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Multiple Goals Dilemma of Residential Water Pricing Policy Reform: Increasing Block Tariffs or a Uniform Tariff with Rebate?

Xunzhou Ma [1,2], Dan Wu [1,3,*] and Shiqiu Zhang [1]

[1] Institute of Environment and Economy, College of Environmental Sciences and Engineering,
    Peking University, Beijing 100871, China; pooreco@163.com (X.M.); zhangshq@pku.edu.cn (S.Z.)
[2] College of Economics, Southwest Minzu University, Chengdu 610041, China
[3] School of Environmental Science and Engineering, Sun Yat-Sen University, Guangzhou 510275, China
*   Correspondence: wudan28@mail.sysu.edu.cn or wudan309@hotmail.com; Tel.: +86-188-1689-8066;
   Fax: +86-20-3933-2742

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Abstract: Water is a basic necessity and its allocation and utilization, especially pricing policies, impose various social, economic, and ecological impacts on social groups. Increasing block tariffs (IBTs) has gained popularity because it is expected to incentivize water conservation while protecting poor people benefiting from the redistribution effects because of its nonlinear tariff structure. However, it results in price distortion under certain circumstances. Researchers have also proposed an alternative practical price system and a uniform tariff with rebate (UTR), with the price level set equal to the marginal social cost and a fixed rebate allocated to the poor groups. This study proceeds with a simulation of the two pricing systems, UTR and IBTs, and empirically explores their fundamental merits and limitations. The results confirm the theoretical perspective that a water price system, compared with an optimal tariff system, simultaneously achieves multiple goals to the greatest possible extent.

Keywords: uniform tariff with rebate; increasing block tariffs; marginal social cost; economic efficiency; fairness

1. Introduction

Economists posit that the focus of environmental policies should be to ensure the efficient use of natural resources by members of society. By definition, efficient use of resources means a pattern of resource use between members of society over time, from which the benefits to society cannot be increased, and the price of any service or commodity should be equated to the cost of serving an additional unit of that very service or commodity, that is, its marginal cost. In theory, that means, to achieve efficiency in natural resource use is to ensure that resource users pay the marginal social costs, which is the sum of marginal production cost, marginal user cost/marginal depletion cost, and marginal environmental cost. Some research evaluates the social cost directly [1]. For at least two reasons, however, the pursuit of efficiency is frequently in tension with commonly held perceptions of fairness and equity, and often at loggerheads with the pursuit of poverty alleviation [2] (p. 204), [3]: First, the poor are often the segment of the population most closely linked to natural resource use; thus, their capacity for substitution with other alternatives may be limited (as is often the case in the context of natural resources). Second, the poor are endowed with the smallest asset and income bases, indicating that resource use (where it is an essential good) forms a significant part of their overall budget. These two effects indicate that the impact of environmental and resource pricing may have significantly regressive impacts across the income distribution of a given population.

Furthermore, the pricing policy introduced affects various social groups in terms of the different income distribution and redistribution effects, and these effects are highly dependent on the design, its implementation, and the supporting policies of a given pricing policy. Water resources also provide values such as recreational values and non-use values for providing ecosystem service. Price policy making should consider the impacts of these values on society. In summary, water pricing policy should not address only one target because it is a multiple-objective policy: a price system that simultaneously fulfills multiple goals to the greatest possible extent may be considered an optimal tariff system [4,5]. Figure 1 shows the multiple goals of water price policy making.
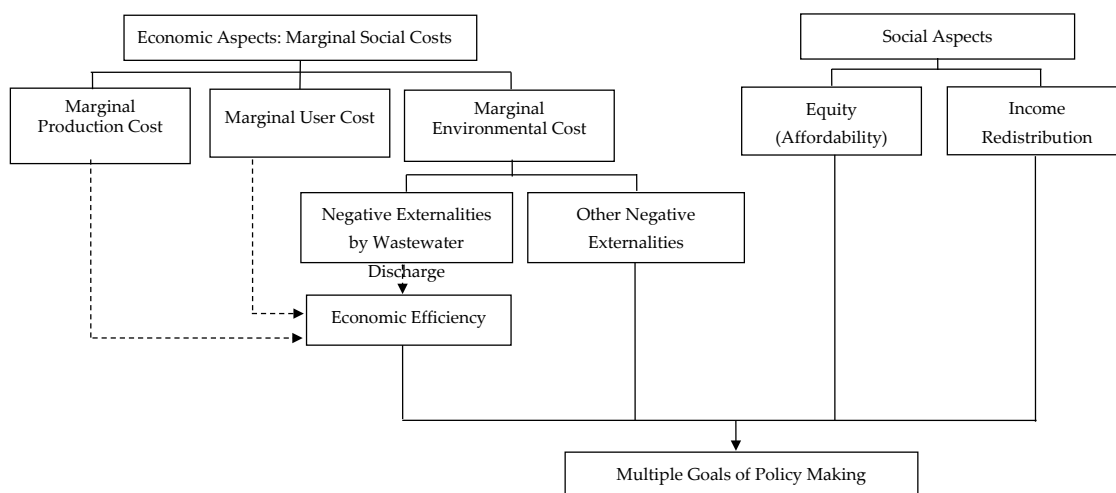
Figure 1. Multiple goals of policy making. Notes: Wastewater discharge creates negative externalities and can be evaluated as the cost of sewage treatment based on the defensive expenditures theory. Notably, the possible externalities, including dam construction damaging local ecosystems and those related to hedonic values, for example, fisheries, tourism, and recreation, are difficult to evaluate in the production stage. Therefore, these costs should be considered separately from the marginal social cost as an additional concern in policy making, and the term "economic efficiency" should be left to the marginal social costs, including the marginal production cost, marginal user cost, and cost of negative externalities caused by wastewater discharge.

Previous literature provide the experiences of water pricing practices. Increasing block tariffs (IBTs) is widespread throughout developing countries because of two accepted justifications. The first is based on a rationale of equity and asserts that IBTs should assist low-income households through cross-subsidies. The second justification for IBT structures is that the higher prices charged beyond the initial block discourage "extravagant" water use and promote water conservation [6]. For example, Chennai of India has implemented four-block tariff with size of initial block equal to 10 m^3 and the price of highest block equal to 0.53 US\$/m^3. However, only about 60% of installed meters are working. Bangalore of India implemented a five-block tariff with the size of the initial block equal to 25 m^3 and the price of the highest block equal to 0.70 US\$/m^3, and almost all the installed meters are working. Colombo of Sri Lanka implemented a six-block tariff with the size of the initial block equal to 10 m^3 and the price of the highest block equal to 0.27 US\$/m^3. Kathmandu of Nepal has implemented a two-block tariff with the size of initial block equal to 10 m^3 and the price of the highest block equal to 0.12 US\$/m^3; however, only about 60% of the installed meters are working, as Chennai [7].

Some literatures conduct policy evaluation comparing the policy effects of the different goals between IBTs and a traditional but widespread pricing system, the uniform tariff with rate (UTR). Rietveld et al. [8] estimated the social welfare consequences effect of switching from current IBTs to the two types of uniform pricing systems (that is, the price level is set equal to the current average price, and the price level of the remaining aggregate demand is unchanged) in Salatiga, a city in Indonesia. The switch favored all households, and the principal beneficiaries were the larger-sized households.

Notably, the current IBTs fail to increase the welfare of poor households, because this policy only favors small-sized households, which includes the poor and wealthy. Pashardes et al. [9] estimated the change in the pricing system in Cyprus and demonstrated that the regionally heterogeneous IBTs cause deadweight loss because of gross price distortions, and the uniform marginal cost pricing system performs better than IBTs in economic efficiency. Notably, the benefits of a uniform marginal cost pricing system are distributed to wealthier families, and the families at the bottom 10% of the income distribution have a negative value of expenditure effect that indicates they will be the net losers should the pricing system change from the current policy of IBTs to a uniform marginal cost pricing system.

The central government of China encourages the implementation of IBTs. The reform of IBTs has been implemented in many cities in China. The aim of implementing IBTs, as declared by the government, is to improve water use efficiency as well as to provide efficient incentives for water savings. However, we observed some commonalities of these implemented IBTs that may lead to failure to achieve the aim: the oversized initial block and the lower level of price differentiation between the blocks. For Beijing, the range of the initial block size is from per capita 3.8 to 15.0 m^3/month. This result may heavily subsidize the households with higher usage, that is, luxurious use is also subsidized. Additionally, the price differentiation between blocks is 2 RMB/m^3 (0.32 US$/m^3), which provides little incentive to conserve water. Before the IBT reform, Beijing implemented a uniform tariff with the price level set equal to 4 RMB/m^3 (0.63 US$/m^3). The IBT reform with such an inappropriate tariff structure is expected to increase the overall amount of water charges rather than balance multiple goals.

The aim of this study is to explore the comparative performances of different goals between IBTs and a uniform tariff with rebate (UTR; the price is set equal to the marginal social cost). This study differs from the literature in two ways. First, this study starts by simulating these two appropriate tariff structures according to their basic framing principles, and pioneers identifying the intrinsic merits and demerits of these two price structures, rather than conducting policy evaluations as in the previous literature. Second, the policy evaluations in the literature have been conducted under the assumption that residents respond to marginal price under IBTs, which is nonlinear tariff structure; Hewitt and Hanemann [10] used the "as if" theory proposed by Friedman [11] (pp. 19–20) to support the assumption that on average households do behave "as if" they knew the rate structure. However, this assumption may not hold under IBTs according to the results of the subsequent empirical studies. Residents have been observed to possibly respond to an average price based on the price level given by total fees divided by total consumption rather than marginal price [12–18].

Identifying the price type that residents respond to is critical to accurately estimating water demand and welfare analysis. For this reason, in conducting this study, we cite the results of a study on residential water consumption behavior in the same research program as Ma et al. [18]. The paper is organized as follows. Section 2 introduces how to design tariff structures under fundamental principles. Section 3 formalizes an economic model of residential water demand and presents the indexes of the performance of policy objectives and a detailed description of the data. Section 4 presents the results of the comparison between UTR and IBTs. The final section concludes the paper.

2. Policy Options and Simulation

2.1. Uniform Tariff with Rebate

The fundamental principles for a UTR structure are presented as follows.

(1) *Marginal social cost pricing rule.* Jaeger et al. [19] define water scarcity as the marginal value of a unit of water on the demand curve. This definition of water scarcity is seen as fundamentally normative and anthropocentric. Water scarcity is a value concept that refers to the opportunity costs of forgone human options caused by insufficient water availability to fully satisfy all competing uses [20]. Beijing encounters water scarcity consistent with this definition. Because water availability was insufficient in Beijing in 2011, 7% of water demand was met by the South-to-North Water Diversion Project (SNWDP) [21]. The unit cost of delivering one ton

of water to Beijing can be regarded as the opportunity cost that society pays for the delivery. So, the investments for other purposes may be crowded out, and the output values of these investments may be reduced. Specifically, the opportunity cost can be regarded as the marginal cost for the increase in water demand, and it includes both marginal production cost and marginal user cost (it is not possible to separate these two kinds of cost from the whole cost (7.00 RMB/m^3)). The cost level is 7.00 RMB/m^3 ($1.11 \text{ US\$/m}^3$) (RMB is the Chinese currency; the exchange rate is 6.3 RMB per dollar in 2011) [22]. As the adoption of the new techniques to reduce the negative externalities increased the cost of sewage treatment, the current sewage treatment cost rose to 1.71 RMB/m^3 ($0.27 \text{ US\$/m}^3$), which we approximate as the marginal cost of negative externalities by wastewater discharge [23]. Therefore, the marginal social cost is 8.70 RMB/m^3 ($1.38 \text{ US\$/m}^3$) (including marginal production cost, marginal user cost, and cost of negative externalities by wastewater discharge). Moreover, as there is no accurate and real data available to allow us to determine the marginal social cost curve of water service, we assume the marginal social cost being equal to 8.70 RMB/m^3 ($1.38 \text{ US\$/m}^3$) has been unchanged over time.

(2) *Rebate mechanism.* Rebates are generally assigned on the basis of eligibility criteria presumed to have a strong correlation with poverty. The eligibility criteria refer to the rebate provided to low-income households whose water expenditures for basic needs exceed the standard of economic affordability. The related question is how to define basic needs, affordability, and low-income households.

   (a) Basic needs. Reed [24] defined the minimum water quantity needed physiologically and set a per capita consumption of 25 L/day as the minimum consumption for survival. We argue it is not appropriate to follow this standard, because the basic needs should be related to a social attribute in an economic study. According to our survey sample, 20% of residents consume less than $2.0 \text{ m}^3/\text{month}$, and 50% less than $2.5 \text{ m}^3/\text{month}$. We propose per capita $2.0 \text{ m}^3/\text{month}$ and $2.5 \text{ m}^3/\text{month}$ as the respective minimal and maximal standards for minimal basic needs.

   (b) Affordability criterion. We follow the criterion suggest by Smita [25] that if water expenditure share exceeds 3%, the poor are discouraged from using the amount of water for basic needs.

   (c) Rebated objects (definition of low-income household). Means-tested programs are conducted by Beijing Civil Affairs Bureau [26] to identify and enroll low-income households. The urban poor is defined as those whose per capita income is less than 480 RMB/month (76.2 US\$/month) by the Beijing Civil Affairs Bureau. These households are eligible to apply for rebate, that is, if their water expenditure share for basic needs is defined as greater than 3%, the government should provide a rebate of 3%.

2.2. Increasing Block Tariffs

The most important factors and parameters to simulate IBTs are presented as follows.

(1) *Initial block.* The initial block is related to fairness and is a rebate mechanism of UTR to assure affordability for basic needs that includes block size and rate.

   (a) Block size. The block size should avoid being oversized or it allows all consumers (i.e., poor and wealthy households) to be heavily subsidized and to take advantage of infrastructure services. For equal consideration with UTR, we select per capita $2.0 \text{ m}^3/\text{month}$ and $2.5 \text{ m}^3/\text{month}$ as the respective minimal and maximal size of the initial block as a lifeline block.

   (b) Block rate. The initial block rate should be set sufficiently low to achieve affordability paired with its block size. Additionally, for political acceptability, we suggest not exceeding the current price [4.00 RMB/m^3 ($0.63 \text{ US\$/m}^3$)]. Thus, we simulated two

rates: 3.00 RMB/m^3 (0.48 US$/m^3) and 4.00 RMB/m^3 (0.63 US$/m^3). Under both rates, the average expenditure share for the basic needs (the consumption at the initial block) of each income group is less than 3% (the income groups' segmenting is presented in Section 3).

(2) *Rate differentiation between blocks.* We start with a two-block tariff simulation. The rate differentiation between the initial block and the second block should be designed to realize two goals: The first goal is that the rate differentiation encourages water conservation for the households with luxurious use and that are sensitive to price change. The second goal is that the rate differentiation charges a greater fee for use in the second block (i.e., the price level is higher than the marginal social cost) to compensate the lower charge for basic needs in the initial block (i.e., the price level is lower than the marginal social cost). We simulated a band of two-block tariff structures with the rate range of the second block from 10.0 RMB/m^3 (1.58 US$/m^3) to 25.0 RMB/m^3 (3.97 US$/m^3).

(3) *Number of blocks.* Additional blocks can further classify luxurious consumption (e.g., a smaller amount of water use for breeding small animals, and a larger amount for garden irrigation or car washing) and charge differently. For example, when turning two-block tariffs into three-block tariffs, by retaining the size and rate of the initial block (assuring affordability), the second block can be extended into two new blocks forming three-block tariffs: lowering the rate of the second block to a new level at the rate of the second block of the three-block tariffs, and increasing the rate of the second block to another new level at the rate of the third block of the three-block tariffs. Increasing the number of blocks mainly influences the pattern of cost sharing between the wealthier households. A design with additional blocks may increase the cognitive cost to understanding the tariff structure that may induce people to respond to other types of rates, rather than the marginal rate of increasing block tariffs [17,18]. If people do not respond to the marginal rate, it would weaken the efficacy of the "increasing block," and we consider efficacy a priority in our research. Thus, in this study, we only extend the structure design to three-block tariffs.

(4) *Size of the second block.* As the block size of the second block is associated with moderate luxurious use, its amount is approximately a maximum per capita 1.0 m^3/month in Beijing based on the statistics. Thus, the size of the second block in the three-block tariff structure is set equal to 1.0 m^3/month.

According to the aforementioned discussion, the two-block and three-block tariff structures in Table 1 are simulated as the representatives, which means these simulated structures are expected to represent the different design philosophies (i.e., a lower rate for the initial block with a higher rate for the second block, or a larger size for the initial block with a higher rate for the second block).

Table 1. Tariff structure simulation.

Serial Number	1F	2F	1P	2P	3P
A-18	2	-	3.00 (0.48)	18.00 (2.86)	-
B-16	2	-	4.00 (0.63)	16.00 (2.54)	-
C-21	2.5	-	4.00 (0.63)	21.00 (3.33)	-
A-25	2	3	3.00 (0.48)	14.00 (2.22)	25.00 (3.97)
B-23	2	3	4.00 (0.63)	12.00 (1.90)	23.00 (3.65)
C-32	2.5	3.5	4.00 (0.63)	17.00 (2.70)	32.00 (5.08)

Notes: 1F and 2F indicate the sizes of the initial and second blocks (per capita m^3/month). 1P, 2P, and 3P indicate the rates of the initial, second, and third blocks [RMB/m^3 (US$/ m^3)].

3. Methodology and Data

3.1. Demand System for Household Water Use

The issue of the functional form to be used in demand estimation has not received extensive attention, and few water demand papers have used flexible functional forms [27]. We use the Quadratic Almost Ideal Demand System (QUAIDS) proposed by Bank et al. [28] because residential water has the characteristics of being a necessity at lower income levels and changing to a luxury at higher income levels. This demand system also satisfies the axioms of choice and aggregates perfectly over consumers without invoking parallel linear Engel curves, etc. The QUAIDS of residential water use is thus as follows:

$$w_h = a + \gamma lns + \beta \left[lnx_h - alns - 0.5\gamma(lns)^2 \right] + \frac{\lambda}{s^\beta} \left[lnx_h - alns - 0.5\gamma(lns)^2 \right]^2 + \\ \varphi_1 lnfreq + \varphi_2 lnavper + \varphi_3 older + \varphi_4 children \tag{1}$$

where w_h is the water expenditure share of the *hth* household; $lnx_h = lny_h - a_0$, lny_h is the log income of the *hth* household; and a_0 is the log income of the subsistence level that indicates the minimal expenditure for living and is set at ln(480 RMB (76.2 US\$)) per capita by the Beijing Civil Affairs Bureau (Beijing Bureau of Civil Affairs, 2010). $s = p/P$, p is water price, and P is the price index summarizing the cost of all goods other than water. The prices of all goods other than water for domestic consumption are fixed; we may normalize $P = 1$. *lns* is the log value of *s*. Water consumption negatively associates with water price in the previous literature [9,29,30]. Water price rises may lead to reduction in water consumption. The reduction is largely contributed by the reduction in luxury use, because the consumption for subsistence need is price-inelastic.

$\alpha, \beta, \gamma, \lambda, \varphi_1, \varphi_2, \varphi_3$ and φ_4 are the parameters to be estimated. α, γ, β and λ measure price effect. β and λ also measure income effect. β is the exponent of the simple Cobb-Douglas price aggregator. λ captures the effect of quadratic term in logarithm of expenditure (see the derivations of the four parameters in Bank et al. [28]). $\varphi_1, \varphi_2, \varphi_3$ and φ_4 are the marginal effects of log billing frequency, log household size, and the marginal effects of the two dummy variables, whether a family has elders or children, respectively.

The demand function also includes other determinants that have been suggested in the literature [29–33]. *lnfreq* represents log billing frequency measured by how often households pay their water bill (on a half-year basis). The previous studies show a higher bill frequency may make households be more familiar with the price rates, resulting in more water savings; or oppositely, lump sum billing may make a stronger shock on households, resulting in a stronger water saving incentive [30,33,34]. *lnavper* is log household size; previous studies show that there may be an inverted U shape between household water consumption per person with household size [32,33,35]. *Older* and *children* are defined as dummy variables based on whether a family has elders or children. As elders and children may spend more time at home, it is expected to increase water consumption. If a family has elders (age > 60 years old) or children (age < 7 years old), the value of *older* (*children*) = 1; if not, the value = 0.

3.2. Assessment of Policy Performances on Multiple Goals

Water tariffs are expected to reach broader social–economic goals, including affordability (fairness), economic efficiency, and the redistributional impact on the welfare of households, and exhibit concern for other negative externalities. In Section 3.2, we introduce the variables expected to be used to compare the differences in the extent to which goals can be fulfilled between UTR and IBTs (Table 2).

(1) ***Affordability (fairness).*** We compute water expenditure shares of different income groups as the indicator of affordability under each simulated price structure and compare them with the maximum value of 3%, as proposed by Smita [25].

(2)   *Economic efficiency.*   We use deadweight to measure economic efficiency loss under the assumption that the marginal social cost [8.70 RMB/m^3 (1.38 US$/m^3)] is unchanged over the consumption of households (hence, the marginal social cost equals the average cost).

Consumer surplus is defined as the area between the demand curve and the charged prices. Producer surplus is defined as the area between the charged prices and the marginal social cost. Social welfare is the sum of consumer surplus and producer surplus.

Specifically, we compute deadweight loss as follows. Suppose household h consumes at the second block (the water consumption is q$_{\text{IBTs}}$), the rate of which is greater than the marginal social cost, the social surplus equals the *area$_{CEG}$* under UTR (consumer surplus is *area$_{CEG}$* and producer surplus is zero) and *area$_{ABEG}$* under IBTs (consumer surplus is *area$_{AFKHIG}$*; and the producer surplus is the value of *area$_{ABKF}$* minuses *area$_{KHIE}$*). Therefore, the deadweight loss is expressed as the *area$_{ABC}$* when price policy switches from UTR to IBTs (Figure 2). In this paper, we use compensating variation (*CV*) instead of variation in consumer surplus to compute the changes in consumers' welfare, because it may be very complex to derive consumer surplus in *QUAIDS*. Hence, social welfare is the sum of the compensating variation and producer surplus. Compensating variation (*CV*) under QUAIDS can be defined as an expenditure index which measures the amount of income that an individual household would be willing or pay (or willing to accept) in order to keep the original tariff structure. It is written as (Pashardes et al. [9] provides the derivation formulas of *CV* under QUAIDS):

$$lnX_h = ln\left(\frac{x_{1h}}{x_{2h}}\right) = (w_{2h} - 0.5\gamma lnp_2)lnp_2 \tag{2}$$

where x_{1h} is the expenditure level required by household h facing price p_1 to maintain utility at the level achieved under the reference price p_2. x_{2h} is the expenditure level and w_{2h} is the water expenditure share under the original tariff structure.
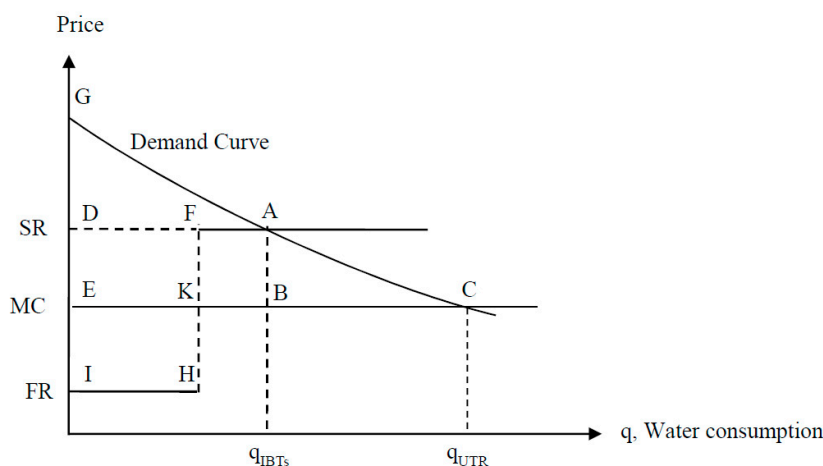
Figure 2. A simple sketch figure conceptually showing how to estimate efficiency loss Notes: "FR" and "SR" are the first and second rate of IBTs, respectively. "MC" is the marginal social cost. Moreover, in this example, we assume household i responds to marginal price. q_{UTR} and q_{IBTs} are optimal consumptions of household h under UTR and IBTs, respectively.

(3)   *Concern for other negative externalities.* Water usage may induce the damage of local ecosystems and negative externalities related to hedonic values, such as fisheries, tourism, and recreation. Notably, concerns may be raised regarding valuation techniques, such as double counting benefits [36] that make the evaluation difficult and increase bias. The evaluation for this concern is out of the scope of this study. We adopted per capita water consumption as a proxy variable to approximately indicate the relative impact on this aspect, that is, the tariff structure encouraging greater water conservation imposes fewer negative externalities.

(4) ***Redistributional impact on welfare of households.*** Any major water price reform has income redistributional effects on the welfare of individual consumers, that is, there will be winners and losers; therefore, considering how to manage potential hardships caused by the water price reform is necessary. We examine how the tariff structure switch, that is, from UTR to the various IBTs, would affect households in different income brackets. Specifically, we derive estimates of the welfare redistribution effected, that is, the *CV* of different income brackets, based on the change of tariff structures.

Table 2. Variables used to compare the difference in the extent to which the goals can be fulfilled between uniform tariff with rebate (UTR) and increasing block Tariffs (IBTs).

Goals	Variables	Description of How to Compare UTR and IBTs
Equity (affordability)	Water expenditure share	Comparing water expenditure share
Economic efficiency (excludes the costs of other negative externalities)	Social welfare	Comparing social welfare [a]
Concern for other negative externalities (which cannot be monetized)	Per capita water consumption	Comparing per capita water consumption
Redistributional impact	Compensating variation	Compensating variation of different income groups when tariff structure switches [b]

[a] We compute the changes in social welfare when the tariff structure switches from UTR to IBTs. [b] Similarly, we compute compensating variation of the income groups when the tariff structure switches from UTR to IBTs.

3.3. Data Sources

The study is based on two data sources. First, the data source for behavioral analysis under UTR is the Chinese Urban Household Income and Expenditure Survey (HIES), collected by the State Statistical Bureau of China. The data collected directly from the Beijing State Statistical Bureau from the urban HIES cover the years 2002 to 2010 on a household level, including monthly data from 1368 households. We use this data to estimate the price and income elasticities under the uniform tariff to perform the welfare analysis. During this period, the uniform tariff was implemented in Beijing.

The second data source is regarding behavioral analysis under IBTs. As IBTs were not implemented in Beijing until 2015, the experimental designs were conducted to collect the data on water use under IBTs. We designed various two-block IBTs that included sufficient variations in size and price of block to obtain consumption of household and demographic variables from the questionnaire survey; next, we identify the price types consumers respond to. This work was completed by Ma et al. [18], and this study cites those results to perform the welfare analysis.

The sample comprises 1104 respondents collected by our program study group between September 2011 and October 2011 by using simple random sampling. The sample covers all urban administrative districts in Beijing and has a population similar in proportion to that of China's official statistics.

In Table 3, we aggregate each of the two data sources to seven income groups that are approximate quintile breaks, except the lowest and highest income groups: the lowest 5% (group 1); 5% < but ≤ 20% (group 2); 20% < but ≤ 40% (group 3); 40% < but ≤ 60% (group 4); 60% < but ≤ 80% (group 5); 80% < but ≤ 95% (group 6); and over 95% (group 7).

Table 3. Disposable income and water consumption of the income groups.

Income Group	1	2	3	4	5	6	7
Disposable Income [a]	366 (58)	935 (148)	1682 (267)	2506 (397)	3582 (568)	5790 (919)	11,486 (1823)
Water Consumption [b]	2.4	3.1	3.0	3.3	3.6	3.5	4.0

[a] Unit: RMB (US$) per person per month. [b] Unit: m^3 per person per month.

4. Empirical Results

4.1. The Regression Results of QUAIDS

The parameter estimations of *QUAIDS* are used to predict water consumption and water expenditure share under a given tariff structure, and to compute compensating variation (CV) when tariff structure switches from one to another. Table 4 provides the regression results. All income groups are sensitive to income changes, since the estimation of the parameters β and λ are significant at 1% for all income groups. In comparison with the other six income groups, Group 7 is not sensitive to price changes, since the estimation of the parameter γ is not significant at 10%. Only household size φ_2 shows significance with positive sign for all income groups, indicating a larger household size leads to a higher per capita water consumption (Table 4).

Table 4. The regression results of the parameters of QUAIDS for the income groups.

Income Group	1	2	3	4	5	6	7
α	0.22 (0.00) ***	0.32 (0.00) ***	0.21 (0.00) ***	0.22 (0.00) ***	0.24 (0.00) ***	0.18 (0.00) ***	0.17 (0.00) ***
β	0.04 (0.00) ***	0.07 (0.00) ***	0.04 (0.00) ***	0.04 (0.00) ***	0.05 (0.00) ***	0.03 (0.00) ***	−0.03 (0.00) ***
γ	−0.006 (0.00) ***	−0.01 (0.01) ***	−0.007 (0.00) ***	−0.007 (0.00) ***	−0.002 (0.00) ***	−0.005 (0.00) ***	0.001 (0.16)
λ	−0.002 (0.00) ***	−0.004 (0.00) ***	−0.002 (0.00) ***	−0.002 (0.00) ***	0.001 (0.00) ***	−0.001 (0.00) ***	0.001 (0.00) ***
φ_1 (billing frequency)	0.0006 (0.49)	−0.0008 (0.58)	−0.001 (0.13)	3.89×10^{-6} (0.99)	0.0003 (0.53)	−0.0001 (0.78)	0.00008 (0.90)
φ_2 (household size)	0.004 (0.00) ***	0.003 (0.00) ***	0.004 (0.00) ***	0.004 (0.00) ***	0.002 (0.00) ***	0.002 (0.00) ***	0.002 (0.00) ***
φ_3 (whether has elders)	0.0001 (0.67)	−0.0007 (0.22)	−0.0001 (0.71)	0.0001 (0.71)	−0.0001 (0.61)	0.0003 (0.10)	0.0001 (0.58)
φ_4 (whether has children)	−0.0005 (0.15)	−0.0002 (0.73)	0.0005 (0.07) *	−0.0002 (0.38)	−0.0001 (0.64)	0.0002 (0.37)	−0.00009 (0.74)

Notes: See the definitions of the parameters in Section 3.1. QUAIDS is the abbreviation for Quadratic Almost Ideal Demand System of residential water use. *p*-values are in parentheses. * $p < 0.05$; *** $p < 0.001$.

4.2. Comparing IBTs with UTR

(1) **Affordability (fairness).** We observe in Figure 3 that average water expenditure shares in the lower income groups are generally less than in the higher income groups, and all income groups are less than the 3% criteria across all IBTs. The water expenditure share of the lowest income group is 5.5% and charged at a marginal social cost, indicating an overburden on low-income households and they deserve a rebate. The amount of the rebate is on average 8.0 RMB/month per capita. Notably, to make rebates feasible, a system must be established and the rebate program must be commensurate with the available funding to fulfill its intended affordability objective. Thus, the program's administrative costs must be considered.

(2)　***Economic efficiency.*** Achievement of fairness by IBTs is at the cost of economic efficiency loss. A utility would have to impose a rate greater than the marginal social cost on higher income users while offering a lower rate to low-income users. The standard efficiency argument requires setting the price level equal to the marginal social cost for all users, which clearly indicates that the increasing block tariff structure distorts the relative marginal prices that different customers incur. This study reported the magnitude of economic efficiency loss by price distortion A-18, B-16, and C-21, with a marginal price lower than the marginal social cost for the first block and a marginal price higher than the marginal social cost for the second block. The results showed the deviation from the social welfare achieved by UTR is per capita 0.42, 0.34, and 0.51 RMB/month (0.07, 0.05, and 0.08 per capita US$/month) for A-18, B-16, and C-21, respectively.

(3)　***Concern for other negative externalities.*** We expected the rate differentiation of IBTs to encourage greater water conservation in contrast to UTR; however, we observed that the evidence is inconsistent with the supposition that UTR (2.80 per capita m^3/month of water consumption) induces a greater incentive to conserve water than B-16 (2.95 per capita m^3/month) and A-18 (2.82 per capita m^3/month). This result may be partially attributed to the majority of households responding to the average price, rather than marginal price. And this attribution implies that households treat IBTs as increasing linear tariffs (in this tariff structure, the price a household pays increases continuously as the quantity of water used increases). Thus, this tariff structure may not incentivize water conservation that exerts discrete choice across blocks under IBTs as powerfully as expected [18], because the price differentiation between the current unit and the decrease in additional units varies much less than the rate differentiation between blocks. This result leads us to question the justification for using IBTs as the best pricing system for water conservation.

(4)　***Redistributional impact on household welfare.*** We observe that the switch from UTR to the various IBTs substantially redistributes welfare to lower income groups (i.e., the three lowest income groups), and consumer welfare in terms of currency increased per capita by greater than or equal to 5 RMB/month (0.82 US$/month; Figures 4–6). Households in the lowest income group benefit most from implementing IBTs, because the rate of the initial block is far less than the marginal social cost, and their substantial consumption located at the initial block associated with basic needs has little variability in relation to price change. The largest transfer occurs in the wealthiest households, decreasing the welfare of households by greater than per capita 7 RMB/month (1.14 US$/month) for all IBTs. Additionally, a much greater share of the redistributed revenue is from the wealthier quintile of households because of more progressive IBTs. Widening the rate differentiation between the initial and second blocks is the impetus for heavier cross-subsidies across income groups and spreads the contribution burden more unevenly among the wealthy households.

To sum up, IBTs offer a policy instrument that redistributes welfare from wealthier to poorer households in different magnitudes across wealthier income groups without administrative efforts, in contrast with UTR, and policymakers can design a single IBT to realize the intended pattern of the social cost shared among income groups. We also detected that the degree of redistributional impact is prominently associated with time interval. Short-term *CV* (the black blocks in Figures 4–6) measures changes in welfare under the assumption that when the pricing system switches, households cannot immediately adjust their water consumption, because the habits of water consumption cannot be changed immediately. Additionally, purchasing water-saving appliances takes time. Thus, water consumption is assumed to be unchanged over a short period, and long-term *CV* is measured according to the responses to price changes. The monetary value of the welfare increases in the long term, that is, approximately per capita 1.87 RMB (0.29 US$), 1.78 RMB (0.28 US$), and 0.97 RMB (0.15 US$) per month greater under A-18, B-16, and C-21, respectively, than in the short term across all income groups. The literature has observed that the welfare gains from the short to long term for middle-income households are obviously greater than for poor households because of a higher elastic response to changes in prices. We suggest that policymakers pay close attention to the short-term *CV* of poor

households, because the results from the literature have demonstrated that the poorest households may suffer welfare loss in the short term caused by price reform [9]. This information may remind policymakers of the emergency measures for rebates required during this period.
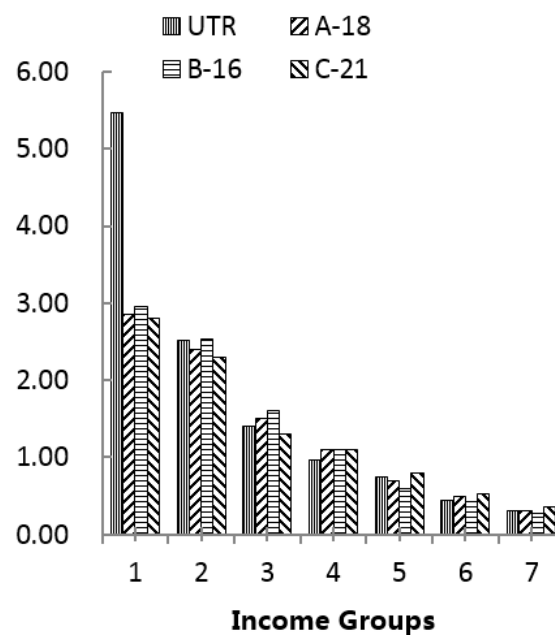
Figure 3. Water expenditure shares of different income groups under UTR and IBTs (%).
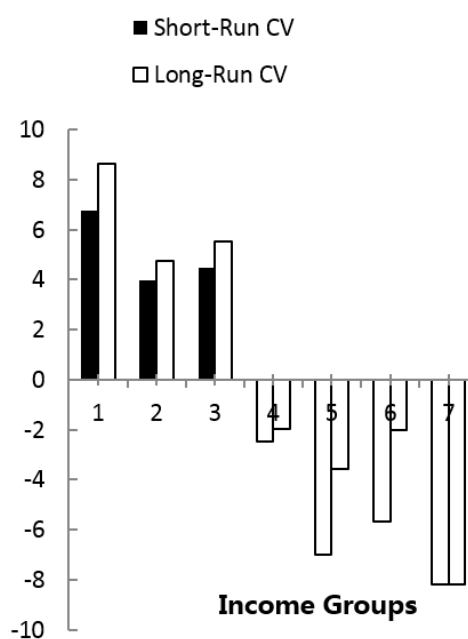
Figure 4. Comparison between UTR and A-18 on consumer welfares (per capita RMB/month) Notes: If *CV* is positive (or negative), welfare is increased (or decreased) when the qw pricing system switches from UTR to IBTs. Similar explanation for Figures 4 and 5.
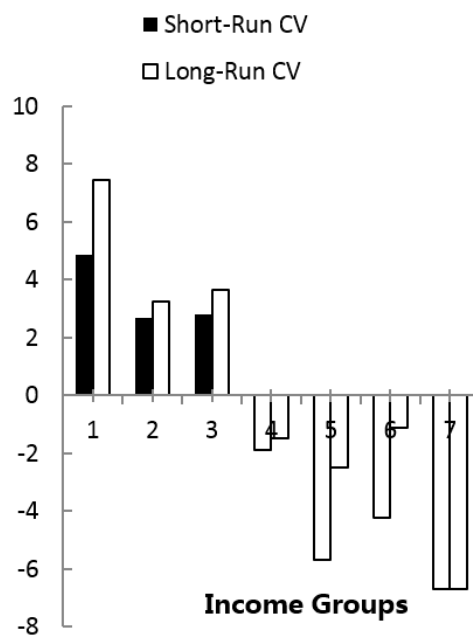
Figure 5. Comparison between UTR and B-16 on consumer welfares (per capita RMB/month).
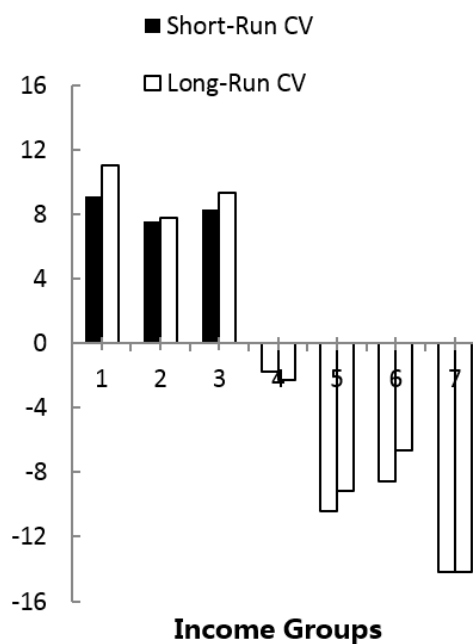
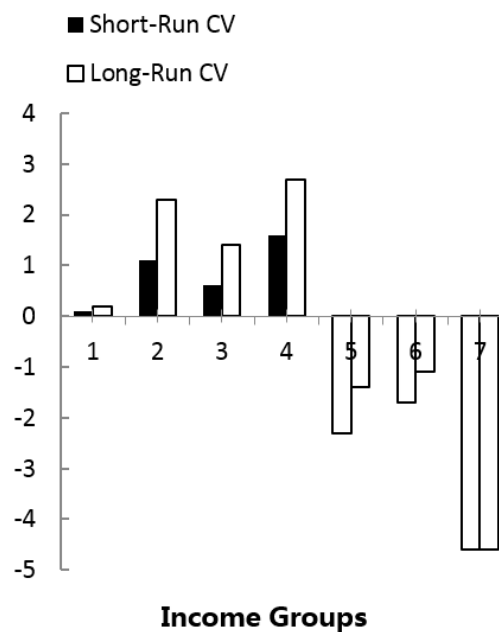**Figure 6.** Comparison between UTR and C-21 on consumer welfares (per capita RMB/month).

We also explored the comparison between IBTs with two and three blocks on the redistributional impact that embodies their major difference. Similarly, we compute *CV* as the pricing system switches from two-block to three-block structures. Because the second-block rate of three-block IBTs is less than that of two-block IBTs, the welfare increases for households with a small amount of luxurious use and decreases for larger-usage households (Figures 7–9).

We assert that Beijing will incur more serious water scarcity in the future. If that is the case, two-block IBTs require a sufficiently high second-block rate that probably places the vast majority of households in the lifeline block, or it will fail to achieve social cost recovery. As a result, all of the burden of social cost recovery is imposed on price-inelastic but large-usage households.

The IBTs with more blocks are expected to make the households with a small amount of luxurious usage remain in the luxurious blocks to enjoy their luxurious usage. Therefore, a more-blocks structure

design may be more appropriate under such a condition, although, in a conflicting manner, additional blocks may pose greater complexity for households, regarding the awareness of the rate structure as it applies to their specific use. Once the cognitive cost of the tariff structure of IBTs exceeds the welfare gains from the decision on marginal price, it causes the IBTs to be considered as an increasing linear tariff [17].
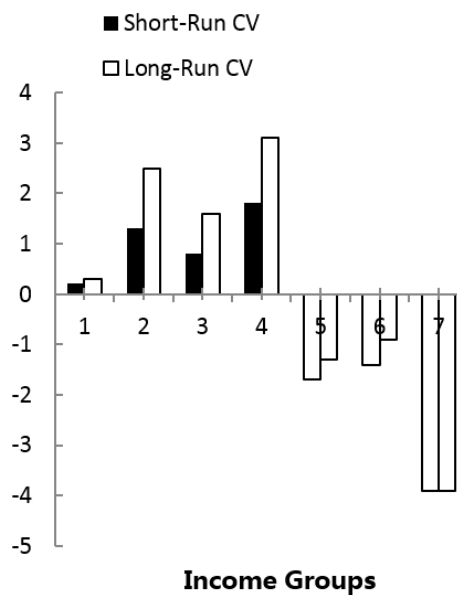
Figure 7. Comparison between A-18 and A-26 on consumer welfares (per capita RMB/month).
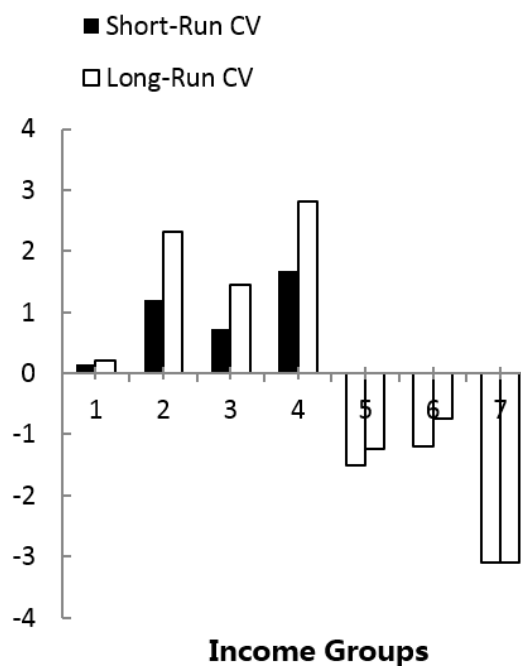
Figure 8. Comparison between B-16 and B-23 on consumer welfares (per capita RMB/month).

Figure 9. Comparison between C-21 and C-32 on consumer welfares (per capita RMB/month).

5. Conclusions and Policy Implications

Water utilities and regulators in many countries are in favor of using price IBTs in contrast to UTR as a water demand management tool, because in theory, IBTs can promote conservation by setting high marginal prices for many consumers while protecting small water consumers and especially the poor, by maintaining a relatively low price for the baseline level of consumption [37]. However, a few scholars have published their arguments against IBTs based on policy evaluations [8,9,38]. This study simulates the effects of the two pricing systems, UTR and IBTs, to explore their fundamental merits and limitations. Our results suggest it is possible to assert that, in contrast with UTR, IBTs are a better management tool, based on the assurance of fairness and a desirable distributional pattern of the social cost among income groups by tariff structure, namely, without extra administrative efforts; however, this outcome would be achieved at the cost of the economic efficiency loss computed in this study. In conclusion, the results of this study indicate neither IBTs nor UTR shows better performance in all policy goals, that is, neither of them should be favored.

For policy suggestions, we might not suggest the UTR reform for Beijing because of political feasibility. If a government implements a UTR pricing system and increases the price level directly up to the marginal social cost (8.70 RMB/m^3 (1.38 US\$/m^3)), the policy may encounter political unacceptability that serves as a focus of public criticism. Thus, we continue to prefer IBTs, and specifically the first block rate, because it is lower than 4 RMB/m^3 (0.63 US\$/m^3) to relieve public pressure and the significant price gaps between blocks.

In practice, both price systems may encounter problems. For UTR, to realize water use subsidies for poor households, the administrative costs of the subsidy program need to be taken into account. For IBTs, (1) shared apartments is an issue. Water charge is metered by household as a unit. If the persons living in the house are not family, weaker cooperation for water savings is expected. IBTs also have a (2) population mobility issue. The sizes of blocks are determined by household size. Hence, water utility must register household size for each household. If the city has a high population mobility leading to frequent changes in household size, calculating water charges for water utility becomes difficult.

Additionally, policymakers should be cautious of the notion of "increasing block" to encourage water conservation, because conservation may depend highly on how consumers respond to price changes. This phenomenon might be the reason why the conservation incentives of IBTs may not

necessarily be greater than those of UTR. Therefore, we conclude that an optimal tariff structure might be difficult to obtain in a case with multiple policy objectives where one may counteract the other, and that the design of effective and efficient tariff structures should prioritize the most urgent problems.

Notably, we must address the important issue of economic efficiency, which may deprecate the marginal cost pricing rule for water service under some conditions, and we failed to perform an empirical analysis because of data unavailability. The marginal cost pricing rule might not achieve the desired socially efficient outcome, or might be practically unfeasible as water supply and sewage treatment are capital-intensive and require lumpy infrastructure investments. The advantage is that water supply and sewage treatment are often subject to increasing returns to scale, frequently to the extent of being a natural monopoly.

This phenomenon has two implications. First, for a given scale or in the short term, the marginal cost of supply or sewage treatment is generally constant or even declining in consumption and lower than the average cost of supply or sewage treatment. This observation means that, due to these decreased investment costs, low levels of consumption have a very high marginal cost compared with higher levels of consumption, and the average cost will decline to a minimum efficient scale. Secondly, and consequently, marginal cost pricing will not recover the full costs of supply and sewage treatment and is not guaranteed to be efficient in the long term, that is, as the size of the distribution and treatment system increases, average costs tend to decrease.

The scope of our study encompasses IBTs and UTR, but actually other price mechanisms exist, such as two-part tariffs [39] and variable unit pricing [40]. These mechanisms are proved to have objective foundations with well-defined formulas to calculate efficient rates. Specifically, Griffin [39] develops the establishment of a basic model for determining the efficient rates of two-part tariffs (a fixed meter charge and a payment for metered consumption) that can achieve the goal of cost recovery without sacrificing economic efficiency. Loehman [40] develops a variable unit pricing that can achieve multiple goals: provide incentives for water conservation and maximize total benefit while achieving cost recovery. Policymakers should pay attention to the domain of water price mechanisms to determine the most appropriate price system.

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