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Multi-Game Theory Analysis of Cooperation Stability of Trans-boundary Water Pollution Governance

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ABSTRACT

The stability of trans-boundary water pollution control alliance is the key to effectively alleviate the problem of water resources shortage. In this research, we use the KMRW reputation model of incomplete information repeated game to analyse the stability of cooperation in trans-boundary water pollution governance, especially, the analysis of the compensation factors influence on cooperation and its mutual restriction of penalty factor. The results of this study suggest that in order to alleviate cooperation opportunism arising from the asymmetric information among parties involved in trans-boundary water pollution governance, the active party should bind cooperation time as long as possible, and the inactive party should input proper signal display. In order to maintain the stability of the alliance in a different situation, we innovatively introduced compensation factor into the reputation model to analyse its impact on cooperative alliances and their mutual restriction with penalty factors and subsidy factors. Hopefully, this paper could give some suggestions to the parties of the trans-boundary water pollution control alliance to make this cooperation more stable.

INTRODUCTION

Water pollution is one of the main reasons for the shortage of water resources and seriously affects the whole river basin's pollution prevention, and economic and social development (Jiang 2009). While among different types of water pollution, border crossing water pollution governance is more challenging because of its regional nature and environmental constraints. As a kind of common pool resources, the basin water resources across the administrative region have the characteristics of quasi-public goods such as externality, integrity and geographical differentiation (Sarker et al. 2008). This kind of situation is easy to cause a conflict of interest in different administrative regions or countries (Gleditsch et al. 2006). Therefore, river basin water pollution alliance cooperation is the most effective way to solve the problem of water pollution within border crossing basins (Benvenisti 1996, Rondinelli & London 2003).

But in doing so, there are some problems with cooperation. Some researchers (Feng & He 2009, Ongley & Wang 2004) stated that legislation for controlling water pollution of border crossing basins is not perfect. While some other (Benvenisti 1996, Hoekstra 2010, Ongley & Wang 2004) analysed this problem from the aspects of basin management. Others found that the pollution costs and benefits of the whole social governance and each governance subject facing are different, make the participation of the main pollution control initiative as not enough, and easy to cause "tragedy of the commons" (Eldakar et al. 2009). What is more, cross-regional water pollution control involves a large number of subjects, hence mutual coordination cost is high. This makes it easy to fall into the "collective dilemma" (Madani & Dinar 2012, Sarker et al. 2008). Above reasons make water pollution governance alliance to break down and greatly reduce the stability of water pollution control cooperation.

Understanding how to keep the cross-regional water pollution cooperation stable is very important for sustainable water resources management. For example, some (Nnane et al. 2011, Sadoff & Grey 2002) deeply analysed the cost and profit allocation of cross-regional water pollution using the game theory. Some (da Silveira & Richards 2013) gave the advice to build a multi-level cross-border water pollution prevention and control cooperation mechanism. Although the above researches describe the necessity of cooperation across regions water pollution governance, analysed the interests of relevant subjects and build a cooperative mechanism. They focused only on the static analysis of cooperation without analysing its long-term dynamic stability.

The stability of the cooperative alliance is the key to the effectiveness of cross-regional water pollution control. Only long-term stability of the cross-regional water pollution governance alliance can ensure the implementation of governance action optimization. If a region continues to invest some resources to show its cooperative attitude and make the other regions believe in its cooperation, pollution control cooperation will be stable. But there are many factors affecting the stability of inter-regional water pollution control cooperation alliance. Study of each participant's reputation in cooperative investment and its influencing factors is very important in order to get insights on how to keep the cooperation stability. Using reputation to build a mechanism to keep the alliance parties cooperation as long as possible is a way to solve this problem.

As for the research on reputation, Adam Smith put forward reputation as an important mechanism to ensure the smooth implementation of the contract more than 200 years ago (Zhao 2005). Fama introduced reputation into the field of economics (Fama 2018). Many scholars using the reputation theory, analysed how the reputation influence the cooperation union's stability (Abdel-Hafez et al. 2014, Bickerton 2000, Cobb-Walgren et al. 1995, Feldwick 1996, Longwell 1994, Riahibelkaoui 1992).

Among the models which are used to combine the reputation with game theory in order to analyse cooperation, stability, one of them is the KMRW. Some researchers (Bickerton 2000, Mu 2015, Niu et al. 2013) used KMRW reputation model to analyse various strategic cooperation problems involving various agents with different interests. More studies on reputation theory and methods can be found by Abdel-Hafez et al. (2014) and Xiao et al. (2004). There are two reasons to use KMRW reputation model for analysing cross-regional water pollution control. One is that it is a game theory method which considers the incomplete information between participants and analyses the long-term dynamic stability of cooperation. The other reason is that it is a game theoretic model, hence it is suitable to capture the strategic nature of cooperation.

To ensure the operation of the alliance, one of the key issues is to rely on the mutual supervision and mutual encouragement of members. This kind of supervision and incentive is based on information identification and delivery among alliance members. The reputation is just the external performance of the recognition and transfer process. Reputation mechanism can restrain and identify non-cooperative members and reduce the number of false cooperative members. Therefore, it is of great significance to study the impact of reputation on the game among the members of the cooperative alliance. Although reputation theory and its application in related fields from different angles and at different levels has been deeply analysed, there is seldom research on how the reputation will influence the cooperation coalition's stability.

In this study, we combined the KMRW reputation model with the hot field inter-regional water pollution control. This research mainly analyses the role of the party with high bargaining power for maintaining cooperation stability.

MATERIALS AND METHODS

Problem description: One of the features of border crossing water pollution governance is the presence of upstream and downstream agents. Generally speaking, the upstream districts are poor and need to develop the economy and more serious pollution demands of water pollution, and therefore bear the heavy responsibility of pollution control (Feng & He 2009), the downstream government is backward in the economy (Cai et al. 2016). In their water pollution control alliance, the downstream government has a strong enthusiasm to participate in cooperation and put the appropriate resources to support. While the upstream government has uncooperative interest motive, it is possible to secede from the union that leads to the alliance stability failure. We assumed that there is a central government to build a platform to urge the upstream and downstream governments to negotiate and deal with pollution problems in the river basin. The downstream government is the leader of the alliance (because it has strong cooperation motivation), the upstream government is a cooperative member in the cooperation alliance. From Fig. 1, we could know the alliance signed a multi-stage cooperative governance contract developed by the central government, and the downstream government has incomplete information on whether the upstream government cooperates or not.

In order to facilitate the analysis, the upstream governments could be divided into a trustworthy member and untrustworthy member. As for the trustworthy member, who is willing to keep or increase pollution abatement investment, while the untrustworthy member refers to the upstream government that will reduce the investment of pollution abatement. According to the stage of the water pollution control results, the downstream government determines whether the cooperative members are trustworthy or not and also decide whether or not to take the same non-cooperative behaviour (punishment or subsidies to the cooperation members).

Model assumption: The hypotheses of this study are as follows:

***Hypothesis 1*:** The model assumes that the upstream gov-

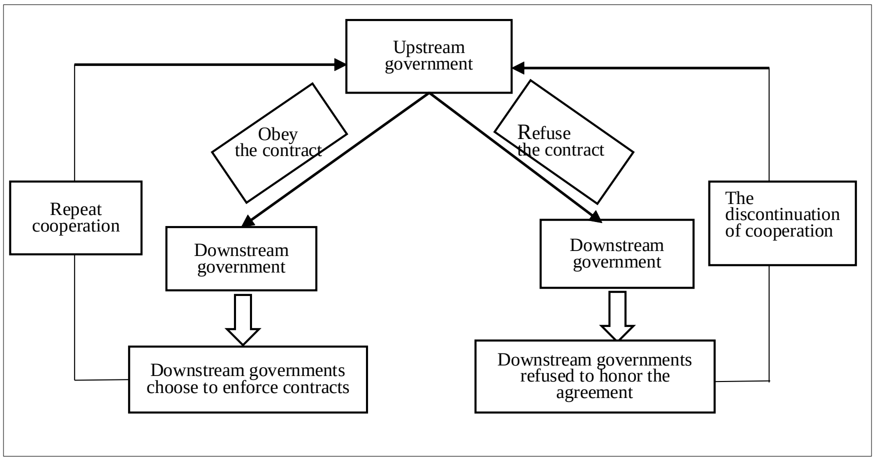

Fig. 1: The game frame of upstream and downstream governments about water pollution discharge.

ernment and the downstream government are two parties in the alliance. The downstream government is assumed to be a good cooperation, who wouldn't betray the alliance and take opportunism choice. The downstream government's choice of this phase will be up to the behaviour of the last phase in the upstream government's decision strategy. And the cold strategy will be used in the game by the downstream government, which means that the upstream government of non-cooperative behaviour will lead to its revenge action. But if the upstream government continue to cooperate, the alliance can start the cooperation again.

***Hypothesis 2*:** There are two types of upstream governments, cooperative and non-cooperative. Due to information asymmetry, whether upstream governments are cooperative is unknown to the downstream governments. Cooperative upstream governments will adopt opportunism to gain extra benefits, while non-cooperative producers will adopt opportunism, but they can also pretend to cooperate to build cooperation reputation.

***Hypothesis 3*:** The upstream government adopts opportunism to reduce the sewage treatment input, which is related to the credibility of the upstream government and the expectation of the downstream government to the upstream government.

***Hypothesis 4*:** When the upstream government decides to cooperate, it will do its best, while the downstream government will decide whether it is trustworthy by judging whether the upstream party is cooperative or not. The downstream government cannot judge whether the upstream government is a cooperative government by the current probability, but it can judge whether the upstream government is a cooperative government by the results of the previous cooperation.

***Hypothesis 5*:** The utility of the upstream government from the cooperative governance is related to the behaviour at the present stage and at a later stage. The utility function of the cooperative member (upstream government) is as follows:

$$F = -\frac{1}{2}q^2 + a\left(q - q^e\right) \qquad ...(1)$$

Among them, F is the reputation utility of the upstream government, a=0 represents that the upstream government is a trustworthy member, while a=1 represents the upstream represents who is not a trustworthy member. q is the upstream government that actually reduce the proportion of pollution treatment investment, q_e (e means expectation) is the downstream government speculated that the upstream government will reduce the proportion of pollution control input. The prior probability of the upstream government as a trustworthy member is p_0, and the probability that it is a member of the trustworthiness is 1-p_0.

***Hypothesis 6*:** Assumes that the water pollution governance alliance is a multi-stage repeated game. m_t represents the probability that the downstream government considers the upstream government trustworthy in stage t ($0<m_t<1$).

$$p_{t+1}(\mathrm{a}=0 \mid q_t = 1) = \frac{Prob(a=0, q_t=1)}{Prob(q_t=1)} = \frac{Prob(q_t=1 \mid a=0) \times Prob(a=0)}{Prob(q_t=1 \mid a=0) \times Prob(a=0) + Prob(q_t=1 \mid a=1) \times Prob(a=1)} = \frac{p_t \times 0}{p_t \times 0 + (1-p_t) \times m_t} = 0 \qquad ...(2)$$

$$p_{t+1}(\mathrm{a}=0 \mid q_t = 0) = \frac{Prob(a=0, q_t=0)}{Prob(q_t=0)} = \frac{Prob(q_t=0 \mid a=0) \times Prob(a=0)}{Prob(q_t=0 \mid a=0) \times Prob(a=0) + Prob(q_t=0 \mid a=1) \times Prob(a=1)} = \frac{p_t \times 1}{p_t \times 1 + (1-p_t) \times m_t} = \frac{p_t}{p_t + m_t \times p_t - m_t} \geq p_t \qquad ...(3)$$

In Eq. (2) the probability of upstream government's trustworthiness at the *t* stage, $q_t = 1$ means upstream government is determined to reduce pollution control investment in *t* stage, it is concluded that if the upstream government do not keep their words' behaviour was found by the downstream government at *t* stage, then the upstream government in the $t+1$ stage (the next stage) think that the upstream government trustworthy posterior probability is 0. Eq. (3) indicates that the downstream government does not discover the upstream government's behaviour of dishonesty in *t* stage, the downstream government considers the posterior probability of the upstream government trustworthy in the $t+1$ stage, because the Eq. (3) is an increasing function, so we got the result that if the downstream government observed at this stage as trustworthy enterprises, then in the next stage the probability of its trustworthiness will rise.

RESULTS

Stability analysis of water pollution control alliance with discount factor: Alliance is based on contract because the partners have the motivation to undermine the alliance in the process of cooperation. In the final stage of cooperation, the cooperative members will choose opportunistic behaviour. According to the upstream government utility function of the water pollution control alliance, in the final stage of cooperation if the upstream government does not keep its words, at this time $a=q_t=1$, then the downstream government's expectation of the upstream government's disobeying is: $q_t^e = 1 - p$.

The utility function of the upstream government is not trustworthy as follows:

$$F_t = -\frac{1}{2}q_t^{\,2} + a\left(q_t - q_t^{\,e}\right) = -\frac{1}{2} + (1-q_t^{\,e}) = -\frac{1}{2} + \left[1-(1-p_t)\right] = p_t - \frac{1}{2} \qquad \text{...(4)}$$

Here, p_t is at *t* stage, the probability of the upstream government trustworthy (cooperation), from $\frac{\partial F_t}{\partial p_t} = 1 > 0$ indicating that the effectiveness of the upstream government increase with the credibility of their cooperation increased. So, the upstream government will actively increase the credibility of their cooperation in order to improve their effectiveness.

Make δ for upstream government discount factor. In a multi-stage water pollution governance alliance cooperation, the alliance has the same utility in all phases except the last two phases, when the parties in the process of game, only in the last two stages due to trustworthy and untrustworthy behaviours make their total utility different, in the last two stages of the repeated game we have:

$$F_{t-1}(1) + \delta F_t(1) = -\frac{1}{2} + (1-q_{t-1}^e) + \delta(p_t - \frac{1}{2}) = \frac{1}{2} - q_{t-1}^e - \frac{1}{2}\delta \qquad \text{...(5)}$$

$$F_{t-1}(0) + \delta F_t(1) = -\frac{1}{2}q_{t-1}^2 + (q_{t-1} - q_{t-1}^e) + \delta\left[-\frac{1}{2}q_t^2 + 1\times(q_t - q_t^e)\right] \qquad \text{...(6)}$$

Where, $F_{t-1}(0)$ means the reputation utility of the untrustworthy status of the upstream government at *t-1* stage, $F_{t-1}(1)$ is the reputation utility for the trustworthiness of the upper government at *t-1* stage, $F_t(1)$ presents the reputation utility of the untrustworthiness for the upstream government at *t* stage. Eq. (5) means the upstream government is trustworthy at the *t-1* stage, while not trustworthy in final stage *t* (this time $q_{t-1} = 0$, $q_t = 1$, $q_t^e = 1-p$), the sum of the last two stages of reputation utility of the upstream government. Eq. (6) means in repeated games, when the upstream government is not trustworthy in *t-1* and *t* stages (this time $q_{t-1} = q_t = 1$), the sum of the last two stages of reputation utility of the upstream government.

In order to make the total effectiveness of the government in the last second stages to take the action of trustworthiness is better than the total utility of the act of not keeping faith, there will be a formula of Eq. (5) >Eq. (6).

$$-q_{t-1}^e + \delta(p_t - \frac{1}{2}) \geq \frac{1}{2} - \frac{1}{2}\delta - q_{t-1}^e \qquad \text{...(7)}$$

From the Eq. (7) we get $p_t \geq \frac{1}{2\delta}$, bring it into Eq. (3), the probability of downstream government thinking upstream government trustworthy is, $m_t = \frac{(2\delta-1)p_t}{1-p_t}$, when $\delta > \frac{1}{2}$, the more downstream government trust the upstream government, to maintain their credibility, the upstream government will become more trustworthy. That means, as long as $p_{t-1} > \frac{1}{2\delta}$, the upstream government will choose to keep the credibility in the *t-1* stage and not to keep faith in the t stage. This means that an increase in the discount factor could help maintain the stability of the alliance.

Promotion to the multi-stage game, δ^t is the discounted value in time of period *t*, when $p_{t-1} > \frac{1}{2\delta}$ if the upstream government choose to keep their promises in the *t-1* stage, then in the previous stage they will choose to be trustworthy, only in the final stage is not trustworthy, this is the

Nash equilibrium of the multi-stage game. $p_0 > \frac{1}{2\delta}$ At this point, the utility of the upstream government can be expressed as:

$$\sum_{t=0}^{T} \delta^t F_t = 0 + 0 + \cdots + \delta^t (p_0 - \frac{1}{2}) = \delta^t (p_0 - \frac{1}{2}) \quad ...(8)$$

Corresponding at that time when $p_0 < \frac{1}{2\delta}$, upstream government does not keep their words at all stages of the union, the posterior probability of downstream government of its trustworthy or not is: $v_0^e = 1 - p_0$, $v_1^e = v_2^e = \cdots = v_t^e = 1$ so the upstream government's total utility as follows:

$$\sum_{t=0}^{T} \delta^t F_t = (p_0 - \frac{1}{2}) + \delta(p_0 - \frac{1}{2}) + \delta^2 (p_0 - \frac{1}{2}) +$$

$$\cdots + \delta^t (p_0 - \frac{1}{2}) = (p_0 - \frac{1}{2}) \frac{1 - \delta^t}{1 - \delta} \quad ...(9)$$

Obviously, Eq. (8) > Eq. (9), that is in the process of multi-stage game, when $p_0 > \frac{1}{2\delta}$ the upstream government's utility level is greater than the utility of $p_0 < \frac{1}{2\delta}$.

From the above analysis, we can see that in the coalition of water pollution control, as long as $p_0 > \frac{1}{2\delta}$ the rational coalition members will choose to keep their words from the beginning to maintain their credibility until the last stage of cooperation when taking the act of disobedience, this time the utility of upstream government's effectiveness is greater than the beginning to take the action of not trustworthy. Therefore, the stability of the alliance depends on the discount factor, even if the nature of the upstream government is not trustworthy, it will "disguise" become trustworthy to achieve Pareto optimality in the game.

Stability analysis of water pollution control alliance with penalty factor: In the process of pollution control cooperation, the effective credit punishment for the opportunism behaviour of member enterprises can restrain the occurrence of undermining alliance behaviour and maintain the stability of the coalition. In the coalition of water pollution control cooperation, the penalty is mainly referred to in the process of cooperation in pollution control, the downstream government through the stage of pollution control results to determine the upstream government trustworthy or not obvious stage, and then punish the upstream government's actions of not faithful.

This paper assumed the penalty factor for ε $(0 < \varepsilon \leq 1)$, and the number of non-trustworthiness is *n*, each time not trustworthy will be punished, so the penalty factor is additive, therefore *s* times not trustworthiness' influence on the utility is $(1-\varepsilon)^s$.

Just like the obvious analysis, first consider the alliance of pollution control's last two stages of the utility function, as follows:

$$F_{t-1}(1) + \delta(1-\varepsilon)^s F_t(1) = -\frac{1}{2} + (1 - q_{t-1}^e) + \delta(p_t - \frac{1}{2})(1-\varepsilon)^s$$

$$= \frac{1}{2} - q_{t-1}^e - \frac{1}{2}\delta(1-\varepsilon)^s \quad ...(10)$$

$$F_{t-1}(0) + \delta F_t(1) = -\frac{1}{2} q_{t-1}^2 + (q_t - q_{t-1}^e) + \delta(c + p_t - \frac{1}{2}) = -q_{t-1}^e + \delta(p_t - \frac{1}{2}) \quad ...(11)$$

Eq. (10) shows that in this repeated game, the reputation utility of upstream government in the last two stages is non-trustworthiness, because it is non-trustworthiness in *t-1* is detected and punished by the downstream government in stage *t*, the times of untrustworthy is 1, so the power of the penalty factor is *s-1*. Eq. (11) represents that in the repeated game, the upstream government in the *t-1* stage of trustworthiness, only in the last cooperation is not trustworthy, and the upstream government's total reputation utility is calculated by Eq. (11). The downstream government has not punished it, this time *s*=0.

If Eq.(11) > Eq.(10), then get: $p_t > \frac{1}{2\delta} + \frac{\varepsilon}{2}$, bring it into Eq.(3): $m_t = \frac{(\frac{2\delta - 1 - \varepsilon\delta}{1 + \varepsilon\delta}) p_t}{1 - p_t}$, it indicates that as long as $\frac{2\delta}{1 + \varepsilon\delta} > 1$, if downstream government is more trustworthy the upstream government, the government has more incentive to invest more and give trustworthy signal to keep credibility. The same applies to multi-stage cooperative game.

The formula also says that the higher the reputation of an upstream government, the more likely it is to pretend that it is complying with the treaty in order to gain maximum benefits. Besides that, if Eq.(11) > Eq.(10), when p_t and δ are constant terms, we could derive $0 < \varepsilon < 2\delta(p_t - 1)$. That means that the higher ε could not reach the best outcome, it should be within a certain range and be determined jointly by p_t and δ the probability of the upstream government. This also indicates that the excessive penalty factor will not only increase the unit cost, but also reduce the cooperation intention of upstream governments, leading to the breakdown of cooperation.

Introducing the penalty factor based on the existing discount factor can find that the credibility of the upstream government has a positive correlation with both discount factor and the penalty factor, that is, the fewer penalties help keep the league stable. The upstream government will camouflage themselves in the alliance duration at *t-1* stage and keep the trustworthy behaviour to maintain cooperation until the final stage before spent with the lifetime established reputation to get the maximum utility. Then achieve the maximum level of utility to reach the game equilibrium results.

Stability analysis of water pollution control alliance with compensating factor: Downstream government is economically developed as well as the beneficiaries of the results of water pollution control. So, in the water pollution control alliance, the downstream government is not only an advocate of coalition stability, but also the sponsor of the alliance (leader). In the process of water pollution governance, the downstream government will invest some money or resource as compensation to the upstream government, encourage them to participate in the Union and comply with the provisions of the alliance and take measures to control pollution. Assuming that c is the proportion of the downstream government's compensation funds (including funds and other inputs) proportion of GDP in the downstream region to the upstream government, which is called the compensation factor. Then the utility function of the upstream government becomes:

$$F = c - \frac{1}{2}q^2 + a(q - q^e) \quad ...(12)$$

In the upstream and downstream governments' cooperation in multi-stage water pollution governance cooperation alliance, in order to simplify the analysis and use the above method, first analyse the last two stages of upstream and downstream government behaviour and its utility function as follows:

$$F_{t-1}(1)+\delta(1-\varepsilon)^n F_t(1) = \text{c}-\frac{1}{2}+(1-q^e_{t-1})+\delta(1-\varepsilon)^n(\text{c}+p_t-\frac{1}{2})= \frac{1}{2}-q^e_{t-1}+\delta(1-\varepsilon)^n(\text{c}+p_t-\frac{1}{2}) \quad ...(13)$$

$$F_{t-1}(0)+\delta F_t(1) = \text{c}-\frac{1}{2}q^2_{t-1}+(q_t-q^e_{t-1})+\delta(\text{c}+p_t-\frac{1}{2}) = -q^e_{t-1}+\delta(\text{c}+p_t-\frac{1}{2}) \quad ...(14)$$

Eq. (13) refers to a two-stage cross-regional water pollution control cooperation alliance repeated games, at the *t-1* and *t* stage upstream government is not trustworthy, in this scenario received once penalty at the *t-1* stage *t* (at this time penalty factor ε's power index n=1), with the joint action of the discount factor, the penalty factor and the compensation factor can get the upstream government's reputation utility of the last two stages. Eq. (14) indicates that the behaviour and utility of other stages are the same and in the process of repeated games, the upstream government trustworthy at the *t-1* stage while at the *t* stage does not keep its words, at t stage did not get punishment (at this time penalty factor ε's power index n=0, which means the penalty factor does not work), the upstream government's reputation utility function at the last two stages. If the Eq. (14) > Eq. (13), we get $p_t \geq \frac{1}{2\delta\varepsilon}+\frac{1}{2}-c$. At the same time, in order to keep $p_t \geq \frac{1}{2\delta\varepsilon}+\frac{1}{2}-c$, $p_t \in [0,1]$, we could derive $\frac{1}{2\delta\varepsilon}+\frac{1}{2}-c \leq 1$. Considering $c \in [0,1]$, we could know that $\delta\varepsilon \geq \frac{1}{3}$, that means $\delta \in [\frac{1}{3},+\infty]$、$\varepsilon \in [\frac{1}{3},1]$. Therefore, in order to make the alliance as stable as possible, the subsidy factor must be increased as much as possible when the discount factor and punishment factor are more than 1/3. In this case the upstream government chooses trustworthy at *t-1* stage, while at the final stage *t* does not keep its words and use up the credibility of the value established before. With this strategy, we can have maximum utility and reach the Nash equilibrium.

DISCUSSION

Consider the upstream and downstream government's multi-stage cooperative game in cross-regional water pollution control cooperation, according to the KMRW theorem, when the probability (p_0) of the upstream government's (the opportunist co-operative member) trustworthy is greater than a certain value, in this analysis.

$p_0 > \frac{1}{2\delta}$, $p_0 > \frac{1}{2\delta}+\frac{\varepsilon}{2}$, $p_0 \geq \frac{1}{2\delta\varepsilon}+\frac{1}{2}-c$. The upstream government will choose to "disguise" as the trustworthy government to maintain its reputation until the final stage. Because of this kind of situation for the utility level greater than at the beginning or in the process of not trustworthy, the existence of discount factor, penalty factor and compensation factor make the value of the upstream government's reputation increased, it will more incentive "camouflage" into a trustworthy government during the existence of the alliance. In this case, the alliance reaches equilibrium. But through the above analysis, the punishment is not the bigger the better. When there is a subsidy factor, it will weaken the role of the punishment factor. It is probably because of the subsidy factor that weakened upstream government's motive of not trustworthy, at the same time enhance the upstream government's power to maintain the cooperation reputation. At this point the investment in punishment becomes redundant. However, moderate punishment is very necessary. The investment of punishment is not the focus of this paper, but can sure that the punishment is not the bigger the better, there are many scholars on the optimal punishment mechanism (Gray & Shadbegian 2004, Zhao et al. 2012).

In general, based on the assumption of the reputation, from the two governments' utility analysis in alliance game, can conclude that to keep the high probability stability of cross-regional water pollution cooperation alliance firstly related to the time of cooperation game. If the cooperation between the upstream and downstream governments only happens once, then based on the principle of benefit maximization, both the upstream and downstream governments will choose to take opportunistic actions to ensure their timely own interests by not violating the contract. This is due to the lack of incentives for future gains. So, it is necessary to sign as long as possible cooperation contract. In reality, due to the change of government leadership, making the cooperation situation changes and difficult to cooperation, but try to extend the cooperation regulations for long-term cooperation stability is necessary. Second, the higher the discount factor δ, the opportunistic members of the alliance have more patience to actively build credibility. Because long-term interests of staying in the Union is greater than the current income, so keeping a high reputation discount factor can increase the stability of alliance. Finally, for the penalty factor and the subsidy factor, when there is no subsidy, the union should establish a greater punitive mechanism so that the member who has the cooperative tendency undermine the alliance's opportunity cost rise. Because at this time the income of not trustworthy is lower than trustworthy, so the member who is not motivated by the trust will become trustworthy and keep the alliance stable. However, when there is a subsidy, it will reduce the uncooperative motivation of the alliance member, and then the investment in punishment will become wasteful. At this time maintaining an appropriate punishment (supervision invests) can keep the stability of the alliance.

CONCLUSIONS

This paper uses the KMRW reputation theorem under repeated games with incomplete information to explain the key factors affecting the construction of the reputation mechanism of the cross-regional water pollution control cooperative alliance members. From the above analysis, we put forward the following suggestions to maintain the stability of the trans-regional water pollution control cooperation alliance.

First of all, a reputation evaluation mechanism should be established, and by establishing a monitoring platform to publicize the sewage treatment effect of upstream and downstream governments on a regular basis, which could promote the strict implementation of treaties by upstream and downstream governments and maintain the stability of the alliance. Secondly, the effect of sewage treatment should be included in the performance evaluation of upstream and downstream governments. Higher level government agencies should take this as the basis for the promotion of officials and resource allocation, so as to promote both upstream and downstream parties to actively implement the treaty. And then a coordination mechanism between upstream and downstream governments should be enacted, strengthen internal communication within the alliance, enhance long-term cooperation patience between upstream and downstream governments, and increase the expected discount rate. What is more, the penalty factor is also a key factor that affects the stability of water pollution governance alliance. In the repeated game, the punishment mechanism makes the members who are not trustworthy to have the enthusiasm to keep their cooperation credibility. But the punishment factor should not be too high. On the one hand, the excessive penalty coefficient will increase the cost of supervision and reduce the final benefit, while on the other hand, the formulation of a punishment mechanism should consider the subsidy factor and embodiment factor, otherwise, the benefit decreases. Finally, the subsidy factor is the incentives of the cooperative behaviour within the union members. The members who benefit more from the alliance achievements subsidies to members who have a tendency of the opportunism behaviour, so that their cooperation enthusiasm is improved and promote the alliance stability.

This study needs to be improved at a later date. (1) Because the downstream government has active motives for cooperation and the benefits it gets from cooperation are huge, and it is impossible to break the alliance stable. Its utility function is not analysed in this study. But downstream agent's subsidy factor will influence its utility, if the subsidy they need to pay is huge, the downstream agent also has the behaviour of undermining the alliance stability, this case is not considered in this paper. (2) The lack of empirical research on the role of reputation.

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NOMENCLATURE

Symbol	Definition
$a=0$	the upstream government is a trustworthy member
$a=1$	the upstream government isnot trustworthy
c	compensating factor
F	the utility function of the upstream government
m	the probability that the downstream government considers the upstream government trustworthy
n	the probability that the government does not trustworthy
t	the time period of game
s	times not trustworthiness
ε	penalty factor
δ	discount factor
q	the upstream government actually reduce the proportion of pollution treatment investment
q_e	the downstream government speculated that the upstream government will reduce the proportion of pollution control input
p_0	the prior probability of the upstream government as a trustworthy member
p_t	the probability of upstream government's trustworthy at the t stage
v_t^e	the posterior probability of downstream government of its trustworthy or not at t stage