

# Evolutionary Game-Theoretic Analysis of Rural Wastewater Treatment Projects

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## Abstract

To address the behavioral coordination challenges among government agencies, wastewater treatment enterprises, and village collectives in rural sewage treatment projects, this study develops a tripartite evolutionary game model to systematically analyze the strategic choices, payoff structures, and evolutionary stability mechanisms of these stakeholders. The research identifies the core interest logics of the three parties: enterprises' compliance decisions depend on cost differentials, subsidies, and penalties for non-compliance; village collectives' supervision is driven by supervision costs, rewards, and damage mitigation benefits; and government regulatory intensity is determined by regulatory costs and marginal governance benefits. The probability of detecting violations serves as the critical nexus linking all three parties, with synergistic efforts between government regulation and village collective supervision significantly enhancing the efficiency of violation detection. The stability of the ideal governance state (active regulation-compliant treatment-proactive supervision) requires meeting three threshold conditions: penalties and subsidies must cover enterprises' non-compliance costs; rewards must cover village collectives' supervision costs; and marginal governance benefits must cover government regulatory costs. The system exhibits eight boundary equilibrium points and mixed equilibrium points, where parameter changes and unilateral strategy adjustments by any single stakeholder trigger tripartite co-evolution, ultimately determining the convergence state of project governance. These findings provide theoretical foundations for policy design and mechanism optimization to ensure the long-term operation of rural sewage treatment projects.

## Keywords

Rural Wastewater; Tripartite Game; Strategy Evolution; Cost-benefit.

## 1. Introduction

Rural wastewater treatment represents a critical component of China's rural revitalization strategy, yet the long-term operational sustainability of such projects remains problematic. A fundamental challenge lies in achieving behavioral coordination among three key stakeholders: government agencies responsible for regulation and funding, wastewater treatment enterprises tasked with facility operation and maintenance, and village collectives capable of local monitoring and feedback<sup>[1]</sup>. These stakeholders operate under divergent incentive structures and constraints, often leading to strategic conflicts-enterprise non-compliance, regulatory erosion, and monitoring fatigue-that undermine project performance<sup>[2]</sup>.

This study addresses this coordination dilemma through an evolutionary game-theoretic framework, developing a tripartite model that incorporates government regulation (active versus passive), enterprise treatment strategies (compliant versus non-compliant), and village collective monitoring (proactive versus inactive) to analyze how cost-benefit calculi, detection probabilities, and strategic interdependencies shape system dynamics. Our analysis reveals

that the probability of detecting enterprise violations serves as the critical nexus linking all three strategies, with the ideal governance state of "active regulation-compliant treatment-proactive monitoring" facing three binding stability thresholds that must be simultaneously satisfied for system convergence. These findings provide theoretical foundations for policy design in rural environmental governance, demonstrating how evolutionary game theory can illuminate strategic dynamics and inform mechanism optimization in multi-stakeholder public service delivery<sup>[3]</sup>.

## **2. Decision-Making Entities**

### **2.1. Government Entity**

In rural wastewater treatment projects, the government fulfills three primary functions: organizational coordination, subsidy or service fee disbursement, and regulatory oversight with performance assessment. The government's concerns regarding project outcomes center on compliance rates, public complaints, and ecological environmental indicators. However, the government operates under tangible constraints: fiscal budgets must remain balanced, regulatory personnel are limited, and the geographic scope of grassroots supervision is extensive. A decline in regulatory intensity facilitates non-compliant practices; conversely, maintaining high-intensity supervision substantially increases fiscal and human resource pressures<sup>[4]</sup>.

Within the tripartite interaction, the government functions primarily as a "provider of rules and funding." When regulations are clearly defined and consistently enforced, enterprises demonstrate greater willingness to sustain their investments; when regulatory frameworks loosen or enforcement becomes erratic, enterprises are more inclined to reduce operational and maintenance expenditures.

### **2.2. Wastewater Treatment Enterprise Entity**

Enterprises bear core responsibilities for facility construction and daily operation and maintenance (O&M). Their project assessments typically revolve around three critical factors: the cost of compliant treatment, the stability of payment collection, and the potential penalties associated with detected violations. Rural stations are geographically dispersed, exhibit significant flow fluctuations, and operate at small individual scales—all of which drive up unit O&M costs for enterprises. When payment delays occur or settlement rules change frequently, enterprises tend to reduce investment intensity, prioritizing the avoidance of "visible problems."

Enterprise behavior demonstrates a pronounced cost-benefit orientation. Compliant treatment incurs higher costs, whereas non-compliant treatment reduces costs but entails fines and reputational damage. Government regulation and village collective supervision alter the probability of violation detection, thereby reshaping enterprises' net benefit calculations<sup>[5]</sup>.

### **2.3. Village Collective Entity**

The rural household collective operates through the institutional form of the "village collective organization," assuming primary responsibilities for coordination, monitoring, and feedback. Village collectives possess observational advantages regarding facility operational status, odor emissions from village drainage channels, and trends in public complaints-information that is typically more timely than external inspection data. However, village collective supervision entails temporal, labor, and coordination costs, alongside potential pressures arising from intra-village social relations. The benefits of supervision derive primarily from direct experiential gains of environmental improvement, complemented by governmental recognition and incentive rewards.

The intensity of village collective participation is critically contingent upon the visibility of benefits and the responsiveness to their inputs. Supervisory engagement is prone to erosion when monitoring costs escalate or when feedback remains unaddressed over extended periods.

### 3. Model Basic Assumptions

#### 3.1. Strategy Space Assumptions

Each stakeholder selects from two alternative strategies, formulated in a straightforward manner without excessive elaboration.

Government strategies:

$G_1$ : Active regulation (conducting spot inspections, verification, penalty enforcement, and contract-based performance assessment)

$G_0$ : Passive regulation (reduced inspection frequency, weakened verification, and attenuated penalties)

Enterprise strategies:

$E_1$ : Compliant treatment (performing O&M as required and achieving compliant discharge)

$E_0$ : Non-compliant treatment (compressing O&M expenditures, reducing treatment intensity, or falsifying operational records)

Village collective strategies:

$V_1$ : Proactive monitoring (patrolling, documenting, feedback provision, and assisting verification)

$V_0$ : Inactive monitoring (no resource allocation to monitoring activities)

Population proportions are represented as probabilities: the proportion of governments selecting  $G_1$  is denoted by  $x$ , enterprises selecting  $E_1$  by  $y$ , and village collectives selecting  $V_1$  by  $z$ , where  $x, y, z \in [0, 1]$ .

#### 3.2. Payoff and Cost Assumptions

Payoffs and costs are specified according to three criteria: observability, interpretability, and direct relevance to project implementation, thereby avoiding abstract formulations.

(1) Benefits and losses arising from governance outcomes

When enterprises adopt compliant treatment, the probability of project compliance is high, yielding governance benefits  $B_g$  for the government and environmental benefits  $B_v$  for village collectives.

When enterprises adopt non-compliant treatment, if violations remain undetected, the government incurs environmental and public opinion losses  $L_g$ , while village collectives incur environmental losses  $L_v$ .

When non-compliant treatment is detected and rectified, losses are mitigated, denoted as  $L_g'$  and  $L_v'$ , where  $0 \leq L_g' < L_g$  and  $0 \leq L_v' < L_v$ .

(2) Direct costs of regulation, operation and maintenance, and monitoring

The government incurs cost  $C_g$  under active regulation. The cost of passive regulation is normalized to zero (or equivalently, understood as negligible routine administrative costs).

The cost of compliant treatment for enterprises is  $C_e$ , and the cost of non-compliant treatment is  $c_e$ , where  $0 \leq c_e < C_e$ .

The cost of proactive monitoring for village collectives is  $C_v$ ; the cost of inactive monitoring is normalized to zero.

(3) Subsidies, incentives, and penalties

The government provides subsidy or service fee premium  $S$  to enterprises adopting compliant treatment (enterprises receive  $S$ , government pays  $S$ ).

The government provides incentive reward  $W$  to village collectives engaging in proactive monitoring (village collectives receive  $W$ , government pays  $W$ ).

When enterprise violations are detected, the enterprise pays penalty  $F$  and bears rectification cost  $K$  and reputational loss  $D$ .

(4) Detection probability specification

The probability of violation detection is jointly determined by government regulation and village collective monitoring. Let:

$p_g \in (0,1)$  be the detection probability under active government regulation, and 0 under passive regulation;

$p_v \in (0,1)$  be the detection probability under proactive village collective monitoring, and 0 under inactive monitoring.

When both mechanisms are present, the combined probability of detection is expressed as:

$$q = 1 - (1 - xp_g)(1 - zp_v)$$

This formulation carries two intuitive implications: stronger regulation and stronger monitoring increase the likelihood of detection; when both mechanisms operate simultaneously, the detection probability increases but remains bounded above by 1.

**3.3. Parameter Specification Assumptions**

To facilitate subsequent derivations, all parameters are consolidated in a single table. Parameter values are not elaborated in this section; specific numerical assignments will be provided in the simulation analysis.

**Table 1.** Parameter Notation and Definitions

Notation	Definition	Value Constraint (Directional)
$B_g$	Government governance benefits from compliant operation	$B_g > 0$
$L_g, L_g'$	Government losses from undetected / detected violations	$L_g > L_g'$
$C_g$	Cost of active government regulation	$C_g > 0$
$S$	Government subsidy or premium for enterprise compliance	$S \geq 0$
$W$	Government incentive for village collective monitoring	$W \geq 0$
$C_e, c_e$	Costs of compliant / non-compliant treatment for enterprises	$C_e > c_e \geq 0$
$F$	Penalty for detected enterprise violations	$F \geq 0$
$K$	Rectification cost upon detection for enterprises	$K \geq 0$
$D$	Reputational loss upon detection for enterprises	$D \geq 0$
$B_v$	Village collective environmental benefits from compliant operation	$B_v > 0$
$L_v, L_v'$	Village collective losses from undetected / detected violations	$L_v > L_v' \geq 0$
$C_v$	Cost of village collective monitoring	$C_v > 0$
$p_g, p_v$	Detection probabilities from regulation / monitoring	$p_g, p_v \in (0,1)$

**4. Payoff Matrix for Tripartite Stakeholders**

The payoff matrix is constructed by first distinguishing between compliant and non-compliant treatment scenarios, then incorporating the detection probability  $q$ .

### 4.1. Government Payoff Analysis

Government payoffs comprise five components: governance benefits or losses, regulatory costs, subsidy expenditures, incentive payments, and penalty revenues from detected violations.

When enterprises adopt compliant treatment: The government obtains  $B_g$ . Under active regulation, the government incurs  $C_g$  and disburses subsidy  $S$  to enterprises. If village collectives engage in monitoring, the government additionally disburses incentive  $W$ .

When enterprises adopt non-compliant treatment: Government losses depend on detection outcomes. The government incurs  $L_g$  if violations remain undetected, and  $L_g'$  if violations are detected and rectified. Under active regulation, the government incurs  $C_g$  and may receive penalty revenue  $qF$ . The incentive payment  $W$  is contingent upon village collective monitoring activity.

### 4.2. Wastewater Treatment Enterprise Payoff Analysis

Enterprise payoffs comprise four components: base operating revenue, treatment costs (compliant or non-compliant), subsidy receipts, and penalties from detected violations. Let  $R$  denote the base operating revenue from the project (interpretable as the contractual service fee benchmark).

Compliant treatment:  $\Pi_E(E_1) = R - C_e + S$

Non-compliant treatment:  $\Pi_E(E_0) = R - c_e - q(F + K + D)$

The critical insight is transparent: cost savings from non-compliance equal  $C_e - c_e$ , while expected penalties from detection equal  $q(F + K + D)$ . Enhanced regulation and monitoring elevate  $q$ , thereby compressing the net benefit of non-compliant behavior.

### 4.3. Village Collective Payoff Analysis

Village collective payoffs derive from perceptible environmental improvement benefits and monitoring incentives, offset by monitoring costs. When enterprises adopt non-compliant treatment, village collectives incur environmental losses contingent upon detection outcomes.

Enterprise compliant treatment:

Proactive monitoring:  $\Pi_V(V_1) = B_v - C_v + W$

Inactive monitoring:  $\Pi_V(V_0) = B_v$

Enterprise non-compliant treatment:

Proactive monitoring:  $\Pi_V(V_1) = -[(1 - q)L_v + \hat{q}L_v'] - C_v + W$

Inactive monitoring:  $\Pi_V(V_0) = -[(1 - q)L_v + \hat{q}L_v']$

This formulation captures an intuitive mechanism: monitoring incurs costs but yields incentives and contributes to elevated detection probability (via  $z = 1$ ), thereby mitigating long-term expected losses.

### 4.4. Construction of the Tripartite Payoff Matrix

The combination of three stakeholders with two strategies each yields eight possible scenarios. For expositional clarity, the payoff matrix is partitioned into two  $2 \times 2$  tables according to government regulatory strategies. Each cell presents the tripartite payoffs in the order  $(\Pi_G, \Pi_E, \Pi_V)$ .

**Table 2.** Payoffs Under Government Active Regulation

	$V_1$ Proactive Monitoring	$V_0$ Inactive Monitoring
$E_1$ : Compliant treatment	$(B_g - C_g - S - W, R - C_e + S, B_v - C_v + W)$	$(B_g - C_g - S, R - C_e + S, B_v)$
$E_0$ : Non-compliant treatment	$(-[(1 - q_1)L_g + q_1 L'_g] - C_g + q_1 F - W, R - C_v - q_1 (F + K + D), -[(1 - q_1)L_v + q_1 L'_v] - C_w + W)$	$(-[(1 - q_1)L_g + q_1 L_g^*] - C_g + q_1 F, q_1 (F + K + D), -[(1 - q_1)L_v + q_1 L_v])$

**Table 3. Payoffs Under Government Passive Regulation**

	$V_1$ Proactive Monitoring	$V_0$ Inactive Monitoring
$E_1$ : Compliant treatment	$(B_g - S - W, R - C_c + S, B_v - C_v + W)$	$(B_g - S, R - C_e + S, B_v)$
$E_0$ : Non-compliant treatment	$-[(1 - q_0) L_g + q_0 L'_g] + \frac{q_0 F - W}{q_0} L'_v - C_v + W, R - c_c - q_0 (F + K + D), -[(1 - q_0) L_v +$	$(-L_g, R - c_v, -L_v)$

Tables 2 and 3 render transparent a critical distinction: when the government adopts passive regulation and village collectives remain inactive, the detection probability equals zero, thereby minimizing the cost of non-compliance; when either active government regulation or proactive village collective monitoring is present, the detection probability increases, and the expected cost of non-compliance rises substantially.

## 5. Solution of the Evolutionary Game Model and Strategic Analysis

### 5.1. Replicator Dynamic Equations for Tripartite Stakeholders

Replicator dynamic equations describe "the directional change in the proportion of a particular strategy over time." The formulation is presented separately for each stakeholder: first calculating the expected payoff for each strategy, then expressing the proportion change through "relative deviation from average payoff."

#### (1) Government

Let  $U_{G1}$  denote the expected payoff for governments selecting  $G_1$ , and  $U_{G0}$  for governments selecting  $G_0$ . The average payoff for the government population is

$$\dot{U}_G = xU_{G1} + (1 - x)U_{G0}.$$

The rate of change in government strategy proportion:

$$\dot{x} = x(1 - x)(U_{G1} - U_{G0}).$$

#### (2) Enterprise

Let  $U_{E1}$  denote the expected payoff for enterprises selecting  $E_1$ , and  $U_{E0}$  for enterprises selecting  $E_0$ . The average payoff is

$$\dot{U}_E = yU_{E1} + (1 - y)U_{E0}.$$

The rate of change in enterprise strategy proportion:

$$\dot{y} = y(1 - y)(U_{E1} - U_{E0}).$$

#### (3) Village Collective

Let  $U_{V1}$  denote the expected payoff for village collectives selecting  $V_1$ , and  $U_{V0}$  for village collectives selecting  $V_0$ . The average payoff is

$$\dot{U}_V = zU_{V_1} + (1-z)U_{V_0}.$$

The rate of change in village collective strategy proportion:

$$\dot{z} = z(1-z)(U_{V_1} - U_{V_0})$$

The following sections express these payoff differentials in more interpretable forms, with each differential corresponding to the "relative profitability" of the respective strategies.

(1) Enterprise Strategy Differential

From Tables 2 and 3, the enterprise differential is determined by three components: the cost differential between compliant and non-compliant treatment, the subsidy, and the expected penalty from detected violations. Let  $q=1-(1-xp_g)(1-zp_v)$  denote the aggregate detection probability. The enterprise differential can be expressed as:

$$U_{E1} - U_{E0} = (c_e - C_e) + S + q(F + K + D)$$

This equation admits a straightforward interpretation: higher compliant costs depress the differential, while subsidies and expected penalties from detection elevate it. When the differential is positive, the proportion of compliant enterprises increases.

(2) Village Collective Strategy Differential

The village collective differential comprises monitoring costs, incentive rewards, and the "loss reduction" attributable to enhanced detection probability through monitoring. Let  $(1-y)$  represent the proportion of non-compliant enterprises. The differential can be written as:

$$U_{V1} - U_{V0} = -C_v + W + (1-y)[(L_v - L'_v) \cdot \Delta q]$$

where  $\Delta$  denotes the "additional detection probability attributable to monitoring," which in this specification equals  $(1-xp_g)p_v$ . This equation conveys a clear intuition: higher monitoring costs or lower incentives impede the growth of monitoring proportions; conversely, greater enterprise non-compliance amplifies the loss reduction benefits of monitoring, facilitating increased monitoring proportions.

(3) Government Strategy Differential

The government differential for active regulation comprises regulatory costs, reduced governance losses, and increased penalty revenues. Let  $(1-y)$  represent the proportion of non-compliant enterprises:

$$U_{G1} - U_{G0} = -C_g + (1-y)[(L_g - L'_g) \cdot \Delta q + \Delta(qF)]$$

In this specification,  $\Delta q = p_g(1-zp_v)$  represents the "additional detection probability attributable to government regulation," and  $\Delta(qF)$  denotes the additional expected penalty revenue from regulation. This equation captures a prevalent empirical regularity: higher proportions of enterprise non-compliance amplify the benefits of loss reduction and penalty revenue, thereby

sustaining active regulation; conversely, excessive regulatory costs undermine the viability of active regulation.

## 5.2. Evolutionary Stability Analysis of Tripartite Stakeholder Strategies

Stability analysis addresses whether "the system, when perturbed near a particular state, will be drawn back to it." With three stakeholders each holding two strategies, there exist eight pure-strategy points, corresponding to  $(x, y, z)$  in  $\{0,1\}^3$ .

A focal point of interest is the configuration of "active regulation-compliant treatment-proactive monitoring," namely  $(1,1,1)$ . Whether this point constitutes a stable equilibrium depends on whether any stakeholder possesses an incentive to deviate from this state. The stability conditions are most transparent when expressed as inequalities:

(1) Condition for enterprise compliance near  $(1,1,1)$

When  $x=1$  and  $z=1$ , the detection probability equals  $q=1-(1-p_g)(1-p_v)$ . Enterprises prefer compliant treatment when:

$$R - C_e + S \geq R - c_e - q(F + K + D)$$

Simplification yields:

$$q(F + K + D) + S \geq C_e - c_v$$

This condition admits a direct interpretation: the combined force of penalties, rectification costs, reputational losses, and subsidies must cover the cost savings from non-compliance.

(2) Condition for village collective monitoring near  $(1,1,1)$

When the proportion of compliant enterprises is high, the "loss reduction" benefit from monitoring diminishes. Whether monitoring can be sustained depends primarily on whether incentives cover costs:

$$B_v - C_v + W \geq B_v \Rightarrow W \geq C_v$$

This condition reflects a practical reality: monitoring entails persistent effort, and insufficient incentives lead to erosion of monitoring activity.

(3) Condition for government active regulation near  $(1,1,1)$

When enterprises are compliant and village collectives monitor, the marginal benefit of government regulation diminishes. Whether active regulation can be sustained depends primarily on whether regulatory costs are bearable. The condition requires that "additional governance benefits and penalty revenues from regulation" cover  $C_g$ :

Marginal benefit of regulation  $\geq C_g$

When enterprise compliance is high, penalty revenues approach zero, and marginal benefits derive primarily from the deterrent effect of "maintaining the compliant state." A more pragmatic formulation: when regulatory costs are excessive relative to marginal benefits, active regulation tends to decline.

These three conditions do not purport to exhaust all possible scenarios; rather, they represent "the most critical thresholds." The enterprise threshold concerns "cost savings from non-compliance" versus "costs of detection"; the village collective threshold concerns "incentives

versus costs"; and the government threshold concerns "regulatory costs versus marginal benefits."

### 5.3. System Equilibrium Point Analysis

System equilibrium points satisfy  $\dot{x} = \dot{y} = \dot{z} = 0$ . The structure of the replicator dynamic equations reveals three categories of equilibria:

#### (1) Boundary equilibrium points

When  $x$  in  $\{0,1\}$  or  $y$  in  $\{0,1\}$  or  $z$  in  $\{0,1\}$ , the proportion of any stakeholder reaching a boundary drives the corresponding equation to zero. The combinations yield eight pure-strategy points:  $(0,0,0)$ ,  $(0,0,1)$ ,  $(0,1,0)$ ,  $(0,1,1)$ ,  $(1,0,0)$ ,  $(1,0,1)$ ,  $(1,1,0)$ ,  $(1,1,1)$

These points correspond to various governance states in practice: "complete laxity," "partial laxity," "complete stringency," among others.

#### (2) Mixed equilibrium points

When all three stakeholders occupy the interior interval  $(0,1)$ , the following must hold:

$$U_{G1} = U_{G0}, \quad U_{E1} = U_{E0}, \quad U_{V1} = U_{V0}$$

Solutions to this system of equations are typically parameter-dependent. The interpretation is intuitive: at some probability level, all three stakeholders are "precisely indifferent," and proportions stabilize at that position. Parameter changes shift this position.

#### (3) Locally stable equilibrium points

Whether an equilibrium point is stable depends on where infinitesimal perturbations near that point drive the system. The standard method involves constructing the Jacobian matrix and examining the signs of its eigenvalues.

When enterprises satisfy "net benefits of compliance exceed net benefits of non-compliance," the compliant proportion moves toward 1; when village collectives satisfy "net benefits of monitoring exceed net benefits of inactivity," the monitoring proportion moves toward 1; when governments satisfy "net benefits of active regulation exceed net benefits of passive regulation," the regulatory proportion moves toward 1.

When all three conditions hold simultaneously, the system is more likely to converge to  $(1,1,1)$ . When any condition fails, the system migrates toward other boundary points, manifesting as regulatory decline, increased non-compliance, or erosion of monitoring.

## 6. Conclusion

This study develops a tripartite evolutionary game model incorporating government agencies, wastewater treatment enterprises, and village collectives to systematically analyze the interaction mechanisms and strategy evolution patterns in rural sewage treatment projects. The core findings are summarized as follows:

(1) Cost-benefit calculus drives stakeholder behavior. All three parties operate under explicit cost-benefit trade-offs. Enterprise compliance depends on the cost differential between compliant and non-compliant treatment, government subsidies, and the expected penalties from violations (determined jointly by regulatory intensity, monitoring effort, and detection efficiency). Village collective monitoring is shaped by monitoring costs, governmental incentives, and the loss-mitigation benefits contingent upon enterprise violation rates. Government regulatory persistence is contingent upon regulatory costs, reduced governance losses from deterring violations, and penalty revenues.

(2) Detection probability serves as the critical nexus. The probability of detecting enterprise violations links the three strategies, determined by the interaction of government regulatory probability, village collective monitoring probability, and their respective detection efficiencies. Synergy between regulation and monitoring directly elevates detection probability, thereby increasing the expected cost of non-compliance and incentivizing enterprise compliance.

(3) The ideal governance state faces three binding constraints. The configuration of "active regulation-compliant treatment-proactive monitoring" represents the optimal governance state for rural sewage treatment projects. Its stability requires three threshold conditions: (i) for enterprises, the sum of subsidies and expected penalties (fines, rectification costs, and reputational losses) must cover the operational cost savings from non-compliance; (ii) for village collectives, governmental incentives must at least cover monitoring costs; and (iii) for governments, the marginal benefits of active regulation (including reduced governance losses, penalty revenues, and compliance deterrence effects) must justify regulatory costs.

(4) The system exhibits multiple equilibria with path-dependent convergence. The strategy evolution system possesses eight boundary equilibrium points and various mixed equilibrium points. The system's convergence depends on the satisfaction of core threshold conditions and parameter configurations. When all three stability thresholds are satisfied, the system converges toward the ideal "complete stringency" state; when any threshold fails, the system migrates toward "partial laxity" or "complete laxity" equilibria characterized by regulatory decline, enterprise non-compliance, or erosion of monitoring.

(5) Strategic interactions generate co-evolutionary dynamics. Unilateral strategy adjustments by any stakeholder trigger behavioral responses from others. For instance, rising enterprise violation rates prompt intensified government regulation and village collective monitoring, while insufficient regulatory intensity or monitoring erosion reduces the expected cost of violations, inducing non-compliant enterprise behavior.

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