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STUDY OF RECLAIMED PRODUCT PRICING MODEL BASED ON COOPERATIVE GAME - A CASE OF RECLAIMED WATER

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Abstract

The paper takes cooperative game analysis method to solve the pricing problem of reclaimed product. First, a cooperative game model is established for the supplier and users of reclaimed product, taking reclaimed water as an example. And then, the Shapley value is introduced to allocate the total interests of the cooperation through analyzing the relationship between supplier and users' interests of reclaimed product. Finally, the reasonable price of reclaimed product under the equilibrium distribution of interests is deduced, which shows the proposed method can be used as a scientific tool for the reclaimed product's integrated decision making in corporations.

Keywords: Reclaimed product, Pricing model, Shapley value, Reclaimed water

INTRODUCTION

With the economic development, population growth and rapid urbanization, people's demand for resource products continues to increase, resulting in further resource scarcity, which has become the bottleneck of sustainable development (Barbier, 2004).

Taking reclaimed water as an example to research on reclaimed product is of great advantage. Reclaimed water is the end product of wastewater reclamation that meets water quality requirements for biodegradable materials, suspended matter and pathogens (Levine and Asano, 2004). Its quality is between sewage and tap water and has the advantages of stable water source, standard water quality and low production cost. Reclaimed water is called the city's second water source. It can be used for irrigation, industrial cooling, municipal greening, road spraying, groundwater recharging and surface water replenishing, and has significant economic, social and environmental benefits (U.S. National Research Council, 1998; Gleick, 2000).

There is no doubt that reclaimed water and its utilization should be more popular, especially in water shortage regions and nations. In the United States, although the water resources are abundant enough, water shortage and the over exploitation of underground water is still a thorny issue in California, Texas, Florida and Arizona. Therefore, reclaimed water is widely used in these states. The federal government gives policy support as well. The financing system of reclaimed water enjoys a great deal of referential policies to encourage the supply and use of it (U.S. Environmental Protection Agency, 2004; Crook and Surampalli, 2005; Stillwell et al., 2011). It can be expected that reclaimed water will account for 40% of additional water by 2020 (Brown, 1999).

Japan is a country that lack of freshwater resources. Water demands in large cities have stressed reliability of water supply systems and necessitated the development of new water resources like reclaimed water. Wastewater reclamation and reuse have been implemented widely in major cities. To encourage the utilization of reclaimed water, the Japanese government subsidize arid area with the rate of 50% (Thayanukul et al., 2013).

In Singapore, reclaimed water has become one of the water supply sources in 2003. The price of reclaimed water is cheaper than tap water which is contribute to the widely use of it. Currently, reclaimed water accounts for more than 15% of daily water supply in Singapore (Tortajada, 2006).

China is a water shortage country in which average water resource per capita is only 1/4 of the global level (Yu and He, 2012; Tan and Liu, 2012) and 2/3 of the cities have problem of water scarcity. But by now, the ratio of reclaimed water in total water utilization is less than 1%. That's mainly because of the high price which due to low production and no subsidy. Tap water whose price is relatively low has always been subsidized by the government (Fang, 2008). It is obvious that reclaimed water also need to be subsidized to promote its utilization. However, the subsidy will be a huge fiscal burden for a nation with a large scale population and a great amount of GDP production. Thus the effective and long-term measurement is fostering the market and bringing it into full play. Before making the subside policy, we should find a suitable way to decide the price of reclaimed water.

A main reason for low utilization of reclaimed water is that the pricing is so difficult that we must propose a reasonable method. When reclaimed water price is too low, suppliers cannot make a profit from it, which will affect the enthusiasm of water treatment plants' investment and reclaimed water production. When reclaimed water price is too high, users cannot obtain the expected consumer surplus so that it won't have incentive effect on the use of it, which will cause sale block and affect the popularization and application. Due to the above dilemma, the reclaimed water pricing method has become a hot issue.

Mahjouri and Ardestani (2010) developed a new game theoretic methodology for interbasin water transfer management which can be utilized as an effective tool for optimal interbasin water allocation management involving stakeholders with conflicting objectives subject to physical and environmental constraints. But the proposed methodology did not apply to reclaimed water which will be our main focus.

Xu et al (2001) used an integrated technical-economic model which simulates potable water production and supply, potable and non potable water demand and consumption, wastewater collection, treatment and disposal, water storage, transportation and reuse to address water management issues in the French island of Noirmoutier.

Ramirez-Acosta and Mendoza-Espinosa (2004) undertook a study to determine the financial feasibility for the reuse of reclaimed water from the proposed wastewater treatment plant Monte de los Olivos, in Tijuana, Baja California. The objective was to promote the exchange of clean water for reclaimed water in industrial activities, the irrigation of green areas, and its transportation and storage for indirect use under market criteria. But the actual pricing model wasn't deduced in the above two researches.

Cuthbert and Hajnosz (1999) summarized results of a survey of rates and pricing strategies used by 23 US utilities that operate reclaimed water systems to illustrate how a utility should price reclaimed water in order to encourage its use. In addition, strategies for setting reclaimed water rates were discussed based on a case study developed for the city of Tucson, Arizona. But the price of reclaimed water wasn't been solved in this research.

The above researches all failed to put forward the accurate pricing model of reclaimed water that may cause the user losing interest in promoting the use of reclaimed water and the suppliers' unwillingness to provide it.

The pricing of a product is determined by cost, technology and market. Similarly, the pricing of reclaimed water is mainly determined by cost which is constrained by the scale effect. This paper set up reclaimed water pricing model in cooperative game under the established cost, aiming at: (1) calculating the accurate price of reclaimed water, but the government should subsidize at the early days of supplying to foster the market; (2) reducing the subsidies then completely removing it when the reclaimed water market is mature enough.

ANALYSIS OF SUPPLY AND DEMAND ALONG WITH INTEREST MODEL

Analysis of supplier and users

The relationship between the supplier and users of reclaimed water is essentially the relationship of supply and demand. Supplier makes a profit by providing reclaimed water, while users save cost by using it, so we can see that the promotion of reclaimed water is beneficial to both supplier and users. Although the use of reclaimed water will bring great benefits, the distribution of interests is a key issue related to the development of reclaimed water industry, and the distribution is mainly reflected in the price of reclaimed water. The relationship between reclaimed water's supplier and users is a cooperative relationship. Without supplier, there will be no reclaimed water provided. Without users, there will be no reclaimed water market. So we can analyze the supplier and users' interest distribution from the perspective of cooperative game, and reclaimed water pricing can be derived from it. Following is the specific analysis of the supplier and the users' interests with the model.

Interest model of supplier and users

Assume that (*M*, 1, 2, 3, …, *n*) represents the alliance of supplier and users, where *M* represents the supplier, 1, 2, 3, …, *n* represents the users that participate in the coalition, the interest of *M* can be indicated by formula (1):

$$l_M = (d - c)\sum_{i=1}^{n} x_i \tag{1}$$

Where l_M represents the interests *M* obtained, the unit is Yuan; *d* represents the reclaimed water's price, the unit is Yuan/ton; *c* represents the reclaimed water's cost, the unit is Yuan/ton; x_i represents user *i* 's daily consumption of reclaimed water, the unit is ton.

The interest of *i* can be represents by formula (2):

$$l_i = \left(p - d\right) x_i \qquad (2)$$

Where l_i represents the interests *i* obtained, the unit is Yuan; *p* represents the price of tap water which replaced by reclaimed water, the unit is Yuan/ton.

It can be seen from the above that, in general, cooperation is the only way that can make both sides benefit for supplier and users. Therefore it is a wise choice to cooperate. Thus reclaimed water's supply and demand is a one-to-many cooperative game model.

CONSTRUCTION OF ONE-TO-MANY COOPERATIVE GAME MODEL

Cooperative game is a game that can achieve binding agreement. In the process of cooperative game, participants not only consider their own interests, but also the overall interests of the game group in order to enter the next round of the game and get further common interests (Gilles, 2010).

In a cooperative game, we generally use *N*={1, 2, 3, …, *n*} to represent the coalition of players. Among them, 1, 2, 3, …, *n* represents the players that participate in the coalition. In addition to mandatory cooperative game, cooperative game should pursue the maximization of total revenue or the minimization of total costs. The distribution of interests of the coalition *N*={1, 2, 3, …, *n*} must meet the following two formulae:

$$\sum_{i \in n} x_i = v\left(N\right) \qquad （3）$$

Where x_i, *i*=1, 2, 3, …, *n* represents the payoff of player *i*; *v*(*N*) represents the coalition's interests. That is to say, the sum of the players' payoff should be equal to the coalition's interests.

$$v\left(\{i\}\right) \le x_i, i \in n \qquad （4）$$

The payoff of players shouldn't be less than the interests accruing from their own separate actions.

Specific to this problem, the coalition *N*={*M*, 1, 2, 3, …, *n*} should meet the following equation:

$$V\left(N\right) = l_M + \sum_{i=1}^{n} l_i = (d-c)\sum_{i=1}^{n} x_i + \sum_{i=1}^{n}\left(p-d\right)x_i = \left(p-c\right)\sum_{i=1}^{n} x_i \qquad （5）$$

For the coalition *S*={*M*, 1, 2, 3, …, *s*} , it should be in coincidence with the following equation:

$$V\left(S\right) = l_M + \sum_{i=1}^{s} l_i = (d-c)\sum_{i=1}^{s} x_i + \sum_{i=1}^{s}\left(p-d\right)x_i = \left(p-c\right)\sum_{i=1}^{s} x_i \qquad （6）$$

INTERESTS DISTRIBUTION AND SOUND PRICING ACHIEVEMENT OF RECLAIMED WATER

Shapley value

The 2012 Nobel Economics Prize winner Lloyd Shapley (1996) made great contributions to the cooperative game theory. He put forward a lot of valuable theories including Shapley value, stochastic games, the Bondareva–Shapley theorem (which implies that convex games have non-empty cores), the Shapley–Shubik power index (for weighted or block voting power), the Gale–Shapley algorithm (for the stable marriage problem) and so on. Another winner Alvin Rose (2007) combined his theories with practices, validating the correctness of his theories through applications and demonstrations.

For the cooperative game problem, Shapley value is the most typical distribution solution which takes the average marginal benefit of players as their contribution rate, and is somewhat reasonable. This paper uses the Shapley value to distribute the alliance's total interests. It is defined as follows:

Explanation of symbols: the coalition *N*= {1, 2, 3, …, *n*} represents the alliance of all players in one cooperative game. Among them, 1, 2, 3, …, *n* represents the players who participate in the coalition; coalition *S*={1, 2, 3, …, *s*} represents an arbitrary subset of *N*, that is to say, $S \subseteq N$.

The Shapley value can be formulated as follows:

$$\varphi_i(v) = \sum_{S \subseteq N} \frac{(|S|-1)!(n-|S|)!}{n!} \left[v(S) - v(S - \{i\}) \right] \qquad (7)$$

Where $\varphi_i(v)$ represents the payoff of player *i*; *v*(*S*) represents the total interests of *S*; $|S|$ represents the number of member *S*; [*v(S)* －*v*(*S*－{*i*})] represents the member *i* 's contribution to coalition *S*.

Equilibrium distribution of interests

i) Shapley value of user

By observing formula (7), we can see that in order to obtain Shapley value of user *i*, the coalition includes *i* should be considered first.

If the coalition is in the form of *S*={1, 2, 3, …, *s*}, namely a coalition only contains users; then *V*(*S*)=0, and it's of no significance. *S*={1, 2, 3, …, *s*} is called invalid coalition. Therefore, the coalition's form should be *S*={*M*, 1, 2, 3, …, *s*}, *s*=1, 2, 3, …, *n*.

When the number of coalition's members is 2, that is $|S| = 2$, $S = \{M, i\}$, clearly $\left[v(S) - v(S - \{i\}) \right] = (p - c) x_i$.

When the number of coalition's members is 3, that is $|S| = 3$, $S = \{M, i, t_1\}$. t_1 represents any one of the other members of the coalition, namely the user is different to *i*. There are $C_{n-1}^{1} = (n-1)$ kinds of t_1 as well as C_{n-1}^{1} kinds of $S = \{M, i, t_1\}$. Such coalitions' interests are the same and can be handled as a category. Clearly $\left[v(S) - v(S - \{i\})\right] = (p-c)x_i$.

When the number of coalition's members is 4, that is $|S| = 4$, $S = \{M, i, t_1, t_2\}$. t_1 and t_2 represents random two other members of the coalition, namely the two users are different to *i*. There are C_{n-1}^{2} kinds of $S = \{M, i, t_1, t_2\}$. Clearly $\left[v(S) - v(S - \{i\})\right] = (p-c)x_i$.

The rest may be deduced by analogy ……

When the number of coalition's members is *n*+1, that is $|S| = n+1$, $S = \{M, i, t_1, t_2, \cdots, t_{n-1}\}$. There are C_{n-1}^{n-1} kinds of $S = \{M, i, t_1, t_2, \cdots, t_{n-1}\}$. Clearly $\left[v(S) - v(S - \{i\})\right] = (p-c)x_i$.

In summary, the Shapley value of user *i* can be calculated as follows:

$$\begin{aligned}
\varphi_i(v) &= \sum_{S \subseteq N} \frac{(|S|-1)!(|N|-|S|)!}{|N|!}\left[v(S) - v(S - \{i\})\right] \\
&= \frac{(2-1)!(n+1-2)!}{(n+1)!}(p-c)x_i + C_{n-1}^{1} * \frac{(3-1)!(n+1-3)!}{(n+1)!}(p-c)x_i \\
&\quad + \cdots + C_{n-1}^{n-1} * \frac{(n+1-1)!(n+1-(n+1))!}{(n+1)!}(p-c)x_i \\
&= \sum_{y=2}^{n+1} C_{n-1}^{y-2} * \frac{(y-1)!(n+1-y)!}{(n+1)!}(p-c)x_i
\end{aligned} \tag{8}$$

Then by $C_{n-1}^{y-2} = \frac{(n-1)!}{(y-2)!(n-y+1)!}$ the above equation can be simplified as:

$$\varphi_i = \frac{1}{2}(p-c)x_i \tag{9}$$

ii) Shapley value of supplier

By $\varphi_M + \sum_{i=1}^{n} \varphi_i = v(N)$, we know that:

$$\varphi_M = v(N) - \sum_{i=1}^{n} \varphi_i = (p-c)\sum_{i=1}^{n} x_i - \sum_{i=1}^{n} \frac{1}{2}(p-c)x_i = \frac{1}{2}(p-c)\sum_{i=1}^{n} x_i \tag{10}$$

Pricing model

From $\begin{cases} l_M = (d-c)\sum_{i=1}^{n} x_i = \varphi_M \\ l_i = (p-d)\,x_i = \varphi_i \end{cases}$, the solution of this equation set is

$$d = \frac{p+c}{2} \qquad (11)$$

CONSIDERING PRICING OF RECLAIMED WATER IN IMPERFECT MARKET

It can be seen from formula (11) that the price of reclaimed water is related to its alternative. It can also be deduced from formula (11) that $p-d=\frac{p}{2}-\frac{c}{2}$, that is, when the cost of reclaimed water remains unchanged, the higher the price of its alternative, the bigger the price difference between reclaimed water and its alternative, and the users' willingness to use the reclaimed water will be more intense.

Early in putting reclaimed water into the market, its production capacity and sales are low, causing the high cost of reclaimed water. If based solely on market pricing, it will inevitably lead to higher pricing of reclaimed water and smaller price difference between reclaimed water and its alternative, and making reclaimed water unsold and reducing the production, thus resulting in a vicious cycle. The effective solution to this problem is taking the cost of reclaimed water, consumer and producer surplus into account and further optimizing the pricing model, specifically as follows:

Consider consumer surplus

The user *I*'s interest of reclaimed water is $l_i = (p-d)\,x_i$.Users will change their old habits only when the interest of reclaimed water is large enough. We can set constraints:

$$l_i = (p-d)\,x_i \ge \alpha p x_i \qquad (12)$$

Where $\alpha p x_i$ is the minimum expected value of user *i* 's interest. $\alpha \in (0, 0.5)$.

Formula (12) can be simplified as $p-d \ge \alpha p$, namely $(1-\alpha)\,p \ge d$.Putting $d=\frac{p+c}{2}$ into it, we can get $c \le (1-2\alpha)\,p$.

When $c \le (1-2\alpha)p$, the price of reclaimed water $d = \frac{p+c}{2}$ can satisfy user's interest expectation. However when $c > (1-2\alpha)p$, the price should be changed to $d = (1-\alpha)p$ so we can make sure that users are willing to use reclaimed water, thus ensuring the promotion of it.

Consider producer surplus

When $d = (1-\alpha)p$, the interest of producer $l_M = (d-c)\sum_{i=1}^{n} x_i = [(1-\alpha)p - c]\sum_{i=1}^{n} x_i$. Similarly, the supplier has its own bottom line of interests. So we can set the constraint:

$$l_M = [(1-\alpha)p - c]\sum_{i=1}^{n} x_i \ge \beta c \sum_{i=1}^{n} x_i \qquad (13)$$

Where $\beta c \sum_{i=1}^{n} x_i$ is the producer's bottom line of interests. Formula (13) can be simplified as $(1-\alpha)p \ge (1+\beta)c$, namely $c \le \frac{(1-\alpha)}{(1+\beta)} p$.

When $(1-2\alpha)p < c \le \frac{(1-\alpha)}{(1+\beta)} p$, the price of reclaimed water $d = (1-\alpha)p$ can meet the expectations of both users and supplier's interest expectation. But when $c > \frac{(1-\alpha)}{(1+\beta)} p$, what price should it be?

Government subsidies

When $c > \frac{(1-\alpha)}{(1+\beta)} p$, in order to promote the development of reclaimed water industry, the price is still $d = (1-\alpha)p$ to ensure enthusiasm to use the reclaimed water, at the same time the government should give subsidies to reclaimed water, subsidies amount is:

$$g = r(t)\left[(1+\beta)c - (1-\alpha)p\right] \qquad (14)$$

Where $r(t) \in [0,1]$, $t = 1, 2, 3, \cdots, n$ represents time, and $r(t)$ decreases with the increasing of t.

However the subsidies won't last forever. When the reclaimed water market functions well and has a stable and reasonable price, the subsidies will be cut (Song, 2013).

In summary, the pricing of reclaimed water is:

$$d=\begin{cases}\frac{p+c}{2}, c\le(1-2\alpha)p\\(1-\alpha)p,(1-2\alpha)p<c\le\frac{(1-\alpha)}{(1-\beta)}p\\(1-\alpha)p, c>\frac{(1-\alpha)}{(1-\beta)}p, g=r(t)\left[(1+\beta)c-(1-\alpha)p\right]\end{cases}\qquad(15)$$

CASE STUDY

We could calculate the price range through formula (15) in the case of Tianjin. In the two categories, the first reasonable price was $d=\frac{p+c}{2}$, and the second was $d=(1-\alpha)p$, the corresponding subsidy *g* could be calculated from it.

According to the cost of reclaimed water 1.5-3.5 yuan/t (when the scale was small, the cost is 3.5 and when the scale was large enough the cost was reduced to 1.5), we could obtain the final results from Tab.1.

Table 1. Reasonable price of reclaimed water

Current price of tap water	Reasonable price of reclaimed water	Current price of reclaimed water
4.9	3.2-4.2 2.5-4.9	5.7

We could see from Tab.1 that in the first stage, the price of reclaimed water should between 3.2 to 4.2 yuan/t. Owing to the present scale of supplying, the price would be 4.2 yuan/t and the corresponding subsidy paid by the government should be 1.2 yuan/t. In the second stage, the price should between 2.5-4.9 yuan/t, and similarly the price would be 4.9 owing to the present scale. The subsidy should be 0.8 yuan/t. That means, the current price of reclaimed water is so high that users' enthusiasm to use reclaimed water will be suppressed. The government should subsidize the supplier to cut the cost and cultivate the market.

CONCLUSION

In this paper, the pricing of reclaimed product was investigated from the perspective of interests distribution of supply and demand. The effective solution of equilibrium distribution of interests was figured out through Shapley value. The optimal price of reclaimed product was determined according to the equality of both supplier and users' interests. To fostering the market in the beginning, subsidy is necessary, but subsidy is not the long-term solution. The reasonable price of reclaimed product would help maintaining the stability of market thereby promoting the spread of it. Thus the problem of the difficulty to price the reclaimed product was solved. However there were still some limitations of this study. First, the quantity of subsidy was hard to measure due to the related policies. Second, the above model only could be used when the supplier and users were able to cooperate but sometimes they failed to cooperate for their own benefits.

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