Design of Ecological Environmental Protection Incentive Model: Based on Game Theory and from the Perspective of Collusion

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Abstract: The coordinated development of river basins requires prioritizing ecological considerations despite persistent institutional challenges. To engage stakeholders in ecological and environmental protection, it is crucial to define the responsibilities and authority dynamics between the central government, local government, and enterprises. Incentive-compatible mechanisms must be established across administrative units to harmonize environmental protection efforts, promote unified approaches, and contribute to sustainable basin development.

The central-local government relationship resembles a principal-agent dynamic. To achieve optimal risk allocation, the central government must exert influence on the local government, enforce contractual obligations, and establish incentivized frameworks. "Free riding" behavior by local governments in ecological protection arises from vested interests. By employing rational game theory, it becomes apparent that an integrated supervisory mechanism allows the central government to maximize basin environmental utility. Aligning standards among the three government levels and increasing the costs of illicit activities by enterprises are essential measures to deter collusion.Based on these analyses, several key policy recommendations emerge. Firstly, elevate the importance of environmental protection performance in the assessment and evaluation of all government levels. Secondly, establish a comprehensive environmental protection coordination organization at the basin level. Thirdly, optimize industrial structure adjustment policies while considering resource and environmental constraints. Fourthly, gradually implement a regional emission trading market within the environmental regulation framework. Lastly, enhance grassroots government enforcement capacities regarding environmental protection laws.

Implementing these policies facilitates the coordinated development of river basins, providing a robust framework for ecological and environmental protection. It ensures sustainable and harmonious basin development while mitigating the adverse impacts of human activities.

1 INTRODUCTION

In order to enhance the ecological and environmental quality of river basins, governments at various levels have acknowledged the inherent trade-off between economic growth and environmental protection. The challenge lies in addressing the conflicting interests between survival and development while simultaneously fostering cooperation, strengthening complementarity, and unifying responsibilities and rights. Extensive research (Fu Y, 2021; Zhang ZM, 2022; Zu J, 2021; Zu J, 2021; Kong SJ, 2021; Li LQ, 2021; Zhang JH, 2022; Wu SM, 2022; Zhang X, 2021) has identified several key factors contributing to the deterioration of watershed environments, which can be categorized as follows:

Firstly, industrial economic growth often results in environmental pollution, with governmental performance evaluations primarily focused on GDP

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metrics.Secondly, the ecological environment is considered a public good, and the prevalence of free-riding mentalities leads to inadequate investment and efforts in comprehensive environmental protection. Disparities in capital investment, environmental protection capabilities, and pollution control levels among local governments hinder collaborative efforts and joint initiatives.

Thirdly, the implementation of environmental protection measures is impeded by the interplay of interests between governments and enterprises, hierarchical conflicts between higher and lower levels of government, and the presence of rent-seeking collusion and fraudulent practices within market conditions. Each entity pursues the maximization of its own interests, which can result in buck-passing, inefficiency, or even inaction.

Effective mechanism design plays a pivotal role in achieving overall utility maximization, thereby facilitating continuous improvement of the basin's ecological environment. Thus, drawing upon game theory as a theoretical framework, this study introduces three levels of environmental protection incentive models. The application of game theory in the realm of environmental resource protection focuses on examining the relationship between upstream and downstream water usage and the development of ecological compensation mechanisms to achieve a balance of interests. Additionally, it encompasses game analyses of environmental regulation strategies among local governments, hierarchical administrative systems, behavioral choices between the central government and local governments guided by GDP performance, and the decision-making processes involving governmental entities and polluting enterprises (Luo Y, 2021; Li X, 2021; Hu HJ, 2017; Hong WH, 2021; Han ST, 2021; Du YT, 2021; Zhou W, 2021; Lu S, 2021; Zhang GH, 2022; Yang L, 2021; Qin JH, 2021; Ye SS, 2019).

2 CENTRAL GOVERNMENT AND LOCAL GOVERNMENT ENVIRONMENTAL PROTECTION INCENTIVE MODEL

The central government assumes the responsibility of formulating pertinent high-level strategies, while local governments serve as the specific executors of various policies, regulations, and agreements. Nevertheless, the presence of "policies at the top and countermeasures at the bottom," compounded by the inherent uncertainty associated with ecological and environmental assessments, renders the central government the "uninformed party" acting as the principal, while the local government assumes the role of the "informed party" as the agent. Consequently, the principal-agent model proves valuable in analyzing the strategic interaction between the central government and local government in the context of protecting the watershed's ecological environment.

Premise 1: The central government, acting as the trustee, does not directly contribute to the enhancement of the basin's ecological environment. Instead, the responsibility for ecological environment protection and improvement lies with the local government, which perceives the central government as being risk-neutral while considering itself as risk-averse.

Premise 2: Due to the lack of direct observation of the environmental protection actions and their outcomes by local governments, the central government faces a dearth of timely, accurate, and sufficient feedback information.

Let us denote A as the set of possible actions available to local governments for ecological environmental protection, where "a" represents a specific action and "$a \in A$". The exogenous random variable θ, representing the state of the natural ecological environment, is beyond the control of both the central government and the local government. Suppose the local government implements action "a", then the joint influence of "a" and the exogenous variable θ determines a quantifiable income denoted as $\pi(a,\theta)$, which serves as a measure of the outcomes achieved. The function π is monotonically increasing with respect to both "a" and θ. In other words, higher values of θ indicate more favorable natural conditions, while larger values of "a" represent more favorable ecological and environmental protection behaviors by the local government, resulting in greater quantifiable benefits for the central government.

Given the inability of the central government to directly observe or measure "a" and θ, the focus is on designing an incentive contract denoted as "$s(\pi)$" that rewards and penalizes local governments (not solely in a physical sense) based on observed outcomes. This incentivizes local governments to take actions that maximize the expected utility function of the central government.

Furthermore, the V-N-M (von Neumann-Morgenstern) expected utility functions of the central government and the local government are defined as *"v[π - s(π)]"* and *"u[s(π)]"*, respectively, where *"v′ > 0"* and *"v″ ≤ 0"* denote the first and second derivatives of *"v"*, and *"u′ > 0"* and *"u″ ≤ 0"* denote the first and second derivatives of *"u"*. To provide a more intuitive interpretation of the mathematical model, let us consider two possible values for *"a"*: *"P"* representing "environmental protection" and *"D"* representing "environmental destruction".

$$\begin{cases} MAX \quad \int v\left[p - s\left(p\right)\right] \; fP\left(p,a\right)dp \\ st. \quad \left(IR\right)\int u\left[s\left(p\right)\right]fP\left(p,a\right)dp - c\left(P\right) \geq \bar{u} \\ \left(IC\right)\int u\left[s\left(p\right)\right] \; fP\left(p,a\right)dp - c\left(P\right) \geq \int u\left[s\left(p\right)\right]fD\left(p,a\right)dp - c\left(D\right) \end{cases} \tag{1}$$

Let *"f(π,a)"* represent the density function associated with the derived distribution function. The variable *"c"* signifies the cost of the action, while *"(I)"* denotes the desired utility obtained when the incentive contract *"s(π)"* cannot be accepted. Formula (IR) represents the participation constraint, and Formula (IC) represents the incentive compatibility constraint.

Let *"λ"* and *"μ"* represent the Lagrange multipliers associated with the participation constraint (IR) and the incentive compatibility constraint (IC), respectively. The first-order condition of the aforementioned optimization problem is as follows:

$$v'fP\left(p,a\right) + l\,u'fP\left(p,a\right) + mu'fP\left(p,a\right) - mu'fD\left(p,a\right) = 0$$

To sort out:

$$v'\left[p - s\left(p\right)\right] / \; u'\left[s\left(p\right)\right] = l \; + m\left[1 - fD\left(p,a\right) / \; fP\left(p,a\right)\right] \tag{2}$$

To achieve the objectives of ecological and environmental protection, the central government must impose constraints on local governments in at least two dimensions. Firstly, there is the participation constraint, which ensures that the expected utility gained by local governments from accepting the incentive contract is not lower than the maximum expected utility attained without accepting the contract. The second dimension involves the conflicting choices that local governments face, often referred to as the opportunity cost of environmental protection. It pertains to the trade-off between pursuing their own interests and engaging in environmental protection efforts.

Furthermore, the incentives provided to local governments must align with the constraints they face. Given that the central government lacks the ability to directly observe the specific behaviors and natural conditions of local governments, local governments will always strive to maximize their expected utility under any given incentive contract. Unless the central government offers adequate incentives to local governments regarding environmental protection policies, it is unlikely that the efforts and actions of local governments in related endeavors will meet the desired expectations.

In Scenario 1, when the behaviors of local governments are observable, the central government can enforce the required actions through compulsory contracts. This entails the diligent implementation of collaborative work plans for ecological and environmental protection in the basin, as issued by the central government. Corresponding payments are provided by the central government to ensure that the local government is either "profitable" or exposed to the lowest possible risk.

In this context, when the central government can monitor the actions of local governments and the associated risks are minimal, a system is established where local governments achieve the minimum environmental targets (guaranteed income), while the central government assumes the full risk for subpar environmental protection (residual income). Through the enforcement of compulsory contracts, the central government can effectively compel local governments to align their actions with the requirements set forth by the central government.

So if I set μ equal to 0, I get

$$u'\left[\pi - s\left(\pi\right)\right] / \; u'\left[s\left(\pi\right)\right] = \lambda$$

(3)

In Scenario 2, when the behaviors of local governments are unobservable, information asymmetry arises between the central government and the local government, resulting in the coexistence of risks and incentives. The optimal risk-sharing contract is determined based on the observed outcomes, whereby greater efforts by the local government lead to higher outputs. When the local government assumes all the risks, the contract incentives are sufficient, enabling the central government to maximize its expected outcomes. However, when local governments bear some of the risks, their level of effort will depend on the incentives provided by the central government.

In reality, μ=0 does not exist because of the asymmetrical information between the principal (central government) and the agent (local government), indicating that μ>0. We represent the risk-sharing contract under μ=0 and μ>0 as $s(\pi)$ and $s\lambda(\pi)$, respectively. If the density function $fP(\pi,a)$ is greater than or equal to $fD(\pi,a)$, the contract $s(\pi)$ is greater than or equal to $s\lambda(\pi)$. Conversely, if $fP(\pi,a)$ is less than or equal to $fD(\pi,a)$, then $s(\pi)$ is less than or equal to $s\lambda(\pi)$. For a given output, if the probability $fD(\pi,a)$ of the agent "damaging the environment" is greater than the probability $fP(\pi,a)$ of "protecting the environment," the agent's expected returns will be adjusted downward, and vice versa.

In summary, to achieve Pareto optimal risk sharing, the central government needs to effectively "compel" local governments to implement "contracts" that involve the decomposition of environmental protection tasks into multiple layers. This requires the central government to have comprehensive and accurate evaluations of the ecological and environmental protection behaviors of local governments through relevant indicators or actual observations. However, within the current governance system, task decomposition is primarily carried out by local governments, rendering the existence of compulsory contracts no longer feasible. Furthermore, the central government still faces considerable uncertainties in assessing watershed ecological environmental protection. Consequently, the present approach is limited to implementing overall constraints on major environmental indicators. Until the two levels of government achieve the Pareto optimal risk-sharing ratio, there remains significant room for strategic interaction and negotiation.

3 GAME ANALYSIS BETWEEN UPPER AND LOWER RIVER BASIN LOCAL GOVERNMENTS

3.1 General Forms of Games Among Local Governments

The concept of a watershed is applicable to both water resources and atmospheric environments. In this context, it is assumed that both the upstream and downstream governments have a comprehensive understanding of each other's strategic space and benefit functions. Consequently, the game of ecological compensation between the upstream and downstream governments in the basin can be characterized as a static non-cooperative game with complete information. By considering the income functions of both parties, a cost-benefit matrix can be established. The upstream government has two strategic choices: protection and non-protection, while the downstream government has two strategic choices: compensation and non-compensation.

The original income of the upstream government is denoted as "b," and it incurs a direct cost "c" for implementing protection measures, as well as an opportunity cost associated with potential losses. Environmental improvement also yields benefits for the upstream government. The original revenue of the downstream government is represented by "b_0," and it incurs a cost "c_0" for providing compensation to the upstream government. Additionally, the upstream environmental protection efforts result in external revenue denoted as "b_1" through environmental improvement. When the upstream government selects the "no protection" strategy and the downstream government chooses the "compensation" strategy, the corresponding payoff is $(b+c,\ b_0+c)$. On the other hand, if the upstream government selects the "no protection" strategy and the downstream government chooses the "no compensation" strategy, the payoff becomes $(b_0,\ b)$. When the upstream government chooses the "protection" strategy and the downstream government selects the "compensation" strategy, the respective benefits are $(b_0\text{-}c_0+b_1,\ b+b_i\text{-}c+c_0)$.For upstream governments, if the benefit "b_i" outweighs the cost "c," they will undoubtedly opt for protection strategies, regardless of whether downstream governments provide compensation or not. In practice, the income lost by the upstream government due to environmental protection measures far exceeds the compensation provided by the downstream government, that is, b_i<c. Therefore, in the absence of external constraints, the upstream government, driven by rational decision-making, tends to pursue a non-protection strategy to maximize short-term self-interest gains.

Table 1: Game models of upstream and downstream governments

		Upstream government	
		Protection	Not protect
Downstream government	Compensation	$(b_0-c_0+b_1,b+b_i-c+c_0)$	$(b_0-c_0,b+c_0)$
	Non-compensation	$(b_0+b_1,b+b_i-c)$	(b_0,b)

The downstream government finds it advantageous not to provide compensation when the upstream government implements protection strategies. Similarly, even if the upstream government does not engage in protection measures, the downstream government will still choose not to provide compensation. Consequently, unless the externality income (b_1) resulting from upstream environmental improvement is greater than zero, downstream governments tend to free-ride and lack sufficient motivation for ecological compensation. Although the establishment of an ecological compensation mechanism can effectively alleviate the conflict between ecological environmental protection and economic and social development in the water source areas of river basins, practical implementation is hindered by ambiguous collaborative positioning at the district and county levels, as well as institutional and procedural obstacles. Additionally, technical challenges arise in measuring the value of ecological services and determining the scope of compensation, which restricts the extent of ecological compensation from downstream to upstream. Currently, negotiations are primarily limited to specific "points and lines" within a certain timeframe, and progress on a broader scale has been sluggish.

3.2 Game between Players and Local Governments

The interactions among local governments in the basin can be compared to a "smart pig game" given the presence of multiple administrative levels as well as significant variations in social and economic scale and structure. Let us denote A as a subset of local governments in the basin characterized by a developed economy and abundant environmental protection funds, while B represents a larger set of local governments in the basin with an underdeveloped economy and limited investment in environmental protection funds.

We assume that the overall ecological environment level of the basin is denoted as X, and the level of improvement in the ecological environment resulting from human action is X+R. Furthermore, X+P represents the input cost of environmental protection required to achieve the corresponding level. For any local government in the basin, without any efforts, its expected income is $E(X+\lambda_{1R})$, where λ_1 represents the probability that the local government does not engage in environmental protection measures but still benefits from the improvement in the ecological environment. On the other hand, the probability that the local government actively participates in environmental protection and contributes to the improvement of the ecological environment is denoted as λ_2, with the associated cost level being $E(X+\lambda_{2P})$. In general, we expect that $\lambda_2 \geq \lambda_1$, indicating that local government investment in environmental protection is conducive to the overall improvement of the basin's ecological environment.

For local government A, it will choose to actively strengthen environmental protection and participate in watershed environmental governance to improve the overall ecological environment level as long as it satisfies the condition $\lambda_{2P} \geq \lambda_{1r}$, or equivalently, $P \geq \lambda_{1r} / \lambda_2$, and P<R. However, for local government B, its investment in environmental protection funds is limited and has little impact on the probability of improving the overall level of the basin's ecological environment. In this case, we can simplify the situation by assuming that $\lambda_2 = \lambda_1$. To motivate local government B to engage in environmental protection, it must meet the condition $P \geq R$. As a result, the cost of environmental protection exceeds the benefits, and local government B chooses not to pursue optimal environmental protection strategies.

The reason why local government B tends to act as a "free rider" is that it perceives "more gains than losses" in actively engaging in environmental protection. It expects other local governments to increase their investment in environmental protection and improve the ecological environment of the basin, from which it can benefit without incurring the associated cost. On the other hand, the intensity of environmental protection investment by local government A determines whether the ecological environment of the basin can be improved. As a result, local government A bears the cost of increasing environmental protection investment, which benefits not only itself but laso other local governments, including B. If local government A chooses not to act or adopts the same behavior as local government B, all local governments in the basin may refrain from increasing their environmental protection efforts, making it challenging to achieve the goal of improving the ecological environment.

There are two potential solutions to address this issue. First, implementing the principle of "those who engage in environmental protection will benefit" More strictly. This approach can help to partially curb the issue of unearned gains, but it requires linking environmental protection to performance rewards and penalties, ensuring a better balance between costs and benefits. The second solution involves clarifying the responsibilities and tasks of each actor and holding them accountable for their lack of action in accordance with assessment requirements, reward systems, and penalties. Ultimately, the core of the local government game lies in defining and allocating property rights, including ownership, use, income, and disposal rights of ecological environmental resources. Breakthroughs in the basin's fiscal and tax system, assessment mechanisms, and existing interest patterns are needed to address this challenge effectively (Yuan RX, 2021; Guo H, 2020; Wang CG, 2022; Kim Y, 2022; Yu Y, 2022; Yang C, 2021; Shi SH, 2022; Zhang PP, 2020; Xie FF, 2021; Yang HF, 2022; Wang N, 2021; Yu HS, 2021; Zhao YW, 2020). Let us consider the scenario without any external constraints. In this context, we define *Uc* as the ecological and environmental benefits accruing to downstream governments, mc as the level of implementation of environmental protection measures, p as the level of environmental damage, *g(mc)* as the cost associated with protection efforts, and *T(p)* as the expenditure required for ecological compensation. On the other hand, *Ud* represents the environmental benefits received by the upstream government, *H(md)* denotes the revenue function of the upstream government, and md represents the level of implementation of environmental protection measures. When the upstream government successfully implements protective measures, it becomes eligible for compensation from the downstream government. It is important to note that environmental damage primarily impacts the downstream region. Additionally, *j(md)* represents the additional cost incurred by ecological compensation for environmental protection, while *T(p)* signifies the ecological compensation received.

$$\max Uc = F(mc; p) - g(mc) - T(p) \quad (4)$$

$$\max Ud = H(md) + T(p) - j(md) \quad (5)$$

It is evident that when the sum of ecological compensation (*T(p)*) and protection costs (*g(mc)*) is relatively low, the environmental benefits received by downstream governments primarily rely on the extent of environmental damage caused by upstream governments. On the other hand, the ecological benefits received by downstream governments are determined by the difference between ecological compensation (*T(p)*) and the additional protection costs (*j(md)*). It is observed that the ecological compensation provided by upstream governments is insufficient to cover the extra costs incurred for protection, rendering the situation "worth the cost." This highlights the presence of conflicting interests between the two parties. As the negative impact of upstream non-protection escalates and downstream motivation for ecological compensation increases, it becomes rational for upstream governments to disengage until both parties return to the negotiation table. However, the irreversible or costly nature of ecological degradation exacerbates the aforementioned contradictions.

To address these challenges, the central government can be reintegrated as the decision-maker within the integration mechanism. In this framework, *"a"* represents the interest subject representing policy makers, while *"b"* represents local governments responsible for policy implementation. Ua and Ub denote the revenue generated by the central government and local government, respectively. The revenue function of the central government is denoted as *I(ma; p)*, where ma signifies the central government's oversight of local governments, and p represents the degree of environmental resource damage and waste. Furthermore, ma is a function of p, represented as *ma(p)*. The maximum utility function of the central government can be expressed as *maxUa=I(ma; p)-i(ma)-L(p)*, where *i(ma)+L(p)* represents the total costs incurred by the central government. Specifically, *i(ma)* denotes the costs associated with central government supervision over local governments, which increase with the magnitude of ma. Meanwhile, *L(p)* indicates that environmental damage prevents the central government from achieving resource protection targets.

Similarly, the maximum utility function of local governments can be expressed as *maxUb=E; ma)-e(ma)-S(mb)*. Here, *E(mb; ma)* represents the revenue function of local governments, where *mb* signifies the level of environmental protection intensity, and *mb* is a function of *ma* denoted as *mb(ma)*. Increased supervision or penalties from the central government prompt local governments to invest more in ecological and environmental protection. The total costs incurred by local governments are represented by *e(ma)+S(mb)*, where *e(ma)* refers to the additional protection costs due to central government oversight, and *S(mb)* represents the costs borne by local governments for environmental protection. The equilibrium relationship that maximizes utility for both parties can be expressed using the following formula.

$$\max Ua = I(ma; p) - i(ma) - L(p)$$
(6)

$$\max Ub = E(mb; ma) - e(ma) - S(mb)$$
(7)

$$\begin{cases} \frac{\partial I}{\partial ma} ma' + \frac{\partial I}{\partial p} - \frac{\partial i}{\partial ma} ma' - L'(p) = 0 \\ \frac{\partial E}{\partial mb} mb' + \frac{\partial E}{\partial ma} - \frac{\partial e}{\partial ma} ma' - S'(mb) = 0 \end{cases}$$
(8)

The solution to this problem lies in identifying a set of optimal values that simultaneously establish $ma^*=ma(p^*)$ and $mb^*=mb(ma^*)$. This entails achieving a delicate equilibrium among the degree of ecological and environmental damage, the level of central government supervision, and the extent of protection input by local governments. By attaining this balance, all parties involved can concurrently maximize their utility..

4 GAME ANALYSIS BETWEEN LOCAL GOVERNMENT AND ENTERPRISE

In the context of ecological environmental protection, local governments play a crucial role in supervision and management, while enterprises serve as the ultimate subjects of behavior (Liu M, 2021; LI WY, 2019; Zhou NQ, 2019; Zhang Y, 2022; Li B, 2021; Dang XY, 2021; Dang YX, 2022; Cheng CS, 2021). However, during the process of law enforcement, regulatory bodies at various levels within the river basin possess significant discretionary power. This discretion often leads to a lack of uniform objective standards and subjective inaction. For instance, the phenomenon of "APEC Blue" resulted from the stringent joint prevention and control efforts undertaken by three local governments. In many cases, information asymmetry exists between the government, regulators, and enterprises, making it challenging for the government to effectively control the enforcement efforts of regulators. This information asymmetry can also give rise to collusive activities between regulators and enterprises to gain illegal profits, as well as instances of regulatory oversight and ineffective investigation of environmental pollution incidents (Yu SK, 2022; Niu Y, 2021; Shima Nasiri, 2022; Liu QS, 2021; Xu J, 2021; Wei P, 2022; Deng XB, 2021; Wei C, 2021; Yuan SH, 2021).

4.1 Model Establishment and Hypotheses

Firstly, it is assumed that there is no collusion between regulators and enterprises to fabricate data. In this scenario, if the local government does not conduct any inspections, the additional income obtained by regulators and enterprises is zero, while the government's income (representing the degree of environmental protection goal attainment) is denoted as R. The income of the government, regulators, and enterprises is recorded as: (R, 0, 0).

Secondly, assuming no collusion between regulators and enterprises, but the government still carries out inspections, resulting in increased costs denoted as S, the income of the government, regulators, and enterprises is recorded as: (R - S, 0, 0).

Thirdly, if the regulator and the enterprise conspire to fabricate data, and the government does not conduct any inspections, the respective earnings of the regulator and the enterprise are denoted as U and V. In this case, the income of the government, regulator, and enterprise is recorded as: *(0, U, V)*.

Fourthly, if the regulator and the enterprise collude to fabricate data, even though the government conducts inspections, it fails to identify the issue. Then, the income of the government, regulator, and enterprise is denoted as *(-S, U, V)*.

Fifthly, if the regulator and the enterprise collude to fabricate data, the government conducts inspections, and the collusion is discovered and punished. Then, the income of the government, regulator, and enterprise is denoted as (-S + G, -O, -T), where G represents the income from government fines, -*O* represents the punishment imposed on the regulator, and -T represents the losses incurred by the enterprise as a result of investigation and punishment.

Lastly, let P_1 represent the probability of collusion between regulators and enterprises, P_2 represent the probability of government inspections, and P_3 represent the probability of government inspections uncovering collusion. The tripartite game model is presented in Table 2.

Table 2: Three-party game model

supervisor	Check (P_2)	Do not check ($1-P_2$)	
	Verify (P_3)	Failure to verify ($1-P_3$)	
Conspiracy to commit fraud (P_1)	(R-S+G,-O,-T)	(-S,U,V)	(0,U,V)
No conspiracy to defraud ($1-P_1$)	(R-S,0,0)	(R-S,0,0)	(R,0,0)

$$\begin{cases} \pi_1 = P_1\left[\left(R - S + G\right)P_3 - S\left(1 - P_3\right)\right] + \left(1 - P_1\right)\left[\left(R - S\right)P_3 + \left(R - S\right)\left(1 - P_3\right)\right] \\ \pi_2 = \left(1 - P_1\right)R \end{cases}$$
(9)

4.2 Model solving

Let us consider the scenario where the probability of collusion between regulators and enterprises is denoted as P_1. In this case, the government's income is determined by two situations: when conducting inspections and when not conducting inspections, which are represented as π_1 and π_2, respectively.

When the expected benefits of government verification and non-verification are the same, it is the optimal probability of collusion between regulators and enterprises when the government is in game equilibrium.Setting $\pi_1 = \pi_2$, we obtain the following.

$$P_1^* = S \,/\, RP_3 + P_3G$$
(10)

Suppose that the probability of the government's verification is P_2, then the enterprise's income from collusion is π_3 and that from no collusion is π_4, respectively:

$$\begin{cases} \pi_3 = P_2\left[P_3\left(-T\right) + \left(1 - P_3\right)V\right] + \left(1 - P_2\right)V \\ \pi_4 = 0 \end{cases}$$
(11)

When the expected returns of enterprises' collusion and non-collusion are the same, it is the optimal probability of the government's verification when enterprises are in game equilibrium. Let $\pi_3 = \pi_4$, we get:

$$P_2^* = V \,/\, \left(T + V\right)P_3$$
(12)

Suppose that the probability of the government's inspection is P_2, then the benefits of collusion by supervisors are π_5 and π_6, respectively:

$$\begin{cases} \pi_5 = P_2\left[P_3\left(-O\right) + U\left(1 - P_3\right)\right] + U\left(1 - P_2\right) \\ \pi_6 = 0 \end{cases}$$
(13)

When the expected benefits of collusion and non-collusion of regulators are the same, that is, when the regulators are in game equilibrium, the optimal probability of the government's verification. Let $\pi_5 = \pi_6$,, we get:

$$P_2^* = U \,/\, \left(U + O\right)P_3$$
(14)

According to equations (10), (12) and (14), Nash equilibrium of the tripartite game model of government, regulators and enterprises can be obtained as follows:

$$\begin{cases} P_1^* = S \,/\, R * P_3 + P_3O \\ P_2^* = V \,/\, \left(T + V\right)P_3 \end{cases}$$
(15)

Or

$$\begin{cases} P_1^* = S \,/\, R * P_3 + P_3O \\ P_2^* = U \,/\, \left(U + O\right)P_3 \end{cases}$$
(16)

The formula presented earlier demonstrates that the probability P1 of collusion between regulators and enterprises is directly proportional to the cost S incurred by the government during inspections. Conversely, the probability P_3 of collusion being detected during inspections is inversely proportional to the government's income R and the penalty income O. This implies that higher enforcement capabilities and technical proficiency of the government in environmental protection verification lead to a lower likelihood of collusion between regulators and enterprises. However, if the cost of government inspections becomes excessively high, the frequency of inspections may be reduced to mitigate expenses, consequently resulting in a corresponding decrease in the probability of collusion between regulators and enterprises. Ultimately, this may lead to a decline in the government's anticipated benefits from environmental protection.

According to the formula, when P_2 is lower than the Nash equilibrium probability P_2^* *(i.e.,* $V/(T+V)P_3$ *or* $U/(U+O)P_3$*)*, the government's inspection probability is below the equilibrium level, prompting enterprises to choose collusion. Conversely, if P_2 is greater than the smaller P_2^* value, enterprises opt not to collude. Assuming a constant value for V, an increase in the loss T incurred due to collusion results in a higher verification probability P_3 during inspections, causing $V/(T+V)P_3$ to decrease and consequently reducing P_2^*. Similarly, if the loss O resulting from collusion becomes larger, the likelihood of collusion decreases. Only when the government's verification probability P_2 falls below the smaller P_2^* value, enterprises are more likely to collude.

Assuming a significant increase in V, leading to a corresponding increase in P_2^*, it is essential for the government to simultaneously raise the actual verification probability P_2. Failing to do so may encourage regulators and enterprises to engage in fraudulent activities. If V reaches a sufficiently high level and T becomes negligible in comparison, enterprises may continue to engage in pollution even if the probability of investigation and verification (P_3) is 1. Therefore, reducing collusion hinges on the government increasing the penalties for collusion, while also augmenting the losses incurred by enterprises during investigations and punishments (i.e., raising the costs of illegal environmental pollution) serves as a potent strategy to deter excessive pollution by enterprises.

5 CONCLUSIONS

5.1 Enhancing the Weight of Environmental Protection Performance in Government Assessment and Evaluation

The resolution of ecological and environmental issues in river basins requires active participation and supervision from the central government. Firstly, the central government should augment the significance of environmental performance in the assessment and evaluation of provincial governments. This can be achieved through the implementation of measures such as "one vote veto" and conducting interviews with government officials. Furthermore, this emphasis on environmental performance should be gradually extended to local governments at the grassroots level. In addition, preferential policies should be introduced to incentivize local governments to increase their investments in environmental protection. These initiatives will serve to guide decision-making behaviors at all levels of government towards actions that facilitate ecological and environmental improvement. Simultaneously, collaborative development assessment indicators should be established to encourage the participation of governments at all levels in watershed environmental protection. The central government can also establish incentive contracts, such as the river basin ecological and environmental protection fund, which will be jointly funded by local governments and the central government. This fund will not only address the issue of insufficient funds for ecological compensation but also serve as a financing source for reward and punishment mechanisms in environmental protection assessments. It is important to note that the assessment of environmental protection performance and collaborative development is fundamentally a subjective evaluation of ecological environment improvement, rather than an objective demonstration. Thus, achieving a broad consensus among all stakeholders will guide the overall improvement of the basin's ecological environment in a positive direction.

5.2 Establishing Comprehensive Environmental Protection Coordination Institutions at the River Basin Level

Efforts should be made to establish a comprehensive environmental protection coordination body that spans administrative river basins. This body should comprise relevant ministries and provincial-level governments, with dedicated functions for river basin management, including planning, monitoring, coordinating, and implementing major environmental protection projects within the basins. It is crucial to promptly define the ecological spatial protection red line for river basins, clarify the roles and responsibilities of local governments, and prioritize environmental capital investment, environmental protection capacity, and pollution control in key river basins. These actions will contribute to the shared long-term goal of coordinated economic, social, and environmental development among the river basins. The coordination body should explore the establishment of mechanisms for environmental protection cooperation and cooperation demonstration zones. It should promote the protection of the environment in economically developed areas while assisting less developed areas in improving their ecological environments. Exploring the feasibility of two-way ecological compensation is also essential. For instance, compensating downstream areas for meeting water quality standards or compensating upstream areas if they fail to meet the required standards. Additionally, exploring mechanisms for cross-border compensation, particularly in areas with persistent air quality issues, can further contribute to environmental improvement.

5.3 Enhancing Industrial Restructuring Policies within Resource and Environmental Constraints

From an industrial perspective, the primary objective of industrial structural adjustment is to mitigate the ecological burden. Firstly, macro-control measures should be optimized while considering resource and environmental constraints, and industrial structure adjustments should be made while accounting for carrying capacity. National investment policies should prioritize the rapid development of the modern service industry and the ecological environmental protection industry. Secondly, there should be a strong emphasis on promoting cleaner production, resource recycling, and upgrading traditional industries and industrial parks. Lastly, it is necessary to establish a unified threshold for industrial environmental protection to prevent the spatial transfer of polluting enterprises during the relocation of non-capital functions and industrial shifts. Industries that cause significant pollution and damage to the water, air, and land environment should be included in a planned manner on the list of prohibited new developments within the river basin.

5.4 Gradually Establishing a Trading Market for Drainage Basin Emission Rights under Environmental Control

As previously mentioned, enterprises play a crucial role in implementing environmental protection measures, and environmental control significantly influences enterprise behavior. It is essential to intensify administrative interventions and increase the cost of environmental pollution for enterprises. Moreover, enterprises can actively contribute to improving the ecological environment. The government can procure environmental protection services from enterprises to enhance the effectiveness of environmental protection funds utilization. To facilitate this, it is advisable to guide the establishment of a trading market for drainage basin emission rights, controlling pollution levels within a predetermined limit. Each enterprise within the basin would be allocated specific emission credits. If an enterprise exceeds its emission limit, it would be required to purchase additional emission quotas from the market. Conversely, enterprises with effective environmental protection measures and surplus emission credits can sell their excess quotas in the market. This approach encourages enterprises to strengthen their environmental protection capabilities and reduce pollution.

5.5 Enhancing Environmental Law Enforcement at the Grassroots Level

To effectively implement environmental protection measures at all levels of government, it is crucial to address the shortcomings in environmental law enforcement teams at the community level. This can be achieved by allocating sufficient resources for personnel and funding, enhancing technical skills, and strengthening overall law enforcement capacity. For instance, in accordance with the new Environmental Law, governments at or above the county level should establish public monitoring and early warning mechanisms for environmental pollution while formulating corresponding early warning plans. Considering the uncertainty surrounding the ecological environment and its public goods nature, procedures for public supervision and information disclosure should be further improved. It is important to involve stakeholders such as representatives of NPC deputies, environmental law enforcement officers, experts, lawyers, judges, enterprises, media, environmental organizations, volunteers, and other relevant parties in the demonstration and decision-making processes regarding significant ecological and environmental protection issues.

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