CHEMICAL ENGINEERING TRANSACTIONS
VOL. 51, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Tichun Wang, Hongyang Zhang, Lei Tian

ISBN 978-88-95608-43-3; **ISSN** 2283-9216

DOI: 10.3303/CET1651187

A Study on the Quantitative Model of Eco-compensation Based on Auction of Property Right for the Water Source Region

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Southern Shaanxi is the water source region in the central line project of south-to-north water diversion. To protect the water resources and the ecosystem, no industrial production projects are launched in this district and the economic development is thwarted. Due to lack of fund, the loss arising from the output of water resources can be hardly compensated.

We first identify the stakeholders involved in the eco-compensation of the water source region in southern Shaanxi and the downstream regions. The property right of the water resources is defined, and an eco-compensation model based on water rights auction is described where the price of water rights is determined under the premise of benefit maximization of the bidders. It is found that (1) defining the stakeholders in the regions that output and receive the water resources as well as the beneficiaries and victims of the allocation of water resources is the first step in identifying the main participants; (2) according to the Coase Theorem, only when the water rights have the features of definiteness, exclusiveness, transferability and mandatoriness will the paid use and optimization allocation of water rights be achieved; (3) under the mechanism of water rights auction, the water rights price will constantly approach the true value of water resources if the quota of water use is limited and if the water rights is clearly defined. Meanwhile, the fund collected by the auction can be used as the compensation for the water output regions; (4) the quantitative model of eco-compensation for the water source region in southern Shaanxi is presented from three aspects: stakeholder identification, defining and auction of water rights, and water rights pricing mechanism. Through water rights trading, the paid use of water resources is realized and the fund is collected as the eco-compensation.

In the last section, we highlight the significance of the auction-based water rights pricing mechanism by which the water rights are more clearly defined, managed and sold. More importantly, the paid use and optimized allocation of the water resources are ensured by this mechanism.

1. Introduction

Sustainable development became the main idea, promising comprehensive development and prosperity since the end of 20th century, starting from ecological movements in the 70s and covering key issues of human being. Water shortage and management issues are crucial and they are on the permanent agenda worldwide. Transboundary rivers management covers practically all regions and many countries worldwide (Kukeyevaet al., 2015).

Qinling Mountains are located in the north and Bashan Mountains in the south of southern Shaanxi, where Han River flows from west to east. Southern Shaanxi has 3 prefecture-level cities, namely, Hanzhong, Ankang and Shangluo. The Han River rises in southwestern Shaanxi, and southern Shaanxi is an important water source region of Shaanxi Province and also a major water output region in the central line project of south-to-north water diversion. About 70% of the water resources in the central line project are supplied by southern Shaanxi. To promote economic development, Shaanxi Province attempts to establish a market-oriented interregional eco-compensation mechanism, but the fund is not easily available due to the underdeveloped economy of this region. Water is a public good for which pricing is difficult. Without a water rights pricing

Please cite this article as: Liu C.J., Qiao C.L., 2016, A study on the quantitative model of eco-compensation based on auction of property right for the water source region, Chemical Engineering Transactions, 51, 1117-1122 DOI:10.3303/CET1651187

system, the interregional eco-compensation mechanism is not possible. As the government has stepped up the investment on regional economic growth, raising funds is another key issue. Strengthening market operation to introduce more financing channels is an effective way to solve this problem (Huang et al., 2015).
Based on the Coase theorem and information economics, an auction-based eco-compensation model is proposed for the trading of water rights. Thus paid use and optimized allocation of the water resources are achieved by the market-oriented interregional eco-compensation.

2. Current experience in market-oriented eco-compensation mechanism

Market orientation is the common practice of market-oriented eco-compensation. By mode innovation and by defining the property rights, eco-compensation may take the form of green payment, quota trading, eco-label, emission rights trading and international carbon trading(shown in Table 1)(US EPA et al., 1997; Merle et al., 1995; Gao, 2006; You et al., 2007; Heimlich, 2002).

Table 1: Typical models of ecological compensation based on market abroad

Operation patterns	Countries	Operation methods
Green payment	U.S.A	Economic compensation to the social groups or individuals who control soil erosion, prevent flood and protect water resources from downstream ecological benefit areas.
	France	Bottled water companies compensate farmers of Water source area for their protecting environment.
Quota transaction	U.S.A	The quota of natural resources and the capacity of the environment are determined by laws, regulations, planning or license. If someone has used excess of the quota, it is necessary to purchase the corresponding credits through the market
Eco-label system	EU	Green certification to the design, production and sale of product to ensure that the process of production can save resources and reduce pollutant emissions.
	U.S.A	With eco-agricultural products affixed to the eco-label, the cost of protecting the nature can be payed through the consumers' choice to pay a higher price for these products.
Emission permit trading	Australia	The ecological service providers gain income through the emission permit transaction in the market transaction.
International carbon sink trade	Costa Rica	The majority of income from additional carbon sink sold to foreign enterprises give compensation to the forest owners.

Chinese scholars have proposed 3 quantitative models of interregional eco-compensation. That is, the compensation criteria can be set based on (1) ecological function valuation, (2) values and opportunity cost offered by the ecological functions, and (3) values created and lost by the ecological functions(Xu et al, 2006; Yang et al, 2006; Wu et al., 2002).
The three key aspects of building the market-oriented eco-compensation model are as follows: identifying the stakeholders, defining the property rights of the resources to be allocated, and pricing of the ecological products and services.

3. Stakeholder identification

Southern Shaanxi is an important water output region. The stakeholders of the interregional eco-compensation between the upstream and downstream regions include the government, enterprises, civil organizations and individuals. The hierarchy of the stakeholders is provided in Figure 1.

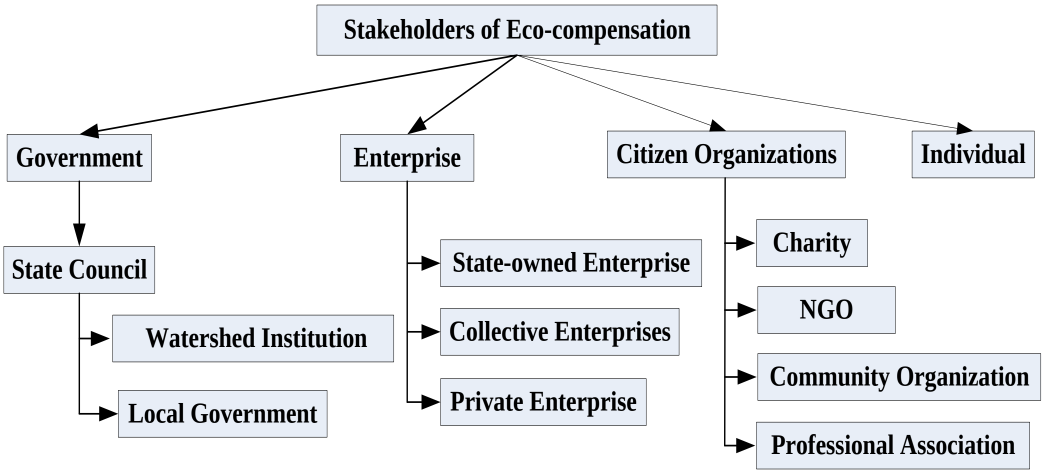

Figure 1: Stakeholder of Eco-compensation

4. Defining the water rights

Economist Coase held the opinions that the externalities of the public goods can be solved by the market. If the property rights are clearly defined and the transaction cost is zero, the allocation of the resources can be optimized by market transaction and reach a Pareto optimal no matter what the initial definition of the property rights is. In other words, when the transaction cost is positive and minimal, the resources allocation can be optimized by defining the property right with the internalization of externalities and by utilizing the market (Coase et al., 1994). Under Coase theorem, water as a limited public good is assigned with the property right. Thus water property right can be sold as any other commodities. This not only represents a means of resources allocation, but also an inevitable trend of the market.

To achieve this goal, water rights should be defined first. In a perfectly competitive market, water rights should have the following features to ensure optimized water resources allocation:

(1) Definiteness: All rights, limits of rights and the penalties regarding the violation of the rights are clearly defined.

(2) Exclusiveness: The owners of the property right have access to all benefits and costs arising from the property.

(3) Transferability: The property right can be sold on the basis of mutual consent.

(4) Mandatoriness: The property right is immune from violation and involuntary deprivation.

5. Overall design of the auction-based eco-compensation model

An auction-based eco-compensation model that ensures incentive compatibility is proposed for water rights. The rules to be followed under this mechanism are as follows.

The total quota granted by the government on water rights in a specific region is b_0 and there are n buyers, who call out their bids and the share of the quota. Then the buyers are ranked in the decreasing order of the unit price. Those ranking among the first get the water rights, and the water rights are so allocated until the sum of the value of the water rights reaches but not exceed b_0.

The mathematical model for describing the water rights auction and the rules is presented.

Let the bidding strategy of the i-th buyer be (q_i, p_i), where q_i is the share of the quota bidded out by the i-th buyer; p_i is the unit price quoted. In the decreasing order of the unit price, there is $p_1 \geq p_2 \geq \ldots \geq p_n$. If there exists a positive number m that makes$q_1+q_2+\ldots+q_m \leq b_0$ but $q_1+q_2+\ldots+q_{m+}q_{m+1} \geq b_0$, then the first m ranking buyers get their shares of the quota at the quoted price.

Here each buyer quotes the bid on a completely voluntary basis and under transparent transaction rules. The price quoted by each buyer is based on their respective valuation of the water rights. Suppose the value estimated by the i-th buyer on the share of quota bidded out is v_i and the bidding strategy is (q_i, p_i), then the payoff function is as function (1).

$$u = \begin{cases} (v_i - p_i)q_i & \sum_{j=1}^{i} q_j \le b_0 \\ 0 & \sum_{j=1}^{i} q_j > b_0 \end{cases} \tag{1}$$

The situation where two or more bidders have the same bid price is omitted. In fact, if the bid price p_i shows continuous distribution, the probability that the same bid price is the same is 0.

According to the above rules, the payoff of each buyer not only depends on their respective bidding strategy, but also on the share q_i of quota bidded out and the bidding strategies of other buyers. Therefore, before bidding, the buyer needs to have a clear payoff estimate of the water rights with a consideration of the bidding strategies of other buyers. Generally, the cost of buying the water rights is private information and not revealed to other buyers. The bid price p_i of the i-th buyer is a function of the value estimate v_i of the water rights, i.e., $p_i=p_i(v_i)$. If the cost c_i for the i-th buyer is a function of the share of quota q_i bidded out, i.e., $c_i = c_i(v_i)$, then the bidding strategy is $\{q_i, u'(q_i)+c_i(q_i)\}$, where $u'(q_i)$is the marginal payoff estimated by the i-th buyer for the share of quota q_i.

We assume that the bid price $p_i(v_i)$ of the i-th buyer is a strictly increasing differentiable function of the value v_i. Apparently, $p_i>1\ge v_i$ cannot be the optimal bidding strategy, because no buyer wants to pay more than the estimated value of the water rights. In a symmetric game, we only need to consider the equilibrium bidding strategy for the bidders.

6. Water rights pricing mechanism

The closing price is the price at which the water rights are sold by the government to the buyers. This price depends on buyers' estimate of water resources utility, water supply amount and the estimate of other buyers' bid price. The closing price can be determined by the equilibrium of the auction game.

Suppose there are two buyers (i=1, 2). The unit price quoted by buyer 1 is $p_1$and the share of the quota is q_1. Buyer 1 knows that q_2 has a uniform distribution in the interval of [0, 3], and buyer 2 knows that q_1 has a uniform distribution in the interval of [0, 1]. Buyer 1's estimate of the value v_1 of q_1 is private knowledge. Both know that v_1 has a uniform distribution in the interval of [0, 1], in addition to the common knowledge that the total quota of water rights to be sold is b_0 ($b_0=2$). Thus the payoff (Zhang et al, 1996) of buyer 1 is as following equation (2).

$$u_1 = (v_1 - p_1)q_1 \Pr ob\{p_2 < p_1, \text{ or } p_2 > p_1 \wedge q_1 + q_2 \le b_0\}$$
$$= (v_1 - p_1)q_1(1 - \Pr ob\{p_2 > p_1\} + \Pr ob\{p_2 > p_1 \wedge q_1 + q_2 \le b_0\}) \tag{2}$$

Suppose $p_2>p_1$and $q_2+q_1\le b_0$are mutually independent:

$$u_1 = (v_1 - p_1)q_1(1 - \Pr ob\{p_2 > p_1\} + \Pr ob\{p_2 > p_1\} \cdot \Pr ob\{q_1 + q_2 \le b_0\})$$
$$= (v_1 - p_1)q_1(1 - 0.5\Pr ob\{p_2 > p_1\})$$

Considering the linear bidding strategy, there are $p_1=\alpha_1+\beta_1 v_1$, $p_2=\alpha_2+\beta_2 v_2$

Because v_2 is uniformly distributed over the interval of [0, 1], p_2 has a uniform distribution in the interval of [α_2, $\alpha_2+\beta_2$]:

$$\Pr ob\{p_2 > p_1\} = \Pr ob\{\alpha_2 + \beta_2 v_2 > p_1\} = 1 - \Pr ob\{\alpha_2 + \beta_2 v_2 \le p_1\}$$
$$= 1 - \Pr ob\left\{v_2 \le \frac{p_1 - \alpha_2}{\beta_2}\right\} = 1 - \Pr ob\left\{v_2 \le \frac{p_1 - \alpha_2}{\beta_2}\right\} = 1 - \frac{P_1 - \alpha_2}{\beta_2} \tag{3}$$

Thus, for buyer 1, the objective function is obtained:

$$\max_{p_1} u_1 = (v_1 - p_1)q_1(1 - 0.5\Pr ob\{p_2 > p_1\}) = \frac{(\beta_2 + p_1 - \alpha_2)(v_1 - p_1)q_1}{2\beta_2} \quad (4)$$

Under optimized first-order conditions, $p_1 = \{(\alpha_2 - \beta_2 + v_1)/2\}$, $p_2 = \{(\alpha_1 - \beta_1 + v_2)/2\}$.
If the total quota b_0 of water rights increases ($b_0' = 3$), then

$$\max_{p_1'} u_1 = (v_1 - p_1')q_1(1 - \Pr ob\{p_2' > p_1'\} + 0.75\Pr ob\{p_2' > p_1'\})$$

$$= \frac{(3\beta_2 + p'_1 - \alpha_2)(v_1 - p'_1)q_1}{4\beta_2} \quad (5)$$

Under optimized first-order conditions, $p_1' = (\alpha_2 - 3\beta_2 + v_1)/2 < p_1$.
It is easy to see that as the total quota of water rights increases, the buyers' valuation of the water rights decreases and the bid price decreases as well. As a result, the water resources are sold at the price below the cost and the allocation efficiency is impaired.

7. Conclusions and discussion

The stakeholders of the interregional eco-compensation between the water source region and the downstream regions in southern Shaanxi are identified and the water rights are defined. Water rights pricing is studied by building the mathematical model for the auction-based eco-compensation. The following conclusions are drawn:
(1) Identifying the stakeholders and the beneficiaries and victims of water resources allocation is the prerequisite for building the eco-compensation model.
(2) According to Coase theorem, the paid use and optimized allocation of water resources are premised upon the four features of water rights, namely, definiteness, exclusiveness, transferability and mandatoriness.
(3) By water rights auction, the water rights price will constantly approach the true value if the government provides limited quota and clear definition of water rights. This is not only important for realizing paid use and optimized allocation of the water resources, but also for mobilizing the compensation fund for the water source regions.
(4) The quantitative model of eco-compensation for water resources in southern Shaanxi is built by identifying stakeholders, defining water rights and water rights pricing. The fund collected by the water rights trading can be used for eco-compensation in the water source region. The present research provides references for formulating criteria and policies of eco-compensation.
Based on the above analysis, two major issues deserve extra attention:
(1) Relationship between bid price and total quota of water rights: The larger the total quota of water rights ($q_2 > q_1$), the lower the buyers' estimate of the value of water rights ($v_2 < v_1$) and the lower the average bid price will be ($p_2 < p_1$). In contrast, the buyers will have greater expectation about payoff. As more buyers want to bid for a share of limited quota (b_0), the scarcity of water resources will become a major concern. Consequently, the buyers will call out higher price and the government can reap more benefits. The auction-based eco-compensation model utilizes this feature so as to increase the unit price of the water rights and to optimize water resources allocation.
(2) An increase in total quota of water rights will impair water allocation efficiency: When the total quota of water rights increases ($b_0' > b_0$), more water resources are available and scarcity is no longer a problem. Thus the buyers tend to underestimate the water rights and the bid price will decrease ($p_1' < p_1$), resulting in an economic loss for the water source regions. When there is no limit on the water use quota, low-cost use or even unpaid use of water resources may occur, leading to negative externality effect of water consumption. Government as the guardian of public interests should properly define water rights and allocate water rights through market transaction. This will not only curb the low-cost or unpaid use of water resources in water source region in southern Shaanxi, but also reverse the negative externality of water consumption. In a word, it is a win-win policy for both the nation and the people.

Acknowledgments

The data set is provided by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) (http://www.resdc.cn). And the work are funded by: Humanities and Social Science Youth Funds of Ministry of education in China (13YJCZH101); Social Science Plan Funds of Xi'an (14J67); the

Special Fund for Basic Scientific Research of Central Colleges, Chang'an University (Humanities and Social Sciences) (0009-2014G6285049; 310828155034). I appreciate the data and financial support.

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