial and operational quality strategies. Under G_1, the same basic-support resource is subject to the stylized project-level OR eligibility rule

$$E_{OR}(s,o) = s + o - so. \tag{4}$$

Thus, S_0O_0 is ineligible, whereas either unilateral upgrading or S_1O_1 passes the screen. The OR rule is a modeling architecture rather than a literal representation of a single Shanghai subsidy program; alternative eligibility architectures are tested in Section 4.

In addition, G_1 provides spatial- and operational-quality rewards R_{10} and R_{01}. When S_1 and O_1 coexist, the joint-performance policy-synergy coefficient κ increases these targeted rewards. It is analytically distinct from λ: κ represents externally financed policy synergy, whereas λ represents utilization complementarity generated by the spatial–operational configuration itself.

The analysis that follows distinguishes activation (whether either quality strategy can emerge), coordination (whether the second quality dimension can be completed), and maintenance (whether S_1O_1 remains attractive after the additional targeted-performance layer recedes while basic support continues). Under this institutional separation, policy architecture governs activation and coordination, whereas post-targeted maintenance depends on configuration-generated utilization returns relative to incremental spatial and operational costs. Section 4.2 relaxes this benchmark architecture in two directions by allowing partial screening of basic support under G_1 and, separately, partial quality contingency of basic support under G_0.

3. Evolutionary Game and Analytical Conditions

3.1. Payoff Structure and Replicator Dynamics

Evolutionary game theory models changes in strategy prevalence when boundedly rational populations adjust behavior according to relative payoff performance. In the replicator tradition, strategies with above-average returns expand their population shares over evolutionary time [41,42]. Applied elderly-care studies have used this framework to examine multi-actor regulation, public–private participation, and service-quality governance [28,29,31]. Following this logic, the present model treats government, stock-space providers, and professional operators as three stakeholder populations whose strategy shares evolve across comparable project-level decision settings.

The model concerns incremental quality choices within continuing elderly-care provision. Accordingly, C_G, C_S, and C_O represent the additional costs of targeted regulation, high-accessibility space, and high-quality integrated operation rather than total project costs.

Under targeted performance regulation G_1, the transfers received by S and O are

$$\begin{aligned} T_S^1 &= \theta BE_{\mathrm{OR}} + R_{10}s(1+\kappa o), \\ T_O^1 &= (1-\theta)BE_{\mathrm{OR}} + R_{01}o(1+\kappa s). \end{aligned} \tag{5}$$

Using the effective-utilization gain δ(s,o), payoffs under G_1 are

$$\begin{aligned} \Pi_G^1 &= \beta_G\delta - C_G - BE_{\mathrm{OR}} - R_{10}s(1+\kappa o) - R_{01}o(1+\kappa s), \\ \Pi_S^1 &= \beta_S\delta - C_S s + \theta BE_{\mathrm{OR}} + R_{10}s(1+\kappa o), \\ \Pi_O^1 &= \beta_O\delta - C_O o + (1-\theta)BE_{\mathrm{OR}} + R_{01}o(1+\kappa s). \end{aligned} \tag{6}$$

Under G_0, basic support continues but is independent of the modeled quality strategies:

$$\begin{aligned} \Pi_G^0 &= \beta_G\delta - B, \\ \Pi_S^0 &= \beta_S\delta - C_S s + \theta B, \\ \Pi_O^0 &= \beta_O\delta - C_O o + (1-\theta)B. \end{aligned} \tag{7}$$

Expected payoff advantages are

$$\Delta U_G = B(1-y)(1-z) - C_G - R_{10}y(1+\kappa z) - R_{01}z(1+\kappa y), \tag{8}$$

$$\Delta U_S = \beta_S q(1+\lambda hz) - C_S + x[\theta B(1-z) + R_{10}(1+\kappa z)], \tag{9}$$

$$\Delta U_O = \beta_O h(1 + \lambda qy) - C_O + x[(1 - \theta)B(1 - y) + R_{01}(1 + \kappa y)]. \tag{10}$$

Because $\beta_G\delta$ is common to G_0 and G_1, it cancels from the government's strategy comparison. The tripartite replicator system is

$$\begin{cases} \dot{x} = x(1 - x)\Delta U_G, \\ \dot{y} = y(1 - y)\Delta U_S, \\ \dot{z} = z(1 - z)\Delta U_O. \end{cases} \tag{11}$$

As in standard replicator dynamics [41,42], exact boundary states are invariant. Numerical tests therefore use strictly interior initial shares unless a boundary subsystem is examined explicitly. Evolutionary time remains dimensionless rather than being interpreted as calendar time.

3.2. Activation and Coordination Conditions

Near S_0O_0 under G_0, the higher-quality supply strategies remain unattractive when

$$C_S > \beta_S q, \qquad C_O > \beta_O h. \tag{12}$$

Basic support does not enter these marginal comparisons because it is quality-invariant under the benchmark G_0 specification.

At exact S_0O_0, Equation (8) becomes $\Delta U_G = B - C_G$. Under benchmark OR screening, targeted regulation is therefore favored when

$$B > C_G \tag{13}$$

This is an architecture-specific fiscal-screening condition, not a general rule for government intervention.

When G_1 is prevalent ($x = 1$) and the other supply-side actor remains at its baseline strategy, the first-mover reward thresholds are

$$R_{10}^* = [C_S - \beta_S q - \theta B]_+, \quad R_{01}^* = [C_O - \beta_O h - (1 - \theta)B]_+ \tag{14}$$

where $[a]_+ = \max(a,0)$. Once one quality dimension is present, the minimum joint-performance policy synergy required by each actor is

$$\kappa_S^* = \left[\frac{C_S - \beta_S q(1 + \lambda h)}{R_{10}} - 1\right]_+, \quad \kappa_O^* = \left[\frac{C_O - \beta_O h(1 + \lambda q)}{R_{01}} - 1\right]_+ \tag{15}$$

for $R_{10} > 0$ and $R_{01} > 0$, with joint coordination requiring

$$\kappa^* = \max\left(\kappa_S^*, \kappa_O^*\right). \tag{16}$$

A higher λ can reduce the policy premium required for coordination, but λ and κ remain distinct mechanisms: λ is configuration-generated utilization synergy, whereas κ acts through targeted rewards. If an actor-specific reward is zero, increasing κ cannot operate through that absent channel.

3.3. Post-Targeted Maintenance and Local Stability

Maintenance is evaluated at $x = 0$, where G_0 and basic support continue but the additional targeted-performance strategy no longer enters the supply-side payoff differences. At S_1O_1, strict maintenance requires

$$\beta_S q(1 + \lambda h) > C_S, \qquad \beta_O h(1 + \lambda q) > C_O. \tag{17}$$

For $q > 0$ and $h > 0$, the minimum utilization-synergy requirement is

$$\lambda^*(q) = \max\left[0, \frac{C_S/(\beta_S q) - 1}{h}, \frac{C_O/(\beta_O h) - 1}{q}\right]. \quad (18)$$

The larger term identifies the binding maintenance constraint.

The absence of B, θ, R_{10}, R_{01}, and κ from Equations (17) and (18) is conditional on the modeled institutional separation: G_0 support is quality-invariant, while eligibility screening and differentiated quality rewards belong to G_1. If quality-contingent transfers persisted under G_0, they would also enter the maintenance conditions. Section 4.2 therefore introduces an explicit robustness extension that relaxes this benchmark assumption. The model thus identifies configuration-dependent maintenance under a specific policy architecture rather than universal policy independence.

Local stability at $G_0S_1O_1$ follows from

$$\begin{aligned} \mu_G &= -C_G - (1+\kappa)(R_{10} + R_{01}) < 0, \\ \mu_S &= -[\beta_S q(1+\lambda h) - C_S], \\ \mu_O &= -[\beta_O h(1+\lambda q) - C_O]. \end{aligned} \quad (19)$$

Strict local asymptotic stability requires both supply-side brackets to be positive. Equality yields a zero eigenvalue and a non-hyperbolic boundary. If $q = 0$ with $C_S > 0$, or $h = 0$ with $C_O > 0$, no finite λ can maintain the affected quality dimension.

Two auxiliary thresholds support interpretation of the $q-\lambda$ regime map:

$$q_0^* = \frac{C_S}{\beta_S}, \quad q_c = \frac{C_S}{\beta_S} - \frac{C_O}{\beta_O} + h. \quad (20)$$

Here, q_0^* is the stand-alone spatial activation threshold under $x = 0$, while q_c marks where the binding maintenance constraint switches when it lies within the relevant positive-boundary parameter domain. The core analytical conditions for activation, coordination, and post-targeted maintenance are summarized in Table 3.

Table 3. Core analytical conditions.

Stage	Core Condition	Interpretation
Supply-side quality lock-in under G_0	$C_S > \beta_S q$; $C_O > \beta_O h$	Stand-alone quality returns do not cover incremental costs
Government activation	$B > C_G$	Benchmark OR-screening advantage
First-mover activation	Equation (14)	Architecture-dependent unilateral upgrading
Joint coordination	Equations (15) and (16)	Policy and utilization synergy jointly shape completion
Post-targeted maintenance under benchmark G_0	Equations (17) and (18)	Under quality-invariant basic support, configuration-generated returns must cover incremental costs

The analytical structure therefore establishes a conditional activation–maintenance divide. Policy architecture governs how coordinated quality is activated and completed, whereas post-targeted local maintenance is governed by configuration-generated utilization returns relative to incremental spatial and operational costs under the modeled institutional separation.

4. Case-Informed Parameterization and Robustness Design

4.1. Reference Configuration and Evidence Status

Shanghai provides the municipal institutional context for the reference configuration, while Pudong New Area, as part of Shanghai, provides more specific district-level pol-

icy, procurement, and market evidence used to anchor selected parameters. This nested use of evidence reflects data availability rather than an attempt to estimate a Pudong- or Shanghai-specific equilibrium. The reference configuration therefore combines verified municipal and district policy benchmarks, market and procurement anchors, and explicitly identified scenario assumptions. Several parameters represent latent utilization or strategic mechanisms that are not directly observable in administrative data, so Shanghai and Pudong should be interpreted as institutional and evidentiary anchors rather than as a fully calibrated empirical case.

The monetary quantities are used as normalized payoff anchors for comparative evolutionary analysis rather than as a discounted project cash-flow account. The five-year horizon is used only as a standardized accounting convention to construct the reference spatial and operating cost proxies in Equations (22) and (23). Basic support remains a one-time policy benchmark, while utilization-related returns and quality rewards are represented as normalized payoff components rather than explicitly annualized cash flows. Accordingly, the model does not claim an intertemporal net-present-value interpretation.

The monetary normalization uses Shanghai's 2021–2025 construction-support framework for community comprehensive elderly-care centers. Under the relevant municipal policy, qualifying centers of at least approximately 800 m^2 were eligible for RMB 1.0 million in municipal construction support, while district-level support was required to match the municipal amount at no less than 1:1 [43]. Pudong's corresponding fiscal-support framework is consistent with district co-financing and performance-linked elderly-care incentives [44]. An approximately RMB 2.0 million project-support benchmark is therefore normalized to

$$B = 1.00. \tag{21}$$

This value is treated as a policy-verified historical benchmark, not as a claim about the current amount available to every project. Recent Pudong policy practice also places greater emphasis on service-quality evaluation and links assessment outcomes to operating support [45]. This contemporary context supports the manuscript's performance-oriented framing but is not used to recalibrate B.

The spatial opportunity-cost proxy C_S combines a lower-market lease anchor with a conservative higher alternative-use benchmark. A Shanghai Stock Exchange disclosure records a lease rate of approximately RMB 2.7/m^2/day for existing business premises in Zhangjiang, Pudong [46]. A Shanghai office-market report provides a higher Grade-A office-market context, with rents above the RMB 5.0/m^2/day value adopted here [47]. These two anchors are intentionally heterogeneous and do not constitute a matched-pair rent estimate. The model therefore uses RMB 5.0/m^2/day as a conservative higher alternative-use scenario rather than as an empirical accessibility premium. For an 800 m^2 facility over a five-year standardized cost-accounting horizon,

$$C_S = \frac{(5.0 - 2.7) \times 800 \times 365 \times 5}{2,000,000} \approx 1.68. \tag{22}$$

Accordingly, CS is a market-informed scenario proxy. The calculation does not imply that the rent difference is caused by accessibility, nor that 2.7 RMB/m^2/day is a public-service rent. It is used only to represent the incremental opportunity cost of assigning a better-located existing property to elderly-care use rather than to a higher-value alternative use. Accordingly, C_S should not be interpreted as an empirically estimated accessibility premium. It is a scenario proxy for the opportunity-cost difference between alternative existing-space choices, which may reflect accessibility together with building condition, ownership, lease terms, neighborhood characteristics, regulatory constraints, and competing uses.

The operating-cost proxy C_O is anchored in official procurement evidence. A Pudong procurement intention for the Tangqiao Community Comprehensive Elderly-Care Service

Center reports a one-year integrated-operation budget of approximately RMB 1.24 million [48], while the associated procurement materials describe the integrated service scope and operational responsibilities [49]. Because the procurement budget covers total integrated operation rather than the marginal cost of moving from O_0 to O_1, the incremental share cannot be directly identified from the available procurement documents. The reference configuration therefore adopts 25% of the total operating budget as a transparent midpoint scenario for the additional staffing, coordination, service diversification, and management requirements associated with O_1. This 25% value is an author-defined reference assumption rather than an empirically estimated cost share. Its role is to provide a reproducible benchmark for mechanism analysis; sensitivity tests vary the assumed share from 15% to 35% to examine how strongly the maintenance threshold depends on this assumption. Over five years,

$$C_O = \frac{1.24 \times 0.25 \times 5}{2.00} = 0.775. \quad (23)$$

Thus, C_o is a procurement-anchored scenario proxy rather than a directly observed marginal operating cost. The 25% reference share and the 15–35% sensitivity range should not be interpreted as empirical estimates or confidence intervals.

The remaining parameters are not treated as empirical estimates. $q = 0.60$ and $h = 0.40$ are case-informed reference scenarios used to illustrate accessibility- and operation-induced utilization gains. $\lambda = 1.50$, $C_G = 0.20$, and $\kappa = 0.50$ are scenario parameters; $\theta = 0.65$ and $(\beta_G, \beta_S, \beta_o) = (1.00, 1.60, 1.00)$ are structural scales. $R_{10} = 0.10$ is a policy-design scenario because no identified policy directly rewards the modeled accessibility strategy. $R_{01} = 0.075$ is a policy-scale-informed scenario: Pudong has performance-linked elderly-care incentives, including rewards associated with sustained excellent evaluations [44,45], but no identified source maps the exact modeled value to a specific O_1 payment.

The reference vector is therefore used for comparative threshold and mechanism analysis rather than as an empirically estimated Shanghai equilibrium. The resulting numerical thresholds are conditional outputs of this reference configuration and should not be interpreted as empirically identified policy cutoffs, forecasts, or universally applicable parameter values. Their analytical purpose is comparative: to show how activation, coordination, and maintenance conditions shift when institutional architecture, spatial costs, operating conditions, or utilization-related parameters change. Numerical precision is retained for reproducibility of the model calculations rather than to imply corresponding empirical certainty.

4.2. Robustness Design

The robustness analysis separates institutional sensitivity from parameter sensitivity. Because probability distributions for the scenario-based parameters are not empirically identified, these exercises are deterministic sensitivity tests rather than probabilistic uncertainty quantification. Their purpose is to assess whether the qualitative mechanism and binding constraints persist when key assumptions change, not to construct confidence intervals for the reported thresholds. Three eligibility architectures are compared: the benchmark OR rule $E_{OR} = s + o - so$, AND eligibility $E_{AND} = so$, and actor-specific eligibility $E_S = s$, $E_O = o$. Under actor-specific eligibility, S receives θB only with S_1, while O receives $(1 - \theta)B$ only with O_1. These alternatives test whether activation and coordination results depend on how basic support is made marginally available under G_1.

Fiscal screening is further relaxed through $\rho \in [0,1]$, defined as the share of basic support withheld from the otherwise ineligible S0O0 configuration under G1. To account

consistently for both government expenditure and the transfers received by the two supply-side actors, define the generalized eligibility factor as

$$E_\rho(s,o) = 1 - \rho(1-s)(1-o) = (1-\rho) + \rho E_{\mathrm{OR}}(s,o). \tag{24}$$

Thus, ρ = 1 reproduces the benchmark OR architecture, whereas ρ = 0 corresponds to no basic-support screening under G1. The associated transfers are

$$T^1_{S,\rho} = \theta B E_\rho(s,o) + R_{10} s(1+\kappa o) \tag{25}$$

$$T^1_{O,\rho} = (1-\theta) B E_\rho(s,o) + R_{01} o(1+\kappa s) \tag{26}$$

The corresponding payoff advantages become

$$\Delta U^{(\rho)}_G = \rho B(1-y)(1-z) - C_G - R_{10} y(1+\kappa z) - R_{01} z(1+\kappa y) \tag{27}$$

$$\Delta U^{(\rho)}_S = \beta_S q(1+\lambda h z) - C_S + x[\theta \rho B(1-z) + R_{10}(1+\kappa z)] \tag{28}$$

$$\Delta U^{(\rho)}_O = \beta_O h(1+\lambda q y) - C_O + x[(1-\theta)\rho B(1-y) + R_{01}(1+\kappa y)] \tag{29}$$

At S_0O_0, the government-activation condition becomes

$$\rho B > C_G \tag{30}$$

Consistent transfer accounting also modifies the first-mover conditions. When G_1 is prevalent and the other supply-side actor remains at its baseline strategy, the reward thresholds become

$$R^*_{10}(\rho) = [C_S - \beta_S q - \theta \rho B]_+ \tag{31}$$

$$R^*_{01}(\rho) = [C_O - \beta_O h - (1-\theta)\rho B]_+ \tag{32}$$

Under the reference configuration, government activation requires only $\rho > 0.20$. However, given the reference rewards $R_{10} = 0.10$ and $R_{01} = 0.075$, the corresponding first-mover conditions require approximately $\rho > 0.954$ for S and $\rho > 0.857$ for O. Partial screening can therefore make G_1 attractive to the government before it is strong enough, together with the reference actor-specific rewards, to remove both supply-side first-mover barriers.

Because the OR-type basic-support screen is already satisfied once either quality dimension is present, ρ affects first-mover incentives but does not enter the subsequent coordination thresholds. Because ρ modifies only the G_1 screening architecture, it does not alter the benchmark post-targeted maintenance condition evaluated at $x = 0$.

A second robustness extension relaxes the benchmark assumption that basic support under G_0 is entirely quality-invariant. Let $\eta \in [0,1]$ denote the fraction of each actor's basic-support allocation that remains contingent on that actor adopting its high-quality strategy under G_0. The corresponding transfers are defined as

$$T^{0,\eta}_S = \theta B[(1-\eta) + \eta s] \tag{33}$$

$$T^{0,\eta}_O = (1-\theta) B[(1-\eta) + \eta o] \tag{34}$$

Accordingly, the G_0 payoffs become

$$\Pi^{0,\eta}_G = \beta_G \delta(s,o) - T^{0,\eta}_S - T^{0,\eta}_O \tag{35}$$

$$\Pi^{0,\eta}_S = \beta_S \delta(s,o) - C_S s + T^{0,\eta}_S \tag{36}$$

$$\Pi^{0,\eta}_O = \beta_O \delta(s,o) - C_O o + T^{0,\eta}_O \tag{37}$$

The benchmark G_0 specification is recovered at $\eta = 0$. Conditional on $x = 0$, the corresponding supply-side payoff advantages are

$$\Delta U^{(0,\eta)}_S = \beta_S q(1+\lambda h z) - C_S + \eta \theta B \tag{38}$$

$$\Delta U_O^{(0,\eta)} = \beta_O h(1 + \lambda qy) - C_O + \eta(1 - \theta)B \tag{39}$$

At S_1O_1, strict post-targeted maintenance therefore requires

$$\beta_S q(1 + \lambda h) + \eta\theta B > C_S \tag{40}$$

$$\beta_O h(1 + \lambda q) + \eta(1 - \theta)B > C_O \tag{41}$$

For $q > 0$ and $h > 0$, the corresponding maintenance threshold becomes

$$\lambda_\eta^*(q) = \max\left[0, \frac{\frac{C_S - \eta\theta B}{\beta_S q} - 1}{h}, \frac{\frac{C_O - \eta(1-\theta)B}{\beta_O h} - 1}{q}\right] \tag{42}$$

Thus, $\eta = 0$ reproduces the benchmark maintenance threshold in Equation (18), whereas $\eta > 0$ allows policy support to re-enter the maintenance condition directly. This extension is used as a structural robustness test rather than as an empirical claim that a particular G_0 support scheme follows this exact formulation.

Parameter sensitivity varies C_S from 50% to 150% of its reference value, the assumed incremental operating-cost share around its 25% reference scenario from 15% to 35%, and h from 0.20 to 0.60. The 15–35% interval is a deterministic scenario range used to test dependence on the assumed marginal-cost share; it is not an empirically estimated confidence interval. Payoff-conversion sensitivity varies β_S independently over {1.20,1.60,2.00} while holding $\beta_O = 1.00$, and varies β_O independently over {0.75,1.00,1.25} while holding $\beta_S = 1.60$. Unless one dimension is varied, all remaining parameters stay at their Table 4 values.

Table 4. Reference parameterization and evidence status.

Parameter	Reference Value	Interpretation	Evidence Status
q	0.60	Accessibility-induced utilization gain	Case-informed reference scenario
h	0.40	Integrated-operation utilization gain	Case-informed reference scenario
λ	1.50	Spatial–operational utilization synergy	Scenario parameter
β_G, β_S, β_O	1.00, 1.60, 1.00	Utilization-payoff conversion	Structural scales
C_S	1.68	Incremental opportunity cost of S_1	Market-informed scenario proxy [46,47]
C_O	0.775	Incremental cost of O_1	Procurement-anchored proxy + 25% assumption [48,49]
C_G	0.20	Incremental regulation cost	Scenario parameter
B	1.00	Basic project support	Policy-verified historical benchmark [43,44]
θ	0.65	Share of B allocated to S	Structural assumption
R_{10}	0.10	Spatial-quality reward	Policy-design scenario
R_{01}	0.075	Operational-quality reward	Policy-scale-informed scenario [44,45]
κ	0.50	Joint-performance policy synergy	Scenario parameter

Path dependence is examined using strictly interior starts. For the x = 0 subsystem, y_0 and z_0 each take 41 equally spaced values over [0.01,0.99], yielding 1681 starts. For the full system, x_0, y_0, $z_0 \in \{0.01, 0.05, 0.10, 0.20, 0.50\}$, yielding 125 starts. These tests evaluate basin dependence and sampled reachability rather than empirical probabilities or global stability.

4.3. Numerical Implementation

Numerical trajectories were integrated in MATLAB R2025a using ode45, with relative and absolute tolerances of 10^{-9} and 10^{-11}, respectively, a maximum step size of 1.0,

and a dimensionless horizon of t = 500. To avoid artificial numerical locking at pure-strategy boundaries, strictly interior strategy shares were integrated using the mathematically equivalent logit-transformed system. Terminal states within 0.01 of a pure-strategy corner were classified as converged. The same numerical settings were applied across all initial-condition tests.

5. Results

Unless otherwise stated, all results use the Table 4 reference configuration. Numerical values are conditional, mechanism-illustrating benchmark outputs rather than empirically estimated Shanghai policy constants or recommended policy cutoffs; their precision reflects analytical calculation rather than empirical confidence.

5.1. Policy-Dependent Activation and Coordination

Under universal/basic support G_0, the higher-quality supply strategies are unattractive near S_0O_0. Substituting the reference values into Equations (9) and (10) at x = 0 gives

$$\Delta U_S = -0.720, \qquad \Delta U_O = -0.375. \tag{43}$$

Thus, quality-invariant basic support can sustain provision without eliminating the marginal barriers associated with high-accessibility space or high-quality integrated operation. In the reference configuration, neither supply-side actor has an autonomous incentive to upgrade from the baseline S_0O_0 state.

Under benchmark OR screening, the government's advantage at S_0O_0 is

$$B - C_G = 0.80 > 0, \tag{44}$$

so targeted performance regulation is initially favored. With G_1 prevalent, the first-mover reward thresholds are

$$R^*_{10} = 0.070, \quad R^*_{01} = 0.025. \tag{45}$$

Both reference rewards exceed their respective thresholds, indicating that either S or O can initiate quality upgrading under the benchmark policy architecture. The spatial provider is the more restrictive first mover in this reference case because its required reward is larger, but this ordering is parameter-dependent rather than structural. The benchmark activation conditions and the corresponding first-mover reward thresholds are illustrated in Figure 2.

Once one quality dimension has been activated, completion of S_1O_1 depends on the second actor's payoff. At $\lambda = 1.50$,

$$\kappa^*_S = 0.44, \quad \kappa^*_O = 0, \quad \kappa^* = 0.44. \tag{46}$$

Because the reference $\kappa = 0.50$, the benchmark lies slightly inside the joint-coordination region. Increasing λ reduces the policy premium required for completion because stronger spatial–operational utilization complementarity raises the private payoff from joining an already-improved configuration. The operator-side coordination premium reaches zero at approximately $\lambda = 1.25$, whereas the spatial-provider requirement reaches zero at approximately $\lambda = 1.615$. Utilization synergy therefore substitutes partially for targeted policy synergy at the coordination stage, although the two mechanisms remain analytically distinct. These coordination relationships under alternative combinations of spatial–operational utilization synergy and joint-performance policy synergy are summarized in Figure 3.

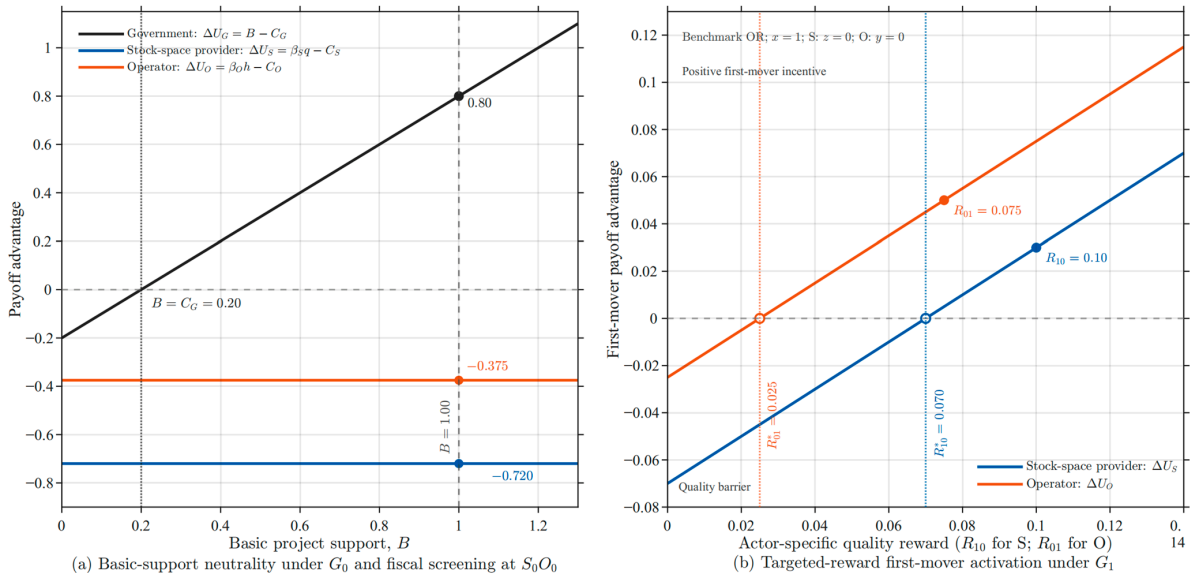


Figure 2. Policy-dependent activation under the reference configuration: (**a**) basic-support neutrality and fiscal screening at S_0O_0; (**b**) targeted-reward first-mover activation under G_1.

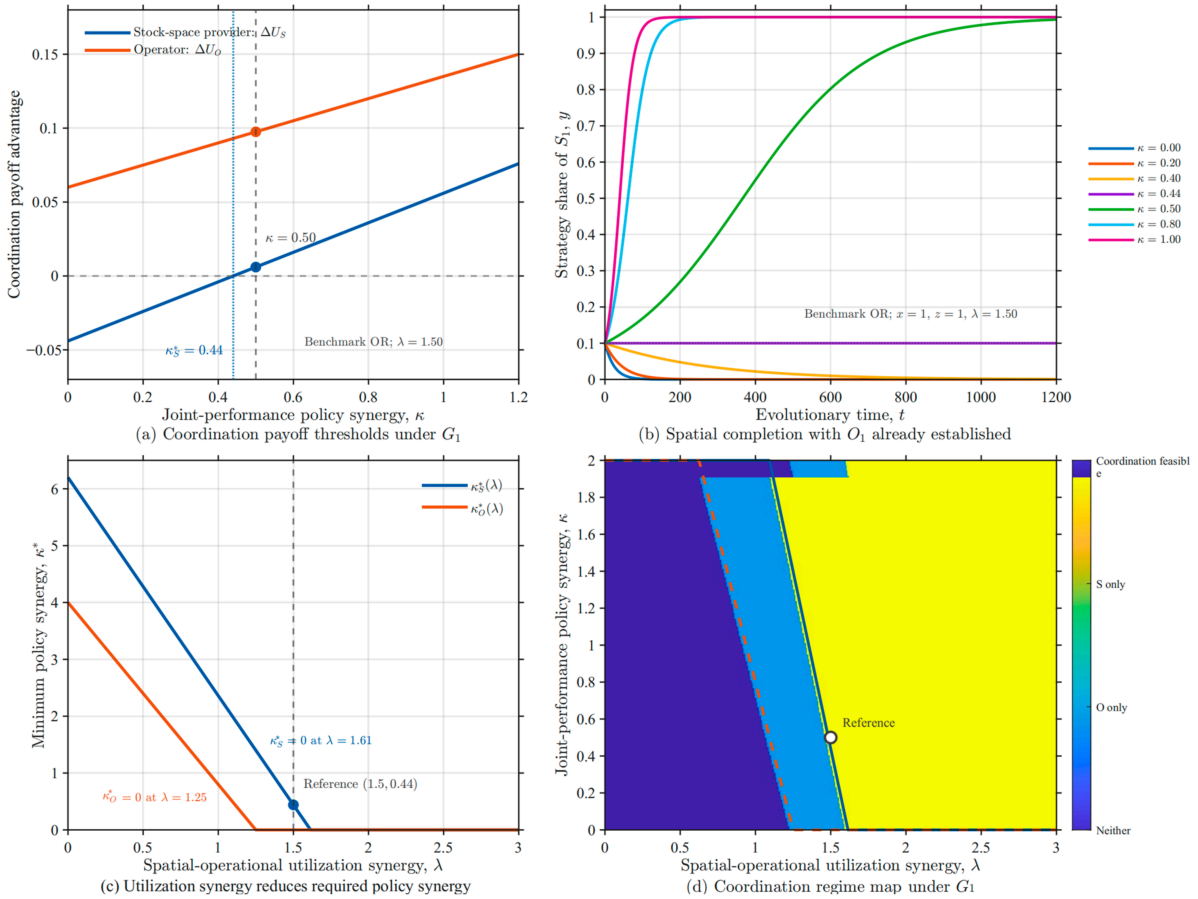


Figure 3. Coordination boundaries under alternative combinations of spatial–operational utilization synergy and joint-performance policy synergy: (**a**) coordination payoff thresholds under G_1; (**b**) spatial completion with O_1 already established; (**c**) substitution between utilization synergy and policy synergy; and (**d**) the utilization–policy coordination phase diagram. Panel (**b**) uses the analytical logistic solution and extends the display horizon to t = 1200 solely to visualize near-threshold convergence; the numerical simulations reported in Section 4.3 use a dimensionless horizon of t = 500.

5.2. Post-Targeted Maintenance and the q–λ Regime Map

Maintenance is evaluated on the x = 0 boundary, where G_0 and basic support continue but the additional targeted-performance layer is absent from the supply-side payoff comparison. Under the reference values of h, C_S, C_O, β_S, and β_O, the actor-specific maintenance boundaries are

$$\lambda_S(q) = \frac{2.625}{q} - 2.50, \quad \lambda_O(q) = \frac{0.9375}{q}. \tag{47}$$

Their upper envelope defines λ∗(q). At q = 0.60,

$$\lambda^* = 1.875, \quad q_0^* = 1.05, \quad q_c = 0.675 \tag{48}$$

The reference λ = 1.50 therefore lies below the maintenance threshold at q = 0.60, even though the same parameterization can achieve policy-supported coordination. This is the clearest numerical expression of the activation–maintenance distinction: a configuration can be reachable under targeted incentives while remaining locally unattractive once the additional targeted layer no longer enters the marginal supply-side comparison. The resulting q–λ regime map combining stand-alone spatial activation and local post-targeted maintenance conditions is shown in Figure 4.

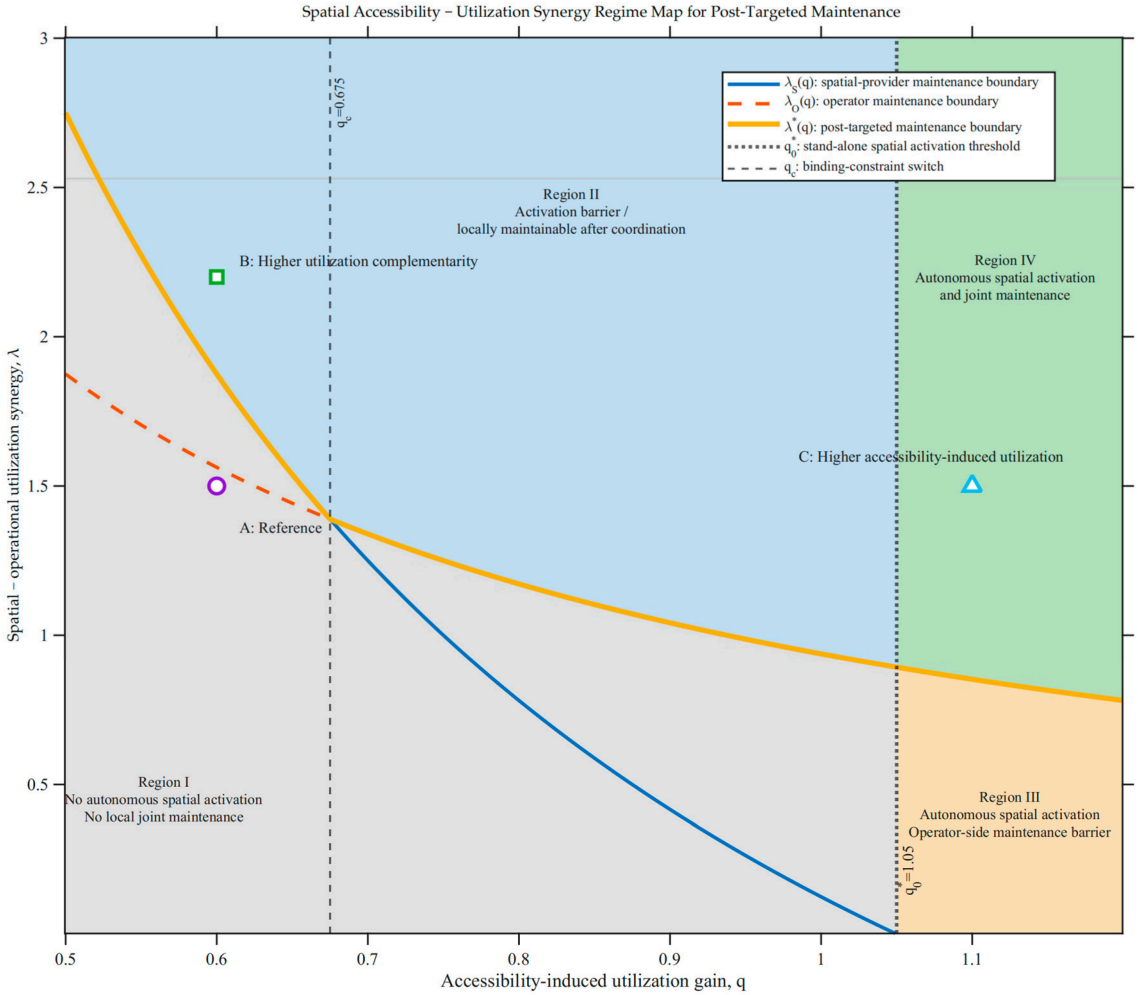


Figure 4. Reference q–λ regime map combining stand-alone spatial activation and local post-targeted maintenance conditions.

The regime map separates four qualitatively different cases. Region I satisfies neither autonomous spatial activation nor joint post-targeted maintenance. Region II, the central theoretical case, satisfies

$$q < q_0^*, \ \ \lambda > \lambda^*(q) \tag{49}$$

Here, high-accessibility space cannot emerge autonomously from the low-quality state, yet S_1O_1 is locally maintainable once established. At q = 0.60, increasing λ from 1.50 to 2.20 moves the reference system from Region I into Region II. Region III permits stand-alone spatial activation without joint maintenance, whereas Region IV satisfies both conditions. These classifications are conditional on the modeled separation between quality-invariant G0 support and the additional targeted-performance layer.

5.3. Dynamic Pathways and Robustness

Figure 5 illustrates the analytical maintenance boundary through dynamic trajectories. At q = 0.60, λ = 1.50, a trajectory initialized near S_1O_1 moves away from coordinated quality because at least one maintenance condition is violated. At the same q but λ = 2.20, both supply-side maintenance inequalities become positive and $G_0S_1O_1$ is locally asymptotically stable.

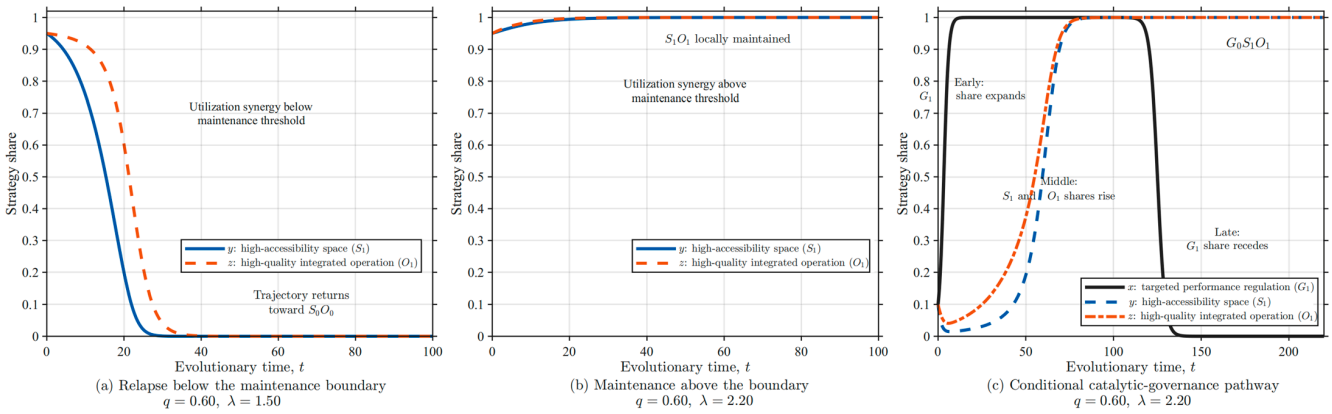


Figure 5. Dynamic illustration of the activation–maintenance distinction: (**a**) relapse below the maintenance boundary; (**b**) maintenance above the boundary; and (**c**) a conditional catalytic-governance pathway in the full tripartite system.

For the full tripartite system at q = 0.60, λ = 2.20, a representative trajectory from $(x_0, y_0, z_0) = (0.10, 0.10, 0.10)$ shows a conditional catalytic pathway. G_1 initially expands when S_1 and O_1 are rare; targeted incentives then help reverse negative supply-side payoffs, after which stronger spatial–operational complementarity reinforces S_1 and O_1. As coordinated quality becomes prevalent, the relative advantage of G1 declines. The dominant-strategy sequence is summarized as

$$G_0S_0O_0 \rightarrow G_1S_0O_0 \rightarrow G_1S_1O_1 \rightarrow G_0S_1O_1. \tag{50}$$

This sequence summarizes continuous changes in strategy shares rather than discrete institutional jumps, and evolutionary time is dimensionless.

The initial-condition tests clarify the distinction between local stability and reachability. For the x = 0 subsystem at q = 0.60, λ = 2.20, the analytical interior saddle is

$$(y^\dagger, z^\dagger) = (0.7102, 0.8523). \tag{51}$$

Among 1681 sampled interior starts, 200 (11.9%) converged to S_1O_1 and 1481 (88.1%) to S_0O_0, with no mixed or unresolved terminal states. The 11.9% share describes this

deterministic initial-condition grid only and should not be interpreted as an empirical probability of reaching the S_1O_1 state. The coexistence of S_0O_0 and S_1O_1 basins shows that local maintainability does not imply automatic reachability.

For the full tripartite system, all 125 sampled interior starts converged to $G_0S_1O_1$ under the benchmark architecture, with no alternative or unresolved terminal states. This result indicates robustness across the sampled initial conditions and shows that the representative catalytic trajectory is not a single-start artifact. It does not, however, constitute a proof of global attraction or global asymptotic stability.

The two additional policy-architecture tests further clarify the scope of these results. Under partial G_1 screening, government activation requires $\rho > 0.20$, whereas the reference actor-specific rewards remove the first-mover barriers only when $\rho > 0.954$ for S and $\rho > 0.857$ for O. Government adoption of targeted regulation therefore need not coincide with supply-side upgrading. Under the G_0 quality-contingency extension, the maintenance threshold at $q = 0.60$ decreases from $\lambda^*_\eta = 1.875$ at $\eta = 0$ to approximately 1.029 at $\eta = 0.50$ and 0.182 at $\eta = 1$. Even at $\eta = 1$, however, the low-state G_0 first-mover payoff advantages remain slightly negative for both S (-0.070) and O (-0.025) under the reference configuration. Persistent quality-contingent basic support can therefore substantially relax the maintenance requirement without, in the reference case, eliminating the initial upgrading barriers by itself. The selected robustness checks and their main structural implications are summarized in Table 5.

Taken together, the robustness results clarify both the persistence and the boundary of the activation–maintenance distinction. Changes in G_1 eligibility architecture and screening strength alter government and first-mover activation incentives, while benchmark post-targeted maintenance remains unchanged as long as G_0 basic support is quality-invariant. Spatial opportunity cost, operating conditions, and payoff conversion continue to shift the maintenance boundary quantitatively. By contrast, when a share of basic support remains quality-contingent under G_0, policy support enters the maintenance comparison directly and lowers the required utilization-synergy threshold. The activation–maintenance divide is therefore a conditional consequence of the modeled institutional separation rather than a claim of universal long-run policy independence.

Table 5. Selected robustness checks and structural implications.

Robustness Test	Selected Result	Structural Implication
Eligibility architecture	$(R^*_{10}, R^*_{01}, \kappa^*)$: OR = (0.070,0.025,0.440); AND = (0.720,0.375,0); actor-specific = (0.070,0.025,0). All give $\lambda^*(0.60) = 1.875$.	Activation and coordination are architecture-sensitive; post-targeted maintenance is unchanged under the modeled G_0/G_1 separation.
Partial G_1 screening	Government activation: $\rho > 0.20$; reference first-mover activation: $\rho > 0.954$ for S and $\rho > 0.857$ for O.	Screening strength affects both government activation and supply-side first-mover incentives; government adoption of G_1 does not itself guarantee upgrading.
G_0 quality contingency	At $q = 0.60$, $\lambda^*_\eta = 1.875$, 1.029, and 0.182 for $\eta = 0$, 0.50, and 1, respectively.	Persistent quality-contingent basic support lowers the maintenance boundary; benchmark policy-independence of maintenance is therefore conditional on quality-invariant G_0 support.
Spatial opportunity cost	C_S at 50%–150% of reference moves $\lambda^*(0.60)$ from 1.563 to 4.063.	Spatial cost can become the binding maintenance barrier.

Table 5. *Cont.*

Robustness Test	Selected Result	Structural Implication
Operating conditions	A 15%–35% incremental-cost share moves λ^* from 1.875 to 2.854; $h = 0.20$–0.60 moves it from 4.792 to 1.250.	The numerical maintenance boundary is sensitive to the assumed marginal operating-cost share and operational effectiveness; the 25% reference value should therefore be interpreted as an illustrative benchmark rather than an estimated constant.
Payoff conversion	Varying β_S independently from 1.20 to 2.00 moves $\lambda^*(0.60)$ from 3.333 to 1.563; varying β_O independently from 0.75 to 1.25 moves $\lambda^*(0.60)$ from 2.639 to 1.875.	Provider- and operator-side utilization-payoff conversion can independently shift the binding maintenance constraint; the result does not depend on keeping their relative payoff-capture ratio fixed.
Initial-condition tests	$x = 0$: 200/1681 S_1O_1 outcomes; full system: 125/125 $G_0S_1O_1$.	Local stability does not imply global attraction; the sampled catalytic pathway is not a single-start artifact.

6. Discussion

6.1. From Physical Reuse to Spatial–Operational Sustainability

The first implication of the model is that the physical reuse of existing urban space and the sustained performance of a community elderly-care facility should be treated as related but analytically distinct objectives. Adaptive-reuse research increasingly evaluates success through functional, economic, social, environmental, and management dimensions rather than through physical retention alone [5–7]. In this broader perspective, reusing an existing building creates a resource-efficiency opportunity, but the long-term value of that reuse depends on whether the new function remains viable and meaningfully used. This distinction is particularly relevant to community elderly care because facility expansion can coexist with persistent underutilization [10].

The present model extends this discussion by focusing on the spatial–operational conditions that shape effective utilization after reuse. Existing empirical studies already show that accessibility and service capacity can jointly influence the realized use of elderly-care facilities [11], while broader community-care research demonstrates that service availability, user need, enabling resources, and service organization do not translate automatically into actual utilization [14–16]. The contribution is therefore not that accessibility or operational capacity matters in isolation, but that their effects are placed within a strategic setting in which different actors bear different incremental costs.

The spatial component is especially important for adaptive reuse. A well-located existing property can improve access to older residents, public transport, healthcare, and daily services, thereby increasing accessibility-induced utilization potential. At the same time, such a property may impose a higher incremental opportunity cost on the stock-space provider. Evidence from Chinese commercial-property markets, including Shanghai, supports a positive but heterogeneous association between accessibility and property value [22,23]. The model translates this empirical regularity into a stylized strategic trade-off between accessibility-induced utilization value and the incremental opportunity cost borne by the stock-space provider. It does not assume that accessibility mechanically determines rent or that all better-located elderly-care properties are more expensive. This qualification matters for public assets, long-term leases, subsidized properties, or buildings whose physical condition limits alternative uses.

A parallel logic applies to operation. Integrated-care research emphasizes coordinated delivery, multidisciplinary organization, continuity, and person-centred service arrange-

ments [24], but these practices require resources. The model captures this through the utilization gain associated with integrated operation and the corresponding incremental operating cost. Again, the framework does not assume that integrated operation automatically produces higher utilization in every context. Instead, its value depends on how effectively operational capability combines with the spatial context.

The resulting contribution is a configuration-oriented interpretation of sustainability. The spatial–operational complementarity term formalizes the additional utilization return generated when higher accessibility and integrated operation coexist. This differs from simply entering accessibility and service capacity as two independent explanatory factors. It allows the model to ask whether a particular spatial–operational configuration can generate enough continuing utilization value to justify the distinct costs borne by S and O. For adaptive-reuse planning, the implication is that sustainable reuse should not be assessed only by whether an existing building can be converted, but also by whether the resulting spatial and operational configuration can sustain effective use over time.

This interpretation also clarifies the sustainability scope of the paper. Adaptive reuse can extend building service life and reduce dependence on new development [4–7], but the present model does not estimate embodied carbon, operational energy, demolition waste, or lifecycle emissions. Likewise, it does not directly evaluate broader social-sustainability outcomes such as equity, affordability, inclusiveness, or welfare. Its direct contribution is narrower: it examines the functional viability and persistence of elderly-care use within an existing urban asset under continuing utilization and cost constraints. Environmental and broader social benefits therefore remain contextual objectives of adaptive reuse rather than outcomes directly estimated by the game model.

6.2. Activation–Maintenance Divide and Conditional Catalytic Governance

The central theoretical contribution concerns the difference between the conditions required to activate coordinated spatial–operational quality and those required to maintain it after the additional targeted-performance layer recedes. This distinction must be positioned carefully because dynamic incentives are already well established in evolutionary-game research.

In elderly-care EGT studies, Mu et al. examine static and dynamic subsidy support [25]; Ren et al. compare alternative subsidy arrangements and their temporal effects [27]; and Wang et al. incorporate dynamic subsidy and penalty mechanisms into elderly-care service-quality supervision [28]. Related urban-regeneration and built-environment studies examine how governance instruments and stakeholder incentives shape cooperation and retrofit performance, including recent elderly-community and medical–elderly-care retrofit games [35,37,38]. Hao et al. discuss weakening government support after cooperation becomes established [39], and Lin et al. explicitly analyze gradually declining subsidy mechanisms in a built-environment evolutionary game [40]. The present study therefore does not claim novelty from dynamic subsidies, subsidy decline, or the general idea that government support can become less intensive over time.

Instead, the novelty lies in the formal separation of two different threshold problems. The first is an activation/coordination problem. When G_1 is active, eligibility architecture, actor-specific rewards, fiscal screening, and joint-performance policy synergy directly alter the payoff differences that determine whether S_1 or O_1 can emerge and whether the second quality dimension can be completed. The OR, AND, and actor-specific robustness tests show that these thresholds can change substantially when the institutional design of support changes even though the underlying utilization and cost parameters remain fixed.

The second is a post-targeted maintenance problem. At the modeled $x = 0$ boundary, G_0 and basic support continue, but the additional targeted-performance mechanism is

absent from the supply-side payoff comparison. Under this institutional separation, the maintenance conditions depend on the utilization gains generated by spatial accessibility and integrated operation, their spatial–operational complementarity, the actors' utilization-to-payoff conversion, and the incremental spatial and operating costs. In substantive terms, the question is whether the established spatial–operational configuration generates enough continuing utilization-related return to offset the additional burdens borne by the space provider and operator.

This yields the paper's main proposition: policy architecture shapes how spatial–operational quality is activated and coordinated, whereas post-targeted maintenance depends on configuration-generated utilization returns relative to incremental spatial and operational costs under the benchmark institutional separation. The proposition is deliberately conditional. The robustness analysis confirms this boundary: when a share $\eta > 0$ of basic support remains quality-contingent under G_0, policy support enters the maintenance comparison directly and reduces the utilization-synergy threshold required for local maintenance. Thus, the benchmark result should not be interpreted as evidence that continued quality maintenance is generally independent of public policy. Rather, it identifies the institutional conditions under which the additional targeted-performance layer can recede without remaining marginally necessary for S and O.

Region II of the accessibility–utilization-complementarity regime map provides the clearest theoretical expression of this distinction. In that region, high-accessibility space cannot activate autonomously from the baseline S_0O_0 state because its stand-alone utilization return remains below its opportunity cost, yet the coordinated S_1O_1 configuration is locally maintainable once spatial–operational complementarity becomes strong enough. This state is neither spontaneous emergence nor permanent targeted-policy dependence. It is a path-dependent configuration in which public intervention can change the route by which the system reaches coordinated quality, while the resulting configuration determines whether that quality remains locally viable under continuing basic support.

The initial-condition analysis strengthens this interpretation by showing that local maintainability and reachability are separate questions. In the $x = 0$ subsystem, the baseline S_0O_0 and coordinated S_1O_1 basins coexist even when S_1O_1 is locally stable.

The full tripartite simulations show that targeted regulation can redirect the sampled trajectories toward the maintainable S_1O_1 state, but 125/125 sampled convergence does not prove global attraction. The resulting governance interpretation is therefore conditional catalytic governance: intervention is catalytic only if it crosses an activation or coordination barrier and the resulting configuration subsequently satisfies the maintenance conditions.

This distinction adds a different analytical question to the existing EGT literature. Prior studies primarily ask how policy instruments can induce desirable strategies, stabilize cooperation, or improve service quality [25,27,28,32,35,37–40]. The present model additionally asks whether the desirable configuration remains locally viable once the marginal targeted mechanism is removed from the supply-side comparison. This is the specific sense in which the activation–maintenance divide extends, rather than replaces, existing dynamic-incentive research.

6.3. Mechanism-Based Implications, Transferability, and Limitations

At the project level, the results provide a mechanism-based interpretive framework organized around diagnosis, activation, coordination, and maintenance. The purpose is not to rank candidate sites or prescribe a project-selection rule, but to identify which mechanism is most restrictive in a particular configuration: high spatial opportunity cost, high incremental operating cost, weak accessibility-induced utilization, weak operational effec-

tiveness, or weak spatial–operational complementarity. The model therefore highlights why elderly-care adaptive reuse cannot be understood simply as a search for vacant floor area.

To illustrate this mechanism-based interpretation, consider two hypothetical existing buildings for community elderly-care reuse. Building A may offer stronger accessibility and therefore a larger expected accessibility-induced utilization gain, but may also involve a higher spatial opportunity cost; Building B may have a lower opportunity cost but weaker accessibility-induced utilization potential. The two configurations can then be interpreted in conjunction with anticipated operational effectiveness, incremental operating cost, and spatial–operational complementarity to examine which activation, coordination, or maintenance mechanism is likely to be most restrictive. This example illustrates how the model organizes project-level trade-offs conceptually; it is not intended as a validated site-ranking or project-selection procedure.

At the project level, the mechanism suggests that activation-oriented policy would need to address the relevant first-mover barrier. Where spatial opportunity cost is dominant, potentially relevant instruments include long-term public leases, priority allocation of suitable public assets, reduced rent exposure, or accessibility-based site screening. Where the operating barrier is dominant, stable procurement, staffing support, operator qualification, and service-capacity development may be more relevant. Evidence from government-purchased elderly-care services further emphasizes clear purchaser–provider responsibilities, management capacity, and periodically updated performance evaluation [50]. These instruments correspond to the model's logic that S and O face different incremental costs and should not necessarily be supported through identical mechanisms.

Coordination requires avoiding isolated upgrading. Accessible space without capable operation may remain underused, whereas strong operation in a poorly connected location may fail to generate sufficient realized use. From this mechanism-based perspective, coordination depends on considering site selection, building adaptability, surrounding community resources, operator capability, service composition, and contractual design together. Governments do not directly determine spatial–operational complementarity; rather, they can shape the physical, institutional, and organizational conditions under which it is more likely to emerge. This coordination logic applies to the configuration of an individual project and should not be interpreted as a citywide optimization of facility locations or service networks.

The maintenance mechanism highlights a different consideration. Once coordinated spatial–operational upgrading has been established, the relevant question is whether continuing utilization can support the additional spatial and operational burden. Reduced reliance on G_1 does not mean government withdrawal. Basic support, statutory regulation, welfare responsibilities, affordability measures, and targeted assistance remain relevant. Recent Pudong practice, which links service-quality evaluation to operating support, illustrates that public involvement can continue even as policy design becomes more performance-oriented [44,45]. The analytical distinction concerns the additional marginal incentives used to activate the modeled quality strategies, not the disappearance of public responsibility.

The interpretive scope of the framework is therefore deliberately limited to project-level mechanism diagnosis and configuration comparison. It is not presented as an empirically validated planning-support or decision-optimization tool. It also does not model the meso-scale spatial-planning processes required to determine the optimal number and distribution of facilities across a city, identify service gaps across neighborhoods, evaluate citywide spatial equity, or allocate resources among multiple competing projects. Those questions require facility-network, demand-allocation, or spatial-optimization models that can complement, rather than be replaced by, the present evolutionary-game framework.

The Shanghai/Pudong reference configuration should therefore be distinguished from the transferable mechanism represented by the model. The specific numerical thresholds depend on local policy architecture, cost conditions, and parameter assumptions and should not be transferred directly to other cities. What is potentially transferable is the diagnostic structure: planners can distinguish whether a project faces an activation barrier, a coordination barrier, or a post-targeted maintenance barrier, and can then identify which spatial, operational, or policy mechanism is most restrictive. Citywide facility-network planning, spatial-equity analysis, and cross-project resource allocation require additional meso-scale models and are not inferred from the present project-level framework.

Importantly, the planning interpretation should not equate higher effective utilization with higher overall service quality or more equitable satisfaction of elderly-care needs. A highly utilized facility may still underserve older adults with limited mobility, low-income households, or other socially vulnerable groups, and high utilization may also reflect concentrated demand or limited alternative service provision. The present framework can therefore assess the viability of a spatial–operational configuration, but equity, affordability, inclusiveness, user-specific accessibility, and care outcomes require complementary empirical assessment.

Transferability nevertheless has limits. First, the binary S_0/S_1 and O_0/O_1 strategies simplify continuous variation in accessibility, building condition, ownership, service quality, contracts, and user demand. Second, accessibility is represented through a binary spatial strategy and its utilization consequence rather than through a directly estimated multidimensional accessibility index, and the accessibility–opportunity-cost relationship is stylized rather than deterministic. Third, Shanghai and Pudong provide an institutional context and evidence anchor rather than an estimated local equilibrium; several reference parameters remain scenario values, structural scales, or proxies, so the reported numerical thresholds should be interpreted as conditional benchmark results rather than transferable empirical cutoffs. In empirical applications, the incremental cost of integrated operation will vary with staffing requirements, service intensity, organizational scale, and operational efficiency; the 25% reference share is therefore not intended to represent a universal cost ratio. Fourth, deterministic replicator dynamics omit stochastic shocks, contractual lock-in, entry and exit, capacity constraints, heterogeneous users, and time-varying demand. Accordingly, post-targeted maintenance should be interpreted as local strategic maintainability under a given demand and parameter environment rather than as a forecast of long-term demographic or neighborhood stability. Finally, effective utilization represents realized service use rather than overall care quality, equity, need satisfaction, or social welfare.

Future empirical work should therefore estimate accessibility-induced utilization gains, operation-induced utilization gains, and spatial–operational complementarity using matched facility-level spatial, operational, and utilization data; examine neighborhood heterogeneity in spatial and operating costs; incorporate user demand, distributional equity, and dynamic contracts more explicitly; and connect the project-level game framework with meso-scale facility-network and spatial-allocation models. The most transferable contribution of the present study is not any single benchmark threshold, but the mechanism-based distinction between policy-sensitive activation and configuration-dependent maintenance, and the analytical interpretation linking accessible existing space, professional operation, and the continued functional viability of adaptive reuse for community elderly care under a given demand environment.

7. Conclusions

This study develops a tripartite evolutionary-game framework for understanding how existing urban space can be adaptively reused for community elderly care through co-

ordinated spatial and operational upgrading. Its principal theoretical contribution is a conditional distinction between activation and maintenance. Targeted regulation can help overcome first-mover and coordination barriers, whereas, under the benchmark architecture with quality-invariant basic support, post-targeted maintenance depends on whether the established spatial–operational configuration generates sufficient utilization-related returns to cover its incremental spatial and operating costs. The robustness analysis further shows that this separation is institutional rather than universal: when quality-contingent support persists within the basic-support regime, policy support re-enters the maintenance ccordingly, targeted regulation can play a conditional catalytic role by helping the system enter a maintainable high-quality configuration. This maintenance result refers to local strategic maintainability under a given demand and parameter environment and should not be interpreted as a forecast of long-term demographic or neighborhood stability. Local maintainability also does not imply automatic reachability or global convergence. The transferable contribution lies in this mechanism-based analytical interpretation rather than in any single Shanghai-specific threshold.

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