

Study on Cross-Basin Ecological Compensation Mechanism and Compensation Standard

Jinren LUO, Yizhi SUN¹, Yihu ZHAO, Qinyao FU, Jiayin LI

Institute of Economics and Management, Lanzhou Jiaotong University, Lanzhou, Gansu, 730070, China

Abstract. Water resources in China's river basins are scarce, and the pollution that shrouds them is serious. Constant disputes have emerged between the upstream and downstream sectors due to the contamination of river basins. Moreover, China's research on ecological compensation mechanisms and compensation standards is still immature at present. Thus, this study establishes a compensation model and introduces the compensation coefficient K , including the compensation coefficient K_1 between the upstream and downstream governments and the compensation coefficient K_2 between the upstream government and the central government. This paper adopts the Bargain Game Model and obtains the value of K_2 through the decision-making process between the central government and the upstream local government. In addition, amendment to the final offer arbitration law is used to acquire the value of K_1 by proving the existence and uniqueness of equilibrium. Then, this paper takes the Taohe River Basin as an example and combines the compensation model to analyze, using the simplified compensation function to determine the amount of emission pollution from upstream to downstream and the compensation that upstream should receive.

Keywords. Ecological compensation mechanism, game model, compensation coefficient, final price arbitration method, compensation standard

1. Introduction

With the rapid economic development of China, the problem of water pollution across river basins has increasingly become an obstacle to social development. Cross-basin water pollution is a kind of trans-boundary externality. Affected by the natural integrity and mobility of the watershed, pollution in a certain area can usually be transferred to another area through the water body, which leads to an imbalance of interests among different areas. Distorted economic and environmental interests have made the environmental protection of China's cross-basin water resources undergo several contradictions and difficulties. These conflicts have also threatened the fair and harmonious development among regions. On this basis, adjusting the benefits

¹ Corresponding Author: Yizhi Sun, Institute of Economics and Management, Lanzhou Jiaotong University, Lanzhou, Gansu, 730070, China; E-mail: sunyizhi0108@163.com

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distribution relationship of relevant stakeholders and promoting the coordinated development of the economy have become academic issues worth studying.

In terms of ecological compensation mechanism, scholars are more inclined to regard it as an economic incentive mechanism for market compensation [1]. The purpose of the ecological compensation is to protect and restore the water and ecological resources that are influenced by human activities and to maintain ecosystem functions provided by the water resource environment [2-3]. James (2005) [4] believed that if the upstream area causes pollution to the downstream area, the upstream area must compensate for the loss of the downstream area due to its pollution; conversely, if the upstream area provides good ecological services to the downstream area and invests in protection cost, the downstream area should give certain compensation to the upstream area. Wunder et al. (2008) [1] posited that the most ideal ecological compensation should fully integrate ecological services into the market. Gong et al. (2010) [5] studied the role of social capital in ecological compensation. They claimed that social capital plays a key role in the success of ecological compensation. Only with strong social capital as a guarantee can stakeholders be promoted in ecological compensation. The selection of behaviors in the compensation mechanism that is conducive to environmental protection will not cause harm to society. Hecken (2010) [6] asserted that ecological compensation can produce positive benefits for society only when it is proven to be reasonable. Therefore, they conducted a deep analysis of whether ecological compensation is reasonable from the perspective of political science. They concluded that ecological compensation is indeed reasonable and effective. Many Chinese scholars study ecological compensation in river basins from the perspective of game theory. Liang (2007) [7] maintained that the ecological problems of the river basin are the result of the individual rationality of the stakeholders in the river basin. To achieve collective rationality, a selective incentive mechanism for ecological compensation in the river basin can be established through the incentive mechanism of upstream ecological protection and the downstream ecological compensation force mechanism to resolve the contradiction between individual rationality and collective rationality in the basin. By studying the ecological compensation in Minjiang River, Han et al. (2009) [8] pointed out that inter-regional ecological compensation in the river basin is a coordinated negotiation among governments representing the public interest in various regions. The researchers highlighted that the key to promote the government to shift from non-cooperative game to cooperation game is the establishment of an incentive and restraint integration mechanism. Song (2009) [9] discussed the benefit distribution of ecological compensation stakeholders from the perspective of game theory and established a game model. The analysis showed that to achieve the optimal ecosystem, long-term ecological compensation goals should be initiated; moreover, a socialized supervision and evaluation mechanism should be established, and ecological property rights and evaluate ecological environmental value should be clearly defined. Cao and Jiang (2009) [10] created a game model for the governments of various regions in the river basin and specifically analyzed the decision-making process of the compensation subject and the object under the established compensation mechanism. Under the constraints of this mechanism, each region in the basin can establish an optimization model based on the local payment function to calculate the impact of pollution discharge and pollution transfer on the economic benefits of the basin. It can also maximize the economic benefits of the region by adjusting its own pollution discharge and pollution transfer volume, thereby improving the ecological environment of the area. Zhan (2016) [11] introduced the corresponding principles and implementation methods, which are based

on the increasingly prominent contradiction between China's current economic growth and environmental protection. Gao et al. (2019) [12] proposed the influencing factors of watershed ecological compensation must be understood from the perspective of how interactions occur among different governments. Moreover, the upstream and downstream governments cannot spontaneously cooperate to implement a watershed ecological compensation system without the supervision of the central government.

Looking at the existing research results of scholars at home and abroad, few game analyses on ecological compensation mechanism exist, and the research methods are too focused on theoretical analysis and quantitative model construction. The results are found in a few scholars, such as Cao and Jiang [10], who used repeated games to analyze compensation for cross-regional pollution. However, the model is too complex to be practically operated and empirically tested.

The criteria for determining the willingness to pay for ecological compensation depends on the respondents' awareness of the importance of the ecological environment and its protection [13]. In addition, it is difficult to reach a compensation agreement on the wishes of both the beneficiary and the supplier [14]. In terms of the compensation standard, Hamdar (1999) [15] used linear programming models to calculate the corresponding compensation amounts according to land use methods based on the investigation of land conversion projects along the Mississippi River. In this type of research, most scholars have used the willingness to pay method [16] and the evaluation of ecological service functions [17]. Li and Hu (2007) [18] applied the ecological reconstruction cost sharing method when studying the issue of ecological compensation standard in the upper and lower reaches of the Minjiang River basin. They pointed out that this method is suitable for determining the economic compensation standard of different river basins. Thus, it is the most appropriate standard accounting method for upstream and downstream ecological compensation at this stage. Jiang (2008) [19] used the water resource value method, cost analysis method, and opportunity cost method to calculate the ecological compensation standard with the water source protection area of the Han River basin as the research object. The researcher believed that the results obtained by using the water resource value method were more appropriate. Mao (2008) [20] adopted the willingness to pay method, cost analysis method, and opportunity cost method to study ecological compensation standard. The researcher pointed out that using the cost method as a quantitative standard when compensating for inter-basin water transfer sources can truly reflect the value of ecological protection. Yuan and Wu (2016) [21] determined the ecological pollution compensation standard of China's industrial sectors as the research object, quantified the upper and lower limits of compensation for heavy and non-heavy polluting industries from the perspective of environmental costs, and used the game to narrow the range gradually and determine the specific compensation standard. Chang (2016) [22] used the willingness to pay method and the opportunity cost method to calculate the ecological compensation standard for the water conservation area in the upper reaches of the Fenhe Reservoir. The researcher determined that the compensation standard ranges from 500 million to 1480 million. Guan et al. (2016) [23] took China's Xiaohong River Basin as an example. They used chemical oxygen demand (COD) as the main pollution evaluation index to calculate the ecological compensation value of the water environment from 2008 to 2012.

In summary, the calculation of the ecological compensation standard is still immature, and many methods are available. The results obtained by each approach are often very different, and the constant recognition of stakeholders in practical applications is difficult to obtain. Two main categories exist: the accounting method and the

negotiation method. The accounting method mainly includes the willingness to pay method, the opportunity cost method, the cost analysis method. The negotiation rule is a method to determine the standard of ecological compensation by negotiating a certain range of ecological compensation based on the accounting method and taking into account the willingness of the compensation subject and object, that is, the price negotiation game. Behind the free negotiation of ecological compensation standard is the economic game process between the beneficiaries and suppliers of ecosystem services. Free negotiation often has difficulty reaching a protection compensation agreement, and an effective negotiation and arbitration mechanism between the compensator and the recipient is required to facilitate stakeholders reach compensation agreements through limited consultations. Yuan and Wu (2016) [21] designed the compensation standard and compensation implementation mechanism. He constructed a multi-level ecological value compensation standard for economic loss-pollution accidents. Moreover, he believed that the polluter and the victim can achieve direct compensation through game. However, no specific demonstration exists for the implementation of the game.

The innovation of this study is to incorporate the central government into cross-regional ecological compensation, and use different bargaining game models to determine different ecological compensation coefficients and then determine the compensation standard.

2. Model Establishment of Upstream Local Government Compensation Mechanism

2.1. Model Assumptions

The upstream government and the downstream government in the river basin, and the central government are all rational economic people, all adopting strategic behaviors to maximize their own interests.

The upstream government, the central government, and the downstream government negotiate with one another on the discharge and treatment of sewage.

The central government compensates the upstream government to urge the upstream and the downstream to follow the principle of “upstream protects, downstream compensates; upstream doesn’t protect, upstream compensates” to maximize the social welfare of the whole society.

2.2. Establishment of the model

2.2.1. Variable setting.

P is the amount of pollutants discharged in the upstream area;

P_0 is the maximum amount of pollution allowed to be discharged in the upstream area;

T is the amount of pollutants transferred from the upstream area to the downstream area;

R is the revenue function generated in the upstream area, which is regarded as a function of P ;

C is the cost function of reducing pollution in the upstream area;

$A(T)$ is the economic impact of upstream’s pollutants area on the downstream area;

M is the total amount of compensation that the upstream obtains from the downstream government and the central government;

K_1 is the compensation coefficient of the downstream area to the upstream area. When the upstream causes less pollution to the downstream, K_1 is a positive number; when the upstream causes more pollution to the downstream, K_1 is a negative number; when the upstream is neither penalized nor compensated, $K_1=0$.

K_2 is the compensation coefficient of the central government to the upstream government. When the upstream causes less pollution to the downstream, K_2 is a positive number; when the upstream causes more pollution to the downstream, K_2 is a negative number; when the upstream is neither penalized nor compensated, $K_2=0$.

2.2.2. The Revenue Function and Its Analysis in The Upstream Area

The strategy of the upstream region is to transfer pollutants to the downstream area and obtain compensation from the central government and the downstream local government to maximize utility.

The utility function of the upstream area is:

$$U(P, T) = R(P) - C(P - T) + A(T)K_1 + A(T)K_2. \quad (1)$$

Formula (1) satisfies the constraint conditions: $0 \leq T \leq P \leq P_0$. Given that the revenue function is continuous, both upstream and downstream parties want to maximize their benefits. The total revenue function and its derivative exist and are continuous. Therefore, the first derivative of the revenue function is equal to 0 and is a necessary condition for maximizing income.

Given the compensation coefficients of the central government and the downstream government, the upstream area must take the pollutant emission decision $a(P, T)$ that

maximizes their own benefits, that is, $\frac{\partial U}{\partial P} = 0, \frac{\partial U}{\partial T} = 0$. Thus, the following equations are obtained:

$$\frac{\partial U}{\partial P} = R'(P) - C'(P - T) = 0, \quad (2)$$

$$\frac{\partial U}{\partial T} = C'(P - T) + A'(T)[K_1 + K_2] = 0. \quad (3)$$

After the compensation coefficients K_1 and K_2 are determined, the upstream decision vector $a(P, T)$ can be obtained according to the equation group to obtain the final income of the upstream area.

2.2.3. The Compensation Standard Function and Analysis of The Upstream Area

The compensation standard function in the upstream area is:

$$M = A(T)K_1 + A(T)K_2 = A(T)(K_1 + K_2). \quad (4)$$

After determining the compensation coefficients K_1 and K_2 , the upstream decision vector $a(P, T)$ can be obtained according to the equations, and the compensation amount of upstream can be determined.

3. The Game Between the Upstream Local Government and The Central Government— K_2 Solution

3.1. Game Method

The determination of the compensation coefficient of the central government is obtained by the bargaining game between the upstream government and the central government. First, the central government proposes a compensation coefficient for the amount of polluted water that must be transferred to the downstream. Then, the upstream government can accept or reject it. If it rejects the coefficient, it will propose its own asking price, and so on. In the whole game process, as long as one party accepts the opponent's plan, the game is over.

3.2. Precondition

The time value of compensation and fixed cost cannot be ignored in the process of bargaining negotiation. One more round of negotiation entails increases in the time cost and the fixed cost.

In the model construction, the number of bargaining times is set as an odd number. Three unsuccessful negotiations require an inverse solution five times. To simplify the model and increase the practical operation feasibility, the number of games is limited. The game is assumed to have three stages at most. The upstream government has to accept the plan in the third round of the game.

Two effects can emerge from the upstream to the downstream according to the amount of sewage: if the amount of transferred sewage is small, the downstream gains benefits, and the central government needs to compensate the upstream; conversely, if the downstream suffers from the sewage, then the central government should punish the upstream government. In this case, the compensation coefficient is negative, that is, the upstream government needs to pay a fine to the central government. Assuming that the amount of sewage transferred from the upstream to the downstream is small and downstream development gains benefits, the central government needs to provide additional compensation to the upstream government.

3.3. Game process

The game process of the compensation coefficient K_2 between the upstream government and the central government is shown (Figure 1). In the first stage, when less sewage T is transferred from the upstream to the downstream, the central government's plan is to compensate the upstream with K_a . Then, the upstream government makes the decision to accept it or not. The negotiation between the two levels of government will end if the upstream accepts. The compensation will be implemented in accordance with the plan of the central government. At the same time, the upstream government will not have made any progress. If the upstream government does not accept it, the next phase will begin. In the second stage, the compensation coefficient requested by the upstream government is K_c ($K_c > K_a$), and the central government chooses whether to accept it. If accepted, the upstream government will obtain the compensation coefficient K_c , and $K_c - K_a$ is the increment. If the central government does not accept it, then the process moves to the

next stage. In the third stage, the compensation coefficient proposed by the central government is K_b ($K_c > K_b > K_a$), which must be accepted by the upstream. The numbers in the above three stages are all real numbers greater than 0.

The key point of this game is that the plan of the central government in the third stage is mandatory, that is, the compensation coefficient proposed by the central government to the upstream at this stage must be accepted by both parties. Every time this game stage is played once more, it is detrimental to the work. Ending the debate on the compensation coefficient as soon as possible is especially beneficial to the upstream government.

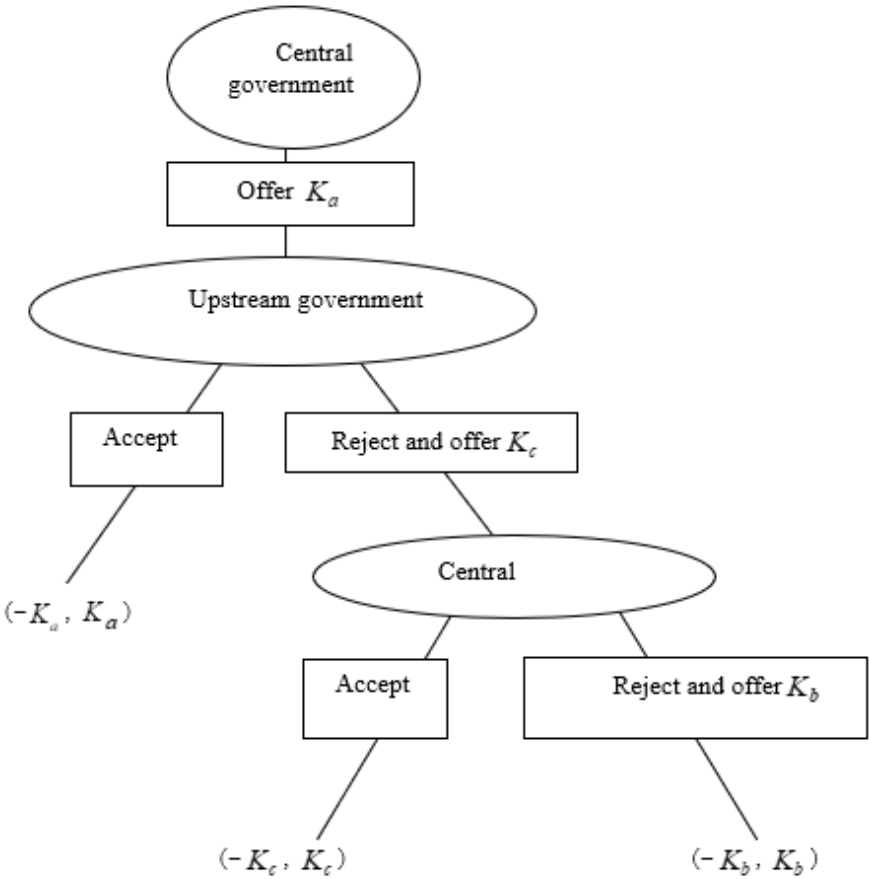


Figure 1. Game process diagram between the upstream government and the central government.

3.4. Game Analysis

The analysis of this game by inverse induction is as follows: in the third stage of this game, the central government proposes the compensation coefficient of the upstream as K_b , and the upstream government must accept it. In the second stage, the upstream

government knows that once the third stage is reached, the central government will insist that the compensation coefficient it receives K_b , which has increased to $K_b - K_a$. To maximize its own benefits, if the upstream government rejects the central government's plan in the first stage, it must propose a plan greater than K_b . If the delivered value proposed by the upstream government, which makes the central government transfers greater benefits than planned in the third stage, then the plan will definitely be rejected by the central government. The analysis must proceed to the third stage and the upstream government obtains the benefits accepted in this stage. Therefore, the plan is deemed the ideal choice if it makes the central government willing to accept and its own benefits can be as large as possible in the third stage. In other words, in the game, either player is willing to accept a bid at this stage, which is no less than that of their own at the next stage. When the upstream proposes the target compensation coefficient K_c , its compensation coefficient is increased to $K_c - K_a$. This increase is larger than $K_b - K_a$, which is the biggest benefit that the upstream may obtain. Then, inverse deduction is made to the analysis of goals proposed by the central government in first stage. Evidently, the central government knew from the beginning that it would transfer the benefits of $K_b - K_a$ to the third stage. It is also aware that the compensation coefficient proposed by the upstream in the second stage is the target of K_c . Therefore, the benefits it is willing to transfer are also $K_b - K_a$, while the upstream is satisfied with the greatest possible benefit, that is, $K_c - K_a$. For this reason, the game must continue from the first stage to the third stage. One point worth explaining in this game is that the above conclusions have a premise that the transfer of interests proposed by the central government in the third stage must be known in advance by both parties. In this game, the central government in a favorable position can guarantee all its own interests without transferring interests only when the central government is not concerned about protracted negotiations at all or when the upstream government's request is unreasonable. In this game of bargaining between the central government and the upstream local government, the central government has two roles, namely, the "participant" (economic man) and the "manager" (administrative person), due to the unequal status of the central government and the upstream government. The central government conducts transactions with a dual identity, which is evidently mandatory. This coercion restricts the game space between governments.

4. The Game Between Upstream and Downstream Local Government—K₁ Solution

4.1. Game Method and Process

The upstream and downstream governments of the Taohe River basin are based on the relationship of "brothers," and they have equal status. The game between these two parties on the compensation coefficient is widely different from the game with the central government, and it generally requires a third party to adjust the arbitration. Farber first proposed the final offer arbitration law. On this basis, Dao-Zhi Zeng (2006)

[24] proposed the amendment final offer arbitration (AFOA) law, on which the following is based to solve the upstream and downstream compensation coefficients.

According to the final offer arbitration law, the final arbitration result is determined by the bid winner (that is, the party closer to the ideal value of the arbitration department). According to the AFOA law, the final arbitration price is based on the failure of the bid the party (that is, the party farther away from the ideal value of the arbitration department) determines as the final arbitration price. The rule is that upstream i and downstream j first offer a price at the same time, assuming that downstream bid is K_j and the upstream asking price is K_i . Both parties notify the arbitration department, and the arbitration department obtains Z , the idea value, on the basis of scientific analysis and calculation.

To reach the optimal benefit for both parties from the game, the amount of sewage discharged from upstream to downstream is less, and the downstream is the compensator. Thus, when $K_i \leq K_j$, the two parties reach an agreement that the final arbitration value is $\frac{K_i + K_j}{2}$. When $K_i \geq K_j$ and $|Z - K_i| < |Z - K_j|$, the bid of downstream j is farther from arbitration Z . Hence, the downstream wins during the arbitration process, and the final arbitration value is $2Z - K_j$. When $K_i \geq K_j$ and $|Z - K_i| > |Z - K_j|$, the asking price of upstream i is farther to arbitration value Z . Therefore, the upstream wins during the arbitration process. The final arbitration value is $2Z - K_i$. When $K_i \geq K_j$ and $|Z - K_i| = |Z - K_j|$, the final arbitration value is $\frac{K_i + K_j}{2}$.

4.2. Proof of Game Feasibility

Dao-Zhi Zeng (2006) [24] proved that in the process of using the AFOA for arbitration, a unique pure strategic Nash equilibrium is reached; the equilibrium value is equal to the ideal value of the arbitration department. Z , K_i , and K_j are assumed to be random variables and are independent of one another.

4.2.1. Proof of Equilibrium Existence

In this game, a pure strategic Nash equilibrium is assumed to exist, that is, both parties bid E .

Given that the upstream asking price is K_i , the downstream bid is K_j . According to the arbitration rules, the solution is as follows:

$$a(K_i, K_j) = \begin{cases} \frac{K_i + K_j}{2}, & K_j \geq K_i; \\ 2Z - K_i, & K_j < K_i, \text{ and } Z > \frac{K_i + K_j}{2}; \\ 2Z - K_j, & K_j < K_i, \text{ and } Z < \frac{K_i + K_j}{2}; \\ \frac{K_i + K_j}{2}, & K_j < K_i, \text{ and } Z = \frac{K_i + K_j}{2}. \end{cases} \quad (5)$$

If $K_j < K_i$, the expected value of the arbitration value $A(K_i, K_j)$ can be calculated as:

$$\begin{aligned} A(K_i, K_j) &= \frac{\left(\frac{K_i + K_j}{2}\right) - 0}{\int_{\frac{K_i + K_j}{2}}^{\frac{K_i + K_j}{2}} (2Z - K_j) dF(z) + \frac{K_i + K_j}{2} \left[\int_{\frac{K_i + K_j}{2}}^{\frac{K_i + K_j}{2}} (2Z - K_i) dF(z) + \frac{K_i + K_j}{2} \left[F\left(\frac{K_i + K_j}{2}\right) - F\left(\frac{K_i + K_j}{2} - 0\right)\right]\right]} \\ &= 2E - K_i + K_i F\left(\frac{K_i + K_j}{2}\right) - K_j F\left(\frac{K_i + K_j}{2} - 0\right) - \frac{K_i + K_j}{2} \left[F\left(\frac{K_i + K_j}{2}\right) - F\left(\frac{K_i + K_j}{2} - 0\right)\right] \\ &= 2E - K_i + \frac{K_i - K_j}{2} \left[F\left(\frac{K_i + K_j}{2}\right) - F\left(\frac{K_i + K_j}{2} - 0\right)\right]. \end{aligned} \quad (6)$$

When the asking price of upstream $K_i = E$ if the bid of downstream $K_j > E$,

$$\begin{aligned} A(E, K_j) &= E + \left(\frac{E - K_j}{2}\right) \left[F\left(\frac{E + K_j}{2}\right) - F\left(\frac{E + K_j}{2} - 0\right)\right] \\ &\leq E + (E - K_j) \frac{F(E) - F(E - 0)}{2} < E. \end{aligned} \quad (7)$$

Similarly, when $K_j < E$, $A(E, K_j) = \frac{E + K_j}{2} < E$ only if $K_j = E$ and $A(E, E) = E$.

Therefore, $K_j = E$ is a strategy to maximize expectations, that is, $K_i^* = K_j^* = E$ is a pure strategy Nash equilibrium.

4.2.2. Proof of Equilibrium Uniqueness

$(K_i^\#, K_j^\#)$ is a pure strategic Nash equilibrium formed between the upstream and downstream local governments in the watershed ecological compensation if $K_j^\# < K_i^\#$. When the upstream increases its asking price, it will be compensated higher than the original asking price. If $K_j^\# > K_i^\#$, let $\varepsilon = K_j^\# - K_i^\# > 0$, it is discussed in two situations:

1) If $F(K_j^\# - \frac{\varepsilon}{2}) = F(K_i^\# + \frac{\varepsilon}{2}) > 0$, then:

$$\frac{\varepsilon}{2}F(K_i^\# + \frac{\varepsilon}{2}) \leq \frac{\varepsilon}{4}F(K_i^\# + \frac{\varepsilon}{2}) + \frac{\varepsilon}{4}F(K_i^\# + \frac{\varepsilon}{4}) < \frac{\varepsilon}{4}F(K_i^\# + \frac{\varepsilon}{4}), \quad (8)$$

$$\frac{\varepsilon}{2}F(K_i^\# + \frac{\varepsilon}{2} - 0) \leq \frac{\varepsilon}{4}F(K_i^\# + \frac{\varepsilon}{4}). \quad (9)$$

Thus,

$$\begin{aligned} A(K_i^\#, K_i^\# + \frac{\varepsilon}{2}) &= 2E - K_i^\# - \frac{\varepsilon}{4}[F(K_i^\# + \frac{\varepsilon}{4}) - F(K_i^\# + \frac{\varepsilon}{4} - 0)] \\ &< 2E - K_i^\# - \frac{\varepsilon}{2}[F(K_i^\# + \frac{\varepsilon}{2}) - F(K_i^\# + \frac{\varepsilon}{2} - 0)] \\ &= A(K_i^\#, K_i^\# + \varepsilon) \end{aligned} \quad (10)$$

$K_j^\# = K_i^\# + \varepsilon$ is the best strategy for downstream j .

2) If $F(K_j^\# - \frac{\varepsilon}{2}) = 0$, then $F(K_j^\# - \frac{\varepsilon}{2} - 0) = 0$. Thus:

$$F(K_j^\# - \frac{\varepsilon}{2}) - \frac{1}{2}F(K_j^\# - \frac{\varepsilon}{4}) + F(K_j^\# - \frac{\varepsilon}{2} - 0) - \frac{1}{2}F(K_j^\# - \frac{\varepsilon}{4} - 0) \leq 0 < 1, \quad (11)$$

and obtain:

$$\begin{aligned} A(K_j^\# - \varepsilon, K_j^\#) &= 2E - K_j^\# + \varepsilon - \frac{\varepsilon}{2}[F(K_j^\# - \frac{\varepsilon}{2}) + F(K_j^\# - \frac{\varepsilon}{2} - 0)] \\ &< 2E - K_j^\# + \frac{\varepsilon}{2} - \frac{\varepsilon}{4}[F(K_j^\# - \frac{\varepsilon}{4}) + F(K_j^\# - \frac{\varepsilon}{4} - 0)] \\ &= A(K_j^\# - \frac{\varepsilon}{2}, K_j^\#) \end{aligned} \quad (12)$$

Therefore, $K_i^\# = K_j^\# - \varepsilon$ is the best strategy for upstream i .

In summary, $K_i^\# = K_j^\#$. The final result that makes both parties agree is k . If $K < E$, then

$A(k, k - 0) = 2E - k < k = A(k, k)$. Therefore, downstream j will not raise a bid lower than k .

Similarly, if $K > E$, then $A(k + 0, k) = 2E - k < k = A(k, k)$. Thus, upstream i will not give an asking price higher than K .

4.2.3. Result Analysis

In summary, k is the only Nash equilibrium of this game. This equilibrium is: $K_i^* = K_j^* = E$.

Now, assuming that the expected value distribution of the arbiter obeys a normal distribution with mean m and variance δ^2 , the density function is:

$$f(z) = \frac{1}{\sqrt{2\pi\delta^2}} e^{-\frac{1}{2\delta^2}(z-m)^2} \quad (13)$$

Therefore, the only Nash equilibrium point is $K_i^* = m, K_j^* = m$, that is, the expectation of the final bid is m .

5. The Determination of The Economic Impact Function of The Upstream Region on Downstream

The economic impact function of the upstream area on the downstream, that is, the specific form of the compensation function, adopts the simplified form proposed by Li and Xu (2003) [25]:

$$A(T) = GDP * W * (e^{\frac{\alpha(T-Q^*)}{a(T-Q^*)+1}} - 1) + M \quad (14)$$

The meaning of each parameter in the formula is as follows: GDP represents the local GDP value of the current year. W represents the loss rate of water quality on the socio-economic impact. Meanwhile, α is expressed as a dimensionless coefficient, an important parameter that characterizes the shape of the curve. It reflects the sensitivity of pollution to the socio-economic impact: the larger the value, the steeper the function curve, thus indicating that the social economy is extremely sensitive to water quality. In contrast, it shows that economic behavior is less sensitive to water quality. T and Q^* , with no unit, respectively, represent the pollution transfer level and the water quality level corresponding to the inflection point. The value is converted according to a certain environmental protection standard for the actual discharge and transfer of pollutants. M is the influence coefficient of the corresponding water pollution loss at the turning point, that is, the turning point of the impact of water quality level on economic loss.

The schematic diagram (Figure 2) and function characteristics of the loss measurement model are as follows: ① Upper and lower limits: when pollutants are reduced to a certain level, the quality of the water environment will not cause economic losses. Conversely, when pollutants increase and the water quality deteriorates to a certain extent, the water body basically loses its due service functions. In addition, the economic loss rate caused by water pollution tends to maintain a constant state and reach the maximum value, assuming it is equal to 1. ② Non-linearity and inflection point: the relationship between water quality and economic impact should be a non-linear continuous gradual process, and the inflection point corresponding to the economic loss rate of water pollution M is assumed to be 0.5. ③ The growth rate of economic losses

usually shows a downward trend and gradually tends to be constant, thus reaching the upper limit of losses caused by water pollution.

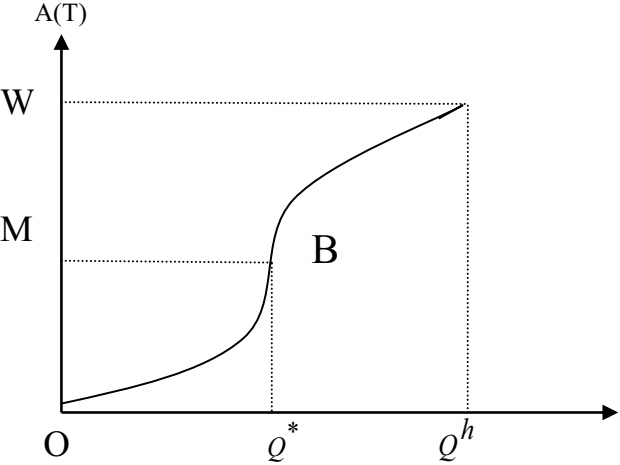


Figure 2. The rivers pollution-economic loss function diagram.

6. Examples and Conclusions

As for the income function of the upper Taohe River area and the cost function of pollution control, the author directly draws on the research results of Cao and Jiang (2009) [10] based on the analysis of the ecological compensation mechanism of cross-basin pollution, namely:

$$R(P) = -2P^2 + 16P, \tag{15}$$

$$C(P - T) = 0.075(P - T)^2 + 0.001(P - T) \tag{16}$$

Given that many areas are involved in the water-receiving areas in the downstream of the Taohe River, for the sake of calculation, the author selects six representative regions to calculate the GDP of the downstream water-receiving areas: Anding, Longxi, Weiyuan, Lintao, Yuzhong, and Huining. According to Luo’s calculation (2012) [26] of the data table of the carrying capacity of Tao River’s water resources (Table 1), the GDP of the water receiving area is calculated as 2,633 million yuan by average. In addition, set $W=0.7$, $a=0.54$, $Q^* = 4$, and $M=0.5$. Therefore, the total income function of the upstream region is:

$$U(P, T) = -2P^2 + 16P - 0.075(P - T)^2 - 0.001(P - T) + (K_1 + K_2) * 263300 * 0.7 * (e^{\frac{0.54(T - 4) - 1}{0.54(T - 4) + 1}} + 0.5) \tag{17}$$

Table 1. Data table of GDP and the value of the three industries in the water-receiving areas of the Yintao project^a.

County	GDP	Primary industry value (10,000 Yuan)	Second industry value (10,000 Yuan)	Third industry value (10,000 Yuan)
Anding	193573.16	56956.62	47672.05	88944.50
Longxi	190385.25	54441.00	60573.25	75371.00
Weiyuan	85948.75	45568.50	6610.25	33770.00
Lintao	167524.00	63356.50	48901.50	55266.00
Yuzhong	749148.75	57132.25	114664.75	63162.00
Huining	193220.50	65371.50	49334.00	78515.00

^aData source: Luo Jinren's "Tao Water Diversion Project and Its Impact on Regional Sustainable Development" compiled from Appendix 8-7.

Table 2. Statistical properties of the used data.

Statistical Property	GDP	Primary Industry Value (10,000 Yuan)	Second Industry Value (10,000 Yuan)	Third Industry Value (10,000 Yuan)
Mean	263300.0683	57137.72833	54625.96667	65838.08333
Maximum	749148.75	65371.5	114664.75	88944.5
Minimum	85948.75	45568.5	6610.25	33770

The statistical properties of the data are summarized in Table 2. According to the previous argument in this article, suppose that the compensation coefficient obtained through arbitration in the upstream and the downstream of the Taohe River is $K_1=0.5$. In addition, the compensation coefficient obtained by the upstream government and the central government through the game is $K_2=0.7$. The utility function of the upstream area is continuous and second-order derivable. Through calculation, the upstream area selects the emission pollution level of 5.3 and transfers the pollution level of 1.39 to the downstream area. According to the five-level water quality conversion standard, the annual transfer of 550 million cubic meters of water from the upstream of the Tao River to its downstream, the amount of pollutants transferred from the upstream to the downstream can be calculated as $T' = 5.5 \times 15 \times 10^8 = 8250$ (tons).

Generally speaking, sewage treatment costs are relatively abstract and cannot be traded through the market. Hence, they are difficult to measure by market prices. Regarding the calculation of sewage treatment costs, many scholars have analyzed it from different angles, and the research results also vary widely. Therefore, this study directly adopts Zhou's (2009) [27] compensation standard on the basis of the compensation factor method as 15,000 yuan/ton.

Therefore, the compensation amount in the upstream area is calculated as:

$M = T' * P * \delta = 8250 * 1.5 * 1 = 12375$ (ten thousand yuan). At this time, the upstream of the Taohe River can obtain the maximum utility.

Evidently, the central government's intervention is highly necessary for the ecological compensation between the upstream and downstream parties of the river basin. The participation of the central government ensures the normal progress of the ecological compensation game between the upstream government and the downstream government. In the issue of ecological compensation in the upper and lower reaches of the river basin, the contradiction in ecological compensation caused by the imbalance of interests between the upstream and downstream governments of the basin will be eased to a large extent as long as a reasonable compensation mechanism is established and reasonable compensation standards are formulated.

7. Issues for Further Research

The study of cross-regional ecological compensation mechanism, on the one hand, involves the impact of the upstream pollution on the downstream economy. Testing such impact is a complicated issue. On the other hand, the bargaining game between the upstream and downstream governments and the central government involves the impact of pollution levels on the compensation coefficient, which makes the pollution coefficient itself endogenous. All of these aspects require further discussion.

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