

Water rights trading: a new approach to dealing with trans-boundary water conflicts in river basins

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Abstract

Climate change and increasing demand of water aggravate the frequency and intensity of trans-boundary water conflicts, which are evolving into one of the most sensitive economic and social issues in trans-boundary areas. This paper analyzes the inefficiency of traditional regional negotiation models to deal with trans-boundary water conflicts, and argues that Coase's theory of property rights is more suitable for dealing with trans-boundary water conflicts. Based on the Bayesian evolutionary game model with incomplete information of property rights, we put forward the following two ways to promote the smooth progress of water rights trading and, furthermore, resolve water resources conflicts: first, to reduce the transaction costs of the upstream and downstream regions; second, to increase utilization efficiency of water resources in the upper reaches. Finally, taking the water conflict of Dayankeng Hydropower Station as a case simulation, we give answers to the three questions: (1) under what conditions, both sides of the conflicts will choose water rights trading; (2) what is the impact of transaction costs on water rights trading, which provided a new way to solve trans-boundary water conflicts; (3) what is the improvement of welfare effects of water conflict participants because of water rights trading.

Keywords: Case simulation; Conflict of trans-boundary water resources; Coordination mechanism; Evolutionary game model; Water rights trading

Introduction

Climate change and population growth accelerate water competition between upstream and downstream areas of a river (Li *et al.*, 2006). As a large country with water consumption, the per capita water resource in China is scarce due to the huge population. Meanwhile, the regional distribution is

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uneven. Water resources in the south to the Yangtze River are relatively abundant, accounting for 81% of the national water resources, while its land area only accounts for 36.5% of the national total. On the contrary, water resources in the north to the Huaihe River Basin are deficient, accounting for 19% of the national water resources, but the land area accounts for 63.5% of the national total (Sun, 2008). With the climate changing and population growing, the scarcity of water resources becomes increasingly severe. Therefore, trans-boundary conflicts over the rights to use and control water resources occur frequently (Zhou & Wu, 2016).

Trans-boundary water conflicts do not only affect the security and supply of water for life, ecology, and production, but bring substantial intricate social issues as well, which set up fierce social conflicts and affect the stability as well as the development of the region (Fisvold & Caswell, 2000; Wu & Whittington, 2006). Substantial research has tried to analyze the causes and solutions of trans-boundary water conflicts. According to the analysis of Ambec & Ehlers (2008) from the perspective of water extraction efficiency, free access extraction of water is inefficient, and the large amount of water extraction in the upper reaches will decrease the water resources in the downstream region, resulting in water resource conflicts. Kilgour & Dinar (2001) pointed out that river flow is characterized by variability, hence the fixed water resource allocation mode cannot adapt to the change of water demand in different regions. Chen & Wu (2010) put forward that by adjusting the allocation of initial water rights, watershed management agencies could effectively solve the conflicts caused by water rights' allocation. Li et al. (2010) designed the coordination scheme of trans-boundary water conflicts in accordance with the characteristics of different forms, and established the coordination mode of water resources conflicts.

In terms of the coordination mechanism of trans-boundary water conflicts, many researchers have tried to study water conflict resolution with a game-theoretic framework (Madani, 2010). Dinar & Hogarth (2015), Just & Netanyahu (1998), and Madani & Hipel (2007) reviewed game-theoretic water conflict resolution studies. Tisdell & Harrison (1992) and Nir & Easter (1997) proposed fair and reasonable distribution of water resources, so as to effectively solve the conflict of water resources. Raquel et al. (2007) analyzed the subjects in trans-boundary water conflicts and their own set of priorities. Chen et al. (2008) proposed that regulatory authorities' increasing reward and punishment measures can effectively inhibit excessive water intake. Niu et al. (2014) suggested that it was fruitless for local governments to solve trans-boundary water conflicts on their own, whereas the intervention and control of the central government was the only way to solve the problem.

The main viewpoints of the research above focus on the following two aspects: first, to emphasize the supervision and coordination of governments, including local governments, water administrative departments, and even the central government; second, to highlight the significance of fairness and rationality in water resource allocation in resolving trans-boundary water conflicts. However, it has been shown that the result of administrative consultation is usually unsatisfactory, and there are obstacles such as interests' preservation and multi-dimensional resistance in the initial allocation of water resources (Kucukmehmetoglu & Guldmann, 2004; Khan et al., 2010). Moreover, water allocation has been completed in major rivers and provinces of China. At the same time, the supervision and coordination of trans-boundary water resources by the government are usually high cost and inefficient (Bjornlund & McKay, 2002). Under such realistic constraints, it is rare to put forward theoretical research on the use of market mechanism to solve the trans-boundary water conflicts in China, but it can be seen that some researchers have made efforts to explore this issue. Liu et al. (2002) proposed to resolve conflicts of interest in water resources by means of property rights trading, but they did not make an in-depth theoretical analysis of the nature and roots of trans-boundary water conflicts. Speed (2009)

also emphasized the property rights system and provided greater freedoms and incentives for water to move between uses and users.

Starting from the theory of property rights, this paper makes a diagnosis of the deep institutional factors of trans-boundary water conflicts, and proposes that property rights trading is a Pareto improvement path to make up for the defects in the administrative allocation of water rights and the low efficiency of cross-regional administrative coordination. By establishing a trans-regional water market and conducting water rights trading, trans-regional water disputes can be solved. Therefore, the main research contents of the paper are as follows: first, based on the theory of property rights, the authors discuss the academic origin of trans-boundary water conflicts, and propose the establishment of water rights trading mechanism for trans-boundary water conflict coordination, according to the principle of welfare economics; second, the authors analyze the feasibility and influencing factors through the evolutionary game model between the two sides of the water rights trading, and carry out numerical simulation through the case of Dayankeng Hydropower Station, so as to prove the social welfare and practical applicability of the property rights approach in trans-boundary water conflicts.

Property rights origin and coordination path of trans-boundary water conflicts

From an economic perspective, it is generally believed that the cause of the conflicts lies in the scarcity of water resources (Li, 2017). Faced with various water demands of living, ecology, and production in administrative regions, it is an indisputable fact that trans-boundary water resources are relatively or absolutely insufficient, especially considering the special national conditions of China: a large population and uneven water distribution (Wang, 2000). However, water resource scarcity does not necessarily lead to trans-boundary water conflicts; the underlying reason lies in the property rights system of water resources (Holden & Thobani, 1999; Gray, 2002). It is generally believed that the property rights of water resources include three parts: water allocation, transaction, and supervision (Wang et al., 2017).

Unreasonable allocation and unclear definition of water resources property rights

Water resources without clearly defined property rights are public goods with low exclusivity and high competitiveness (Tian et al., 2016). Due to the lack of restrictions, the utilization of public goods or resources are often prone to overuse, leading to the tragedy of the commons (Wolf, 2000; Liu et al., 2007). A clear system of property rights contributes to a perfect solution to the external problems (Wang, 2005).

Deficiencies of water resources property rights trading to improve inefficiency in the allocation process

At present, China mainly carries out the initial allocation of water resources in accordance with the government's instructions, and government departments usually allocate water resources based on the historical water consumption of each region in the initial allocation of water resources, leading to low efficiency of water resources allocation and fierce conflicts over water resources (Tian & Zhang, 2015). Coase believed that the externality or non-efficiency of the economy could be corrected through the negotiation of stakeholders, so as to maximize the social benefits (Libecap, 2008).

Inadequate supervision of water resource property rights and low cost of property rights embezzlement

As for the use of water resources, the decentralization of water users and the high cost of supervision result in the inadequate administrative supervision of water rights. Water users use public water resources at low cost or even freely, which neither reflects the supply and demand relationship of water resources nor reflects the value of water resources (Challen, 2000).

Based on the three reasons above, three ways of trans-boundary water conflict coordination are derived. First, to optimize water rights allocation, which will inevitably lead to a decline in a part of people's interest, together with the fact that the water rights holders have a rigid understanding of their existing ownership, and are unwilling to sacrifice their personal interests for the overall interests (Chen et al., 2011). Therefore, it is difficult to redistribute water rights and reduce the vested interest of some water rights holders for the sake of social welfare, let alone the other consequences like initiating societal conflicts, increasing the reform costs (Garrido, 2000; Cason & Gangadharan, 2003). Second, to strengthen the supervision of property rights; this has been gradually explored and strengthened since the 19th National People's Congress, but the current measures are inefficient. Third, to compensate the interests of both parties involved in the conflict through water rights trading, which could give full play to the market in resource allocation and realize the secondary correction of allocation, with small social costs and large overall social welfare.

The second law of welfare economics states that all the government must do is change the initial allocation of endowments between individuals, and the rest shall be the market's part (Simpson & Ringskog, 1997). It can be seen that it is the general trend to give full play to the role of market mechanism to solve trans-boundary water resource conflicts, but the complicated and changeable water resources trading environment needs the corresponding water resources trading pattern (Supalla et al., 2002; Chew et al., 2009). However, China has not set up fully mature and perfect trading forms (Tian & Wei, 2019). Existing theories divide the water rights market into two levels: the primary market is the initial allocation market of water rights, which means the water resources are distributed to users by the state or water resources management agencies; the secondary market refers to the reallocation of the water rights which the users have (Feng & Ji, 2006). This paper mainly deals with the secondary market of water rights trading, in which the purpose of resolving conflicts is achieved through the conversion of water rights between water users.

Bayesian evolutionary game model of incomplete information in water rights trading to coordinate trans-boundary water conflicts

Model hypothesis

Player hypothesis. Stakeholders of trans-boundary water resources are likely to be the players in the conflict game model. These stakeholders are mainly water users in the upper and lower reaches of the basin, including agricultural irrigation water users, industrial water users, residential water users, ecological environment water users, etc. Considering that the above-mentioned water users are scattered, the local governments in the upper and lower reaches of the trans-boundary basin are generally seen as the representative of the scattered water users. In this model, the players refer to the supply and demand sides of water rights (Dinar, 2004). Therefore, the upstream local government generally

serves as the demand side of water rights, while the downstream local government serves as the supply side of water rights.

Behavior strategy space hypothesis. The strategy space of upstream and downstream government contains two strategies: trading and non-trading. According to the usual assumptions of the players in the game model, it is assumed that the players can independently make decisions and be responsible for the benefits or losses. This is because water rights in China are well protected by law and China's *Property Law* provides that the water intake right is a kind of usufruct, which is sacred and inviolable just as other property rights. Under the framework of water rights conferred by laws and regulations, no subject (including the superior government) can intervene regarding the behavior of the player, so that the players in a trans-boundary water resource conflict can independently make choices in the behavior strategy space.

Incomplete information hypothesis. Due to the information asymmetry between the two sides of trading behavior, the upstream government and the downstream government do not fully grasp each other's actual information. The upstream government knows nothing about the actual situation and local policies of the downstream region, nor does the downstream government know the actual water shortage of the upstream region.

The rational economic man hypothesis. It is assumed that the upstream and downstream governments in the trans-boundary river basin can accurately ratiocinate in the decision-making process. Whether the upstream and downstream governments are willing to adopt water rights trading to resolve trans-boundary water resources conflicts is based on whether the net benefit after transaction is greater than before. Moreover, according to *The Interim Measures for the Management of Water Rights Transaction* promulgated by China's water administration department, the water rights trading that may cause inadequate supply of domestic water or ecological environment water is not allowed in China.

Transaction price hypothesis. Since July 2014, China has carried out pilot work on water rights trading in seven provinces, including Ningxia, Jiangxi, Hubei, Inner Mongolia, Henan, Gansu, and Guangdong (Zhao et al., 2008). In 2016, China Water Exchange was officially established (Department of Water Resources Management, 2018). The price of water rights trading in this paper is assumed to be a constant (P) determined by the market.

Payoff hypothesis. The payoffs of both players in the process of water rights trading will be affected by the trading behavior (Bekchanov et al., 2015). Suppose that the amount of water rights transacted by both parties is V . In an ideal situation, the payoff per unit volume of water resources is R . φ_S and φ_D is the utilization efficiency of water resources per unit area of downstream and upstream government, respectively. Opportunity cost is I_D . The transaction costs incurred by water rights trading in this study, in the case of trans-boundary water resources conflicts, are mainly information consultation and search costs, trading negotiation costs, agreement signing costs, measurement and supervision costs of water withdrawals after the trading (Carey et al., 2002). C_D and C_S are the transaction costs borne by the upstream government and the downstream government, respectively.

Payoff matrix

In the process of the downstream government's strategic selection, $P \times V$ that represents payoff is earned by the downstream government if the trade succeeds (the upstream government also chooses the trading strategy). $\Delta\pi_1$ is referred to as the losses due to the reduction of water rights suffered by the downstream government. $\Delta\pi_2$ is referred to as having some additional benefits. C_S is referred to as the corresponding transaction cost suffered by the downstream government. If the trade fails, the water rights still belong to the downstream government, and the downstream government continues to make use of the payoff ($\varphi_S \times V \times R$) brought by the water rights, but the downstream government still does substantial information consultation, information search, and measurement work of water rights in order to trade the water rights. Therefore, although this water right has not been successfully traded, the transaction costs paid will still be borne by the downstream government. For convenience, the costs of failed trade shall be the same as the successful ones. U_{S2} is referred to as the payoff obtained by the downstream government.

If the downstream government chooses not to trade, the downstream government continues to hold the water rights and gains payoff ($\varphi_S \times V \times R$). For convenience, the transaction cost is assumed to be 0. When the upstream government chooses to trade or not, U_{S3} and U_{S4} are, respectively, referred to as the payoffs achieved by downstream government. The payoffs mentioned above are presented in the Appendix.

In the process of the upstream government's strategic selection, if the trade is successful, the upstream government can get the payoff ($\varphi_D \times V \times R$) of the water rights, but also needs to pay the corresponding costs ($P \times V$) to the supplier, and bear the transaction cost (C_D) caused by the transfer-in behavior. In addition, $\Delta\pi_3$ is referred to as the additional benefits generated by the upstream governments due to the trade of water rights. Accordingly, the upstream government gains U_{D1} . If the trade fails, the upstream government can use the fund for other investments and obtain benefits (I_D), but the upstream government still has to bear the corresponding transaction costs and losses ($\Delta\pi_4$) due to the lack of the water rights. For convenience, U_{D3} is referred to as the payoff obtained by the upstream government.

If the upstream government chooses not to trade, the transaction will fail. At this time, the upstream government needs to bear the corresponding losses ($\Delta\pi_4$), but the upstream government will use the fund for other investments and get profit (I_D). For convenience, the transaction cost is assumed to be 0. When the downstream government chooses to trade or not, U_{D2} and U_{D4} are, respectively, referred to as the payoffs got by upstream government. The payoffs mentioned above are presented in the Appendix.

The payoff matrix of the game between upstream government and downstream government is shown in Table 1.

The solution of the model is fully described in the Appendix.

Equilibrium analysis

The details of the evolutionary stable strategy of downstream and upstream government are presented in the Appendix. The dynamic relationship between upstream government and downstream government is represented by a coordinate plane, as shown in Figure 1. The x axis denotes the proportion of departments that chooses to trade water rights in downstream government, and the y axis denotes the proportion of departments that chooses to trade water rights in upstream government, line $y = \alpha$ and

Table 1. The payoff matrix of the game in water rights trading.

Participants and the strategies		Upstream government	
		Trade <i>y</i>	Not to trade $1 - y$
Downstream government	Trade <i>x</i>	U_{S1}, U_{D1}	U_{S2}, U_{D2}
	Not to trade $1 - x$	U_{S3}, U_{D3}	U_{S4}, U_{D4}

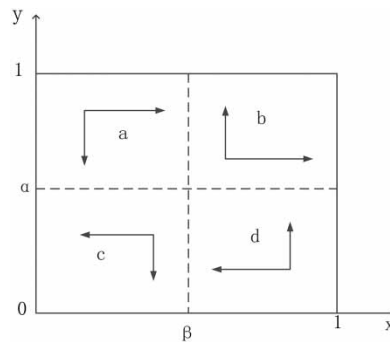


Fig. 1. Replicated dynamics and strategy evolution of water rights players.

$x = \beta$ divide the plane into four regions of *a*, *b*, *c* and *d*, and the arrows indicate the directions of movement of points falling in four areas.

As shown in Figure 1, according to the direction of the arrow, $x^* = 0, y^* = 0$ and $x^* = 1, y^* = 1$ are the two evolutionary stable strategies in this game. When the initial point falls in region *b*, it will converge to the evolutionary stable strategy $x^* = 1, y^* = 1$, which means that the upstream government and the downstream government all choose to conduct water rights trading. Actually, the final expectation we want is the deal-making strategy that both sides choose. Therefore, increasing the area of region *b* can increase the probability of both parties entering the water rights trading market, and meanwhile increasing the area of area *b* can be achieved by reducing the values of α and β . The values of α and β can be defined inductively as follows:

$$\alpha = \frac{C_S}{P \times V - \Delta\pi_1 + \Delta\pi_2 - \varphi_S \times V \times R} \tag{1}$$

$$\beta = \frac{C_D}{\varphi_D \times V \times R - P \times V + \Delta\pi_3 + \Delta\pi_4 - I_D} \tag{2}$$

As can be seen from the above equations, there are the following two ways to reduce the values of α and β .

The first is to decrease C_S and C_D , that is, to reduce the transaction costs of both the upstream region and the downstream region. To reduce costs, it is necessary to understand the composition of transaction

costs (Shen, 2004). The main components of the transaction costs of water rights are as follows. (1) Costs of searching information. Water rights suppliers should know which groups need to buy water rights, and water rights buyers also need to know which groups sell excess water rights. If the market is too large and there are too many trading groups, the search costs will be relatively high, thus affecting the trades between the two parties. At this time, the third-party intermediary can be established, and both parties of the trade can publish the information in the institution, so as to reduce the costs of information search (Chen et al., 2006). (2) Costs of bargaining. Price is an important factor that affects the process of water rights trading. The prices here are market-determined and therefore cannot be reduced anymore. (3) Contract costs. Water rights trading is usually associated with a large amount of money, and it usually needs a written contract, which consumes substantial manpower and material resources. (4) Costs of water rights measurement. The basis of water rights trading is to accurately measure water rights, which depends on the level of technology and engineering quality (Erfani et al., 2014). This will also bring some costs to water rights trading. Then there are the costs of supervising, seeking compensation, preventing infringement, and so on. In order to increase the probability of water rights parties entering the water rights market, it is necessary to reduce the transaction costs above and increase the area of region b .

The second way is to increase $\varphi_D \times R$, that is, to increase the yield of water resources per unit in the upper reaches. When the utilization efficiency of water resources in the upstream region increases and reaches a single degree of scale economy, the rate of return on investment will increase substantially, especially of resources such as technology, capital, and labor. In this way, the upstream government's demand for water rights will increase, then, their preference and willingness to pay for water rights will become stronger, which means the upstream government is willing to pay more price to the downstream government to obtain water rights. Therefore, the downstream government will save water resources and increase investment in water rights with the support of water rights trading funds. Hence, the trade of water rights will be promoted.

Water rights trading design for coordination of trans-boundary water conflicts

Based on the analysis of Bayesian evolutionary game model with incomplete information to coordinate trans-boundary water conflicts through property rights trading, the feasibility of water rights trading is demonstrated theoretically. On this basis, the following coordination mechanism of cross-regional water resources conflicts is designed from the perspective of property rights trading (Liu et al., 2015). The specific process is shown in Figure 2.

Several core points in the water rights trading coordination mode of conflicts are as follows:

1. Trans-boundary water resources are in short supply, and the industrial structures in upstream and downstream areas are different, which results in the clear difference in water resources utilization and the benefits of utilization between different areas. The shortage of water resources has led to conflicts in the upper and lower reaches of the river basin. If the water resources are sufficient to meet any demand, then no water conflicts will occur. When water resource conflicts occur, it is not necessary to take water rights trading as a method. Only if the water users in the upper and lower reaches of the trans-boundary basin have different preferences for water use can the water rights trading occur. Therefore, due to the different uses of water resources by water users in the upstream and

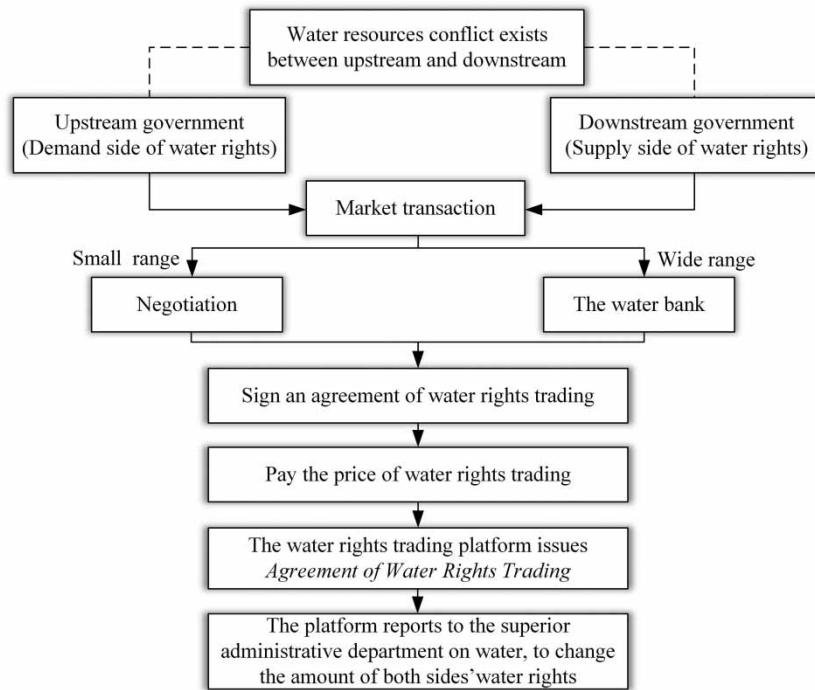


Fig. 2. Inter-regional water resources conflict coordination mechanism.

- downstream areas, there is a large difference in preferences for water resources, and this difference has become the motivation for using water rights trading to resolve trans-boundary water conflicts.
2. Clear allocation of water rights in trans-boundary basins. The root cause of the conflict of water resources in trans-boundary basins is whether the ownership of water resources is clear. The clarification and registration of water rights in trans-boundary basins is a prerequisite for the use of water rights trading to resolve conflicts in water resources. Only clarifying the amount of water that can be used by upstream and downstream water users, and registering with legal documents (such as water withdrawal license, water right certificate), can water users choose to use these water resources themselves or transfer excess water resources to other water users. In China today, the precondition for trans-boundary water rights trading is in place, because China has approved water allocation schemes regarding 41 rivers which are trans-provincial. In 2019, the Ministry of Water Resources also issued *The Notice on Carrying out Work on a New Batch of Trans-provincial River Basin Water Allocation* and newly launched water allocation work of 30 trans-provincial river basins. Not all countries have implemented a water rights system, and some countries do not even have a concept of water rights. Thus, in such countries where the water rights are not clear, the amount of water can be measured according to the status quo. Taking the proportion of water use in the upstream and downstream areas before the water rights conflict as a starting point, if the water consumption in the upstream area exceeds this ratio, it is necessary to negotiate with the downstream area to resolve the water conflict by purchasing excess water.

3. Coordinating participants. The government plays the main role in water rights trading, and more reflects the independent economic subjective function of its government departments (Wang & Huang, 2002). The government is the main player of water rights, rather than the administrative government. In the water rights trading coordination, the central government and administrative measures play a weak role.
4. Objects of coordination. In the coordination mode of water rights trading in trans-boundary water conflicts, the object of coordination is the share of water rights.
5. Effectiveness and stability of coordination. It is easier to resolve trans-boundary water conflicts by way of transaction coordination, it is away from moral hazards, and the transaction contract is relatively more stable.
 - (a) Negotiations. For small-scale conflicts between upstream and downstream, water rights trading can be promoted through negotiations between upstream and downstream governments. Both parties determine the quantity and unit price of the trading water rights through negotiation. The negotiation method can reduce the transaction costs and promote the progress of water rights trading.
 - (b) The water bank. ‘Water bank’ is a metaphor, and it is a reallocation mechanism of water resources (Zhang & Lv, 2007). Water users with sufficient water store excess water rights and obtain certain benefits from them; water users with scarce water resources purchase water rights by paying certain funds to meet water demand. In cross-basin or large-scale water conflicts, one-to-one water rights trading obviously costs substantial manpower and material resources, and the establishment of water banks can greatly reduce the costs of transaction. Moreover, from a macro point of view, the establishment of water banks can realize the reallocation function of the market, as well as reduce the construction of some unnecessary infrastructure. The mechanism of water banks is in line with the requirements of sustainable development (Zhai & Sun, 2002).
6. The change of amount of water rights after the trading. In China, water rights trading involving trans-boundary river basins is, in principle, recommended to be traded through water rights trading platforms such as China Water Exchange or the local water rights storage and transfer center. After the water rights trading agreement is signed, the transferee pays the trading service fee to the water rights trading platform according to the charging standard. It is also necessary to pay the water rights trading price to the platform in accordance with the agreement, and the water rights trading platform undertakes the settlement function, thereby ensuring that the water rights trading and the payment are smoothly completed in accordance with the agreement. The security deposit paid by the transferee can be converted into trading service fees and trading prices. After receiving the trading service fee and confirming the settlement of the trading price, the platform will issue a *Water Rights Trading Certificate* to both sides. The water rights trading platform will promptly notify the water administrative department in writing of the trading agreement and the *Water Rights Trading Certificate*. The trading entity shall apply for procedures such as the change of the water withdrawal permit in accordance with the relevant provisions. In this way, the water rights transferee increases the amount of water rights and the transfer correspondingly reduces the amount of water rights.
7. Reasonable compensation to stakeholders. The stakeholders of trans-boundary water resources are mainly water users in the upper and lower reaches of the basin, including agricultural irrigation water users, industrial water users, residential water users, and ecological environment water users. Whether or not the upstream government engages in the trading of water rights has the biggest impact on the increase or decrease of the power generation revenue of hydropower stations, which has little effect on the

water users in the upstream area. However, for downstream regions, water rights trading by downstream governments has a great impact on the use of local water resources. A reduction in incoming water volume will result in a lower irrigation guarantee rate, which will cause a reduction in production and output. Therefore, it is necessary for the downstream government to invest in water-saving facilities with the income from the water rights trading to improve the downstream irrigation level. At the same time, the water users including agricultural irrigation water users, industrial water users, residential water users, and ecological environment water users must be compensated accordingly.

Case simulation and analysis

Dayankeng Hydropower Station is located in the Dayankeng of Nanyang stream, Qingyuan County, Zhejiang Province. As a tributary of the Oujiang River in Zhejiang Province, the Nanyang stream together with the Jiaoxi River and the Toxi River, forms the boundary river of Zhejiang and Fujian Province. At the end of 2000, the construction of Dayankeng Hydropower Station in Qingyuan County reduced Shouning County's water supply, and caused the water conflict between Qingyuan County and Shouning County. A map of the location of the Dayankeng Hydropower Station is shown in Figure 3.

Using the Bayesian evolutionary game model with incomplete information, the government of Shouning County in the downstream is the water rights supplier. Dayankeng Hydropower Development



Fig. 3. Map of the location of the Dayankeng Hydropower Station.

Co., Ltd, authorized by the County government of Qingyuan County, Zhejiang Province, located upstream, is the demander of water rights. Based on MATLAB, the evolutionary game model above is simulated and analyzed.

Setting of initial parameters

1. Transaction price of water rights (P): According to the official website of China Water Exchange, the trading price of water rights is set at 0.6 yuan/m³ based on the comprehensive estimation of the price of existing water rights trading cases.
2. Trading volume of water rights (V): According to the design report, the annual amount of water diversion of the Hydropower Station across the basin is 26.22 million m³. Therefore, it is assumed that the amount of water rights traded by both governments is 26.22 million m³.
3. Economic benefits ($\varphi_D \times R$) of unit water resources in upstream region: The annual amount of water diversion is 73.49 million m³, and the annual average generated energy is 88.46 million kWh. Based on the electricity profits of 0.5 yuan/kWh, the generation profit of unit water resources is 0.602 yuan/m³.
4. Economic benefits ($\varphi_S \times R$) of unit water resources in downstream region: The water used in the diversion area of Shouning County is mainly for agricultural irrigation. In 2017, the agricultural output value of Shouning County was 704 million yuan, and the average annual flow of water resources 1.781 billion m³. Thus, the yield from water resources of per unit area is 0.395 yuan/m³.
5. The opportunity cost (I_D): The yield is calculated by buying the interest on the five-year national debt at 4.27%. The transaction price is 0.6 yuan/m³, the transaction volume is 26.22 million m³, and the opportunity cost is 0.6718 million yuan.
6. Additional losses ($\Delta\pi_1$): Compared with no water diversion, the annual average power generation of Niutoushan Hydropower Station decreased by 11.27 million kWh, and the power generation profits decreased by 5.635 million yuan according to the loss of 0.5 yuan/kWh.
7. Additional profits ($\Delta\pi_2$): Similarly, the interest earned by purchasing five-year national debt with this fund, which is 0.6718 million yuan.
8. $\Delta\pi_3$ means the profits obtained by the upstream government: The income obtained is mainly power generation income, so the extra profits can be ignored.
9. $\Delta\pi_4$ means the losses incurred by the upstream government if the trade fails: In this case, $\Delta\pi_4$ is estimated at 2 million yuan.

Simulation in MATLAB

It is assumed that the transaction cost (C_S) of the supplier (the government of Shouning County) is 0.4119 million yuan, and transaction cost (C_D) of the demand side (Dayankeng Hydropower Development Co., Ltd) is 1.3806 million yuan. Therefore, the proportion x_0 of the downstream group choosing the trading strategy is equal to 0.5, and the proportion y_0 of the upstream group is equal to 0.5. The value ranges of x, y are $[0, 1]$, and the initial value of x, y is set at 0.1–0.9 (every 0.1 is an interval). Using MATLAB, the simulation results of the strategic selection of evolution path can be obtained, which is shown in Figure 4.

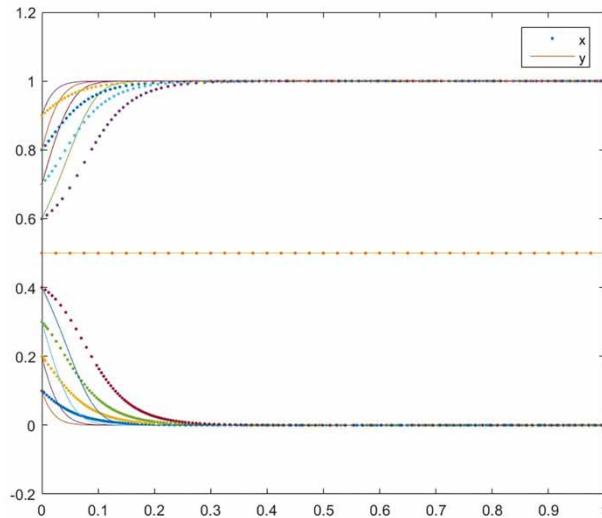


Fig. 4. Simulation diagram under initial conditions.

As can be seen from Figure 4, under the initial condition, if the initial value of x and y is lower than 0.5, the government of Shouning County and Dayankeng Hydropower Development Co., Ltd will move towards (0, 0), and neither side will adopt trading strategy. If the initial value of x and y is higher than 0.5, then both sides will move towards (1, 1). When the initial values of x and y are (0.5, 0.5), the strategic choice of both sides remains unchanged over time, presenting a straight line.

1. The influence of the change of C_S on the evolutionary path: When the transaction cost (C_S) of the water rights supplier (the government of Shouning County) increases, assuming that the increase is 50%, i.e., $C_S = 0.6179$ million yuan. When the transaction cost (C_S) of the water rights supplier (the government of Shouning County) decreases, assuming that the decrease is 50%, i.e., $C_S = 0.2059$ million yuan, the simulation figure can be obtained (see Figures 5 and 6).

Similarly, for Shouning County government, reducing transaction cost is also helpful to promote the trade between the two sides.

2. The influence of the change of C_D on the evolutionary path: When the transaction cost (C_D) of the water rights demand side (Dayankeng Hydropower Development Co., Ltd) increases, assuming that the increase is 50%, i.e., $C_D = 2.0709$ million yuan. When the transaction cost (C_D) of the water rights demand side (Dayankeng Hydropower Development Co., Ltd) decreases, assuming that the decrease is 50%, i.e., $C_D = 0.6903$ million yuan, the simulation figure can be obtained (see Figures 7 and 8).

When the transaction cost of the demand side increases, x and y tend to be 0, and neither side will adopt trading strategy, but when it decreases, x and y tend to be 1, and both sides tend to adopt the

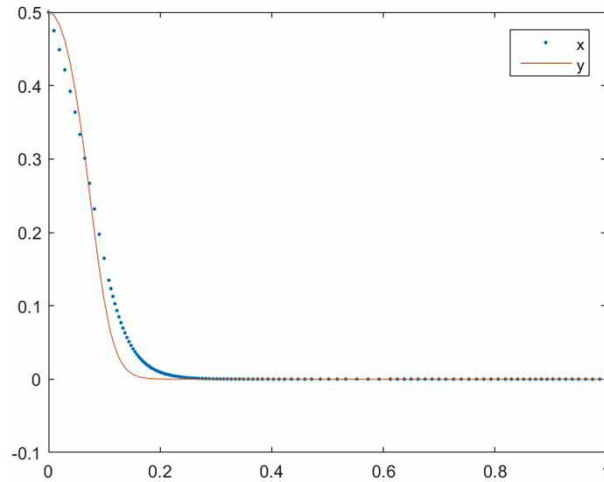


Fig. 5. Simulation diagram when C_S increases.

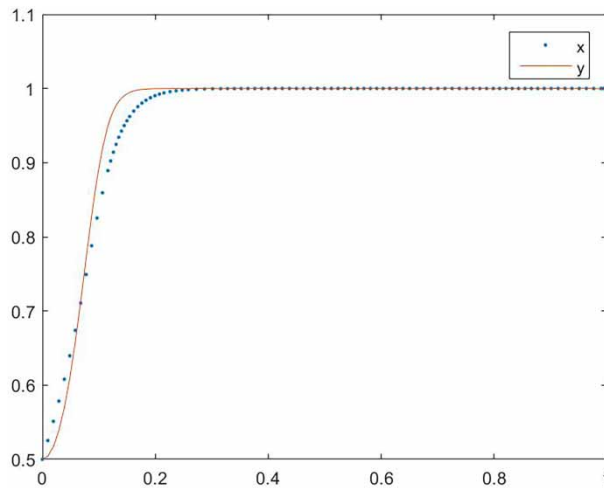


Fig. 6. Simulation diagram when C_S decreases.

trading strategy. Therefore, for Dayankeng Hydropower Development Co., Ltd, reducing transaction cost is also helpful to promote the trade between the two sides.

Accordingly, reducing transaction cost is of great practical significance for both sides to trade. In this case, the Taihu Lake Basin authority, as a third-party organization, actively applies the water rights theory with the Water Resources Department of Zhejiang and Fujian provinces, and proposes the implementation of inter-basin water transfer. On the premise of fully considering the living, production, and ecological water use in the downstream areas, the necessary compensation for the downstream areas of the river and the implementation of paid water transfer are carried out. The compensation greatly reduces the costs of negotiation between Zhejiang and Fujian provinces, and promotes the completion of the trade.

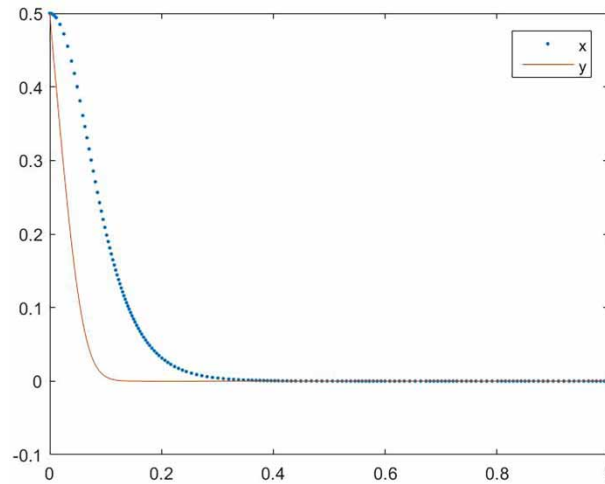


Fig. 7. Simulation diagram when C_D increases.

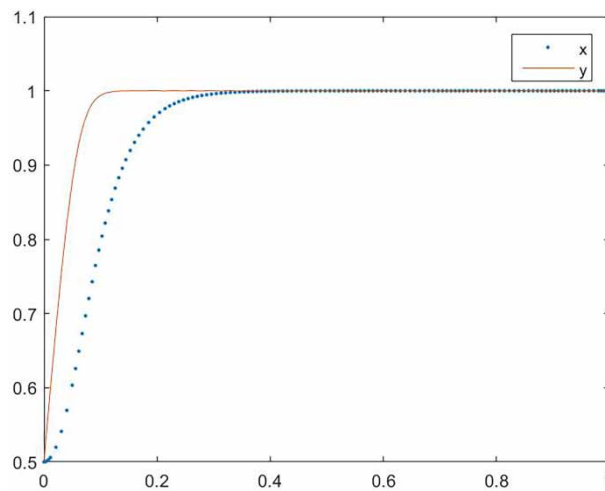


Fig. 8. Simulation diagram when C_D decreases.

Through the game simulation of water resources conflict of Dayankeng Hydropower Station, it is indicated that when the transaction costs of demanders and suppliers of water rights is low enough, both sides will tend to trade, that is, the water rights trading can be carried out well. At this time, the upstream will get the payoffs from power generation, and the downstream will get the compensation from funds. The ‘mutual benefit’ situation will be realized, and the social welfare will increase. This is mainly because the water resources in downstream Shouning County are mainly used for agricultural irrigation, and the economic benefits are relatively low. The upstream Dayankeng Hydropower Development Co., Ltd, which is the buyer of water rights, uses water resources to generate electricity with high economic benefits. In the process of resolving water resource conflicts through the rights trading,

the water resources have been transformed from low-efficiency agricultural irrigation to high-efficiency hydropower development. Therefore, the utilization efficiency of water resources has been greatly improved. Reasonable distribution was made through water rights negotiation. Not only upstream and downstream water users have improved economic benefits, but from the overall level of the river basin, social welfare also greatly improved. Therefore, it can be indicated that it is feasible and practical to apply water rights trading to solve trans-boundary water conflicts.

Conclusions

The trans-boundary water conflict has become a crucial social and economic problem with the growing shortage of water resources. Due to its high cost and low efficiency, the traditional administrative coordination methods have increasingly prominent disadvantages in the resolve of trans-boundary water conflicts. Property rights theory is the logical choice of cognizing the contradiction in resources' competitive using, and it is an effective supplement to the traditional administrative allocation patterns. Some successful cases in administrative practices confirm this viewpoint. At the end of 2000, the construction of Dayankeng Hydropower Station in the tributary of Nanyangxi in Qingyuan County, and the excavation of diversion tunnels from the Tuoxi River on the Zhejiang–Fujian boundary to divert water across the river basin triggered the inter-provincial boundary water conflict between Qingyuan County and Shouning County. Through three years of unremitting efforts, a coordinated plan acceptable to all parties was finally formed at the end of 2003. The agreement is as follows: Dayankeng Hydropower Station compensated Shouning Country 3 million yuan for its losses; the state offered a subsidy of 4 million yuan to Shouning County for constructing reservoirs; Dayankeng Hydropower Station transferred 26.22 million m³ of water annually from the Toxi River and the Houcang Creek. This case set up a typical example for carrying out trans-basin water rights trading and a model for calculating compensation standards. However, the water rights trading was actually carried out passively, which not only increases the complexity of the trading process, but also increases the trading coordination costs. Therefore, it is necessary to conduct an in-depth analysis of the interest demands and behavior choices of all game players from a theoretical perspective, so as to build a theoretical basis for the replication and promotion of the property rights model of trans-boundary water conflict coordination.

Based on the conflict regarding Dayankeng Hydropower Station, this paper proposes to start with the property of water resources conflicts by establishing the evolutionary game between the two sides of water rights trading, and provides a new way to solve water disputes in trans-boundary areas through water rights trading and establishment of water market. The three conclusions are as follows:

1. When the transaction costs in the upstream and downstream regions are sufficiently low, or when the water utilization efficiency in the upstream region is sufficiently high, the two sides will trade water rights. After the upstream region reaches a certain degree of economies of scale, the return on investment of technology, capital, labor, and other resources will also increase significantly. This will increase the demand of the upstream government for water rights, and also enable the downstream government to save water resources, increase investment in water rights, and promote water rights trading.
2. When the transaction costs are sufficiently low, both sides will tend to trade, and water rights trading can be carried out well. Reducing transaction costs can help facilitate the trading between the two

sides. The water rights trading platform is an efficient platform that provides sufficient information on water rights trading, reduces the transaction cost, and facilitates water rights trading. It can reduce the negotiation and transaction cost, and it is actually a scientific and authoritative water accounting agency after the trading, helping both sides complete the change of water rights. The Chinese government has established the China Water Exchange at the national level, and will continuously establish water rights trading platforms at the basin and local levels to effectively promote water rights trading between upstream and downstream water users in trans-boundary basins with conflicts in water resources, relying on market trading to efficiently resolve water conflicts.

3. Water rights trading improves participants' welfare in two aspects: first, the optimal allocation of water resources in the basin through the market can effectively alleviate the contradiction between upstream and downstream, and can achieve the purpose of preventing water conflicts, promoting unity and water control in the border areas, and maintaining the social stability; second, trans-boundary water rights trading in the basin can result in obvious economic benefits, which can not only solve the problem of water demand in the downstream areas, but also improve the economic benefits of the upstream areas, such as power generation revenue. The downstream government can also use the trading funds to invest or upgrade water-saving facilities, and improve irrigation levels, so as to effectively compensate for the reduction of water resources. Furthermore, it can provide financial compensation to downstream stakeholders and improve the production and living standards of various stakeholders.

Water rights trading is an innovative way to coordinate trans-boundary water resource conflicts. Compared with administrative coordination, water rights trading has obvious advantages in trans-boundary water affairs, which can enrich the practice of basin water rights and water market theory, optimize the allocation of water resources, and cultivate the water market. In order to make the water rights issue of the Dayankeng Hydropower Station clear and resolved effectively and timely, it is vital to ensure the legitimate rights and interests of different stakeholders upstream and downstream. Several works must be carried out simultaneously:

1. Asset and capital verification is necessary for Dayankeng Hydropower Station, especially the development investment and conversion issues. Replacement value should be checked by the asset evaluation intermediary agency.
2. The downstream government should further count the quantity and type of irrigated crops, and the amount of drinking water for humans and livestock. The water resources department should determine the amount of drinking water and irrigation water according to the drinking water quota and the crop irrigation quota.
3. The water administrative department shall, in accordance with the requirements of the *Measures for the Assessment, Calculation and Management of Water Fees of Water Conservancy Projects*, check the water fees for water supply. The department shall fully take into account the cost of water supply, water resources or raw water, and the environment cost such as pollution control.

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Supplementary material

The Supplementary Material for this paper is available online at <https://dx.doi.org/10.2166/wp.2020.180>.

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