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Research Article

Compensation Mechanism for Ecological Diversity Governance in Chinese River Basins Application Based on Low-Carbon Water Quality Game Theory

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Abstract

Background: Taking the construction of ecological civilization as an important core of the overall layout of the "Five in One" and the coordinated promotion of the "Four Comprehensives" strategic layout, combined with the global concept of ecological environment governance, provides a new direction for the reform and innovation of China's watershed ecological compensation system through diversified governance.

Subjects and methods: This article focuses on ecological compensation in river basins, exploring collaborative cooperation models between upstream and downstream of the basin under the dual constraints of "low-carbon" and "water quality", to achieve a "win-win" situation between the ecological environment of the basin and all parties involved in basin protection. Based on the theory of evolutionary game theory, the indicators of "carbon emissions" and "water quality" are introduced to construct a diversified ecological co-governance compensation strategy model for the watershed. By exploring the optimal strategies among various entities in the upstream and downstream of the watershed.

Results: (1) In the initial stage, the optimal strategy for ecological compensation in the watershed among stakeholders cannot achieve a stable balance through their evolution; (2) In the mature stage, based on the regulation of the superior government, interest subjects will choose a mutual supervision strategy to avoid bearing high penalties, to achieve Pareto effectiveness in achieving a stable overall economy of the basin; (3) By paying for high-quality resources from downstream and implementing carbon trading among basin entities, we can promote internal resource digestion, reduce intermediate transaction costs, and deeply promote the overall green and sustainable development of the basin. Through analysis, it has been proven that the conclusion is effective, providing decision support for the diversified co-governance of watershed ecosystems. Based on building an ecological community with a shared future in the watershed, we aim to achieve the construction of a community with a shared future for mankind.

Introduction

Changes in global climate and water bodies will also have a profound impact on the construction of ecological civilization. Climate change can trigger extreme weather events that can wreak havoc on human societies and ecosystems. At the same time, water pollution and overexploitation can also affect the supply and quality of water resources, further threatening the ecological balance and human health. The construction of ecological civilization emphasizes the harmonious coexistence of human society and the natural environment and aims to achieve sustainable economic, social, and environmental development. Globally, strengthening ecological civilization can be achieved by adopting a series of measures, such as reducing greenhouse gas emissions, protecting aquatic ecosystems, rationally using water resources, and promoting clean energy. These measures not only help to alleviate problems such as climate change and water pollution but also promote the restoration and protection of ecosystems and create a better ecological environment for human beings. General Secretary

Xi Jinping put forward the governance concept of "joint construction, joint governance, and sharing", and regarded the construction of ecological civilization as an important core for promoting the overall layout of the "five-in-one" and the strategic layout of the "four comprehensives" in a coordinated manner. Combined with the concept of global ecological environmental governance, it provides a new direction and practice for the reform and innovation of the ecological compensation system of China and even the global watershed. We believe that countries around the world should work together to strengthen international cooperation, take effective measures to address the challenges facing climate change and aquatic ecosystems and promote the construction of ecological civilization to achieve the sustainable development of human society and the health of the earth's ecosystem.

The watershed has the characteristics of integrity, linkage, multi-subjectivity, and strong externalities [1]. Due to the fuzzy boundaries of the compensating subject and object, the subjects of all parties seek to maximize their interests, resulting in the smooth flow of environmental elements between administrative areas [2]. Under environmental governance, value-oriented thinking has caused frequent problems such as common conflict of interest in watersheds, fragmentation of environmental effects [3], and overconsumption of public resources, resulting in local governments relying on vertical compensation and lack of horizontal cooperation to improve watershed ecology. To this end, this study focuses on the construction and analysis of a low-carbon-water-quality constraint compensation game model for the Chinese basin. Through the introduction of dynamic game theory, it studies the problem of decision-making equilibrium of all parties [4], simulates the optimal strategy for resolving conflicts between basins [5], and explores the ecological diversity and co-governance mechanism of the basin to provide decision-making support for the benefit distribution and coordinated development between basin subjects.

Research theory

Game theory is a discipline that studies the interrelationship between the conflict structures of multiple subjects. It describes the strategic relationship between stakeholders according to their preferences and interacting to achieve an equilibrium state. Von Neumann first proposed the basic principles of game theory in 1928, and then Von Neumann and Morgenstern [6] published Game Theory and Economic Behavior, laying the foundation for the application of game theory systems to the field of economics. At present, game theory has gradually become one of the important analytical tools for studying economic problems, and is widely used in computer science, ecological economics, environmental science, and other interdisciplinary disciplines. At present, the normalization of water scarcity in China and the rational resolution of conflicts underwater resource allocation and utilization are important problems faced by policy researchers, resource stakeholders, and scholars. Game theory provides an effective analytical way to solve this problem. So far, scholars at home and abroad have conducted a lot of research on ecological pluralistic co-governance compensation from different game perspectives. In terms of the game of river basin cooperation: Peng Xiang [7] verified the drawbacks of open water use, advocated the improvement of institutional defects and absolute rationality, and proposed that local governments need to adopt a cooperative approach to rationally allocate water resources in the Yellow River Basin. Zhou Xia (2001) believes that the establishment of a long-term cooperative water rights system has promoted the basin to reach Pareto effectively [8]. Li Weiqian and some researchers [9], based on the DEA cooperative game model, and through the introduction of improved Shapley, obtained compensation amount, providing a fair and reasonable compensation standard for the diversified co-governance of the watershed. Teague A., Sermet Y [10] constructed a game framework for hydrological disasters, assisting river basin community members to participate in water resource planning and decision-making through cooperation; in terms of river basin resource allocation: Chen Zhisong [11] used evolutionary game theory in river basin compensation to conduct strategic stability analysis by optimizing the expected allocation of all parties. Liu Wenqiang [12] used game theory to explain the allocation of water rights in the basin and explore the optimal countermeasures taken by all parties in the event of a water resource crisis. Ansink [13] introduced climate variables as a game model reference factor to assess the stability of water resource allocation in the basin; Sadegh and Mahjouri [14] focused primarily on the mode of water resource allocation, proposing the utilization of the Shapley model to achieve optimal allocation of water resources. Through a case study on the large-scale water transfer from the Karun River Basin to the Rafsanjan Plain, they validated the effectiveness of the Shapley game model. Neng Qian, and Ching Leong [15] used Singapore's recycled drinking water policy, known as NEWater, as a case study. They incorporated factors such as psychological aversion and social issues as game preferences into their evolutionary analysis of the adoption of new norms. Their conclusion found that public acceptance of NEWater was gradually expanding, which, to a certain extent, facilitated the optimal allocation of water resources. In terms of river basin pollution control, SHI [16] proposed a model for pollution removal and emission reduction in river basins based on fundamental game theory. This model optimized the collaborative ecological governance model between upstream and downstream regions. Xu Dawei [17] used the evolutionary game model to solve the contradiction between economic and environmental pollution and ecological destruction. Hemati, Abrishamchi [18] Comprehensively considering the changes in water resources affected by climate and user needs, the artificial neural network and quantile mapping method were used to predict the water consumption behavior of users in the Zarine Rude Basin under the two methods of bargaining game and Nash bargaining. The results show that the water resource management plan and bargaining game can effectively allocate water resources. Li Sheng [19] introduced the signal transmission and pollution control factors of river basin pollution, established a game model, and analyzed the behaviors of the central government and local governments. The research conclusions show that multiple cooperation between river basin entities is necessary to maximize common benefits.

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In summary, at present, game theory focuses on compensation allocation, compensation amount, and pollution control in watershed ecological pluralistic co-governance compensation mechanisms. In the existing compensation mechanism, only supervisory supervision is introduced, and there is no systematic discussion on the constraints of both sides. Therefore, based on existing research, this paper introduces new low-carbon and water quality constraint indicators based on the characteristics of the watershed, explores the cooperation and co-governance mechanism between various ecological compensation subjects in China's watershed, based on the fundamental interests of the watershed, and intends to provide a reference basis for the ecological compensation of the whole watershed.

China's basin ecological compensation game model construction

When exploring the ecological compensation mechanism of the river basin, it is necessary to conduct an in-depth analysis of the "rights, responsibilities, and benefits" of each subject. In this paper, the evolutionary game method is applied to carry out a combination simulation of the decision-making behavior of the river basin stakeholders to solve the problem of conflicts of interest in the river basin, balance the needs of all parties, and achieve the optimal Pareto in the river basin.

Basin evolution game path analysis

China's basin ecological compensation mechanism has the characteristics of conflict of interest, unclear jurisdiction, and serious externalities. To solve the current dilemma, this paper studies the basin's ecological compensation mechanism from the following two stages: (1) In the initial stage, by building an evolutionary game model, it simulates the ecological behavior of local governments and depicts the strategic changes of both sides in the game process. (2) Mature stage: Introduce a higher-level government supervision mechanism to reasonably monitor the performance of the contract between the entities; increase the cross-sectional water quality constraints and carbon indicators to simplify the trading system, achieve the goals of "water quality compliance", "carbon neutrality, carbon peak", and promote the sustainable high-quality development of the basin.

Initial stage: In the initial stage of watershed ecological protection, the participants in ecological compensation only involve upstream and downstream local governments, and the two sides play an evolutionary game to maximize their economic benefits.

Basic assumptions and parameter settings: By studying the ecological protection policy and compensation agreement of the watershed, the evolutionary behavior in the ecological protection process of both parties was simulated. Assuming that the upstream government can choose the "protection" strategy by restricting the development of polluting enterprises, etc. so that the downstream water use is guaranteed. At this time, the ecological restoration cost of the upstream government is C, the additional ecological benefit of the upstream is B1, and the additional ecological benefit of the downstream is B2. When the upstream government uses unrestricted water resources to develop the economy, at this time, the sewage flowing downstream will increase the downstream government use cost. When the upstream adopts the "no protection" strategy, the self-circulating income of the upstream ecosystem is N1, and the self-circulating income of the downstream ecosystem is N2. In the watershed ecological strategy behavior, the upstream selection of the "protection" strategy probability is X. For the upstream government decision-making behavior, the downstream adopts the "compensation" and "no compensation" strategies based on the judgment of its rights and interests. At this time, the compensation amount that the downstream government is willing to spend is M and the compensation probability is Y. The meaning of the model parameters in the initial stage is shown in Table 1.

Initial stage game return matrix: This stage is an economic game between the upstream government and the downstream government. There is no overall planning by the superior government. Both parties have full decision-making power over policy formulation. The game income matrix in the initial stage is shown in Table 2.

Model construction: According to the analysis of the income matrix: When there is no supervision by the superior government, the downstream government cannot force the upstream government to choose protection measures. Similarly, the upstream government cannot force the downstream government to adopt compensation strategies. $C - M < C - N_1$ At that time, when the compensation amount obtained by the upstream is higher than the self-circulating income of the system when no protection measures are taken, the upstream will choose the protection strategy; $M \leq B$ when the compensation amount paid by the downstream is lower than the ecological benefits brought by the watershed protection, the downstream government will consider the compensation strategy. The time variable t is introduced at the same time, assuming that the strategies of the upstream and downstream

Table 1: Meaning of model parameters in the initial stage.

Scenario1: Initial phase	Parameters parameter	Description
	C	The total economic cost for upstream ecological protection and restoration
	B_1	Ecological benefits generated after upstream ecological protection
	B_2	Ecological benefits generated after ecological protection
	$1 - X$	Upstream Unprotected Probability
	X ([0,1])	Upstream Protection Probability
	N_1	Under no-protection strategy: Upstream ecosystem self-circulation gains
	N_2	Unprotected strategy: self-circulating benefits of downstream ecosystems
	M	Downstream willingness to pay compensation�Implement according to the national standards of that year�
	Y ([0,1])	Downstream Compensation Probability
	1 – Y	Downstream uncompensated probability

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governments will evolve with time t. Calculate the income matrix in Table 2. Under the decision of "protection" and "not protection", the expected income of the upstream government is U_{11}, U_{12}, and the average income is $\overline{U_1}$:

$$U_{11} = Y(B_1 + N_1 - C + M) + (1-Y)(B_1 + N_1 - C) \quad (1)$$

$$U_{12} = Y(N_1 + M) + (1-Y)N_1 \quad (2)$$

$$\overline{U_1} = XU_{11} + (1-X)U_{12} \quad (3)$$

The expected income of downstream governments under the decision of "compensation" and "non-compensation" is $U_{11,}$ respectively, and U_{12} the average income is $\overline{U_2}$:

$$U_{21} = X(B_2 + N_2 - M) + (1-X)(N_2 - M) \quad (4)$$

$$U_{22} = X(B_2 + N_2) + (1-X)N_2 \quad (5)$$

$$\overline{U_2} = YU_{21} + (1-Y)U_{22} \quad (6)$$

According to the Malthusian [20] dynamic equation theory, the replication dynamic equations obtained from the evolutionary analysis of equations (1), (3), (4), and (6) are:

$$F(X) = \frac{dx}{dt} = X(U_{11} - \overline{U_1}) = X(1-X)(B_1 - C) \quad (7)$$

$$F(Y) = \frac{dy}{dt} = Y(U_{21} - \overline{U_2}) = Y(1-Y)(-M) \quad (8)$$

Evolutionary pathways and evolutionary stability strategies:

Situation 1: Evolutionary analysis of the ecological protection and stability strategy of the upstream government: From (7), it can be seen that for the upstream government to have a stable strategy, it needs to be met *F(X)* = 0. The strategic analysis is as follows:

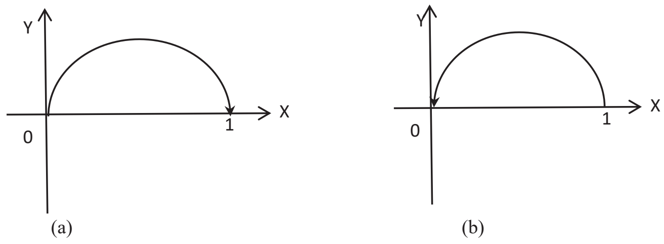
(1) It can be seen from formula (7) that at that $B_1 - C = 0$ time *F(X)* = 0, in this state, the strategy tends to be stable; $B_1 - C = 0$ at this time, the additional ecological benefits that the upstream government chooses to protect are consistent with the total cost of ecological protection. Combined with the actual situation, the upstream does not obtain any benefits from the ecological protection strategy, and even when the conservation strategy is implemented, there is a probability that there will be additional silence costs. Since the upstream and downstream of the basin are independent individuals in the initial stage, the upstream only considers its interests, in this case, the protection strategy will be rejected.

(2) When $B_1 - C \neq 0$ *X* the values 0 and 1 are the two stable strategy points *F(X)* = 0, the first derivative of the formula (7) can be obtained:

$$F'(X) = (1-2X)(B_1 - C) \quad (9)$$

In the evolution game, when the accidental error of the strategy deviates from the steady state, it can be adjusted by copying the dynamic equation to restore the steady state of the strategy itself. Mathematically, when X * is used as a stabilization strategy, if there is an error disturbance that causes X * to change, when x x<x* F(x) is always more than 0 when x> *, F (x) should be constant less than 0, at this time, the derivative of the replicated dynamic equation is required to be constant less than 0 (F '(x) < 0).

(1) Based on the above analysis if $B_1 - C > 0$, then $F'(0) > 0$, $F'(1) < 0$ only when $F'(X) < 0$, the strategy will become stable [21], so the upstream government will achieve an evolutionary stable state, only when *X* = 1. (The probability of upstream adopting protection is 1) That is, when the additional ecological benefits of upstream are higher than the cost of protection, the upstream government will choose to gradually tilt from the "no protection" strategy to the "protection" strategy to achieve a stable state in ecological decision-making until the "protection" strategy gradually becomes a stable strategy.



(2) If $B_1 - C < 0$, it can be seen $F'(1) > 0$, $F'(0) < 0$, $F'(X) < 0$ that when the strategy tends to be stable, the evolutionary stabilization strategy of the upstream government is *X* = 0. (The probability of upstream adopting non-protection is 1) That is, when the cost of upstream protection of water resources is too high, the upstream government favors non-protection policies in ecological decision-making.

Situation 2: Evolutionary analysis of the downstream government ecological compensation stability strategy: For the same reason (8), it can be seen that for the upstream government to have a stabilization strategy, it needs to be met *F(Y)* = 0. The strategic analysis is as follows:

Table 2: Initial game yield matrix.

Upstream Government (Upstream government)	Downstream Government	
	Compensation (Y)	not-compensation (1 – Y)
protect (X)	($B_1 + N_1 - C + M$, $B_2 + N_2 - M$)	($B_1 + N_1 - C$, $B_2 + N_2$)
Do not protect not protect (1 – X)	($N_1 + M$, $N_2 - M$)	(N_1, N_2)

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(1) $M = 0$ At $F(Y) \equiv 0$ that time, in this state, the strategy tends to be stable; $M = 0$ when the willingness of the downstream government to pay compensation is extremely low, the downstream government adopts a non-compensation policy.

(2) When $M \neq 0$ Y the values 0 and 1 are the two stable strategy points of $F(Y) \equiv 0$, the first derivative of the formula (8) can be obtained:

$$F'(Y) = (1-2Y)(-M) \tag{10}$$

(1) If $M > 0$, as can be seen $F'(0) < 0$ $F'(1) > 0$, the strategy tends to be stable $F'(Y) < 0$ at that time, the downstream government will still adopt a non-compensation strategy ($Y = 0$) when it is willing to pay the compensation amount to achieve the evolutionary stability strategy. In the process of implementation, the downstream government will bias the non-compensation policy in ecological decision-making until the "non-compensation" strategy gradually becomes a stabilization strategy.

(2) If $M < 0$, at this time, it is inconsistent with the assumed situation, the downstream compensation amount should always be greater than 0.

In summary, to achieve the stable state of the game strategy, for scenario 1, the upstream government will adopt the "protection" strategy only when the additional ecological benefits under the protection strategy are greater than the total cost of protection. However, because the upstream repair costs, protection costs, and abandoned development opportunity costs are too high in reality, it is difficult to generate more ecological protection benefits. Therefore, in the independent selection stage, the upstream government will likely choose the "no protection strategy". According to scenario two, the downstream constant chooses the "no compensation" strategy.

Equation (7) (8) constitutes a dynamic replication system of the watershed ecological compensation game. According to the Friedman [22] method, the local equilibrium point stability analysis of the Jacobi matrix of the system is performed. To test the stability of the equilibrium point between the upstream ecological protection strategy and the downstream ecological compensation strategy, the Jacobian matrix corresponding to the game combination composed of equation (7) (8) is:

$$J = \begin{bmatrix} \frac{\partial F(X)}{\partial X} & \frac{\partial F(X)}{\partial Y} \\ \frac{\partial F(Y)}{\partial X} & \frac{\partial F(Y)}{\partial Y} \end{bmatrix} = \begin{bmatrix} (1-2X)(B_1 - C) & 0 \\ 0 & (1-2Y)(-M) \end{bmatrix} \tag{11}$$

$$\det.J = \frac{\partial F(X)}{\partial X} \times \frac{\partial F(Y)}{\partial Y} - \frac{\partial F(X)}{\partial Y} \times \frac{\partial F(Y)}{\partial X} = (1-2X)(B_1 - C)(1-2Y)(-M) \tag{12}$$

$$tr.J = \frac{\partial F(X)}{\partial X} + \frac{\partial F(Y)}{\partial Y} = (1-2X)(B_1 - C) + (1-2Y)(-M) \tag{13}$$

In order to optimize the ecological compensation of the watershed, this paper expects that the social effects to be satisfied should adopt the "protection" strategy for the upstream and the "compensation" strategy for the downstream. According to Friedman's thought, only when $\det.J > 0$ and $tr.J < 0$, the strategy reaches a stable equilibrium, and the (protection, compensation) strategy be brought into the equation. The following conditions should be met:

$$\begin{cases} \det.J = (B_1 - C)(-M) > 0 \\ tr.J = (C - B_1) + M < 0 \end{cases}$$

Since there is a contradiction and the corresponding solution cannot be found, the (protection, and compensation) strategy cannot reach a stable equilibrium state in the game, indicating that in the primary stage, the upstream and downstream governments cannot reach a stable equilibrium through their evolution in the ecological compensation of the watershed. The mechanism may be because since there is no unified regulation between the watersheds, the upstream and downstream governments, as independent individuals, will only consider their interests. At the same time, the lack of supervision of the performance of both parties by the superior government will cause the socially expected (protection, compensation) strategy to be difficult to achieve. Given this, this paper refines the compensation standards in the study of river basin ecological compensation mechanisms in the mature stage and introduces higher governments for decision-making and management.

The mature stage: The mature stage Introduce the feedback supervision system of the superior government in the mature stage. The information of the upstream government, the downstream government, and the superior government is not completely symmetrical and limited. The division of powers and responsibilities of the superior government is clear. It has higher decision-making power and management power than the upstream government and the downstream government. The reward and punishment are used to determine the ecological protection behavior or compensation behavior that affects the game subject. Based on the above conditions, a low-carbon-water quality constraint compensation strategy game model is constructed:

Basic assumptions:

(1) In the mature stage, if one party fails to perform its duties, then the other party's government can choose to appeal, and the superior government will make a reward and punishment judgment for the behavior of both parties. If both parties fail to perform their duties, the superior government will directly punish both parties. The superior government does not directly participate

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in the game but only determines the income structure of the subject through reward and punishment of the subject.

(2) If the upstream chooses the "protection" strategy and the downstream chooses the "compensation" strategy, the superior government will reward both, with the reward amount of *A*; if the upstream chooses the "protection" strategy and the downstream chooses the "no compensation" strategy, the superior government shall reward the upstream and punish the downstream, on the contrary, the superior government shall reward the downstream and punish the upstream, with the reward amount of *A*, with the penalty amount of *E*; if the upstream chooses the "no protection" strategy and the downstream chooses the "no compensation" strategy, the superior government will punish both, with the penalty amount of *G*.

(3) Introduce the cross-sectional water quality testing and assessment mechanism, and investigate whether the water quality meets the standards according to the national water quality inspection standards. Assuming that when the upstream adopts the "protection" strategy, the water quality can meet the standards, and the downstream compensation for the upstream is. *H* When the upstream adopts the "no protection" strategy, the water quality fails to meet the standards, and the upstream subsidy for the downstream is *I*.

(4) Introduce a carbon index trading mechanism to investigate carbon sequestration and production behavior according to the nationally approved carbon index standards. When the upstream adopts the strategy of "protecting" water resources, through ecological conservation behavior, the carbon sequestration capacity increases, and excess carbon indicators are generated, which can be transferred to the downstream through the trading behavior. At this time, the upstream carbon index surplus amount and the downstream carbon index purchase amount are *K*.

Parameter setting: (Table 3)

Model construction: According to the game return matrix in Table 4, the expected returns of upstream governments under the decisions of "protection" and "non-protection" are respectively U_{31}, U_{32} and the average returns are $\overline{U_3}$:

Table 3: Meaning of model parameters.

Scenario 2: Mature Stage	Parameters	Description (penalty amount: Implement according to the national standards of that year)
	A	Rewards on Performance
	E	Unilateral non-performance penalty amount
	G	Amount of penalty for non-performance by both parties
	H	Compensation for water quality compliance
	I	Subsidy for substandard water quality
	K	Carbon Metric Amount

Table 4: Maturity Game Return Matrix.

Upstream Government	Downstream Government	
	Compensation (Y)	No Compensation (1 – Y)
Protected (X)	$(B_1 + N_1 - C + M + A + H + K, B_2 + N_2 - M + A - H - K)$	$(B_1 + N_1 - C + A + H + K, B_2 + N_2 - E - H - K)$
Not Protected (1−X)	$(N_1 + M - E - I, N_2 - M + A + I)$	$(N_1 + G - I, N_2 - G + I)$

$$U_{31} = Y(B_1 + N_1 - C + M + A + H + K) + (1-Y)(B_1 + N_1 - C + A + H + K) \quad (14)$$

$$U_{32} = Y(N_1 + M - E - I) + (1-Y)(N_1 - G - I) \quad (15)$$

$$\overline{U_3} = XU_{31} + (1-X)U_{32} \quad (16)$$

The expected income of downstream governments under the decision of "compensation" and "non-compensation" is U_{41}, respectively, and U_{42} the average income is $\overline{U_4}$:

$$U_{41} = X(B_2 + N_2 - M + A - H - K) + (1-X)(N_2 - M + A + I) \quad (17)$$

$$U_{42} = X(B_2 + N_2 - E - H - K) + (1-X)(N_2 - G + I) \quad (18)$$

$$\overline{U_4} = YU_{41} + (1-Y)U_{42} \quad (19)$$

According to the Malthusian dynamic equation, the replication dynamic equation of the regional government obtained by the evolution analysis is:

$$F(X) = \frac{dx}{dt} = X(U_{31} - \overline{U_3}) = X(1-X)(B_1 - C + A + H + K + G + I + Y(E-G))$$

$$F'(X) = (1-2X)(B_1 - C + A + H + K + G + I + Y(E-G)) \quad (20)$$

$$F(Y) = \frac{dy}{dt} = Y(U_{41} - \overline{U_4}) = Y(1-Y)(-M + A + G + X(E-G))$$

$$F'(Y) = (1-2Y)(-M + A + G + X(E-G)) \quad (21)$$

Evolutionary paths and evolutionary stabilization strategies:

Scenario 1: Evolutionary Analysis of Ecological Protection and Stability Strategies for Upstream Governments: From (20), it can be seen that for upstream governments to have stabilization strategies, they need to be satisfied *F*(*X*) = 0. The strategic analysis is as follows:

(1) When $B_1 - C + A + H + K + G + I + Y(E - G) = 0$, $F(X) \equiv 0$, , in this state, the strategy tends to be stable. At this time, $y = y^* = \frac{C - B_1 - A - H - K - G - I}{E - G}$

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$(0 \le \frac{C - B_1 - A - H - K - G - I}{E - G} \le 1)$,$F(X)$ = 0will always be the result. The total cost paid by the upstream government for ecological protection is too high, which is significantly greater than the value of the benefits added by the ecological protection behavior (ecological benefits, performance incentives received, compensation when the water quality reaches the standard, carbon sequestration surplus carbon index income, etc.). At this time, the upstream government will refuse to adopt the "protection" strategy.

(2) When $y = y* = \frac{C - B_1 - A - H - K - G - I}{E - G} \ne 0$, then x takes the values of 0 and 1, which are the $F(X) \equiv 0$ two stable strategy points.

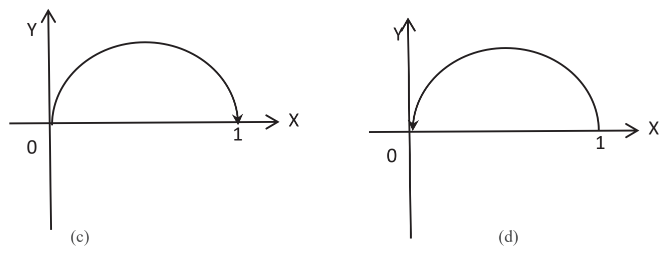
(1) If $y > y* = \frac{C - B_1 - A - H - K - G - I}{E - G}$, if $E > G$, then $F'(0) > 0$, $F'(1) < 0$, then the evolutionary stabilization strategy of the upstream government is $X = 1$. That is, when the penalty for unilateral non-compliance is higher than the penalty for non-compliance of both parties $C > B_1 + A + H + K + G + I$, at this time, although the upstream protection cost is high, in order to achieve a stable state, the upstream government will still favor the protection policy in ecological decision-making. As shown in Figure (a), from "no protection" to protection, until the "protection" strategy gradually becomes a stabilization strategy.

(2) If $y < y* = \frac{C - B_1 - A - H - K - G - I}{E - G}$, if $E < G$, then $F'(0) < 0$, $F'(1) > 0$, then the evolutionary stabilization strategy of the upstream government is $X = 0$. Bias upstream governments towards unprotected policies in ecological decision-making. As shown in Figure (b), there is a gradual tilt from "protection" to "no protection" until the "no protection" strategy gradually becomes a stabilization strategy.

Scenario 2: Evolutionary analysis of the downstream government ecological compensation stability strategy: For the upstream government to have a stable strategy, it needs to be satisfied $F(Y) = 0$. The strategic analysis is as follows:

(1) A − M + G + X(E − G) = 0 At $F(X) \equiv 0$that time, in this state, the strategy tends to be stable; in the downstream evolution process, the proportion X of the upstream government adopting the "protection" strategy approaches 1, that is, $A = M + G$ the amount of reward from the higher government at the time of contract performance, which can cover the compensation amount of the downstream government and the penalty amount for failure by both parties. This scenario is inconsistent with the concept of long-term sustainable development of the watershed.

(2) When X = A − M + G + X(E − G) ≠ 0, then Y has a value of 0 and 1, which are the $F(Y) \equiv 0$ two stable strategy points.



(1) If $x > x* = \frac{M - A - G}{E - G}$, if $E > G$ then $F'(0) > 0$, $F'(1) < 0$, the strategy tends to be stable at that, $F'(X) < 0$ time, the evolutionary stabilization strategy of the downstream government, at this time M > A + G, the downstream compensation amount is higher than the penalty amount $Y = 1$ when both parties fail to perform, the strategy will remain stable at that time, and the downstream government will favor the "no compensation" policy in ecological decision-making. As shown in Figure (c) above.

(2) If $x < x* = \frac{M - G - A}{E - G}$, if $E < G$, then $F'(0) < 0$, $F'(1) > 0$, the penalty amount for non-performance shall be higher than the compensation amount after deducting the performance reward (in M - A, < G) When the evolutionary stabilization strategy of the downstream government is $Y = 0$ the ecological decision will be biased towards the non-compensation strategy, as shown in Figure (d) above.

In summary, to achieve the evolutionary stabilization strategy of social expectations (protection, compensation), it is necessary to make $E > G$. Then, when the G、E difference is greater, the upstream adopts "protection", and the probability of adopting "compensation" policies downstream is higher. Therefore, the higher the government's penalty amount for unilateral non-performance, the more it meets social expectations. Equations (20) and (21) constitute the dynamic replication system of the watershed ecological compensation game. According to Friedman's theory, the local equilibrium point stability analysis of the Jacobian matrix of the system is carried out. Therefore, to test the stability of the equilibrium point between the upstream ecological protection strategy and the downstream ecological compensation strategy, the corresponding Jacobi matrix is (Table 5):

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Table 5: Local Stability Analysis.

Equilibrium	det.J	tr.J
(0, 0)	$-(B_1 - C + A + H + K + G + I)(M - A - G)$	$(B_1 - C + A + H + K + G + I) - (M - A - G)$
(1, 0)	$(B_1 - C + A + H + K + G + I)(M - A - E)$	$-(B_1 - C + A + H + K + G + I) - (M - A - E)$
(0, 1)	$(B_1 - C + A + H + K + E + I)(M - A - G)$	$(B_1 - C + A + H + K + E + I) + (M - A - G)$
(1, 1)	$-(B_1 - C + A + H + K + E + I)(M - A - E)$	$(M - A - E) - (B_1 - C + A + H + K + E + I)$
(X*,Y*)	$(1-2X^*)(B_1 - C + A + H + K + G + I + Y^*(E-G))$ $(1-2Y^*)(-M + A + G + X^*(E-G))$ $-X^*(1-X^*)(E-G)Y^*(1-Y^*)(E-G)$	$(1-2X^*)(B_1 - C + A + H + K + G + I + Y^*(E-G))$ $+(1-2Y^*)(-M + A + G + X^*(E-G))$

$$J = \begin{bmatrix} \frac{\partial F(X)}{\partial X} & \frac{\partial F(X)}{\partial Y} \\ \frac{\partial F(Y)}{\partial X} & \frac{\partial F(Y)}{\partial Y} \end{bmatrix}$$

$$J = \begin{bmatrix} (1-2X)(B_1 - C + A + H + G + I + K + Y(E-G)) & X(1-X)(E-G) \\ Y(1-Y)(E-G) & (1-2Y)(-M + A + G + X(E-G)) \end{bmatrix} \quad (22)$$

$$\det.J = \frac{\partial F(X)}{\partial X} \times \frac{\partial F(Y)}{\partial Y} - \frac{\partial F(X)}{\partial Y} \times \frac{\partial F(Y)}{\partial X}$$
$$= (1-2X)(B_1 - C + A + H + K + G + I + Y(E-G))(1-2Y)(-M + A + G + X(E-G))$$
$$-X(1-X)(E-G)Y(1-Y)(E-G) \quad (23)$$

$$tr.J = \frac{\partial F(X)}{\partial X} + \frac{\partial F(Y)}{\partial Y}$$
$$= (1-2X)(B_1 - C + A + H + K + G + I + Y(E-G)) + (1-2Y)(-M + A + G + X(E-G)) \quad (24)$$

In order to achieve the optimal ecological compensation of the watershed, this paper expects that the social effects to be met upstream of the "protection" strategy and downstream of the "compensation" strategy, that is, (1, 1) The strategy meets social expectations and should meet the following conditions:

$$\begin{cases} \det.J = -(B_1 - C + A + H + K + E + I)(M - A - E) > 0 \\ \text{tr}.J = (M - A - E) - (B_1 - C + A + H + K + E + I) < 0 \end{cases} \quad (25)$$

The result is: $\begin{cases} B_1 - C + A + H + K + E + I > 0 \\ M - A - E < 0 < B_1 - C + A + H + K + E + I \end{cases}$ (26)

Now, B_1 _ $C + A + H + K + G + I$ is O ; M _ A _ G is L, then there are four different combinations, and each group corresponds to five different sets of strategies, as shown in Table 6:

From Table 6, to meet the upstream "protection" strategy, the downstream "compensation" strategy is the only stable and feasible strategy, and the corresponding equation is:

$$\begin{cases} B_1 - C + A + H + K + E + I > 0 \\ M - A - E < 0 \\ B_1 - C + A + H + K + G + I > 0 \\ M - A - G > 0 \end{cases}$$

$$\begin{cases} B_1 - C + A + H + K + E + I > 0 \\ M - A - E < 0 \\ B_1 - C + A + H + K + G + I > 0 \\ M - A - G < 0 \end{cases}$$

$$\begin{cases} B_1 - C + A + H + K + E + I > 0 \\ M - A - E < 0 \\ B_1 - C + A + H + K + G + I < 0 \\ M - A - G < 0 \end{cases}$$

Corresponding Table 6 constructs a dynamic replication phase map and stabilization strategy for upstream and downstream groups in the watershed. The results are shown in Table 4-8 below. Scenario 1 corresponds to Table 6 (1-3) strategy; Scenario 2 corresponds to Table 6 (4) strategy;

In summary, in terms of the ecological compensation of the basin, the upstream government and the downstream government game can know: the relevant parameters such as the upstream basin ecological protection income, the total cost of the basin ecological protection, the subsidy for the substandard water quality, the surplus income of the carbon index during the protection; the compensation when the downstream water quality meets the standard, the compensation amount and other parameters; the strategic choices of the superior government for the unilateral performance reward, unilateral non-compliance punishment, non-compliance punishment and other parameters jointly affect the evolution game of decision-making. To meet social expectations and achieve

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Table 6: Local equilibrium steady state under each combination.

Remarks	Equilibrium point	det.J	tr.J	Result
O > 0, L > 0	(0, 0)	-	±	unstable
	(1, 0)	-	±	unstable
	(0, 1)	+	+	unstable
	(1, 1)	+	-	ESS
	(X*,Y*)	+/-	0	Saddle Point
O > 0, L < 0	(0, 0)	+	+	unstable
	(1, 0)	-	±	unstable
	(0, 1)	-	±	unstable
	(1, 1)	+	-	ESS
	(X*,Y*)	+/-	0	Saddle Point
O < 0, L < 0	(0, 0)	-	±	unstable
	(1, 0)	+	±	unstable
	(0, 1)	-	±	unstable
	(1, 1)	+	-	ESS
	(X*,Y*)	+/-	0	Saddle Point
O < 0, L > 0	(0, 0)	+	-	ESS
	(1, 0)	-	+	unstable
	(0, 1)	+	+	unstable
	(1, 1)	+	-	ESS
	(X*,Y*)	+/-	0	Saddle Point

sustainable development quality development in the river basin, the compensation amount given upstream by the downstream should be lower than the reward and punishment amount of the superior government for the downstream. At the same time, the penalty amount of the superior government for the failure to perform by both parties should be higher than the penalty amount for the unilateral failure to perform. In this scenario, the local governments in the river basin can choose to supervise each other to avoid assuming a higher penalty amount.

Construction of compensation mechanism for ecological diversified co-governance of watersheds from a game perspective

From the above analysis, The ecological diversity and co-governance mechanism of the watershed is shown in Figure 1 below: All parties involved need to adopt a win-win cooperation model, and the higher-level government should use "overall planning" and "reward and punishment mechanisms" to promote coordinated cooperation and common prosperity between upstream and downstream governments; Local governments adopt methods such as "supervision cooperation", "cross-sectional water quality inspection", and "carbon quota trading" to balance resource factors. The higher-level government aims to protect the ecology and promote economic development and provides relevant policy guidance, rewards and punishments, and supervision to the lower-level government. Local governments are responsible to the higher-level government for meeting carbon and water quality standards by following relevant policies and regulations. If the higher-level government finds that the relevant indicators are not up to standard through methods such as "cross-sectional water quality inspection" and "carbon index trading", it can adopt subsidies and compensation to enable the higher-level and lower-level governments to carry out lawful administration, coordinated management, and equal negotiation in watershed ecological governance. Only by establishing a mechanism for cooperation and supervision among governments at all levels can we achieve green and sustainable development of the watershed by integrating resources, allocating watershed elements reasonably, and breaking down administrative divisions among regional entities.

The higher-level government coordinates and plans to improve the compensation mechanism for ecological diversity governance in river basins

Introduce the overall planning of the superior government to achieve the common prosperity of the whole region of the river basin. (1) Through the intervention of the superior government, coordinate the management of the river basin, negotiate on an equal footing, and build a river basin integration pattern. The superior government should based on the overall and regional characteristics of the river basin, combine the location characteristics and functional positioning of the main bodies of the river basin, comprehensively plan the overall development goals, achieve the basic demands of individuals, and deploy long-term policy guidelines for the functional area of the river basin. (2) Establish a reward and punishment mechanism to give full play to the subjective initiative of the protection of the local government of the river basin, supervise and coordinate the ecological behavior of the subjects, and balance the protection costs, economic development opportunities, ecological compensation and other contradictions between the main bodies of the river basin by adjusting the reward and punishment. Under the leadership of the higher-level government, an ecological governance linkage mechanism has been formed with the local government to explore upstream behaviors such as actively protecting water sources and improving water quality, "unilateral performance rewards" for downstream behaviors such as actively compensating and sharing costs, "unilateral default penalties" for upstream behaviors such as not actively protecting, and downstream behaviors such as not actively compensating, and "unilateral default penalties" for both parties to passively deal with the ecological behavior of the basin. As an important means of regulating the ecological compensation mechanism of the basin, a scientific compensation mechanism for ecological diversity and co-governance of the basin has been formulated.

Establishing a linkage and cooperation mechanism among local governments

In the development and utilization of production activities, the upstream is dominated by natural resources. From material civilization to spiritual culture, it is shared with nature [23,24]. The upstream governments of the watershed pay excessive ecological protection costs to protect biodiversity, maintain the ecological balance of the watershed, and promote their development. At the same time, they lose a lot of potential development benefits, thus restricting the development of the local economy. Therefore, to solve the development requirements of the upstream government and reduce the cost of local ecological protection, the ecological compensation of China's watersheds is mainly compensated by the vertical central government, and there are problems such as insufficient horizontal compensation and limited financial

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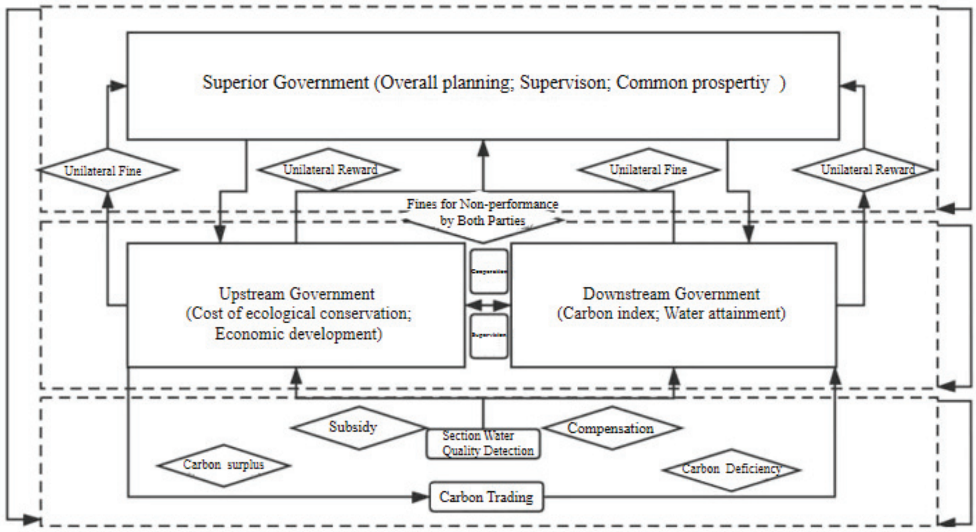

Figure 1: Flowchart of the ecological diversity and co-governance mechanism of the basin from the perspective of the game.

compensation by the downstream local governments [25]. It is necessary to improve the initiative of upstream governments and reasonably safeguard their interests, and at the same time strengthen the guidance of downstream governments to pay for high-quality resources: (1) supervision and cooperation. To avoid high penalties, upstream and downstream will adopt mutual supervision and cooperation to jointly maintain the watershed ecology; (2) Introduce cross-sectional water quality monitoring, rationally adjust the upstream industry structure, vigorously support green and sustainable energy research and development, and use, and promote the transformation of upstream high-pollution and energy-consuming industries. If the water quality of the outlet section is up to standard, the downstream government should pay for the upstream government's "high-quality resources" based on the use of good water quality, and give the upstream government a prescribed amount of "water quality compensation". If the water quality of the outlet is not up to standard, the upstream government should give the downstream government a "water quality subsidy"; (3) Establish a carbon index suggestion trading mechanism to make the basin water when the upstream is actively protecting the basin water resources. The improvement of soil conservation energy value, based on the carbon sequestration effect of the ecological service function [26] of the river basin, leads to an upstream carbon index surplus. At this time, the downstream can purchase excess carbon indicators from the upstream in the simple trading of internal carbon indicators due to its own development needs, thus strengthening the internal benefit compactness [27] of the river basin, and realizing the sustainable development path of the river basin "green water and green mountains are golden mountains and silver mountains".

Suggestions for compensation for ecological diversity cooperation in the Chinese basin

Overall planning by the higher-level government to integrate the rational layout of resources

In the compensation of watershed ecological diversity and co-governance, only the upstream government and the downstream government cannot achieve stable optimal decision-making. It is necessary to introduce the higher-level government to carry out the basin ecological protection reward and punishment mechanism for relevant stakeholders, reward the performing subject, punish the defaulting subject, and meet the conditions of the higher-level government that the penalty amount for both parties' failure to perform should be higher than the penalty amount for unilateral failure to perform, to achieve the Pareto optimally.

Deeply explore the value of watershed protection and promote sustainable development of the watershed

Due to the overall characteristics of the basin, the overall development of the basin depends on the upstream strategy. Therefore, digging deep into the protection value of the basin and promoting the sustainable development of the upstream is a necessary prerequisite that needs to be considered. This paper believes that to maximize the overall utility of the basin, the following ways can be used: 1) The local governments supervised by the superior government downstream compensate and support the upstream government, and the superior government at the same time gives the upstream basin protection incentives through transfer payments; 2) Sectional water quality assessment, the downstream is paid for "high-quality resources", forming a practical and universal water right purchase system; 3) Establish a carbon index suggestion trading mechanism to promote the close integration of government interests between the upstream and downstream, achieve the goal of "dual carbon", and jointly build a long-term green development mechanism [28]. For example. The development and protection mode of the upper and lower reaches of the Yangtze River Basin needs to comprehensively consider multiple aspects such as ecology, economy, and society. The multi-stakeholder governance mechanism for ecological environment protection in the Yangtze River Basin emphasizes the joint participation and collaborative governance of upstream and downstream

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regions, governments, enterprises, social organizations, and the public. Eight working mechanisms have been established, including joint meetings, information sharing, clue transfer, case cooperation, litigation linkage, ecological restoration, joint actions, and personnel exchange, to fully leverage the functions of judicial and administrative organs to serve the protection of resources, pollution prevention and control, ecological restoration, and green development in the Yangtze River Basin. This mechanism aims to promote the continuous improvement and sustainable development of the ecological environment in the Yangtze River Basin through information sharing, joint action, ecological compensation, and other means.

Building an ecological community with a shared future for river basins and promoting regional prosperity

To build a community of shared future for watershed ecology, deeply implement the concept of co-construction and sharing, and clarify the responsible parties and rights and responsibilities of watershed governance. Each party should clarify their rights and responsibilities, establish a multi-party linkage governance mechanism, implement a cross-regional collaborative model of “one zone, one responsibility”, and define the responsibilities and obligations of relevant parties in the upstream and downstream, left and right banks of the watershed through institutionalized means, ensuring that all parties can clearly understand their responsibilities in the watershed governance process and avoid responsibility shifting or overlapping. Secondly, in response to the cross-spatial and holistic characteristics of the watershed, it is necessary to form diversified collaborative governance models and operational mechanisms. This includes establishing systematic thinking, strengthening collaboration and linkage between regions, and achieving goal synergy, policy synergy, and work synergy. At the same time, develop collaborative governance plans and action agreements to guide watershed governance practices, and standardize the reduction of inappropriate behavior by watershed stakeholders in watershed governance. In addition, digital technology can be used to empower comprehensive watershed governance, such as establishing watershed monitoring systems, improving early warning capabilities, etc. Smart means can be used to improve information sharing and process interconnection, promote policy unity and implementation coordination, and form a joint force to promote watershed governance. Again, by increasing investment and support, we can help rural areas improve their infrastructure, and public services, and narrow the urban-rural gap. At the same time, encourage all sectors of society to participate in watershed governance and protection work, and create a good atmosphere of common concern and support from the whole society; Ensure that the achievements of watershed governance can benefit the general public, especially allowing rural residents to enjoy more development dividends. By promoting the development of characteristic industries and increasing farmers’ sources of income, farmers can achieve employment and income growth right at their doorstep. At the same time, we will strengthen publicity and education on ecological environment protection, raise public awareness of environmental protection, guide people to choose green and low-carbon lifestyles, and jointly maintain a beautiful ecological environment. Based on jointly building a watershed ecological community, we aim to achieve the construction of a community with a shared future for mankind.

Conclusion

The issue of ecological civilization is a high-level transformation from “China’s industrial development” to “sustainable and high-quality development”. The Party Central Committee, with Comrade Xi Jinping as the core, has put forward the concept of global ecological environment governance, which regards the construction of ecological civilization as an important core for coordinating the overall layout of the “Five in One” and the coordinated promotion of the “Four Comprehensives” strategic layout. Based on the characteristics of Chinese river basins, this article introduces two types of constraint indicators, low-carbon, and water quality, and explores the cooperative governance mechanism among various ecological compensation entities in Chinese river basins. It is believed that Chinese river basins have integrity, continuity, and externalities. Due to their flow through multiple administrative regions and involvement in multiple fields such as economy, society, and ecology, ecological compensation in river basins is a behavior that requires diverse participation. Ecological compensation in river basins should be established based on a clear understanding of the compensation subject and object; Secondly, develop appropriate compensation models for stakeholders; Once again, based on the actual situation, the compensation standards will be calculated after examining multiple factors including economy, society, and ecology; Finally, establish a reasonable watershed compensation mechanism to provide effective guarantees for the long-term operation of watershed ecological compensation.

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