The research of eco-compensation for basin water resources based on new regulatory economics

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Abstract. The economist J Tirole has obtained the Nobel Prize for Economics by the theory of new regulation economics, which provides a new way for the regulation of various fields. Based on this theory, the new regulation of water resources eco-compensation in watershed is analyzed. In view of the information asymmetry between compensation subject and compensation object, a new method of determining compensation standard is put forward by using the new regulation model. Taking the eco-compensation of the water source area of Shitou River as an example, the application mode of the new regulation is explored. Firstly, information rents can be eliminated. Secondly, the dynamic and accuracy of the compensation standard can be improved, and government budgets will be more accurate according to the interval range of compensation funds. Thirdly, the overall welfare level of the society can be guaranteed.

1. Introduction
As public goods, water resources have the characteristics of non-exclusive and externality. It is inevitable to generate interest conflicts in the process of developing and utilizing between upstream and downstream area. By internalizing the externalities, eco-compensatory mechanisms aim to protect natural resources, biodiversity, ecological functions, ecosystem services and other kinds of values [1]. Thus, a reasonable and effective compensation mechanism for basin water resources is the precondition of ensuring the normal operation of eco-compensation in watershed.

At international level, researches mainly focus on the exploration of ecosystem service function of basin water resources [2], the assessment of the value of eco-service function [3], the delineation eco-compensation standard [4], the theoretical basis of water resources compensation [5], the analysis of effective operation of eco-compensation mechanism [6], the discussion of rational allocation and protection method of water resources [7]. In China, a lot of theoretical research and practical exploration have been carried out in the area of basin water resources eco-compensation, which mainly focus on the identification of the compensation subject and object [8], compensation method [9], compensation standard [10] and financing [11] and other aspects. However, there are few unified theoretical studies on quantitative calculation method of compensation standard. This results in the lack of the theoretical framework of the compensation standard calculation for basin water resources eco-compensation.

In response to this problem, the following views are presented. In the first place, this paper holds that eco-compensation of water resources in river basin is a way to protect the ecological environment of the watershed, and to redistribute the cost and benefit of the stakeholders in river basin, mainly...
through economic means. In the next place, the new regulation economics theory has been used well in the public service of telecom industry and power sector in developed countries, which provides a new idea for establishing a unified theoretical framework for the calculation of eco-compensation standard for basin water resources.

2. A summary of new regulation economics theory

The basic hypothesis of asymmetric information was introduced by Jean-Jacques Laffont and Jean Tirole in regulation problems. The government can only obtain the observed production costs, but do not know the effort level that company made to cut costs. The optimal regulation schemes for pricing, production, service, quality and access of regulated enterprises under asymmetric information conditions were analyzed by using the analysis tool of contract theory. Then, the “new regulatory economics” had been created. Its greatest innovation is to apply incentive theory to actual supervision, and to improve the relevant model and mechanism for developing countries. On this basis, the regulation problem is transformed into the optimal mechanism, and the principal-agent model and the mechanism design theory are combined to solve the information asymmetry in government regulation. The regulation of natural monopoly industry must strike a balance between efficiency and information rents. Today, the information barrier between enterprises and government is more prominent. This phenomenon also exists in the area of basin water resources eco-compensation. Hence, the emergence of new regulation economics provides a set of theoretical framework for the effective regulation of government, and provides reference for the regulation of eco-compensation.

3. Optimal regulation model of basin water resources eco-compensation under incomplete information

Using $q$ represents the production level. The utility brought by the product is $S(q)$. $P(q)$ represents the inverse demand function, and $\eta(p)$ represents the demand for price elasticity.

The cost function of natural monopoly enterprises is expressed by:

$$C = (\beta - e)q + K$$  \hspace{1cm} (1)

Where $K$ is a fixed cost; $\beta - e$ is marginal cost, which is composed of the specific characteristics $\beta$ and the effort degree $e$ of the regulated, and $c$ represents the marginal cost; $\beta$ ranges in $[\underline{\beta}, \bar{\beta}]$, meanwhile, the effort degree $e$ will decrease with marginal cost due to the negative effect $\psi'(e)$ of manager as well as $\psi'' > 0, \psi'' > 0, \psi'' \geq 0$.

Regulators pay transfer payments $\hat{t}$ for enterprises to achieve the maximum social welfare. The net transfer payment is:

$$\hat{t} = \hat{t} + qP(q) - (\beta - e)q - K$$  \hspace{1cm} (2)

According to the basic theory of the new regulation economics, the equation (3) represents the welfare of the natural monopoly enterprise, and the public utility level is expressed by equation (4).

$$U = \hat{t} + qP(q) - (\beta - e)q - K - \psi(e)$$  \hspace{1cm} (3)

$$V = S(q) + \lambda qP(q) - (1 + \lambda)[(\beta - e)q + K + \psi(e)] - (1 + \lambda)U$$  \hspace{1cm} (4)

$W=V+U$ can be used to represent the social welfare that regulators created. It can be yield as:

$$W = S(q) + \lambda qP(q) - (1 + \lambda)[(\beta - e)q + K + \psi(e)] - \lambda U$$  \hspace{1cm} (5)

The compensation subject is regulator, and the regulated is the compensation object. The total costs can be observed, but effort degree $(e)$ cannot be observed. The compensation subject just knows the range of $\beta$, and the probability of $\beta$ taking $\bar{\beta}$ is $i$, $\beta$ is $1-i$.

The objective function of compensation objects isn’t negative, which is the participation constraint:
\[ U = t - \psi(\beta - c) \]  

(6)

\[ \Phi(e) \] is an incremented convex function, equal to \( \psi(e) - \psi(e - \Delta \beta) \). The incentive constraint is:

\[ U_{\bar{t}} = t - \psi(\beta - c) \geq \bar{U} + \Phi(\bar{e}) \]  

(7)

\[ \bar{U} = \bar{t} - \psi(\bar{\beta} - \bar{c}) \geq U - \Phi(e + \Delta \beta) \]  

(8)

Under constraint of motivation and participation, the objective function of optimal regulation is:

\[
\max_{(q,e,\bar{U})} \left\{ \left( S(q) + \lambda q P(q) - (1 + \lambda) \left[ (\beta - e) q + \psi(e) + K \right] \right) - \lambda \bar{U} \right\} + (1 - i) \left( S(\bar{q}) + \lambda \bar{q} P(\bar{q}) - (1 + \lambda) \left[ (\bar{\beta} - \bar{c}) \bar{q} + \psi(\bar{c}) + K \right] \right) - \lambda \bar{U} \}
\]

(9)

According to regulation theory [12], \( \bar{U} = 0 \) and \( U = \Phi(\bar{e}) \) can be obtained. Take them to equation (9), and maximize \( (q,e) \) and \( (\bar{q},\bar{e}) \), then get the following four functions:

\[ \psi'(e) = q \]  

(10)

\[ \frac{p - (\beta - e)}{p} = \frac{\lambda}{1 + \lambda} \frac{1}{\eta} \]  

(11)

\[ \psi'(\bar{e}) = \bar{q} \]  

\[ \frac{\lambda}{1 + \lambda} \]  

(12)

\[ \frac{\bar{p} - (\bar{\beta} - \bar{e})}{\bar{p}} = \frac{\lambda}{1 + \lambda} \]  

(13)

The equations (10) and (11) revealed that the low cost compensation object can realize the effort and production level under the condition of complete information and decrease the information rent. \( U = \Phi(\bar{e}) \) will reduce the intensity of regulation. The equations (12) and (13) reflect that if the regulated has the characteristic of high cost, the effort and production level will decrease, and there’s no information rent. The compensation subject hopes to reduce the rent. Due to \( U = \Phi(\bar{e}) \) and \( \Phi' > 0 \), therefore, \( \bar{e} \) should be diminishing.

The cost compensation rules are used to analyze the equations (10) and (12). Assume that the ratio of the cost that compensation subject compensate to the object is \( \theta \), meanwhile, the objective function (14) is solved by the compensation object to reduce the cost. Furthermore, \( \psi'(e) \) equals to \( (1 - \theta)q \) through a certain effort level.

\[ \min_{e} (1 - \theta)(\beta - e)q + \psi(e) \]  

(14)

Then, the formula (10) can be regarded as the case of \( \theta = 0 \). Namely, the compensation subject does not compensate to the object for the cost. The low-cost compensation object will choose the fixed compensation mechanism, because it will not affect the rent the object gets. The case corresponding to the equation (13) is derived as follows:
\[ \bar{\theta} = \frac{1}{q} \frac{\lambda}{1+\lambda} (1-i) \Phi'(\bar{e}) \] (15)

The compensation ratio of compensation object cost is \(\bar{\theta}\), which will lead to the effort of compensating object to pay much lower than the best level. The higher the \(\bar{\theta}\), the lower the level of the induced effort, the weaker the incentive. The formula \((1-\bar{\theta})\) represents the intensity of the incentive. The effort degree will increase as the intensity of stimulation increases. For the eco-compensation of watershed water resources, the establishment of more effective incentive intensity on the basis of guaranteeing the basic interests of the damaged area will help to mobilize the enthusiasm of ecological protection and reduce the cost to achieve the maximization of social welfare.

4. New idea of eco-compensation of water source in Shitou River basin under new regulation

4.1. A new pattern of eco-compensation standard calculation for water source in Shitou River

Shitou River is located in Shaanxi Province. After flowing out from Xieyuguan located at Mei County, the main stream flow into Weihe River, the first major tributary of the Yellow River [13], at Huajiazhai located at Qishan Country. The length is 68.4 km and the basin area is 778.7 km². Shitouhe Reservoir located in Xieyuguan. It is an important urban water supply source in the Midwest of Shaanxi Province. As shown in figure 1. To ensure the water in Shitou River is not polluted, the farmers, Taibai County Government and the Shitou River Irrigation District Authority have invested a lot of human and financial resources which should be the object of compensation. The local governments of Xi’an, Baoji, Xianyang and Yangling are the direct beneficiary area, and the Shaanxi provincial government is the main beneficiary as the superior authority, they four are the subject of compensation. The direct cost of the construction project in the Shitouhe Reservoir area and the missed opportunity cost should be regarded as the total cost of the ecological environment protection in the upstream of the Shitou River water source.

![Figure 1. The map of the study area.](image-url)
Figure 2. Eco-compensation of water source in Shitou River basin under new regulations.

Under the condition of incomplete information, the optimal regulation model of eco-compensation is applied to the eco-compensation of Shitou River. A new compensation process is shown in figure 2. The initial compensation standard includes construction cost, opportunity cost, information rent due to asymmetric information between compensation object and compensation subject, and initial excitation strength should be measured with water quality index. Obviously, the compensation subject of information rent cannot immediately recognize the effort level ($e$) and characteristic parameter ($\beta$) of the compensation object, and then it needs to pay information rents. Firstly, on the basis of self and social interests, the compensation subject provides the compensation object with initial compensation standard. After that, the object of compensation modifies the standard according to its own interests and characteristics. The two sides play multiple games, which can also be called negotiation. In this process, the compensating subject can identify the effort level and the characteristic parameter of the object to some extent. By using the new regulation theory and model, the final compensation standard which accords with the characteristic of compensation object could be calculated. Final compensation criteria include fixed compensation and effective excitation strength. While, the former includes only construction cost and opportunity cost. Information rent is gradually eliminated in course of the games. The incentive intensity is also adjusted to the best effect in the course, which cannot only arouse the intention of compensating object to improve the ecological environment in the protected area, but also induce the object to try to reduce the cost.

It can be seen that, by applying the theory of new regulation economics, the calculation of water resources eco-compensation standard becomes a dynamic process, and the compensation standard is more accurate. For a period of time, under the premise that the amount of water resources is basically
unchanged, the compensation standard must be floating in a stable range with the change of water quality index, which provides a reliable range for the compensation subject to raise funds, and provides a credible digital basis for the government's economic budget.

4.2. Implementation effect and analysis

The model analyzes two extreme special situations, but the actual problems are often somewhere in between. According to the new pattern, the eco-compensation standard has been established for the period of 2015 (status quo year)-2020 (planning year). In 2015, the compensation object supplies the class III water (the Environmental Quality Standards for Surface Water of China) with a quantity of $8.4 \times 10^7$ m$^3$ to the compensation subject. Water is a public product, so value of ‘$q$’ is 1. Efficiency parameters range from 0.3 to 0.8. The social cost of tax is 5%. Generally, the elasticity coefficient is 0.15. The total cost of eco-compensation provided by the compensation object is 129.29 million yuan (including construction and protection costs of 71.37 million yuan, opportunity cost of 57.92 million yuan), which is equivalent to 1.54 yuan/m$^3$. In the area of environmental management, the technical and labor efficiency of our country is relatively low. Based on this judgment, the compensation subject puts forward the initial compensation standard of 1.2 yuan/m$^3$ (total 100.8 million yuan). After many consultations, the final compensation standard with incentive strength was determined. The details are as follows. The basic compensation standard is 1.08 yuan/m$^3$. If water quality meets the class II water standard, the compensation increases 0.45 yuan/m$^3$. And, if water quality meets the class I water standard, compensation standard raise to 1.98 yuan/m$^3$.

The final eco-compensation standard shows that the compensation object has characteristics of high cost and low efficiency (around 0.55). Under the new standard, when water quality reaches the class II water level, the compensation standard raises to 1.53 yuan/m$^3$, total 128.52 million yuan which is almost equal to the initial cost (129.29 million yuan) calculated by compensation objects. Due to the existence of incentives, the compensation object is willing to pay more efforts to reduce costs while improving water quality. Obviously, the initial cost includes information rents. However, under the new standards, a part of information rents has been eliminated or used to improve water quality. After 2020 years, the cost of environment treatment will be lower and the compensation object will be more efficient.

5. Conclusions

In the case of asymmetric information, the calculation of eco-compensation standard of watershed water resources lacks the unified theoretical framework. This study applies the theory and model of new regulation economics to the eco-compensation of watershed water resources. Taking the eco-compensation of Shitou river water sources as an example, the new application mode has been presented, and concludes as follows:

- According to the general method, the compensation standard usually contains information rents. Based on the new regulation economics theory, the compensation subject identified two parameters in games with the object, so it can eradicate some of the information rents. The new compensation standards including the excitation strength and the fixed compensation are obtained.

- After analyzing the subject and object of compensation in Shitou River basin, the paper advances an application mode of new regulation. Finally, in a certain period of time, when the amount of water resources is basically unchanged, the change interval of compensation standard is 1.08-1.53 yuan/m$^3$, which provides the reliable reference for compensation financing.

- The research shows that the new theory can effectively reduce the cost and improve the efficiency. This study has a certain catalytic effect on the formation of unified theoretical framework of compensation standard calculation, which can be applied to other regions.
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References
[1] Shang W C, Gong Y C, Wang Z J and Stewardson M J 2018 Eco-compensation in China: theory, practices and suggestions for the future J. Environ. Manage. 210 162-70
[2] Chen D D, Jin G, Zhang Q, Arowolo A O and Li Y 2016 Water ecological function zoning in-Heihe River basin, northwest China Phys. Chem. Earth 96 74-83
[3] Mamat Z, Ümit H, Keyimu M, Keram A and Nurmamat K 2018 Variation of the floodplain forest ecosystem service value in the lower reaches of Tarim River, China Land Degrad. Dev. 29 47-57
[4] Sheng W P, Zhen L, Xie G D and Xiao Y 2017 Determining eco-compensation standards based on the ecosystem services value of the mountain ecological forests in Beijing, China Ecosyst. Serv. 26 422-30
[5] Engel S, Pagiola S and Wunder S 2008 Designing payments for environmental services in theory and practice: an overview of the issues Ecol. Econ. 65 663-74
[6] Liu G H, Wen Y H, Jin T T, Hao H G and Liu S F 2013 Designing of watershed ecological compensation mechanism based on the key ecological function zone: a case study in the source area of Dongjiang River AMR 807-809 962-75
[7] Tang Z, Shi Y L, Nan Z B, et al 2012 The economic potential of payments for ecosystem services in water conservation: a case study in the upper reaches of Shiyang River Basin, Northwest China Environ. Dev. Econ. 17 445-60
[8] Meng H, Bai Y, Huang Y C, Wang M, Yan Z C, Shi D R, Huang S F and Wang L 2012 Research progress for ecological compensation mechanism of water resources China Popul. Resour. Environ. 22 86-93 (In Chinese)
[9] Hong S Q, Wu X Q, Duan C Q, Chen C Q and Ye W H 2001 The compensation channel and diversity provide base and guarantee for eco-compensation Environ. Sci. Technol. 24 40-2
[10] Fu Y C, Ruan B Q, Xu F R and Chu L M 2012 Water related eco-compensation standard study for the Yongding River basin J. Hydraul. Eng. 39 740-8 (In Chinese)
[11] Guan X J, Chen M Y and Hu C H 2015 An ecological compensation standard based on emergy theory for the Xiao Honghe River Basin Water Sci. Technol. 71 1463-70
[12] Laffont and Martimort 2002 The Theory of Incentives (New Jersey: Princeton University Press)
[13] Wang N, Li J W, Xie J C and Fang Z 2013 Dynamic calculation of ecological water demand by Wei River J. Hydroelectr. Eng. 32 76-81 (In Chinese)