Analysis of price rate models for household water consumption in urban China

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Abstract

Price rate models are used for a variety of purposes including water conservation, what's more, it is an effective and feasible method to establish a water-conserving society. The survey of household water consumption was conducted in a residential community in Hebei Province. An analysis of the survey data shows that an average family's water consumption is 6.4t per month, the standard is level 3. Three price rate models are proposed, the principle of the first model is the decrease of water consumption in level 1 and no increase in level 2, the second model is no change in level 1 and an increase in level 2, the third model is no increase for 80% of families and only 20% increased. After an analysis and comparison of water consumption and expenses corresponding to the three models, this paper presents these three models as a valuable reference for department decisions. The results of the first model should be adopted in Hebei Province, the demarcation point of every level is 8t and 13t, the price of every level is 3.04 RMB/t, 4.56 RMB/t and 9.06 RMB/t.

Keywords: Price rate model, Resident water consumption, Data survey, Water conservation

1 Introduction

China is lacking in water resources, the average possession of water resource per person is only 1/4 of the worldwide average, especially in urban areas. In order to alleviate this supply and demand contradiction, many scholars have suggested the use of economic leverage to manage water consumption [1]. Amidst the many suggestions, the price rate model has been widely accepted. Historically, determination of water price in China has been under government control, low prices of water for urban water supply enterprises has resulted in years of losses [2]. The government supports the normal operation of the urban water supply but this also carries with it a heavy financial burden.

The "*Document about Promoting Water Price Reform and Water Conservation*" was issued by the State Council on April 19th, 2004. The document states that price rate models should be implemented no later than the end of 2005 in China. However, the implementation of this document has not been as ideal as supposed even today.

The National Development and Reform Commission (NDRC) and the Ministry of Housing and Urban-Rural Development (MHUD) have issued "*Introductory Advice about Establishing Stepped Water Pricing for Urban Chinese Households*" (hereinafter referred to as "*Introductory Advice*") on January 3rd, 2014. The "*Introductory Advice*" states that a reasonable price rate system should be established, it's precondition is to ensure the availability of needed water.

The "*Introductory Advice*" proposes that all related regions should implement a system of price rate models by the end of 2015. The water consumption amount should be divided into at least three levels. The first water consumption level should cover 80% of urban residents' monthly water usage, and the second level should cover 95% of urban resident's monthly water usage. The price rate ratios for the three levels are to be set at no less than the ratio of 1:1.5:3. The suggested amount of level 1 water consumption is 2.6 t per person per month in Hebei province. The suggested amount of level 2 water consumption is 4.3 t per person per month.

2 Analysis of the price rate of water consumption

The price rate of water consumption is determined by the number of levels in the current rate system and the price of each level. Research suggests that a price rate system for water conservation significantly improves the efficiency of water use and allocation of resources [3, 4]. The relationship between water consumption and water price is shown in Figure 1. The number of levels is set at 3.

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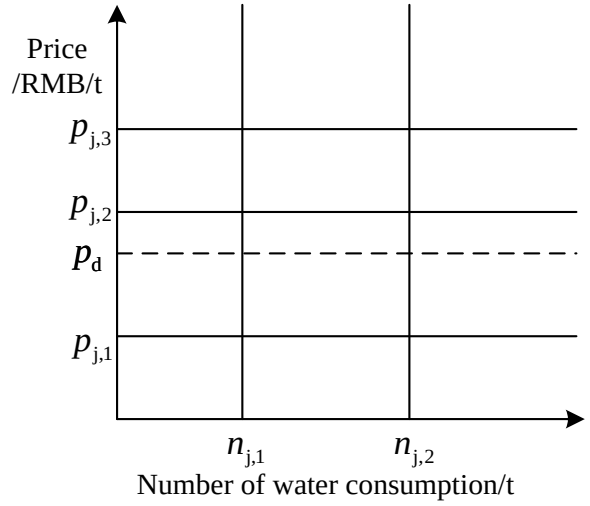

FIGURE 1 The relationship between water consumption and water price

In Figure 1, p_d is the current price, $p_{j,1}$, $p_{j,2}$ and $p_{j,3}$ are the prices of the first, second and third levels respectively. $n_{j,1}$ and $n_{j,2}$ are the upper limits of the first and second water consumption levels respectively. Therefore, the price rate of water consumption is determined by the values of five variables when the p_d is given.

According to "*Introductory Advice*", the price of each level is estimated by the following equations:

$$p_{j,2} \geq 1.5 p_{j,1} \tag{1}$$

$$p_{j,3} \geq 2 p_{j,2} \tag{2}$$

$$p_{j,3} \geq 3 p_{j,1} \tag{3}$$

However, if the only given value is p_d, the other five variables can not be obtained. In order to obtain these values, some other parameters should be acquired by the survey of urban residents' water consumption [5].

3 Water consumption survey of urban residents in Hebei province

Water consumption of a residential community in Hebei Province was surveyed in December 2013. The survey sample was 815. Table 1 shows the ratio of residents' water consumption.

According to Table 1, 80% of all household's water consumption is less than 8t, and 95% of all household's water consumption is less than 10t. The data substantiates that water consumption and its proportions satisfies normal distribution, the average value of water consumption is 6.4 t per month. The plotted result is shown in Figure 2.

TABLE 1 The ratio of residents' water consumption

Water Consumption	Households	Ratio/%	Cumulative Ratio/%
(0,2]	15	1.84	1.84
(2,3]	28	3.44	5.28
(3,4]	48	5.89	11.17
(4,5]	123	15.09	26.26
(5,6]	158	19.39	45.64
(6,7]	149	18.28	63.93
(7,8]	125	15.34	79.26
(8,9]	97	11.90	91.17
(9,10]	38	4.66	95.83
(10,15]	24	2.94	98.77
(15,20]	10	1.23	100.00
(20,+∞)	0	0.00	100.00

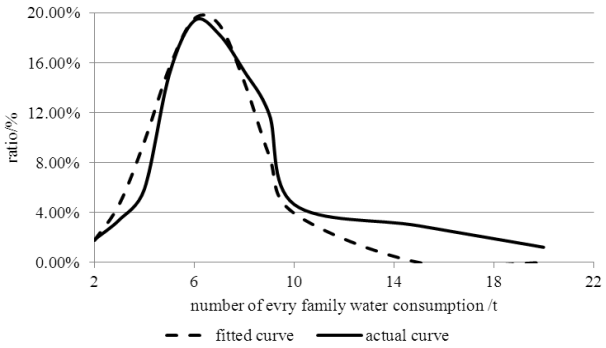

FIGURE 2 The plot of water consumption and proportion

4 Methodological approach and model construction

Based on the survey, there are very few households with a water consumption beyond 10 t per month, therefore, the number of levels beyond 3 is unnecessary. Three levels are suitable.

According to "*Introductory Advice*", the upper limit of first-level water consumption is 8t, which is in agreement with actual survey results. What's more, it is almost the same as advised values 7.8t. The upper limit of second-level water consumption is 13t. The water consumption of 95% of households is less than 10t, and it is also less than 12.9 t which is given in "*Introductory Advice*". Because of the fluctuation of water consumption and the limited samples, the value can be selected as 13 t. The third-level water consumption is beyond 13 t. Models M1 and M2 are developed under these conditions.

Another method is used to confirm the upper limit of first-level water consumption. The average water consumption is 6.4 t, the value can be set at 7 because of rounding. The upper limit of second-level water consumption is 13t. With these parameters, the model M3 is established.

When the price rate is used in water consumption, the expenses should decrease for those whose water consumption is less than the upper limit of the first-level [6-7]. The expenses should not increase for those whose water consumption is between the upper limit of the first-level and the second-level. The model M1 is given by:

M1: s.t. $p_{j,1} < p_d$, (4)

$$p_{j,2} > p_d, \quad (5)$$

$$p_{j,1} \times n_{j,1} + p_{j,2} \times (n_{j,2} - n_{j,1}) = p_d \times n_{j,2}, \quad (6)$$

$$p_{j,2} \geq 1.5 p_{j,1}, \quad (7)$$

$$p_{j,3} \geq 2 p_{j,2}, \quad (8)$$

$$p_{j,3} \geq 3 p_{j,1}, \quad (9)$$

where Equation (4) expresses the first-level price rate is less than the current price, and Equation (5) and Equation (6) express the second-level price rate is higher than the current price. Equation (7-9) are the same as Equation (1-3).

Substituting $p_d = 3.63$, $n_{j,1} = 8$ and $n_{j,2} = 13$ in M1, the following results can be obtained: $p_{j,1} = 3.04$, $p_{j,2} = 4.56$, $p_{j,3} = 9.06$. Both Equation (10) and Figure 3 show the result.

$$P_1 = \begin{cases} 3.04 n_1 & n_1 \leq 8 \\ 24.32 + 4.56(n_1 - 8) & 8 \leq n_1 \leq 13 \\ 47.12 + 9.06(n_1 - 13) & n_1 \geq 13 \end{cases}. \quad (10)$$

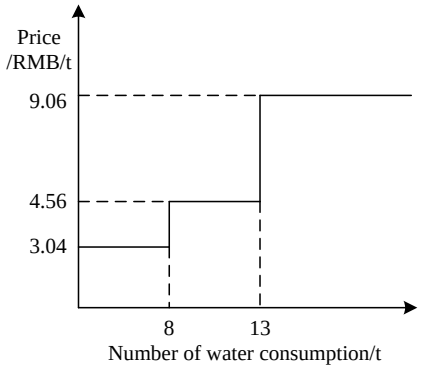

FIGURE 3 The result of model M1

Model M2 is based on the following hypothesis: the expenses of those whose water consumption is less than the upper limit of the first-level is equal to the current price, and the expenses of those whose water consumption is between the upper limit of the first-level and the second-level should increase. The model M2 is given by:

M2: s.t. $p_{j,1} = p_d$, (11)

$$p_{j,2} \geq 1.5 p_{j,1}, \quad (12)$$

$$p_{j,3} \geq 2 p_{j,2}, \quad (13)$$

$$p_{j,3} \geq 3 p_{j,1}, \quad (14)$$

where Equation (11) expresses the first-level water price is equal to the current price. Equation (12-14) are the same as Equation (1-3).

Substituting $p_d = 3.63$, $n_{j,1} = 8$ and $n_{j,2} = 13$ in M2, the following results can be obtained: $p_{j,1} = 3.63$, $p_{j,2} = 5.45$ and $p_{j,3} = 10.89$. Both Equation (15) and Figure 4 show the result.

$$P_2 = \begin{cases} 3.63 n_2 & n_2 \leq 8 \\ 29.04 + 5.45(n_2 - 8) & 8 \leq n_2 \leq 13 \\ 56.29 + 10.89(n_2 - 13) & n_2 \geq 13 \end{cases}. \quad (15)$$

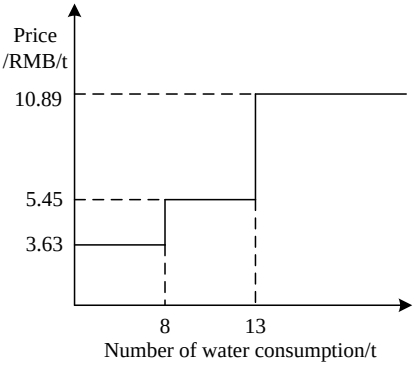

FIGURE 4 The result of model M2

The expenses of those whose water consumption is below the average are decreased, and the expenses of 80% of all households are not increased, while the expenses of 20% of all households are increased. The M3 is given by:

M3: s.t. $p_{j,1} < p_d$, (16)

$$p_{j,2} > p_d, \quad (17)$$

$$p_{j,1} \times n_{j,1} + p_{j,2} \times (n_{80\%} - n_{j,1}) = p_d \times n_{80\%}, \quad (18)$$

$$p_{j,2} \geq 1.5 p_{j,1}, \quad (19)$$

$$p_{j,3} \geq 2 p_{j,2}, \quad (20)$$

$$p_{j,3} \geq 3 p_{j,1}, \quad (21)$$

where Equation (16) expresses the first-level water price is less than the current price, and Equation (18) and Equation (19) express that the second-level water price is higher than the current price. Equation (19-21) are the same as Equation (1-3).

Substituting $p_d = 3.63$, $n_{j,1} = 7$, $n_{80\%} = 8$ and $n_{j,2} = 13$ in M3, the following results can be obtained: $p_{j,1} = 3.42$, $p_{j,2} = 5.13$ and $p_{j,3} = 10.26$. Both Equation (22) and Figure 5 show the result.

$$P_3 = \begin{cases} 3.42n_3 & n_3 \le 7 \\ 23.94 + 5.13(n_3 - 7) & 7 \le n_3 \le 13 \\ 54.72 + 10.26(n_3 - 13) & n_3 \ge 13 \end{cases}. \quad (22)$$

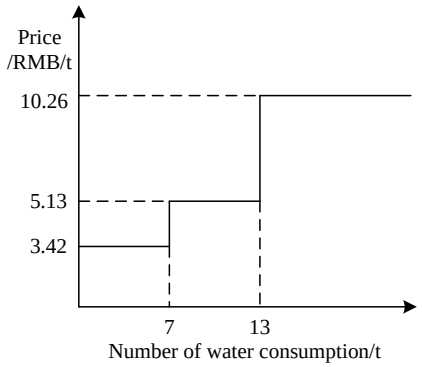

FIGURE 5 The result of model M3

5 Result Analysis

This paper establishes three models (M1, M2 and M3) based on different goals. Figure 6 shows each result, comparing it with the current price.

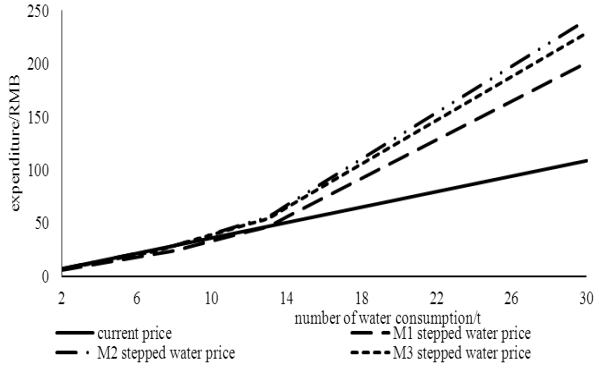

FIGURE 6 The comparison of models M1 M2 and M3

The following values shown in Table 2 are given to help more clearly comprehend the results.

According to Figure 6 and Table 2, water expenses are not increased when water consumption is below the first-level consumption. What's more, water expenses are decreased when water consumption is less than the first-level upper limit, even if the maximum increase of 25.41 RMB only accounts for incoming 0.93%.

When water consumption reaches the second-level, water expenses are slightly increased, even if the stepped water price of M2 is only increased by 9.1 RMB. The maximum increase of 56.29 RMB only accounts for incoming 2.1%.

TABLE 2 Water expenses at different water price rates

Water Consumption/t	Current Price/RMB	Water Price of M1/RMB	Water Price of M2/RMB	Water Price of M3/RMB
2	7.26	6.08	7.26	6.84
3	10.89	9.12	10.89	10.26
4	14.52	12.16	14.52	13.68
5	18.15	15.20	18.15	17.10
6	21.78	18.24	21.78	20.52
7	25.41	21.28	25.41	23.94
8	29.04	24.32	29.04	29.07
9	32.67	28.88	34.49	34.20
10	36.30	33.44	39.94	39.33
11	39.93	38.00	45.39	44.46
12	43.56	42.56	50.84	49.59
13	47.19	47.12	56.29	54.72
14	50.82	56.18	67.18	64.98
15	54.45	65.24	78.07	75.24
16	58.08	74.30	88.96	85.50
17	61.71	83.36	99.85	95.76
18	65.34	92.42	110.74	106.02
19	68.97	101.48	121.63	116.28
20	72.60	110.54	132.52	126.54
21	76.23	119.60	143.41	136.80
22	79.86	128.66	154.3	147.06
23	83.49	137.72	165.19	157.32
24	87.12	146.78	176.08	167.58
25	90.75	155.84	186.97	177.84
26	94.38	164.90	197.86	188.10
27	98.01	173.96	208.75	198.36
28	101.64	183.02	219.64	208.62
29	105.27	192.08	230.53	218.88
30	108.90	201.14	241.42	229.14

When water consumption reaches the third-level, the water expenses are increased quickly. Taking 30 t as an example, this paper presents three results. When water expenses were close to or over 200 RMB, compared with the monthly income of a family, which was more than 8000 RMB, the proportion of them are higher than 2.5%. However, compared with the monthly income of a family of 5000 RMB, when the water consumption reaches 20 t, the proportion of water expenses is higher than 2%. Xu notes that the residents started to care about water rate, attention to water conservation when the ratio between water expenses and family income is more than 2% [8]. Considering the public welfare of water resources and the goals of stepped water pricing, this paper presents that the result of model M1 is more suitable.

6 Conclusions and recommendations

Stepped water pricing is a widely accepted method for solving the problem of water waste. The NDRC and the MHUD have both issued documents stating that all related regions should carry out stepped water pricing before the end of 2015. With this in mind, this paper analyses the stepped water and pricing problem of Hebei Province, while at the same time establishing three models. The result of model M1 is regarded as the most suitable. However, other models can also be used as a reference for future studies.

Further research needs to be conducted to deal with more factors, and to seek out other possible ways. The best method and analysis remains relatively difficult, and so improvements in this area are also welcomed.

References

[1] Zhao L G, Lin J, Wang X Y 2013 Studies on potential water resources crisis based on STIRPAT model: a case from Zhejiang in China *Nature Environment and Pollution Technology* **12**(4) 631-6

[2] Chen H, Yang Z F 2006 Scalar urban water pricing model based on utility function *Resources Science* **28**(1) 109-112

[3] Wang L F, Chen C X, Xing T 2011 An econometric model of multistep water pricing for urban household water consumption and its application *Journal of Yangtze River Scientific Research Institute* **28**(5) 5-8

[4] Zhang D Z, Chen X Q 2003 Thinking on determination of domestic water price in Chinese cities *Journal of East China Normal University* (2) 81-5

[5] Hari P S, Sharma M R, Quamural H, Naved A 2010 Sustainability of traditional drinking water sources in Himachal Pradesh *Nature Environment and Pollution Technology* **9**(3) 587-92

[6] Chen Y D 2001 Sustainable development and management of water resources for urban water supply in Hong Kong *Water International* **26**(1) 119-28

[7] Patamanska G, Chehlarova S S 2012 Changing existing irrigation systems and management in Bulgaria for sustainable use of water *INMATEH - Agricultural Engineering* **38**(3) 73-8

[8] Xu Z C 2002 The reform project of the price of water supply in Shijiazhuang City *The Economy of Water* (5) 23-6

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