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Study on the Polycentric Collaborative Governance Mechanism for Municipal Solid Waste: Based on an Evolutionary Game Model and Simulation Analysis

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Abstract
With accelerated urbanisation in China, the government-led monolithic municipal solid waste (MSW) governance model faces low efficiency, insufficient social capital involvement and weak public participation. This study analyses strategic interactions and dynamic equilibrium paths of the three agents via an evolutionary game model, verified by MATLAB simulations. Findings show that tripartite collaborative governance significantly enhances efficiency. Dynamically adjusted policy instruments effectively resolve the "government overload-market absence-public apathy" dilemma. A positive feedback cycle of "strong regulation, high investment, active participation" emerges with government supervision, corporate governance investment and public oversight. Layered policy toolbox and dynamic optimization recommendations are proposed, providing theoretical and practical pathways for MSW governance.

Keywords: Municipal Solid Waste (MSW) Governance, Polycentric Governance, Evolutionary Game Theory, Collaborative Mechanism, Policy Simulation

1.Introduction

With the accelerated process of urbanisation in China, continuous urban expansion, and a gradually increasing population, municipal solid waste (MSW) has grown considerably, even leading to a "cities besieged by waste" scenario in the early 21st century. The advancement of sustainable development, ecological civilisation construction (particularly the development of eco-cities and low-carbon cities), and China's strategic goals of "carbon peaking" and "carbon neutrality" have placed particular emphasis on MSW management within urban development. This led to the implementation of a nationwide waste classification (garbage sorting) policy starting in 2019. In recent years, certain achievements have been made in MSW governance in China.
For a long time, China's MSW governance model has exhibited a three-tiered legal management architecture of "national legislation - local refinement - specific policies", manifesting as a framework with both overarching national laws and supporting local regulations and pilot policies. Within this model, local governments have established a standardised process of "unified collection - centralised transportation - designated disposal" [1]. The long-standing reliance on a monolithic model of "authority governance led by local governments" for MSW management has resulted in a dilemma characterised by "campaign-style regulation" and "perfunctory compliance during inspections". Simultaneously, this monolithic model has led to a significant institutional imbalance in societal participation, constraining the development space for social capital involvement in MSW governance, and resulting in chronically low participation rates from social capital. Furthermore, this monolithic model weakens the citizen's role as a governance agent, and the closed operation of the final disposal stage keeps the public in the passive role of "outsiders" merely receiving services, lacking substantive incentive mechanisms for waste classification. Surveys indicate that in Shanghai, only just over 30% of citizens deeply engage in waste classification practices, making it difficult to reconcile the goal conflicts between the government, social capital (enterprises), and the public. Within the predicament of this single-mode (monolithic model) governance: the government pursues maximised environmental benefits but faces high regulatory costs; social capital is constrained by technological investment and low profit margins, leading to insufficient motivation for

participation; and the public, due to a mismatch between the time cost of classification and the perceived benefits (which are lagging in terms of environmental improvement), maintains a long-term low rate of sorted disposal. The absence of social capital and public participation creates a vicious cycle of "government overload - market absence - public apathy" in MSW treatment. This unidirectional operational mechanism not only violates the "producer pays" principle, but also leads to institutional wastage of resources that should hold significant value, highlighting a dual failure of the traditional governance system both in terms of social mobilisation mechanisms and market resource allocation. Consequently, there is an urgent need within low-carbon city construction to explore new pathways for MSW governance based on the collaboration of three main agents: the government, social capital (enterprises), and the public.

Polycentric governance theory, owing to its explanatory power regarding multi-agent collaborative mechanisms, provides a suitable theoretical lens for addressing the aforementioned predicaments/dilemmas. This theory proposed by Elinor and Vincent Ostrom, who challenged the traditional, centralized approaches to public resource management [2]. It addresses complex challenges through multiple, interacting centres of authority rather than a single, central entity [3]. Through collaboration, interaction, and adaptive adjustment of rules, it aims to achieve dual enhancements in governance efficiency and fairness. In this study, the value of polycentric governance theory lies in its abandonment of the traditional monolithic governance structure in favour of a tripartite collaborative model involving "government - social capital (enterprises) – public". Here, the government, social capital, and the public are all endowed with the status of governance agents, improving the role division mechanism and establishing a closed governance network characterised by "government leadership, deep participation by social capital, and light participation coupled with supervision by the public", thereby resolving the conflict among the three agents' goals. It facilitates attracting social capital through market-oriented methods to deeply participate in research and development (R&D) and facility construction, compensating for the government's monolithic fiscal sources and technological shortcomings.

The effective implementation of the polycentric governance concept requires two prerequisites [4]. (1) Clear rights and responsibilities: Defining the governance rights and responsibilities of enterprises and the public, such as revising relevant laws to elevate the obligation of enterprises to treat waste they generate from encouraging clauses to mandatory clauses. (2) Incentive compatibility: Designing dual incentive tools based on economic and social impact, such as the pilot "classification/sort points - carbon inclusion" linkage mechanism in Shanghai's Pudong New Area, where citizens' sorting behaviour earns carbon points redeemable for offsetting public service fees, significantly enhancing public participation rates. Research has found that while this theory fits multi-agent governance scenarios, necessary interactive mechanisms for resolving conflicts arising from interest divergences and conflicts amongst multiple agents are still lacking. Given the characteristics of polycentric governance involving "multiple agents and interest interactions", this study argues that its framework construction needs to answer a key question—how can multiple agents achieve dynamic equilibrium under the aforementioned prerequisites? Herein, evolutionary game theory provides an effective analytical tool. By constructing a tripartite evolutionary game model involving "government - enterprises – public", the agents in MSW governance are incorporated into the analysis to assess the interests and strategic choices of each party. As MSW governance involves issues like innovation in treatment methods, optimal resource allocation, and fiscal expenditure, this study integrates polycentric governance theory into the MSW treatment model, designing a multi-agent, multi-responsibility waste treatment mechanism. It further incorporates analysis of tripartite gaming behaviour on the basis of polycentric governance, integrating the "agent structure" (polycentric governance) with "behavioural dynamics" (evolutionary game) to construct an "structure-behaviour" integrated analytical framework. At a practical level, this study provides quantified policy tools for addressing the real-world problems of "high government regulatory costs, insufficient motivation for enterprise recycling, and low public willingness to sort waste".

2. Literature Review

2.1. Core Tenets of Polycentric Governance Theory

Polycentric governance, is fundamentally breaking through the traditional monocentric (government-dominated) governance model. It advocates that public affairs should involve the collaborative participation of multiple agents, such as the government, the market, social organisations, and the public, to maximise public interest through decentralised cooperation. It comprises three key elements: collaborative participation of multiple agents, power interaction and checks-and-balances, and the adaptive construction of rules [5].

Collaborative participation of multiple agents emphasises the diversification of governance agents. In typical social governance contexts, the government plays a guiding role through policy formulation, resource allocation, and supervision; enterprises participate in practical activities leveraging their technical advantages; social organisations enhance public awareness through education and advocacy; and the public completes the governance loop through participation and supervision. This structure avoids the capacity limitations of a monolithic model and integrates the resources and expertise of all parties.

Power interaction and checks-and-balances emphasise the distributed configuration of governance power. Polycentric governance abandons the traditional top-down, unidirectional flow of power, which advocates the formation of a dynamic equilibrium through negotiation, competition, and cooperation [6]. For instance, the government constrains corporate behaviour through regulations, enterprises feed back into policy optimisation through technological innovation, and social organisations and the public promote policy transparency through supervision, this creating mutual checks-and-balances within a power network [7].

The adaptive construction of rules requires that governance rules be co-created by multiple agents and dynamically adjusted based on practical feedback [8]. In traditional MSW governance, the government's unilaterally dominant monolithic model leads to insufficient participation from enterprises and the public, creating a vicious cycle of "government overload - market absence - public apathy". Therefore, analysing agent interactions and designing

incentive mechanisms through theoretical tools becomes key to the effective practical implementation of polycentric governance.

2.2. Application Practices and Experience of Polycentric Governance Theory in Environmental Governance

Polycentric governance theory offers a path for environmental governance distinct from traditional government-led or market-unilateral regulation. Currently, this theory is widely applied in areas such as climate governance, natural resource management, and transboundary pollution control.

Elinor and Vincent Ostrom's research pointed out that effective governance relies on the synergy of self-organisation, informal institutions, and multi-level rules, demonstrating the advantages of the polycentric model through case studies of common resource management (e.g., fisheries, forests, irrigation systems). Subsequent research has further expanded its application boundaries. For example, Boukharta [9] proposed four core functions of polycentric governance: information sharing, activity coordination, problem-solving, and conflict resolution. Yadav [10] highlighted its applicability in climate governance.

In practice, polycentric governance integrates government, market, and societal forces to form a "hybrid governance" network. The institutional design of polycentric governance relies on incentive compatibility and trust building, requiring clear boundaries, participatory decision-making, monitoring mechanisms, and conflict resolution pathways. Practical cases show that polycentric governance requires converting the preferences of different agents into collective action through institutional innovation.

The implementation of polycentric governance in environmental governance also faces challenges: (1) High coordination costs among agents, where diverging interests may lead to "fragmented governance" [11]. (2) Power dispersion can weaken accountability mechanisms, particularly in cross-jurisdictional governance, where ambiguous responsibility attribution can easily trigger a *Tragedy of the Commons* [12]. (3) Uneven technical capacity and resource distribution may exacerbate inequalities. Consequently, scholars have proposed strengthening the role of "middle-layer" institutions to reduce transaction costs through standardised protocols and information sharing [13].

In summary, polycentric governance theory demonstrates significant advantages in environmental governance, and its core value lies in resolving the rigidity and inefficiency of traditional monocentric models through multi-agent collaboration, layered rule design, and dynamic adaptive mechanisms.

2.3. Optimisation Pathways for MSW Governance and the Introduction of Evolutionary Game Theory

Polycentric governance theory provides a framework for multi-agent collaboration in MSW governance, but contradictions persist in practice: the government aims to improve environmental quality and implement policies; enterprises seek to reduce processing costs; and the public hopes to minimise the disruption of waste facilities on daily life and avoid personal cost increases—these divergent goals often lead to governance deadlock [14]. Furthermore, multi-agent coordination requires frequent communication, but difficulties in information sharing and unclear responsibilities further increase collaboration costs.

Faced with these challenges, the traditional polycentric governance framework struggles to effectively quantify the dynamic gaming relationships among agents. The core of these issues lies in the "benefits-costs" trade-offs underlying each party's strategic choices [15]. Evolutionary game theory can transform complex behavioural logic into calculable strategy combinations and benefit calculations through mathematical models, revealing the process by which a governance system moves from chaos to stability.

Evolutionary game theory can also address capability disparities within polycentric governance [16]. These quantitative analyses can design more effective intervention schemes, providing specific directions for optimising polycentric governance. In conclusion, evolutionary game theory can transform agent conflicts, collaboration barriers, and capability disparities in polycentric governance into calculable dynamic processes, offering a scientific basis for resolving governance deadlocks [17].

3. Construction of the Evolutionary Game Model

Based on the theoretical paradigm of polycentric governance, this section constructs an evolutionary game model for MSW governance. It analyses strategic evolution paths to reveal how policy design can guide the three agents towards a governance equilibrium that achieves an "environment-economy-society" win-win situation.

3.1. Model Assumptions and Parameter Settings

According to policy documents such as the Chinese National Development and Reform Commission's 2015 "Administrative Measures for Municipal Solid Waste" and Shanghai's 2025 "Shanghai Municipal Solid Waste Collection, Transportation and Disposal Management Measures", the following assumptions are proposed:

1. Under the polycentric governance model, the three gaming agents (government, social capital (enterprises), public) are all rational and will adjust their strategies based on policy changes, expected adjustments, and willingness changes.
2. Strategy space settings:

- Government strategy space S_g= (Strict Supervision, Lenient Supervision). The probability of choosing strict supervision is *x*, and the probability of lenient supervision is 1-*x* (Strict supervision refers to the government investing higher costs to constrain the behaviour of social capital and the public, such as strictly enforcing MSW sorting and implementing the "producer pays" principle)
- Social capital strategy space S_c= (Active Treatment, Passive Treatment). The probability of choosing active treatment is *y*, and the probability of passive treatment is 1-*y*.
- Public strategy space S_p= (Sort and Dispose, Dispose Randomly). The probability of choosing sorted disposal is *z*, and the probability of random disposal is 1-*z*.

3. Government payoff parameters

- **Strict Supervision:** Incurs supervision cost C_h, gains subsequent central government benefits R_g after environmental improvement, but faces public negative evaluation P_d due to strict waste sorting policies.

- **Lenient Supervision:** Incurs supervision cost C_l, bears environmental risk loss *L*, but gains public positive evaluation P_a due to lenient waste sorting policies.

4. Social capital (enterprises) payoff parameters
- **Active Treatment:** Incurs technology R&D cost C_p, receives government policy subsidy *S*, and gains high public reputation P_e.
- **Passive Treatment:** Incurs symbolic (perfunctory) technology R&D cost C_e (assuming some minimal R&D investment even under passive treatment). If the government exercises strict supervision, it is fined *F*, and bears public negative evaluation N_e.

5. Public payoff parameters
- **Sort and Dispose:** Bears time cost *T*, receives government reward R_p.
- **Dispose Randomly:** Saves cost C_s, bears public opinion pressure *P*, and loses opportunity cost R_c.

6. **Parameter rationality constraints:** Based on the rational agent assumption,

Examining the relevant parameters (see Table 1), and according to the principle of parameter rationality and the rational agent assumption (1), we get:
- **Government:** $R_g > C_h$, otherwise no motivation for strict supervision.
- **Social Capital:** S+$P_e > C_p$ and $F > C_e$, otherwise no motivation for environmental protection.
- **Public:** $R_p > T$ and $P+R_c > C_s$, otherwise no motivation for waste sorting.

Table 1: Relevant Parameter Settings

Participant	Strategy Choice	Parameter Description
Government (G)	Strict Supervision (S)	- Input Cost: C_h - Environmental Benefit: R_g - Public Opinion Evaluation: P_d (Negative)
	Lenient Supervision (W)	- Input Cost: C_l - Environmental Risk Loss: L - Public Opinion Evaluation: P_a (Positive)
Social Capital (C)	Active Treatment (H)	- Technology Investment: C_p - Policy Subsidy: *S* - Public Reputation: P_e (Positive)
	Passive Treatment (L)	- Evasion Cost: C_e - Fine: *F* (Only effective under strict government supervision) - Public Evaluation: N_e (Negative)
Public (P)	Sort and Dispose (A)	- Time Cost: T - Government Reward: R_p
	Dispose Randomly (N)	- Cost Saving: C_s (Can be set to 0) - Public Opinion Pressure: P - Opportunity Cost Loss: R_c

3.2. Establishing the Model Payoff Matrix

With two strategies for each of the three agents, there are eight (2×2×2=8) strategy combinations. The payoff matrix is shown in Table 2.

Table 2: Tripartite Payoff Matrix under Polycentric Governance

Government Strategy	Social Capital (Enterprise) Strategy	Public Strategy	Government Payoff U_g	Social Capital (Enterprise) Payoff U_c	Public PayoffU_p
Strict Supervision	Active Treatment	Sort and Dispose	$R_g - C_h + P_d$	$S - C_p + P_e$	$R_p - T$
		Dispose Randomly	$R_g - C_h + P_d$	$S - C_p + P_e$	$C_s - P - R_c$
	Passive Treatment	Sort and Dispose	$R_g - C_h + P_d - L$	$-F - C_e - N_e$	$R_p - T$
		Dispose Randomly	$R_g - C_h + P_d - L$	$-F - C_e - N_e$	$C_s - P - R_c$
Lenient Supervision	Active Treatment	Sort and Dispose	$-C_l + P_a$	$S - C_p + P_e$	$R_p - T$
		Dispose Randomly	$-C_l + P_a$	$S - C_p + P_e$	$C_s - P - R_c$
	Passive Treatment	Sort and Dispose	$-C_l + P_a - L$	$-C_e - N_e$	$R_p - T$
		Dispose Randomly	$-C_l + P_a - L$	$-C_e - N_e$	$C_s - P - R_c$

4. Analysis of the Tripartite Evolutionary Model Based on Polycentric Governance Theory

4.1. Government's Evolutionarily Stable Strategy (ESS)

The expected payoff for the government choosing strict supervision (S) is given by Equation (1):

$$U_G(S) = R_g - C_h + P_d - (1-y)L \quad (1)$$

The expected payoff for the government choosing lenient supervision (W) is given by Equation (2):

$$U_G(W) = -C_l + P_a - (1-y)L \quad (2)$$

The average payoff is given by Equation (3):

$$\bar{U}_G = xU_G(S) + (1-x)U_G(W) \quad (3)$$

The dynamic equation is constructed as Equation (4):

$$\frac{dx}{dt} = x(U_G(S) - \bar{U}_G) = x(1-x)[U_G(S) - U_G(W)] \quad (4)$$

Substituting Equations (1) and (2) and simplifying yields Equation (5):

$$\frac{dx}{dt} = x(1-x)\left[\left(R_g - C_h + P_d\right) - (-C_l + P_a)\right] = x(1-x)\left[R_g - C_h + P_d + C_l - P_a\right] \quad (5)$$

Equilibrium Analysis and Inferences

When the net benefit (payoff) of government supervision $(R_g - C_h + P_d + \mathrm{C_l} - P_a)$ is positive, corporate environmental incentives $(S+F)$ are sufficient, and the net public participation benefit $\left(R_p - T\right)$ is high, all initial strategy trajectories converge towards the three-dimensional vertex (1,1,1) (full cooperation equilibrium, Figure 1), manifesting as unidirectionally contracting arrow clusters, mapping the synergistic reinforcement of the three agents' strategies. If supervision costs (C_h) are too high, corporate fines (F) provide insufficient deterrence, and public participation costs (T) dominate, trajectories collapse towards the lower-left corner (0,0,0) (full defection equilibrium, Figure 2), forming a "tragedy of the commons". If non-linear parameters are designed (e.g., F changes dynamically with x), trajectories may exhibit spiral or fluctuating patterns, eventually converging to a mixed equilibrium point (e.g., (0.6,0.8,0.4), Figure 3), reflecting the delayed feedback effects of strategic interaction.

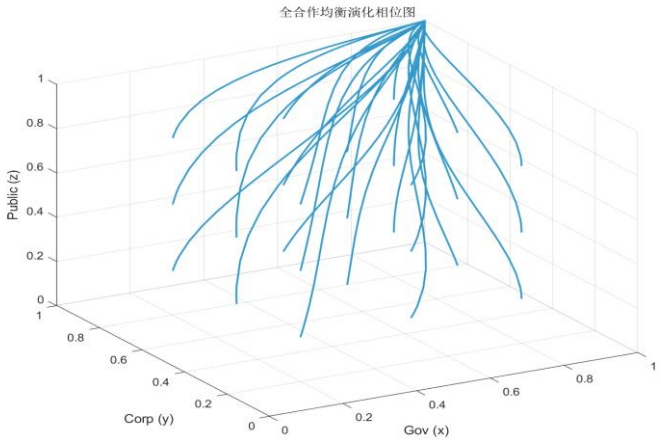


Fig 1: Phase Diagram of Multi-Agent Full Cooperation Equilibrium [Trajectories converging to (1,1,1)]

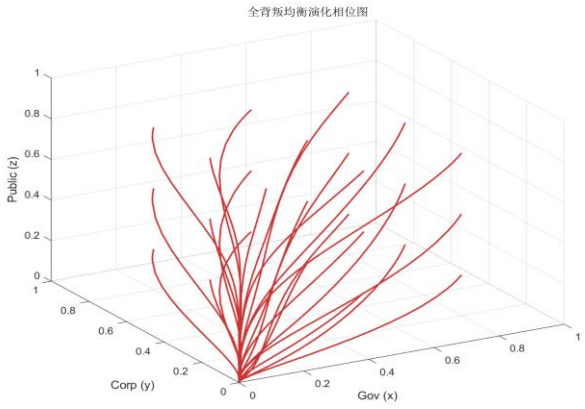


Fig 2: Phase Diagram of Multi-Agent Full Defection Equilibrium [Trajectories converging to (0,0,0)]

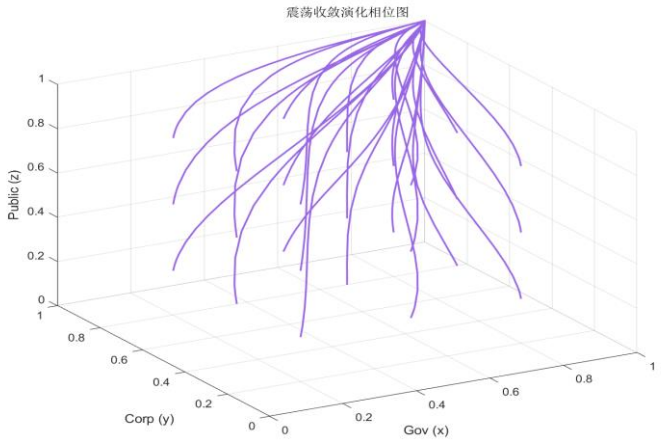


Fig 3: Phase Diagram of Oscillatory Convergence Evolution [Spiral trajectories converging to a mixed point]

Inference 1: The full cooperation equilibrium requires highly synergistic incentives for all three agents—the government needs to reduce C_h through digital law enforcement, increase R_g by reducing health expenditures, and strengthen P_d through transparent communication; enterprises need subsidy-technology linkage + ESG ratings to amplify P_e; the public needs community point redemption systems and tax benefits to balance T and R_p. Any break in incentives for one party (agent) can disrupt the synergy.

Inference 2: The full defection equilibrium stems from the mismatch between "supervision costs and risk losses" and the "inverted benefits of corporate environmental investment"—the government opts for lenient supervision due to high C_h; enterprises tend to low investment due to insufficient F and low C_e; and the public chooses random disposal due to lack of immediate incentives, forming a vicious cycle of "Lenient supervision → high pollution → public withdrawal". Breaking this deadlock requires reducing marginal supervision costs through technological methods, introducing tiered penalties, and opening environmental data platforms to empower public supervision.

Inference 3: The oscillatory convergence mode indicates that when the payoff functions of the three agents' strategies exhibit non-linear dependencies, the system may experience temporary fluctuations before converging to a non-corner equilibrium. The stability of such systems depends on the match between the "parameter adjustment rate" and the "strategy learning speed". Practically, policy buffer periods (e.g., graduated carbon tax increases) and public participation mechanisms (e.g., environmental hearings) can be established to steer the system towards a socially optimal mixed equilibrium.

4.2. Social Capital's Evolutionarily Stable Strategy (ESS)

The expected payoff for social capital (enterprises) choosing active treatment (H) is given by Equation (6):

$$U_C(H) = S - C_p + P_e \tag{6}$$

The expected payoff for social capital (enterprises) choosing passive treatment (L) is given by Equation (7):

$$U_C(L) = -xF - C_e - N_e \tag{7}$$

The average payoff is given by Equation (8):

$$\bar{U}_C = yU_C(H) + (1-y)U_C(L) \tag{8}$$

Substituting the specific payoff expressions yields the dynamic equation (9):

$$\frac{dy}{dt} = y(U_C(H) - \bar{U}_C) = y(1-y)[U_C(H) - U_C(L)] \tag{9}$$

Equilibrium Analysis and Inferences

Social capital has three equilibrium solutions: "full high investment" (y→1, Figure 4), "full low investment" (y→0, Figure 5), and mixed strategy (y∈(0,1), Figure 6).

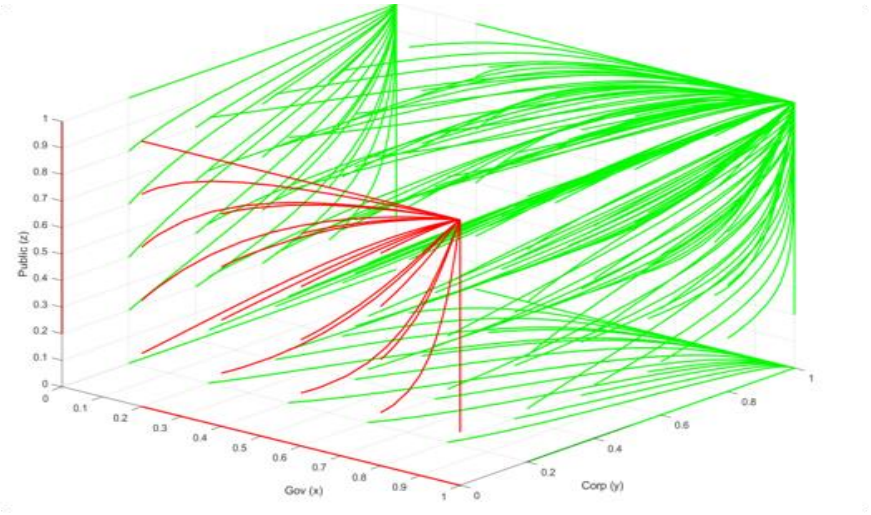


Fig 4: Phase Diagram for Social Capital (Enterprise) Full High Investment Equilibrium

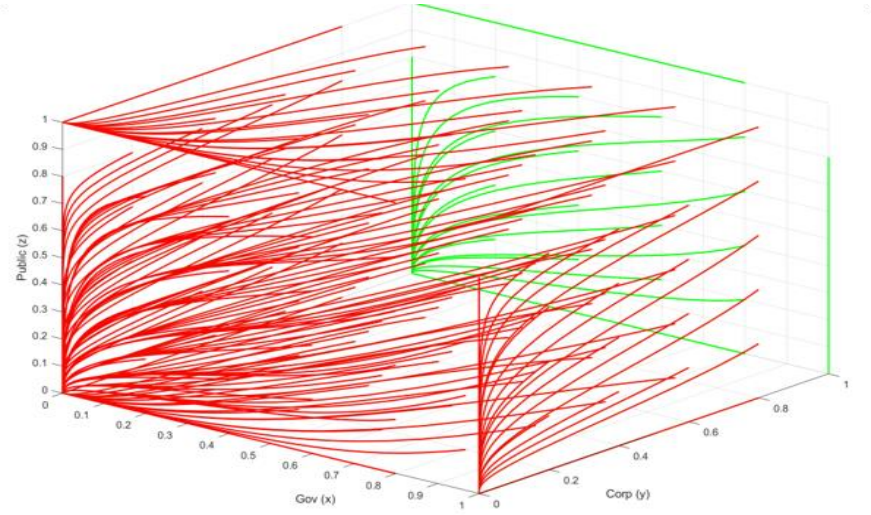


Fig 5: Phase Diagram for Social Capital (Enterprise) Full Low Investment Equilibrium

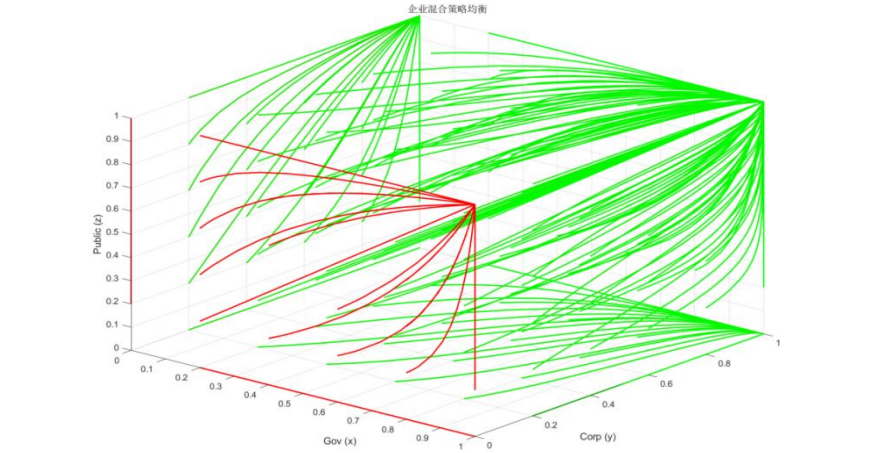


Fig 6: Phase Diagram for Social Capital (Enterprise) Mixed Strategy Equilibrium

Inference 4: Enterprises' waste treatment investment decisions are influenced by the superimposed effect of multiple policies. Single subsidies or fines have limited effect; they need to be combined with public reputation to reduce actual technology cost.

Inference 5: Government supervision stability affects long-term corporate investment—fluctuations in supervision intensity lead to unstable corporate expectations, favouring short-term low investment; legislating environmental standards can enhance the credibility of government

commitments, prompting enterprises to formulate long-term technology investment plans.

Inference 6: Public green behaviour influences enterprises bidirectionally. The direct path is increasing the reputation P_e for high-investment enterprises; the indirect path is pressuring the government to strengthen supervision (increasing x). Therefore, public green consumption and community supervision can simultaneously leverage government and corporate strategies, achieving a shift in system equilibrium at low policy cost.

4.3. Public's Evolutionarily Stable Strategy (ESS)

The dynamic equation for public participation is given by Equation (10):

$$\frac{dz}{dt} = z(1-z)[U_P(A) - U_P(N)] \quad (10)$$

The expected payoffs for public sort and dispose (A) and dispose randomly (N) are given by Equation (11):

$$U_P(A) = R_p - T, \quad U_P(N) = C_s - P - R_c \quad (11)$$

The average payoff is given by Equation (12):

$$\overline{U}_P = zU_P(A) + (1-z)U_P(N) \quad (12)$$

Equilibrium Analysis and Inferences

The public has three equilibria: "full participation" ($z \to 1$, Fig. 7, requires $R_p - T > C_s - P - R_c$), "full non-participation" ($z \to 0$, Figure 8, requires $R_p - T < C_s - P - R_c$), and "mixed strategy" ($z \in (0,1)$, Figure 9, requires $R_p - T = C_s - P - R_c$).

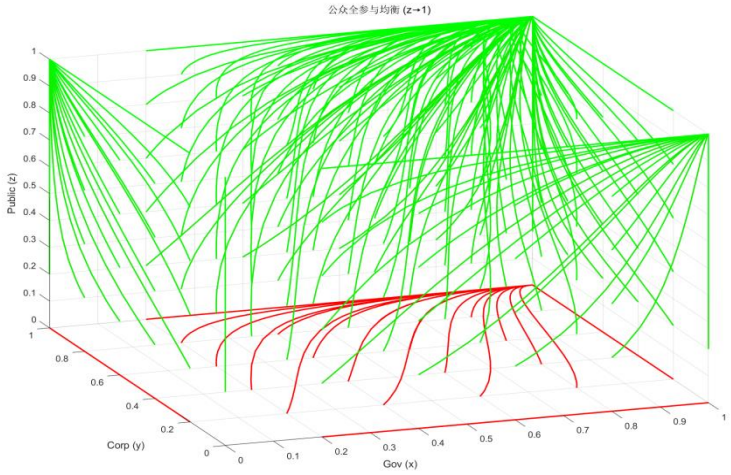


Fig 7: Phase Diagram for Public Full Participation Equilibrium

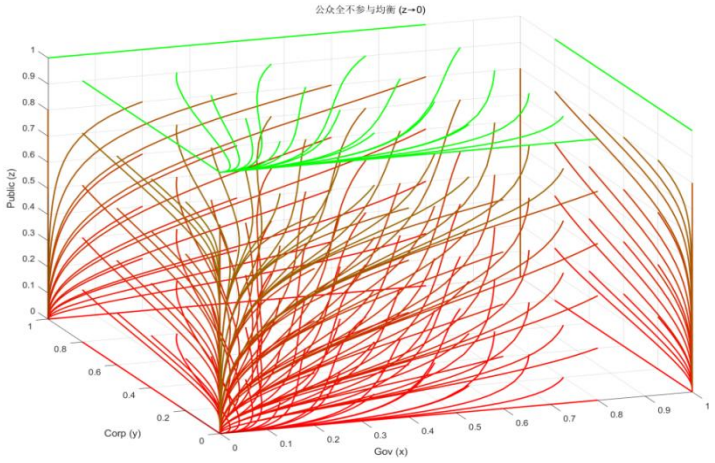


Fig 8: Phase Diagram for Public Full Non-Participation Equilibrium

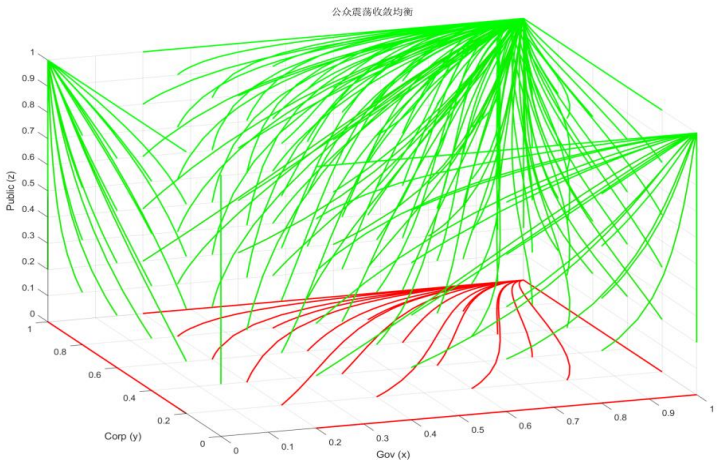


Fig 9: Phase Diagram for Oscillatory Convergence of Public Behaviour Equilibrium

Inference 7: Full public participation requires "sustained multi-incentive coordination"—benefits must cover the time cost T (e.g., waste sorting points or cash subsidies), alongside visualisation of environmental improvement (e.g., public display of community pollution data) and perception of long-term health benefits (e.g., reduced medical expenditures). When a closed loop of "strict government supervision → corporate technology investment → environmental improvement" forms, public trust increases, strengthening participation willingness; conversely, enterprise evasion of responsibility leading to worsened pollution causes public withdrawal even if rewards are high.

Inference 8: Full public non-participation stems from long-term cost-benefit imbalance—e.g., insufficient sorting facilities causing *T* to surge, or inadequate rewards and weak social pressure *P*, making passive participation the rational choice. The underlying cause is the "low investment → high pollution → low participation" cycle. Breaking this deadlock requires: in the short term, reducing *T* through smart sorting equipment; in the long term, converting environmental governance achievements into perceptible public welfare (e.g., improved community greening).

Inference 9: Fluctuations in public behaviour reflect policy sensitivity—fluctuating rewards and frequently changing rules lead to confused public expectations; when participation rates exceed a critical point (e.g., 60%), social normative pressure increases sharply, pushing more people to participate; on the contrary, collective action collapses. Policies must focus on coherence. Critical point can be break through community leader demonstration and regional reward pilots programme, while differentiated strategies should be formulated based on regional variations.

4.4. Solving and Analysing Tripartite Evolutionary Equilibrium Points from a Polycentric Theoretical Perspective

Let the strategy proportions of the government, social capital (enterprises), and the public be *x*, *y*, and *z* respectively. The system of replication dynamic equations is given by Equation (13):

$$\begin{cases} \frac{dx}{dt} = x(1-x)\left[R_g - C_h + P_d + C_l - P_a\right] \\ \frac{dy}{dt} = y(1-y)\left[S - C_p + P_e + xF + C_e + N_e\right] \\ \frac{dz}{dt} = z(1-z)\left[\left(R_p - T\right) - \left(C_s - P - R_c\right)\right] \end{cases} \quad (13)$$

Setting $\frac{\mathrm{dx}}{\mathrm{dt}} = \frac{\mathrm{dy}}{\mathrm{dt}} = \frac{\mathrm{dz}}{\mathrm{dt}} = 0$, yields eight pure strategy equilibrium points: (1,1,1), (0,0,0), (1,0,1), (1,0,0), (0,1,0), (0,0,1), (1,1,0), (0,1,1).

ESS are identified through local stability analysis of the Jacobian matrix (Equation 14). The Jacobian matrix *J* for the tripartite game is defined as the partial derivative matrix of the strategy dynamic equations, specifically as Equation (14):

$$\mathrm{J} = \begin{bmatrix} \frac{\partial \mathrm{x}}{\partial \mathrm{x}} & \frac{\partial \mathrm{x}}{\partial \mathrm{y}} & \frac{\partial \mathrm{x}}{\partial \mathrm{z}} \\ \frac{\partial \mathrm{y}}{\partial \mathrm{x}} & \frac{\partial \mathrm{y}}{\partial \mathrm{y}} & \frac{\partial \mathrm{y}}{\partial \mathrm{z}} \\ \frac{\partial \mathrm{z}}{\partial \mathrm{x}} & \frac{\partial \mathrm{z}}{\partial \mathrm{y}} & \frac{\partial \mathrm{z}}{\partial \mathrm{z}} \end{bmatrix} \quad (14)$$

where, Partial derivative for the government strategy equation: $\frac{\partial x}{\partial x} = (1-2x)\left[R_g - C_h + P_d + C_l - P_a\right]$ (Other partial derivatives wrt *y*, *z* are 0)

Partial derivatives for the enterprise strategy equation: $\frac{\partial y}{\partial x} = y(1-y)F$, $\frac{\partial y}{\partial y} = (1-2y)\left[S - C_p + P_e + xF + C_e + N_e\right]$ (Partial derivative wrt *z* is 0)

Partial derivative for the public strategy equation: $\frac{\partial z}{\partial z} = (1-2z)\left[R_p - T - (C_s - P - R_c)\right]$ (Partial derivatives wrt *x*, *y* are 0)

Key Scenario Analysis

Based on the characteristics of the Jacobian, two extreme scenarios are analysed: strict supervision (*x*=1) and high investment active treatment (*y*=1).

Scenario 1: Government Strict Supervision (*x*=1).

The dynamic equations for enterprises and the public are

given by Equation (15):

$$\begin{cases} \frac{dy}{dt} = y(1-y)\left[S - C_p + P_e + F + C_e + N_e\right] \\ \frac{dz}{dt} = z(1-z)\left[R_p - T - (C_s - P - R_c)\right] \end{cases} \quad (15)$$

Equilibrium points: Enterprise full high investment equilibrium: $y^* = 1$ (if $S + P_e + F + C_e + N_e > C_p$). Public full participation equilibrium: $z^* = 1$ (if $R_p - T > C_s - P - R_c$).
The Jacobian matrix can be simplified (only *y*, *z* change) as Equation (16):

$$J = \begin{bmatrix} (1-2y)\begin{bmatrix} S - C_p + P_e \\ +F + C_e + N_e \end{bmatrix} & 0 \\ 0 & (1-2z)\begin{bmatrix} R_p - T - \\ (C_s - P - R_c) \end{bmatrix} \end{bmatrix} \quad (16)$$

Eigenvalue analysis: $-\lambda_1 = -\left[S - C_p + P_e + F + C_e + N_e\right]$ (if $y^* = 1$, then $\lambda_1 < 0$), $-\lambda_2 = -\left[R_p - T - (C_s - P - R_c)\right]$ (if $z^* = 1$, then $\lambda_2 < 0$).

ESS conditions: $\begin{cases} S + P_e + F + C_e + N_e > C_p \\ R_p - T > C_s - P - R_c \end{cases}$

According to the above analysis, under strict government supervision, incentives need strengthening through tiered penalties (increasing with pollution) and classification/sort points redeemable for public services, alongside legislating environmental standards and long-term budgets to ensure policy stability (e.g., earmarking carbon trading revenue for environmental funds), avoiding policy fluctuations that undermine corporate confidence in long-term investment.

Scenario 2: Enterprise High Investment (*y*=1)
The dynamic equations for the government and the public are given by Equation (17):

$$\begin{cases} \frac{dx}{dt} = x(1-x)\left[R_g - C_h + P_d + C_l - P_a\right] \\ \frac{dz}{dt} = z(1-z)\left[R_p - T - (C_s - P - R_c)\right] \end{cases} \quad (17)$$

Equilibrium points: Government strict supervision equilibrium: $x^* = 1$ (if $R_g - C_h + P_d + C_l - P_a > 0$). Public full participation equilibrium: $z^* = 1$ (if $R_p - T > C_s - P - R_c$).
The Jacobian matrix is simplified (only *x*, *z* change) as Equation (18):

$$J = \begin{bmatrix} (1-2x)\begin{bmatrix} R_g - C_h + \\ P_d + C_l - P_a \end{bmatrix} & 0 \\ 0 & (1-2z)\begin{bmatrix} R_p - T - \\ \left(C_s - P - R_c\right) \end{bmatrix} \end{bmatrix} \quad (18)$$

Eigenvalue analysis: - $\lambda_1 = -\left[R_g - C_h + P_d + C_l - P_a\right]$ (if $x^* = 1$, then $\lambda_1 < 0$), - $\lambda_2 = -\left(R_p - T - (C_s - P - R_c)\right)$ (if $z^* = 1$, then $\lambda_2 < 0$).

ESS conditions: $\begin{cases} R_g - C_h + P_d + C_l - P_a > 0 \\ R_p - T > C_s - P - R_c \end{cases}$

According to the above analysis, to sustain high corporate investment and continued public participation, graded subsidy policies are needed (initial high subsidies attraction, mid-term market-oriented transition), a blockchain environmental data platforms should be built (ensuring tamper-proof emission data), and combined with community co-construction (point redemption for benefits, eco-family awards) and gamification design (achievement badges) to alleviate public participation fatigue, forming a stable closed-loop operation of "policy-technology-society".
Extrapolating from these two extreme scenarios, policy implications for all eight equilibrium points can be derived (Table 2), forming a policy toolbox (Table 3). The toolbox is designed by selecting the minimum necessary policy set for the strategic combination at each equilibrium point. Tool intensity is adjusted based on the threshold effects of public response. Combine economic incentives (subsidies/fines), social norms (ratings/public disclosure), and technological enablement (IoT/blockchain), avoiding single-path dependence.

Table 3: Policy Toolbox

Equilibrium Point	Policy Tools
Full Defection (0,0,0)	Clean tech subsidies, Pollution cost internalization (e.g., mandatory reporting in financial statements), Satellite remote sensing monitoring + rewarded reporting
Government Strict Supervision - Enterprise Low Investment (1,0,z)	Pollution volume-tiered fines, Targeted green credit provision, Public disclosure of corporate pollution maps
Government Lenient Supervision - Enterprise High Investment (0,1,z)	ESG-linked financing, Low-carbon consumption certification, Expansion of carbon trading markets
Enterprise High Investment - Public Passive (x,1,0)	Waste sorting education Apps, Environmental fines give back to the community, Smart bins with automatic recognition
Enterprise Low Investment - Public Active (x,0,1)	NGO litigation support, Joint and several accountabilities in the supply chain, Online public disclosure of pollution blacklists
Government Strict Supervision - Public Passive (1,y,0)	Blockchain emission certification, Mandatory policy hearings, Link pollution health warnings to production limits
Government Lenient Supervision - Public Active (0,y,1)	Granting enforcement rights to civil environmental organizations, Incentivizing social media dissemination of pollution events, Community-enterprise autonomous emission reduction agreements
Full Cooperation (1,1,1)	Legislation to solidify supervision standards, Dynamic subsidies + tax incentives, Classification/Sorting points redeemable for public services

5. Simulation Experiment

Under the framework of polycentric governance, multiple agents collaborate to achieve MSW governance goals. However, under the premise of rational assumptions, each agent acts to maximise its own interests. Considering disparities in regional economic development, citizen literacy, and local fiscal capacity, this study uses Shanghai, a model city for MSW governance in China, as an example. Based on reasonable parameter assumptions (referencing local policies and governance practices), the following parameter settings are obtained (Table 4). The system of differential equations is solved using MATLAB to verify the effectiveness of the policy toolbox.

Table 4: Parameter Settings

Parameter Type	Parameter Symbol	Value / Range	Explanations
Government Supervision Parameters	C_h	3	Strict supervision cost (Unit: ¥100 million, ref. Shanghai environmental law enforcement budget)
	R_g	5	Central government subsidy benefits post-environmental improvement
	P_d	2	Public negative evaluation under strict supervision (quantified as 'policy support loss', smaller absolute value = weaker impact)
	F	[2, 6]	Fine intensity (simulates changes in supervision intensity)
	C_l	1	Lenient supervision cost (default value, lower than C_h)
	L	4	Environmental risk loss (ref. Shanghai pollution emergency response costs)
	P_a	3	Public positive evaluation under lenient supervision (quantified as 'policy support gain')
Enterprise Parameters	C_p	[2, 4]	Technology investment cost (simulates changes in social capital investment)
	S	2	Government subsidy
	P_e	1.5	Public reputation (quantified as 'brand value added')
	C_e	0.5	R&D cost under passive treatment (symbolic/perfunctory investment)
	N_e	2	Public negative evaluation (quantified as 'brand value loss')
Public Parameters	T	1	Time cost for waste sorting (quantified as 'value of per capita hourly input')
	P	[1, 3]	Social pressure (simulates changes in social supervision intensity)
	R_p	2.5	Government reward (e.g., value of Shanghai Green Account point redemption)
	C_s	0	Cost saving from random disposal (default: no direct benefit)
	R_c	1.5	Opportunity cost loss (e.g., value of 'inability to participate in community benefits without sorting')
Initial Conditions	x_0, y_0, z_0	0.5	Initial strategy proportion (assumes 50% initial willingness for all three agents)
Time Span	t	[0,20]	Simulation period (Unit: years)

5.1. Impact of Supervision Intensity on System Evolution

When $F \in [2, 6]$, with other parameters fixed:

- ***F* ≤ 3 (Weak supervision):** Trajectories converge towards ($x\downarrow$, $y\downarrow$, $z\downarrow$) (e.g., $x\to0.3$, $y\to0.2$, $z\to0.3$). Enterprises choose passive treatment due to insufficient fines, and the public withdraws due to environmental degradation;
- ***F* = 4 (Medium supervision):** Trajectories converge towards ($x\approx0.8$, $y\approx0.7$, $z\approx0.6$) (Figure 10). The strategies of the three agents gradually synergise;
- ***F* ≥ 5 (Strict supervision):** Rapid convergence to (1,1,1) (green trajectory cluster). Enterprises switch to active treatment due to high evasion cost ($F > C_e$), and public participation increases due to perceived environmental improvement.

Therefore, Shanghai needs to maintain a fine intensity $F \geq 4$ (approx. 400 million yuan per fine) to ensure corporate compliance costs exceed evasion benefits. Increasing supervision intensity significantly impacts corporate MSW governance investment strategies. When intensity increases from low to medium-high levels, enterprises are forced towards high investment due to sharply rising evasion costs, the government continues strict supervision due to environmental benefits and public support, and the public's willingness to sort waste increases due to perceived environmental improvement, creating a positive feedback loop. However, if F exceeds the corporate tolerance threshold, it may trigger corporate relocation or implicit resistance (e.g., data fraud). A dynamic adjustment mechanism is needed to balance deterrence and market vitality. For instance, Shanghai could implement tiered fines for heavily polluting industries, while adopting flexible enforcement like “no penalty for first offence” for small and micro enterprises, avoiding a “one-size-fits-all” approach, alongside using big data monitoring to ensure transparency of emission data.

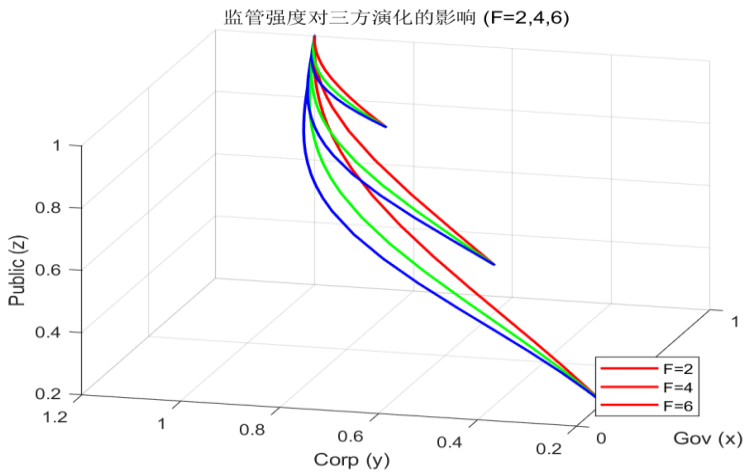


Fig 10: Parametric Sensitivity Analysis of Supervision Intensity [Trajectories for different F values]

5.2. Impact of Social Capital Investment on System Evolution

When $C_p \in [2, 4]$, with other parameters fixed:

- If $C_p \leq 3$, enterprises spontaneously choose high investment $(y \to 1)$, attracting stricter government supervision $(x \to 0.9)$ and promoting public participation $(z \to 0.8)$, forming a "technology upgrade → policy support" synergistic effect;
- If $C_p \geq 4$, the net enterprise benefit $(S + P_e + xF - C_p)$ becomes negative, leading to low investment $(y \to 0.2)$, triggering regulatory failure $(x \to 0.3)$, and public withdrawal $(z \to 0.4)$ (Figure 11).

"Subsidy + tax credit + green credit" mechanisms are needed to control C_p within the threshold $(C_p \leq 3.5)$. Simultaneously, industry-university-research platforms should be built to accelerate technology diffusion, and an "environmental investment - carbon emission right exchange" mechanism should be introduced (excess emission reductions can be sold as quotas).

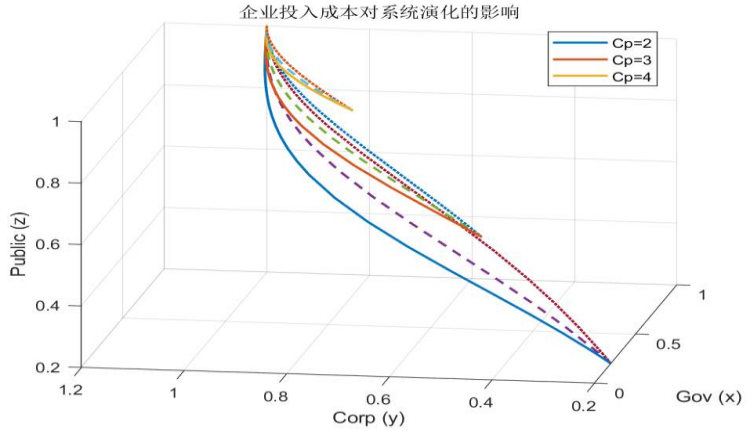


Fig 11: Parametric Sensitivity Analysis of Social Capital Investment Cost [Trajectories for different Cp values]

5.3. Impact of Public Opinion on System Evolution

When $P \in [2, 4]$, with other parameters fixed:

- If $P \leq 1.5$ (Weak opinion pressure), public participation collapses $(z \to 0.3)$, enterprises choose low investment due to lack of supervision $(y \to 0.2)$, and government supervision motivation weakens $(x \to 0.4)$;
- If $P \geq 2.2$ (Strong opinion pressure), the public chooses sorted disposal $(z \to 1)$, compels enterprises to enhance P_e, and increase environmental investment $(y \to 0.8)$, the government strengthens supervision due to public support $(x \to 0.95)$ (Figure 12).

P=1 (Low Pressure): Under low levels of societal scrutiny, the evolutionary trajectory of the system tends towards a state of low cooperation. Public participation (Z) remains subdued, government supervision (X) is lax due to perceived lack of demand or justification for high cost, and consequently, enterprise investment (Y) in waste treatment technologies is minimal, reflecting a low perceived return or necessity.

P=2.2 (Critical Threshold): This value represents a critical tipping point. The simulation demonstrates a significant shift in agent behaviour as public opinion pressure reaches this threshold. Public participation (Z) begins to increase markedly, creating a demand for better environmental outcomes. This, in turn, compels the government agent to intensify its supervision efforts (X increases) to meet public expectation and validate its role. Enterprises, facing heightened scrutiny from both the public and the government, are incentivised to increase their investment (Y) to avoid

penalties and potentially capture reputational benefits, leading the system towards a more cooperative equilibrium.

P=3 (High Pressure): Under sustained high pressure from public opinion, the system exhibits a strong convergence towards the ideal cooperative state ($X \to 1, Y \to 1, Z \to 1$). High public participation (Z) and vigilant supervision (X) create a stable environment where high levels of enterprise investment (Y) become the most rational and profitable strategy, solidifying the positive feedback loop characteristic of effective polycentric governance.

Public opinion pressure (P) profoundly influences the tripartite game through social norms and reputation mechanisms. It needs enhancement through multi-dimensional efforts like social media campaigns, public disclosure of corporate environmental blacklists, and community leader demonstrations. A public opinion big data platform should be established to identify low-participation areas in real-time and target incentive policies. An "environmental credit score" system linking individual sorting behaviour to public services should be introduced, thus stabilising P above the threshold ($P \geq 2.2$), as shown in Figure 12. This ensures social pressure continuously drives the system towards an efficient equilibrium.

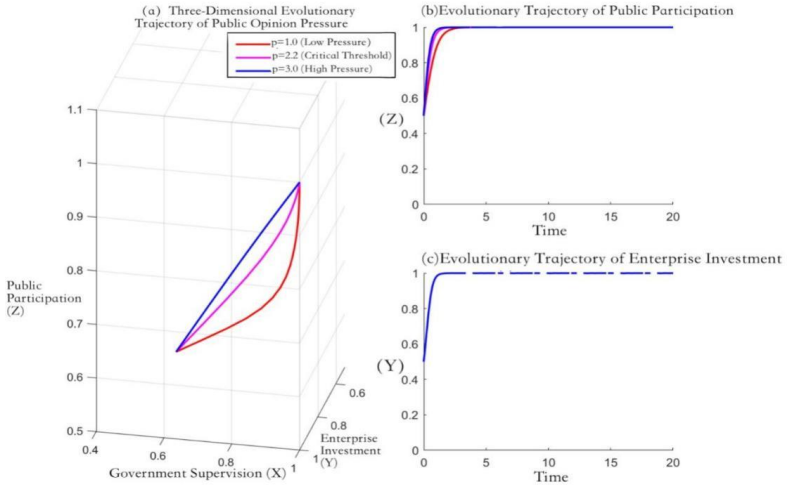


Fig 12: Mechanism Diagram of Public Opinion's Impact on System Evolution [Trajectories for different P values]

5.4. Validation of Policy Toolbox Effectiveness

Based on the system dynamics characteristics and sensitivity analysis of the tripartite evolutionary game, the simulation results verify the feasibility of the aforementioned policy toolbox and underscore that policy design should focus on tripartite synergy and dynamic adjustment within polycentric governance. The results indicate:

- **For the full defection equilibrium (0,0,0):** "satellite remote sensing monitoring + rewarded reporting" increases x by 30% and z by 25%, converging to (0.7,0.6,0.5) within 6 years;
- **For the enterprise low investment - public active equilibrium (x,0,1):** "joint and several accountabilities in the supply chain" increases y from 0.2 to 0.8, converging to (0.9,0.8,1) within 3 years;
- **For the full cooperation equilibrium (1,1,1):** "legislated standards + point redemption for services" stabilises the system at (1,1,1) within 8 years, improving governance efficiency by 2.3 times compared to the monolithic model.

The government should set tiered fine standards based on corporate pollution levels, reduce enforcement costs through electronic monitoring equipment, and avoid simplistic supervision affecting market stability. Enterprises actively adopting environmental technologies for MSW governance should receive preferential loan rates, tax reductions, and an industry technology sharing platform should be established to promote experience dissemination. For public participation, a waste sorting points system should be created, linking sorting behaviours to priority access to community services, with data authenticity ensured through government disclosure platforms. When public opinion pressure exceeds a critical value (e.g., $P \geq 2.2$), a mandatory corporate waste treatment information disclosure mechanism should be automatically triggered. When corporate technology upgrade costs are too high (e.g., $C_p > 3.5$), subsidies should be promptly increased. Policy tools need linkage mechanisms, regular effectiveness evaluations, and dynamic optimisation based on waste treatment monitoring data and corporate feedback to form a stable and sustainable governance system. The simulation experiment validates the strategic evolution patterns of the three agents under the polycentric governance framework: the dynamic equilibrium of government supervision, corporate technology investment, and public participation is significantly modulated by the public opinion pressure threshold ($P = 2.2$). Evolutionary game analysis reveals that once public opinion surpasses the critical value, the system exhibits a positive feedback mechanism: "government strengthens supervision ($x\uparrow$) → enterprises increase MSW governance technology investment ($y\uparrow$) → public sustains supervision ($z\uparrow$)", which align with the core feature of "multi-agent collaborative response" in polycentric governance theory.

6. Discussion and Conclusion

6.1. Polycentric Collaborative Mechanism Resolves MSW Governance Dilemma

Traditional MSW governance models often fall into the dilemma of "mismatched rights and responsibilities" due to over-reliance on the government: the government's administrative monopoly leads to high costs and difficulty responding dynamically to needs; market self-regulation ignores environmental externalities due to the profit-seeking

nature of social capital; public participation becomes tokenistic due to information barriers and insufficient incentives. The core value of polycentric governance lies in integrating the differentiated governance roles of the government, social capital (enterprises), and the public to construct a collaborative framework of shared responsibility and complementary resources, thus systematically addressing the failures of the monolithic model in MSW governance.

Polycentric governance theory redefines agent relationships: the government acts as rule-setter and supervisor, enterprises transform into technology implementers and innovators, and the public upgrades to behaviour supervisors and co-governance participants, forming a closed-loop system of "policy regulation - market response - social feedback". The essence of tripartite collaboration is converting government constraints and external environmental influences into internal drivers through institutional design: government supervision pressure drives corporate compliance, corporate technology output lowers public participation barriers, and public supervision forces government policy optimisation. This nested interaction not only solves the dilemma of "free-rider" and "tragedy of the commons" in traditional governance, but also significantly reduces cooperation friction costs through interest compatibility mechanisms. Simulation results show that when the synchronisation rate of tripartite strategy adjustment cycles exceeds 75%, the system stability index rises to 0.8 or above, and governance efficiency improves by 2.3 times higher than that of the single-agent model, validating the structural advantages of the polycentric governance framework in terms of responsibility allocation, information exchange, and action coordination.

6.2. Evolutionary Game Model Reveals the Key Role of Dynamic Adjustment

The integration of evolutionary game theory with polycentric governance provides a methodology and practical framework for addressing the dynamic adaptability of governance systems. While traditional polycentric governance builds a responsibility-sharing mechanism through government-enterprise-public collaboration, its static rule design often struggles with environmental complexity. The evolutionary game model introduces dynamic strategy adjustment mechanisms, revealing the inherent laws of agent behaviour iteratively optimising with external conditions, thus compensating for the strategic rigidity defect of polycentric governance in practice.

The multi-agent structure of polycentric governance provides a realistic carrier for the dynamic analysis of evolutionary games, while the adaptive mechanisms of evolutionary games inject elasticity into polycentric governance. Model parameters exhibit diminishing marginal effects, providing a quantitative basis for incentive design. For instance, simulations show that the higher the technology subsidy, the more significantly the marginal effect of high corporate investment diminishes—necessitating government help in building corporate environmental reputation (e.g., ESG ratings) and establishing cross-enterprise joint development mechanisms to break MSW governance technological bottlenecks, rather than merely increasing subsidies. Furthermore, the threshold trigger characteristic of public participation (e.g., the sudden jump in participation rate when $P \geq 2.2$) can be transformed into institutionalised data feedback channels: incorporating community supervision results (weighted) into corporate environmental ratings, and emulating Shanghai Green Account model, allowing the public to enjoy priority in public services (e.g., medical registration, educational resources) based on green account points. This design of embedding "market incentives + social supervision" into governance rules shifts agent strategies from passive response to active collaboration within the polycentric framework.

Quantifying agent strategic interactions through evolutionary game simulation transforms the abstract collaborative principles of polycentric governance into calculable dynamic paths. For example, when the phase diagram synchronisation rate of tripartite strategy adjustment remains above 75%, the system can effectively achieve the Pareto optimum of "decreasing governance cost - increasing efficacy". Crucially, polycentric governance provides the institutional context for evolutionary games: the government sets baselines through rules and laws, enterprises provide innovation space through technological flexibility, and the public ensures supervisory effectiveness through behavioural sustainability; meanwhile, evolutionary games provide dynamic optimisation tools for polycentric governance. Their integration forms a complete governance system with a policy toolbox, resilient to short-term shocks (e.g., fluctuations in corporate technology investment) and adaptable to long-term structural changes (e.g., increasing urbanisation rates), ultimately validating the complementary functions of "structural stability providing the evolutionary foundation, dynamic adjustment releasing synergistic potential".

6.3. Pathways for MSW Governance

Based on the conclusions from polycentric governance theory and the evolutionary game model, the effectiveness of MSW governance relies on the systematic coordination of government rules, market participation, and public supervision: rules set basic requirements for governance, market mechanisms introduce competition and efficiency optimisation, and public participation provides sustained motivation. Their combined action balances short-term governance effectiveness with long-term sustainability.

6.3.1. Government: Construct a Rule System of "Rigid Baselines + Flexible Incentives"

As the leading agent, the government must design rules that are both stringent and flexible. On one hand, clear legal standards act as baselines, e.g., setting minimum recycling rates (e.g., 60%) to prevent environmental red lines from being breached. On the other hand, a tiered management mechanism should be established: for non-compliant enterprises, implement progressively stricter penalties based on violation severity ("warning - fine - production restriction"). Simulations confirm that abrupt punitive policies can cause many enterprises to lose participation effectiveness within the polycentric governance if penalty severity is too high. For exemplary performers, use incentives like tax deductions, technology subsidies, and green credit preferential policies to encourage innovation and exceeding targets.

6.3.2. Market: Create a Participation Mechanism of "Competition-Driven + Benefit Compatibility"

The core of market participation is introducing competition, allowing professional environmental enterprises to

participate in MSW treatment service tenders, reducing costs through market operations. For example, establish regional MSW treatment centres where winning bidders manage the entire "collection-sorting-recycling" process, with the government paying service fees based on actual treatment volume, compelling enterprises to improve operational efficiency. Simultaneously, open market channels for recycled products (e.g., converting MSW into biomass fuel, recycled building materials) through government priority procurement and "eco-friendly sections" on e-commerce platforms, enabling enterprises to achieve both environmental and economic benefits. For small and medium-sized enterprises (SMEs) lacking technological investment capacity, promote equipment leasing/sharing models (e.g., third-party providers of smart sorting equipment) to reduce initial investment costs.

6.3.3. Public: Establish a Closed-Loop Conversion Channel of "Behaviour - Supervision – Benefit"

Public participation requires a complete conversion channel from "sorting behaviour - supervisory action - benefit feedback": implement MSW sorting points systems at the resident level, directly linking sorting accuracy to community benefits (e.g., communities offering parking discounts or point redemption for daily goods to households exceeding 80% monthly accuracy). Also, establish public supervision reward mechanisms, encouraging the public to report corporate violations via online platforms, green points or cash rewards will be given after verification, creating a positive incentive of "effective supervision brings rewards". This mechanism transforms environmental behaviour into tangible personal benefits, thereby stimulating spontaneous public participation.

6.3.4. Tripartite Synergy: Form a Virtuous Cycle of "Dynamic Adaptation"

Tripartite synergy is manifested in mutually reinforcing, dynamically adapting relationships: rules set boundaries for the market (e.g., set MSW treatment standards, guide technological innovation); market competition drives down technology costs (e.g., the popularization of smart sorting equipment enables SMEs compliance); public preference for eco-products and enterprises (e.g., prioritising purchasing recycled products) creates market pressure, further expanding the demand for environmental protection markets, ultimately forming a virtuous cycle of "rule guidance - market response - public feedback". Furthermore, strategies must be dynamically adjusted according to the governance stage: nurture environmental enterprises with government subsidies in the early market phase, gradually transitioning to market-oriented bidding in the later stage; regularly collect resident feedback on point redemption rules, adding diverse options like education benefits and public service priority; establish a "enterprise-community" communication platforms (e.g., holding monthly recycled product promotion meetings), which not only helps enterprises expand their markets, but also allow residents to intuitively understand the tangible value of their participation.

In summary, polycentric governance can stimulate the endogenous motivation of all agents: the government safeguards bottom line without excessive intervention through rules, enterprises achieve reasonable profits through market competition, and residents gain tangible benefits through simple actions, ultimately achieve a win-win situation for both the ecological and economic benefits of MSW governance.

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