

Evaluating the Performance of Alternative Municipal Water Tariff Designs

*Quantifying the Trade-offs between Cost
Recovery, Equity, and Economic Efficiency*

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Abstract

The design of municipal water tariffs requires balancing multiple criteria such as financial self-sufficiency for the service provider, equity, and economic efficiency for society. A modelling framework is developed for analysing how alternative municipal water tariff designs affect these three criteria. It is then applied to a hypothetical community in which a municipal water utility provides metered, piped water and wastewater services to 5,000 households. We analyse how the shift from a uniform volumetric tariff to different increasing block tariff (IBT) designs affects households' water use and water bills, and how these changes in turn affect measures of equity and economic efficiency for different financial self-sufficiency targets. We calculate how changes in assumptions about 1) the correlation between household income and water use, and 2) households' response to average or marginal prices affect the tariffs' performance in terms of these three criteria. The results show that IBTs perform poorly in terms of targeting subsidies to low-income households regardless of the magnitude of financial subsidies that a utility receives from high-level government. When cost recovery is low, the distribution of subsidies under IBTs is even worse if the correlation between water use and household income is high. IBTs introduce price distortions that induce economic efficiency losses, but we show that these welfare losses are relatively small when households respond to average prices instead of marginal prices.

Key Words: tariff design, increasing block tariffs, water pricing

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1. Introduction

There are many reasons to get water prices right. Increasing water scarcity and climate change now need to be added to the list. Climate change, in particular, presents water and wastewater utilities with a complex new set of management and strategic challenges, especially in developing countries. One important way for water utilities to deal with the uncertainty introduced by climate change is to maintain cash reserves that can be deployed to address problems as they arise. But few water utilities generate sufficient cash to cover their full costs, and typically are unable to invest to protect strategic capital assets from extreme events or to build new capital facilities to address changes in rainfall and streamflow variability.

It is thus increasingly important for water utilities to adopt financially and economically sound water tariff designs that enable them to provide essential services to their customers. This requires that water utilities have access to the expertise to understand how tariff reforms will affect water use, revenues, and capital investment needs, and how these, in turn, affect the multiple criteria that are used to assess the performance of water tariffs. This capability to carefully model the full array of consequences of a tariff reform process is currently not well developed in either water utilities themselves or in the community of consultants who support them.

It is widely recognized that the design of municipal water tariffs requires balancing multiple criteria such as financial self-sufficiency for the service provider, equity (especially for poor households), and economic efficiency for society. However, the actual trade-offs between these competing criteria are rarely quantified for policy makers. As a result, policy makers typically do not have a clear picture of the choices they face. They are thus forced to rely on their intuition to judge these trade-offs.

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In this paper, we develop a modelling framework for analysing how alternative municipal water tariff designs affect the criteria of cost recovery, equity, and economic efficiency. We then apply this model to a hypothetical community in which a municipal water utility provides metered, piped water and wastewater services to 5,000 households. We make assumptions about the costs of services, household income, and household water use that are similar to many cities in industrialized countries. Our analysis is also applicable to cities in developing countries where households have metered, piped connections, but assumptions about the magnitude of some parameters such as household income and costs of services would need to be adjusted to more closely reflect local conditions.

We focus our analysis on the performance of increasing block tariffs (IBTs) because these are now the most popular tariff structure globally. We do not claim to identify a tariff structure that finds the optimal balance between the three criteria of cost recovery, equity, and economic efficiency.¹ Rather, we analyse how the shift from a uniform volumetric tariff to different increasing block tariff designs affects households' water use and water bills, and how these changes, in turn, affect measures of equity and economic efficiency for different financial self-sufficiency targets. We calculate how changes in assumptions about 1) the correlation between household income and water use, and 2) households' response to average or marginal prices affect the tariffs' performance in terms of these three criteria.

Some of our results are new and surprising. For example, we find that IBTs perform poorly in terms of targeting subsidies to low-income households regardless of the magnitude of financial subsidies that a utility receives from high-level government. We also show that, when cost recovery is low, the distribution of subsidies under IBTs is even worse if the correlation between water use and household income is high. IBTs introduce price distortions that induce economic efficiency losses, but we show that these welfare losses are relatively small when households respond to average prices.

This study adds to the empirical literature on subsidy targeting in the water sector (see Whittington et al. 2015). A number of authors have investigated how IBTs perform in terms of distributing subsidies to the poorest households but fewer have considered the trade-off between redistribution and economic efficiency. Borenstein (2012) asks similar questions for the

¹ Other authors (e.g., Szabo 2015) have attempted to derive an "optimal" tariff from the perspective of the single criterion of economic efficiency. Such derivations typically depend on the same series of (often implicit) assumptions discussed in this paper.

residential electricity sector. He explores trade-offs between wealth transfer and efficiency using household billing data provided by three large Californian electric utilities combined with block-level income data provided by the United States Census Bureau, and finds that Increasing Block Pricing for electricity does redistribute income from wealthier to poorer households but that transfers are fairly modest in comparison to the substantial loss in economic efficiency.

2. Background

Policy makers and water professionals often rely too heavily on their intuition to assess how changes in water tariff designs and prices will affect financial self-sufficiency, equity, and economic efficiency. Quantitative modeling of a tariff reform process requires the specification of a set of nonlinear relationships with numerous parameters, and then a simulation procedure for analyzing how changes in the tariff structure and price levels affect outcomes of policy interest. Intuition is an unreliable guide for understanding the behavior of systems of nonlinear equations.

Policy makers often make implicit assumptions about both the parameters in this system of nonlinear equations and the functional relationships themselves. Three parameters in this system of nonlinear equations have received insufficient attention; they stand out as both important to the outcomes of a tariff reform process and often uncertain in a particular local setting.

2.1. Correlation between Household Income and Water Use

The first is the correlation between household water use and income. Water professionals typically assume that the correlation between household income and water use is high, i.e., that rich households use more water than poor households. There is, however, surprisingly little empirical evidence reported in the literature to support this assumption. To address this gap, we gathered household surveys from both developed and developing countries and estimated the correlation between income and water use (measured here by the Spearman's rho). We do not argue that this is a representative sample of households in either developed or developing countries, but, in the absence of more comprehensive analyses, we suggest that it is likely to be illustrative.

We combined data from several sources (see Table 1). Evidence from industrialized countries mainly comes from the 2008 OECD Environmental Policy and Individual Behaviour

Change (EPIC) survey, which includes eight OECD countries (Australia, Canada, France, Italy, South Korea, Netherlands, Norway, and Sweden).² About 1,000 households were interviewed in each country about their environmental behavior and attitudes in different sectors (water, energy, waste, food, and personal transport) and their household income. For a subset of households in each country, the survey collected data on the household's annual water bill and annual water use.³ In addition, we had access to water use and income information for a sample of 2,240 households from 13 Portuguese municipalities.⁴ Whittington et al. (2015) provide a description of the survey data covering the cities in four developing countries (Sri Lanka, El Salvador, Senegal, and Kenya) in Table 1.

Table 2 presents the mean and median household monthly water use (in m³) and the mean household income (in US\$ per month) for each of the eight countries covered by the OECD survey. Median household monthly water use varies from 8 m³ in France to 18 m³ in Korea. Mean monthly income varies from a low of US\$3,051 in Korea to US\$7,199 in Norway.

Table 1 shows the correlation between household income and water use in the surveys we analyzed. In four of the thirteen country data sets, the correlation was not statistically significant. For the remaining nine data sets in which the correlation was statistically significant, it varies between +0.1 and +0.3. The correlation between household water use and income is thus typically (but not always) positive, but surprisingly low. This means that there are many rich households that use small amounts of water, and many poor households that use large quantities of water.

2.2. Relationship between Marginal and Average Cost

Efficient water pricing requires that households face a price that reflects the opportunity costs that their incremental use imposes on the water utility (and society), i.e., the full social

² For more details on the EPIC surveys and related publications, see OECD (2011) and <http://www.oecd.org/env/consumption-innovation/households.htm> (accessed December 13, 2015).

³ These variables are missing for a large number of households, for different reasons: either these households were not charged for water based on their consumption and did not receive a bill; or water charges were included in their rent and did not appear as a separate item; or they were not able (or not willing) to look for bills when answering the questionnaire. For greater details on the water-specific data in the OECD survey, see OECD (2011) and Grafton et al. (2011).

⁴ The database includes both primary data obtained from households (including income) and their actual monthly water use and billing data provided by utilities over the period July 2011-June 2012 (for more details, see Correia et al. 2015).

marginal cost. However, water utilities often do not know the relationship between their average and marginal costs. Textbook expositions of natural monopolies present marginal costs below average costs, with increases in output that result in falling marginal costs, which pull down average costs (Boardman et al. 2011). Some components of the water and wastewater delivery system exhibit economies of scale and falling marginal and average costs, but others may exhibit diseconomies of scale and increasing marginal costs. For example, as water scarcity increases and water utilities go farther from urban centers to find new raw water sources, the costs of the incremental water supply will increase. Similarly, adding desalinization facilities increases the cost of raw water supplies. But raw water supplies typically constitute only a small portion (5-10%) of the total costs of water and wastewater services, so increasing costs of raw water supply may be offset by economies of scale in the piped networks and treatment components. Where the balance lies from a system-wide perspective is often unclear for a specific water utility at a particular time, and the relationship between the system-wide marginal and average costs is rarely explicitly stated in analyses of the consequences of tariff reforms.

2.3. Customers' Response to Marginal vs. Average Prices

The tariff determines the relationship between average and marginal prices. For example, increasing block tariffs create a price differential between the lower and higher blocks so that average volumetric prices are below marginal prices for customers who use more water than specified in the first (lifeline) block. Economic theory would suggest that a rational, observant customer would respond to the marginal price of the highest price block into which his household's water use falls, and might adjust his household's water use to avoid it falling into a higher price block of the tariff.

There are, however, three main reasons why customers might respond to average prices rather than marginal prices. First, complex tariff structures can be difficult to decipher for customers, and it may be too much trouble for households to try to figure out how to respond to marginal prices. Second, many utilities charge such low water prices (i.e., both average and marginal prices are low) that households simply may not find it worth the trouble to think about adjusting their water use to marginal prices. Third, households may have difficulty actually controlling the aggregate use of multiple household members; thus, the household unit may fail to respond to the marginal price signal.

Ito (2014) finds evidence that households in Southern California respond to average, not marginal water prices. We consider it likely that households in many developing countries also

respond to average instead of marginal prices because water prices are low and tariff structures complex, and thus marginal prices are unlikely to be salient or known to households.

However, as tariffs are reformed to reflect a greater portion of the supply costs, marginal prices are likely to become more salient. If households then start to focus on what is driving their higher water bills, it seems plausible that households will shift from responding to average prices to responding to marginal prices. There is little empirical evidence on this issue, and water professionals rarely make explicit their assumption about whether households will respond to average or marginal price. Yet it is a critical parameter in a simulation model of the consequences of a tariff reform (see also Borenstein 2012, for a related discussion).

3. Modelling Strategy, Assumptions, and Data

We assume that the initial, status quo situation is a municipality in which the water utility uses a uniform volumetric tariff (UP) to determine the water bills of its customers, i.e., all customers pay the same volumetric price no matter how much water they use. This utility is assumed to operate under constant returns to scale from a system-wide perspective. In other words, economies of scale in one component of the municipality's water and wastewater supply system are counterbalanced by dis-economies of scale in other components, so that average costs equal marginal costs. This assumption is consistent with empirical evidence that average-sized utilities are characterized by a scale factor equal or close to one in some countries (Saal et al. 2013).

The uniform volumetric price charged to households is equal to the full average cost of supplying water and wastewater services, and this price is the efficient marginal price that reflects the full cost of incremental supply. We then ask the question, "Would a change from this uniform volumetric tariff structure to an increasing block tariff (IBT) design result in improved measures of our three criteria?"

We model the consequences of moving from the UP structure to nine different IBT designs (Table 3). All of the IBT designs have two price blocks: 1) a lower (lifeline) block, and 2) an upper block. We examine IBTs with three different sizes of lifeline blocks: 5 cubic meters (m^3), 10 m^3 , and 15 m^3 per month. We assume that households' monthly water bill is determined by a volumetric component and a fixed charge. For each of the three sizes of lifeline blocks, we consider three levels of fixed charge: zero, US\$10 per month, and US\$15 per month.

A challenge analysts face when they want to understand how changes in tariffs affect poor households is that the utility's customer billing records do not include information on

households' income and other socioeconomic and demographic characteristics. If a connection is metered and used solely by members of the household, a utility knows how much water the household uses, its water bill, and the tariff structure. But analysts who want to study the equity consequences of a tariff reform need a procedure for matching customers' billing records with household income (Fuente et al. 2015).

Our approach to link household water use and income is to assume a hypothetical community of 5,000 households, each with a metered, private connection to a piped water and wastewater network. We calculate the effects of the shift from a UP to an IBT structure on each of these 5,000 households. Individual household data on water use and income are obtained by draws from two log-normal distributions calibrated using the OECD household survey data described in the previous section.

From the reported household-specific data on water use and income from these eight OECD countries, we estimate a log-normal distribution for household monthly water use with a mean of 2.61 and standard deviation of 0.91 (which corresponds to a mean of 24 m³/month and a standard deviation of 41 m³/month). Similarly, we use these OECD data to estimate a log-normal distribution for household monthly income with a mean of 8.21 and a standard deviation of 0.58 (which corresponds to an average monthly income of US\$4,295 and a standard deviation of US\$22,99).

We use a procedure proposed by Johnson and Tenenbein (1981) and described in Whittington et al. (2015) to draw household-specific pairs of income and water use data that maintain an assumed overall correlation for the 5000 households. Thus, an important assumption embedded in our model is this assumed correlation between water use and income. We run simulations under two different assumptions about the correlation between water use and income. We first assume a low correlation (Spearman's rho of +0.1), which seems to be realistic based on the empirical evidence presented in Table 1. We then test to see how our findings change under the assumption of a high (but unrealistic) correlation between water use and income (+0.8).

We assume a price elasticity of demand of -0.2, in line with empirical evidence from a large set of countries that price elasticity is quite often in the range -0.1 to -0.4 (Nauges and Whittington 2010; Grafton et al. 2011). When the new IBT tariff is put in place, households will face a price that is different from the uniform volumetric price. If a household chooses a quantity and associated price under the IBT that is lower than with the uniform volumetric price, its water use will increase (because of the assumed negative non-zero price elasticity). In contrast, if a

household chooses a quantity with a higher price under the IBT than with the uniform volumetric tariff, its water use will decrease.

We assume that households respond to average price rather than marginal price. We test the effect of assuming that households respond to marginal price. The average cost of supplying water and wastewater services is assumed to be US\$5 per cubic meter (Whittington et al. 2009).

For each specific tariff design presented in Table 3, we simulate two levels of cost recovery: 100% or full cost recovery (i.e., the bills paid by the 5,000 households generate revenues that exactly cover costs) and 50% cost recovery (i.e., the revenue from the bills only covers half of the costs). Because there is an infinity of pairs of prices in the IBT with two blocks (price in the lifeline block and price in the upper block) that could achieve the targeted cost recovery level, we assume that the volumetric price of water in the lower block will always be set at half of the price of the upper block. As a consequence, the only unknown parameter is the price of the upper block. Our simulation program solves for the price in the upper block that achieves the targeted level of cost recovery, taking into account that the quantity of water a household uses responds to the average price change.

We assume that household's monthly water use has a lower limit of 5 m³ below which it is insensitive to price changes. We run a total of 36 scenarios (see Appendix for characteristics of each scenario). Each scenario is run 100 times, and we report the average outcome over the 100 replications in terms of the quantity of water used, the water bill paid, and the performance indicators for our three criteria.

We assume a zero income elasticity water demand.⁵ The income elasticity is usually found to be low, around 0.1 to 0.3, and the bill-to-income ratio is generally in the range 1-3%. As a consequence, the quantity effect induced by the income change would be insignificant, and we assume it can be ignored. A dynamic simulation model of a tariff reform process would need to incorporate exogenous changes in household income that would be anticipated over the planning horizon of the simulation.

Table 4 summarizes the main assumptions underpinning the calculations, both the assumptions that are varied and those that are not.

⁵ Income effects are also ignored in Borenstein (2012).

4. Quantifying the Performance of Alternative Tariff Structures in Terms of Three Criteria: Financial Self-Sufficiency, Equity, and Economic Efficiency

The implementation of a new tariff in a community changes the prices different households face, the quantity of water they use, and the amount of the water bill they pay to the utility. We assess how these changes affect three criteria: financial self-sufficiency (cost recovery), distribution of subsidies (equity), and economic efficiency (welfare gains and losses). We report the consequences of the change in tariff structure from a UP design to each of the nine IBT designs in terms of these three criteria.⁶

4.1. Financial Self-Sufficiency (Cost Recovery)

The criterion of financial self-sufficiency requires that the revenues the utility receives in total from all its customers (5,000 households in our calculations) are equal to the total costs of providing these customers with water and wastewater services. There is a continuum from zero cost recovery (in which case the utility provides all of its customers with free services) to 100% cost recovery (the utility does not receive any financial subsidies from higher levels of government). The majority of water utilities in low-income countries fall on the low end of this continuum; few achieve more than 50% cost recovery. Many operate with only 10-25% cost recovery. Some of their operating costs, and essentially all of their capital costs, are paid by higher-level government authorities or donors. Even in high-income countries, relatively few water utilities actually achieve 100% cost recovery (cf. Table 1 in Reynaud 2015).

If a water utility does achieve 100% cost recovery, the financial self-sufficiency objective is fully satisfied. But this does not necessarily mean that all of its customers pay the full costs of the services they receive. However, if one group of households pays less than its full costs of service, another group of households must pay more than its costs of services so that in aggregate the revenues received from all its customers equal the costs of serving all customers.

If a water utility achieves 50% cost recovery, the financial self-sufficiency criterion is not satisfied, but perhaps the equity criterion is better satisfied than if 100% cost recovery was achieved. However, even if revenues only cover 50% of the total costs of serving the utility's customers, this does not necessarily mean that all customers pay less than their costs of service.

⁶ The consequences of moving from an existing IBT tariff to a uniform volumetric tariff would be the reverse (the negative) of the changes in criteria reported here.

It is still possible that some customers could pay more than their costs of services, in which case others would pay much less.

To ensure that our specified cost recovery target (either 50% or 100%) is achieved, the water bill is calculated for each of the 5,000 households using the household's water use (Q_i) under the new tariff structure. For example, if the water utility used an IBT tariff structure with a lifeline block of 10 m^3 , the price in the upper block was P^* , there was no fixed charge, and $Q_i > 10 \text{ m}^3$, the water bill for household i (WB_i) would be ...

$$WB_i = [10 \text{ m}^3 \times 0.5 \times P^*] + [(Q_i - 10 \text{ m}^3) \times P^*] \quad (1)$$

Assume the average total production cost per cubic meter is AC ; then the subsidy received by household i (SUB_i) is⁷ ...

$$SUB_i = (AC \times Q_i) - WB_i \quad (2)$$

The total revenues received by the utility from the 5,000 households ($TOTREV$) and the total subsidies provided to the 5,000 households ($TOTSUB$) are

$$TOTREV = \sum_{i=1}^{5000} WB_i \quad (3)$$

$$TOTSUB = \sum_{i=1}^{5000} SUB_i = AC \times \sum_{i=1}^{5000} Q_i - TOTREV \quad (4)$$

Cost recovery is 100% when $TOTSUB = 0$. Cost recovery is 50% when

$$TOTSUB = TOTREV, \text{ and} \quad (5)$$

$$TOTSUB + TOTREV = AC \times \sum_{i=1}^{5000} Q_i \quad (6)$$

4.2. Equity

Concerns about the equitable provision of municipal water and wastewater services can be defined and measured in numerous ways. For example, one could calculate an affordability indicator that expresses each household's water bill as a percent of its income. If water and wastewater expenditures exceed a specified percent, then the tariff has generated water bills for

⁷ Depending on the level of the average cost and characteristics of the water tariff, the subsidy could be negative. In this case, households in one income quintile would provide cross-subsidies to households in other income quintiles.

at least some households that are “unaffordable.” This is then judged to be a negative attribute of that specific tariff design. Alternatively, one could also analyze whether similar households received similar water bills. If they did not, this might be considered inequitable even if the water bills were affordable.

In this paper, we propose to measure equity by reporting the distribution of subsidies across different income groups. For both the status quo UP tariff and the new IBT, we calculate the share of the total subsidies received by households in each income quintile j ($ShareSUB_{IQ_j}$) as

$$ShareSUB_{IQ_j} = \sum_{i \in IQ_j} SUB_i / TOTSUB \text{ for } j = 1, \dots, 5 \quad (7)$$

Because this result is dependent on the specific draw of 5,000 household income and water use pairs, we do this calculation a hundred times, and then calculate the average of the share of the total subsidies received by households in each income quintile j ($ShareSUB_{IQ_j}$) over the hundred replications. The result is our best estimate of the share of total subsidies received by households in each income quintile for the specific tariff. We then compare the change in the distribution of subsidies under the UP and new IBT tariff. We assume that a tariff that targets more of the available subsidies to poor households is performing better.

4.3. Economic Efficiency

We calculate the welfare change due to the shift from the status quo UP design to one of the new IBT alternatives in Table 3 by measuring the change in consumer’s surplus resulting from the price change that each of the 5,000 households experiences, using the calculation method proposed by Hausman (1981). The household’s water demand function is assumed to be log-log, which allows the calculation of the change in surplus analytically. The household’s demand function for water is assumed to be as follows:

$$\ln Q = \alpha + \beta \ln(P) + \sum_{j=2}^J \delta_j \ln(X_j) \quad (8)$$

where Q is household’s water use, P is price to which the household responds (either marginal or average) and X a set of household characteristics. β is the price elasticity of demand. If we apply the exponential to both sides of equation (8), we have:

$$Q = \exp \left[\alpha + \beta \ln(P) + \sum_{j=2}^J \delta_j \ln(X_j) \right] = e^\alpha P^\beta \prod_{j=2}^J X_j^{\delta_j} = A \cdot P^\beta \text{ with } A = e^\alpha \prod_{j=2}^J X_j^{\delta_j}. \quad (9)$$

So the demand function for water is equivalently written as:

$$Q = A.P^\beta \text{ where } A = e^\alpha \prod_{j=2}^J X_j^{\delta_j} \quad (10)$$

The change in surplus (ΔS) following a change in price from P_0 (the UP price) to P_1 (either the average or marginal price under an IBT) is calculated from the demand curve as:

$$\Delta S = - \int_{P_0}^{P_1} A.P^\beta dP = - \frac{A}{1+\beta} \left(P_1^{(1+\beta)} - P_0^{(1+\beta)} \right) \quad (11)$$

The change in surplus depicted in (11) remains valid whether P_1 is greater or less than P_0 , i.e., P_1 (the average or marginal price under the new IBT) can be above or below the UP price P_0 , and the calculation of the surplus experienced by the household (either positive or negative) remains correct.

In order to calculate the change in surplus, one needs information on P_0 , P_1 , price elasticity of demand and A . Our simulation program generates the initial water use for each household (Q_i), and we have made the assumption that the price elasticity β is -0.2. The initial UP price (P_0) is known since we assume uniform volumetric pricing ($P_0 = \text{US\$5 per m}^3$). The price under the IBT is calculated for each household once their water use is determined following the change to an assumed IBT design. The only term missing in the calculation of the change in the household's consumer surplus is A , which we infer from Q , P and β using (10):

$$A = \frac{Q}{P_0^\beta}$$

In addition to the change in consumer surplus experienced by the household, we measure the deadweight loss suffered by society as a result of the shift to an IBT structure. In this calculation, we take into account the subsidies taxpayers are paying to recover costs when cost recovery is lower than 100%.

5. Results

5.1. Benchmark Case: IBT 0-10: Cost Recovery = 50%; Income-Water Use Correlation = +0.1

We first examine the consequences of our benchmark case, a shift from the uniform volumetric price tariff (UP-0) to an IBT with no fixed charge, cost recovery of 50%, and a correlation between household income and water use of +0.1. These assumptions approximate conditions in numerous cities around the world. Our simulation model finds prices for the IBT

that achieve 50% cost recovery: US\$1.6 per m³ for the first (lifeline) block and US\$3.2 per m³ for the upper block.

On average over the 100 replications, 1,753 households (35%) fall into the lifeline block and 3247 households (65%) fall into the upper block. Average monthly household water use varies modestly across income quintiles from 20 m³ in the poorest quintile to 26 m³ in the richest. The average monthly water bill also varies modestly across income quintiles, from US\$49 in the poorest to US\$66 in the richest.

The assumption that cost recovery is 50% means that there are substantial subsidies to be distributed from taxpayers to the utility's customers.⁸ However, our results show that, from an equity perspective, the shift from a uniform volumetric tariff to this IBT has not delivered these subsidies to households in the poorest quintile. Households in the poorest quintile receive only 18% of the total subsidies; households in the richest quintile receive 22%, a proportionately larger share. Households in the poorest quintile receive an average monthly subsidy of US\$51; households in the richest quintile receive an average subsidy of US\$63. These results are essentially the same as under the uniform volumetric tariff: under a uniform volumetric tariff with 50% cost recovery, households in the poorest quintile receive 18% of the subsidies, which corresponds to an average of US\$50 per household.

The main reason that the IBT has not delivered subsidies effectively to poor households is that the price of water and wastewater services in the upper block (P^*) is below the average cost of providing these services, so that the more water a household uses, the more subsidies it receives. Because the correlation between income and water use is positive (although low), rich households on average use more water than poor households and thus receive more subsidies. There are no cross-subsidies from rich households to poor households because all water is sold below cost and all households are receiving subsidies. This situation, in which the price of water in the upper block of an IBT is below average cost, is quite common in many water utilities, especially in low-income countries. We conclude that, in the benchmark case, the IBT is not attractive from the perspective of the equity criterion.

From the perspective of economic efficiency, the results in Table 5 show that the shift to the IBT-0-10 has resulted in welfare gains (increased consumer surplus) to all households

⁸ Of course, there is substantial overlap between taxpayers and household water users. Depending on the sources of public finances, taxpayers are probably largely paying themselves these water and wastewater subsidies.

because all households experience a reduction in their average price compared to the UP. These welfare gains are less than the value of the subsidies received because, at the margin, the subsidized water is not worth as much to a household as it costs the utility to supply. The average monthly welfare gain to households is US\$53 but this comes at a cost to taxpayers of US\$57. The average welfare gain for households in the poorest quintile (US\$47) is less than the welfare gain for households in the richest quintile (US\$58). The resulting societal (deadweight) loss is US\$22,938 per month for the community of 5,000 households (approximately US\$4.6 per household per month).

The result of the shift from a uniform volumetric tariff to this benchmark IBT has reduced economic efficiency and done nothing to improve equity. By assumption, the UP and IBT designs achieve the same (50%) level of cost recovery. In other words, there is no trade-off between equity and economic efficiency from this policy intervention given our assumptions. The IBT makes economic efficiency worse without improving equity.

5.2. What Happens If the Size of the Lifeline Block Changes? (IBT-0-5, IBT-0-15)

Figure 1 illustrates how changes in the size of the lifeline block affect the average water price. As shown, a small lifeline block (e.g., 5 m³) entails higher average prices because at low levels of water use a higher proportion of a household's total water use is charged at the rate in the upper block. However, changing the size of the lifeline block has only a small effect on the water use, water bills, the average subsidy received, and the percent of subsidies received by different income quintiles, compared to the benchmark case. Our simulation model finds prices for IBT-0-5 that achieve 50% cost recovery: US\$2.4 per m³ for the first (lifeline) block and US\$4.9 per m³ for the upper block. Reducing the lifeline block from 10 m³ to 5 m³ results in average monthly water use of 23 m³, the same as the benchmark case, ranging from 20 m³ in the lowest quintile to 26 m³ in the richest quintile. The average water bill is US\$57 (the same as in the benchmark case), ranging from US\$49 in the poorest quintile to US\$66 in the richest quintile. The average monthly subsidy is US\$57 (same as the benchmark case), ranging from US\$51 in the poorest quintile to US\$64 in the richest quintile.

With a lifeline block of 5 m³, the welfare gains to households are essentially the same as the benchmark case (US\$53). Deadweight losses decrease about 5% because more households respond to an average price closer to the marginal cost.

Increasing the size of the lifeline block has small effects in the opposite direction. Our simulation model finds prices for the IBT-0-15 that achieve 50% cost recovery: US\$2.4 per m³

for the first (lifeline) block and US\$4.9 per m^3 for the upper block. Increasing the lifeline block from 10 m^3 to 15 m^3 results in average monthly water use of 23 m^3 , ranging from 20 m^3 in the lowest quintile to 26 m^3 in the richest quintile. The average water bill is US\$57 (the same as in the benchmark case), ranging from US\$49 in the poorest quintile to US\$66 in the richest quintile. The average monthly subsidy is US\$57 (same as the benchmark case), ranging from US\$51 in the poorest quintile to US\$64 in the richest quintile.

With a lifeline block of 15 m^3 , the welfare gains to households are almost the same as in the benchmark case (<1% difference). Deadweight losses increase about 3% because the price distortion is increased as more households respond to an average price farther from the marginal cost.

Reducing the size of the lifeline block decreases deadweight losses without much effect on the distribution of subsidies across income quintiles. But the key message is that changing the size of the lifeline block does not change our main result that the shift from a uniform volumetric tariff to this benchmark IBT has reduced economic efficiency and done nothing to improve equity when cost recovery is 50% and the correlation between household income and water use is +0.1.

5.3. What Happens If a Positive Fixed Charge is Added to the Volumetric Component of the IBT? (IBT-10-10, IBT-15-10)

Adding a positive fixed charge to the volumetric component of a water bill is common practice. The fixed charge is especially attractive to utility managers because it increases revenue stability. Figure 2 illustrates how the average water price (US\$/ m^3) changes as a function of monthly water use (m^3) under three IBT tariffs with a positive fixed charge and two sizes of the LLB: 5 m^3 and 10 m^3 per month. As shown, a positive fixed charge results in high average water prices at low levels of water use. The average price first falls as water use increases as the fixed charge is spread over higher water use, but then rises as more and more water is billed at the price of the upper block.

The shift from a uniform volumetric tariff to an IBT with a fixed charge makes the equity and efficiency outcomes of the IBT designs worse, assuming a 50% cost recovery target. Our simulation model finds prices for IBT-10-10 that achieve 50% cost recovery: US\$1.3 per m^3 for the first (lifeline) block and US\$2.6 per m^3 for the upper block. Adding a fixed charge of US\$10 per month while maintaining the 50% cost recovery target again results in similar average monthly water use and water bills as the benchmark case. Water bills for households in the poorest quintile and the subsidies they receive are essentially the same as for the benchmark

case. Households in the richest quintile still receive a larger share of the total subsidies (23%) than households in the poorest quintile (18%).

With a fixed charge of US\$10 per month, the welfare gains to households are almost the same as in the benchmark case. Deadweight losses decrease about 8% because more households respond to an average price closer to the marginal cost. Adding a fixed charge does create a modest efficiency vs. equity trade-off: a higher fixed charge increases economic efficiency at the expense of poor households. Increasing the size of the fixed charge (e.g., IBT-15-10) accentuates this trade-off. But again the key message is that adding a positive fixed charge does not change our main result that the shift from a uniform volumetric tariff to this benchmark IBT has reduced economic efficiency and done nothing to improve equity.

5.4. What Are the Consequences of Increasing the Cost Recovery Target to 100%? (IBT-0-10)

Table 6 shows the changes that result from a shift from an UP tariff to an IBT (with a lifeline block of 10 m³ and no fixed charge) in which the prices in the lower and upper blocks are set to achieve 100% cost recovery. One can also compare the results in Table 6 with the results for the benchmark case presented in Table 5 to see the consequences of increasing the cost recovery target from 50% to 100%, holding other parameters in the simulation model constant.

The implications of increasing the cost recovery target from 50% to 100% are far reaching. Our simulation model finds prices for IBT-0-10 that achieve 100% cost recovery: US\$3.2 per m³ for the first (lifeline) block and US\$6.4 per m³ for the upper block. Because the simulation model forces the 100% cost recovery target to be achieved, there are no subsidies provided by taxpayers. There are, however, cross-subsidies between households. On average over the 100 replications, 3,614 households receive subsidies, and 1,386 households make “excess payments” above their costs of services. The average monthly water use of the 3,614 households that receive subsidies is only 11-12 m³ in all five quintiles. Their average water bill is US\$46, and the range across the quintiles is small (from US\$43 per month in the poorest quintile, to US\$49 in the richest).

One would hope that rich households cross-subsidized poor households, but Table 6 shows that this is not the case. The 3,614 households receiving subsidies are distributed relatively evenly across the income quintiles, from 770 households in the poorest quintile to 673 households in the richest. These 3,614 households receive an average monthly subsidy of US\$11.3, with little variation in the size of the subsidy across income quintiles (from US\$11.4 in the poorest quintile to US\$11.2 in the richest). Only 21% of the cross-subsidies are received by

households in the poorest quintile. So, just as is the case when subsidies are paid by taxpayers in the 50% cost recovery benchmark case, the cross-subsidies in the 100% cost recovery case are not well-targeted to the poor.

The 1,386 households that make “excess payments” above their costs of services are distributed throughout the income distribution. Only 24% of these households making excess payments are in the richest quintile. These 1,386 households use much more water per month than the households receiving subsidies. Their average monthly water use is 45 m³, ranging from 43 m³ in the poorest quintile to 47 m³ in the richest quintile. Their average water bill is US\$254, ranging from US\$241 in the poorest quintile to US\$267 in the richest. The fact that these water bills seem so high reinforces our point that few water utilities even in industrialized countries actually achieve 100% cost recovery.

For the 3,614 households receiving subsidies, they experienced an average welfare gain of US\$11 per month compared to the UP tariff. In the benchmark case, the average welfare gain was US\$53 per month for all households, so these 3,614 households receiving subsidies are unsurprisingly much worse off in the 100% cost recovery case than with 50% cost recovery. For the 1,386 households making excess payments, their average welfare loss is US\$30 per month, instead of a welfare gain of approximately US\$53 in the 50% cost recovery case. But taxpayers benefit compared to the benchmark case because they no longer provide any subsidies.

There is still a small deadweight loss for society (about US\$0.40 per month per household) that results from the price distortion introduced by the IBT. This is so small due to our assumption that households respond to average instead of marginal prices, a point to which we return below.

Cost recovery of 100%, coupled with the IBT-0-10 tariff, shifts the costs of provision from taxpayers to water users, and creates a cross-subsidy from large water users to small water users. Because the correlation between household income and water use is low, however, the cross-subsidies are not flowing from rich to poor households. There are many poor and middle-income households with high water use cross-subsidizing other middle-income and rich households.

The shift to 100% cost recovery compared to our benchmark IBT-0-10 with 50% cost recovery has achieved the financial self-sufficiency objective and shifted the financial costs away from taxpayers. Because we assume that households respond to average not marginal prices, the societal deadweight losses are almost eliminated compared to the benchmark case, and are similar to the UP tariff. But it is difficult to conclude that equity has been improved compared to

the UP tariff because the cross-subsidies are poorly targeted. Large water users are providing modest cross-subsidies to low water users, but many of the households making excess payments are poor and many of the households receiving subsidies are rich.

5.5. What Happens to the Results of the Benchmark Case (IBT-0-10) If the Correlation between Household Income and Water Use Is High (+0.8) Instead of Low (+0.1)?

Intuition might suggest that equity (i.e., the share of subsidies targeting poor households) would improve if the correlation between household income and water use is higher, but this is incorrect if the cost recovery target is 50%. Assuming a 50% cost recovery target and a correlation between household income and water use of +0.8, our simulation model finds prices for IBT-0-10: US\$1.6 per m³ for the first (lifeline) block and US\$3.1 per m³ for the upper block. Average monthly household water use is 23 m³, ranging from 8 m³ in the poorest quintile to 39 m³ in the richest. The average water bill is US\$57, ranging from US\$13 in the poorest quintile to US\$144 in the richest. But households in the poorest quintile only receive 9% of the total subsidies; households in the richest quintile receive 39%. Strikingly, the average subsidy received by households in the poorest quintile is US\$25 compared to US\$112 in the richest quintile. IBTs do even worse targeting subsidies to poor households when the correlation is high than when it is low if cost recovery is also low (as in the benchmark case). This is because all of the water that the utility sells is sold below average cost, so the more water a household uses, the more subsidies it receives—and rich households use more water than poor households if the correlation is high.

If the correlation were +0.8, the average household welfare gain would be US\$53, but it is only US\$22 for households in the poorest quintile, compared to US\$105 for households in the richest quintile. So households in the poorest quintile would be much worse off than in the benchmark case, in which their average welfare gain was US\$47 per month.

There are no cross-subsidies in this case, so all the subsidies received by households are paid by taxpayers. Because the value of the total subsidies paid by taxpayers is greater than the welfare gain received by households, a societal deadweight loss of US\$22,913 per month remains for the community of 5,000 households (approximately US\$4.6 per household per month), essentially equivalent to the deadweight loss in the benchmark case.

We emphasize that we consider this high correlation case for illustrative purposes. The correlation between household income and water use is not something that the utility or social planner can control, and it is unlikely that the correlation will be this high (+0.8). If a utility

discovered that this correlation was high in its service area, and it was not recovering the full costs of supply, shifting from a UP tariff to an IBT would make the targeting of subsidies to poor households much worse.

5.6. What Happens If Both the Cost Recovery Target Is High (100%) and the Correlation between Income and Water Use Is High (+0.8)?

To the best of our knowledge, this combination of parameters does not exist in any water utility today. A small portion of water utilities in industrialized countries may be recovering close to full long-run supply costs, but most are not. The majority of water utilities in developing countries are recovering less than 50% of total costs, many much less. And although the data on the correlation between household income and water use are sparse, there is no indication from any of our data sets (Table 1) that the correlation is above +0.5, certainly not as high as +0.8. Nevertheless, it is important to consider this case because it is here that the IBT does, in fact, offer some advantages in terms of equity compared to the UP design, and this is the case that many water professionals (mistakenly) have in mind when they recommend IBTs.

Figure 3 shows the distribution of subsidies across household income quintiles for four combinations of percent cost recovery and the correlation between household income and water use for an IBT with a lifeline block of 10 m³ and no fixed charge: 1) 50% cost recovery; +0.1 correlation (NW cell); 2) 50% cost recovery (NE cell); +0.8 correlation; 3) 100% cost recovery; +0.1 correlation (SW cell); and 4) 100% cost recovery; and +0.8 correlation (SE cell). Case 1 is our benchmark case. Moving from Case 1 to Case 4 (from NW to SE) does improve the distribution of subsidies across income quintiles substantially. Case 4 is the only one of the four cases in which poor households receive a much higher proportion of the total subsidies than rich households. But note that Case 4 requires 100% cost recovery, so although the distribution of subsidies is improved, the absolute magnitude of the subsidies delivered is small.

The welfare gains to poor households are much smaller in Case 4 than in Cases 1 and 2. The main beneficiaries of the 100% cost recovery target are taxpayers, not poor households (although of course poor households also pay taxes). Moreover, the correlation between household income and water use is largely exogenous (outside the control of the water utility), so a water utility with a low correlation (Cases 1 and 3) cannot simply choose to move to Case 4 to improve subsidy targeting.

Figure 4 presents the cumulative distribution of subsidies as a function of income percentile for the four cases in Figure 3. The two cases with a correlation between household income and water use of +0.1 are close to 45-degree lines, meaning that subsidies are evenly

distributed to households throughout the income distribution. The two cases with a correlation between household income and water use of +0.8 are different. The case with 50% cost recovery and a correlation of +0.8 shows a distribution of subsidies skewed toward the rich. The case with 100% cost recovery and a correlation of +0.8 shows a distribution of subsidies skewed toward the poor.

We believe most water utilities, especially in developing countries, are probably closer to Case 1 in the typology shown in Figure 3 than to the other three cases. Utilities in industrialized countries are on a continuum between Case 1 and Case 3. Although some water professionals probably imagine there are many utilities in Case 2, we think this is very unlikely. But this is, in fact, fortunate because in Case 2 households in the richer quintiles receive the majority of the subsidies under IBTs. Some water utility professionals may imagine that they are in Case 4, where IBT tariffs target subsidies to households in the poor quintiles most effectively, but we consider this unlikely on two counts: 1) few utilities are actually recovering 100% of full costs; and 2) there is no evidence that the correlation between household income and water use is this high.

5.7. Summary of Results

Tables 7 and 8 summarize our results, comparing each of the nine IBT designs in terms of our three criteria, for two cost recovery targets (50% and 100%) and the two assumed correlations between household income and water use. As shown in Table 7, if the correlation between household income and water use is low, subsidies are always poorly targeted, regardless of the level of cost recovery, the size of the lifeline block, or the size of the fixed charge. With a low level of cost recovery (50%), the magnitude of the subsidy to households in the poorest quintile is substantial (about US\$50 per household per month), but relatively insensitive to changes in the IBT design. Increasing the size of the fixed charge makes the targeting of subsidies to poor households slightly worse because it increases the average price of water to households with low water use (Figure 2). With 50% cost recovery, societal efficiency losses are relatively low (about US\$4-5 per household per month) because the assumption that households respond to average prices keeps the price distortion modest.

Increasing cost recovery to 100% reduces the magnitude of the average subsidy to poor households (to about US\$3-13 per household depending on the tariff design), and does not improve the targeting of subsidies to poor households. Increasing cost recovery to 100% does essentially eliminate the societal efficiency losses, given our assumption that households respond

to average price. Increasing the fixed charge and reducing the size of the lifeline block raise average prices at low levels of water use and further reduce economic efficiency losses.

None of the tariff designs presented in Table 7 accomplish the equity objective of targeting the majority of subsidies to poor households. Efficiency losses are modest with 50% cost recovery and insignificant with 100% cost recovery if households respond to average prices. Increasing the cost recovery target (from 50% to 100%) reduces the subsidy to poor (and rich) households but also reduces the burden on taxpayers. Importantly, with a low correlation between household water use and income, none of the IBT designs improve upon a simple, transparent volumetric tariff structure in terms of any of the three objectives.

Table 8 summarizes the results for the case where the correlation between household income and water use is high. The targeting of subsidies to poor households is improved for a 100% cost recovery target (households receive 39% of total subsidies), but only if there is no fixed charge and if the lifeline block is small. In these results, the effect of adding a fixed charge falls heavily on poor households, reducing both the percentage of subsidies and the magnitude of the subsidy received by poor households. Economic efficiency losses are similar to these in Table 7 (about US\$4-5 per household per month for a 50% cost recovery target, and minimal for a 100% cost recovery target).

5.8. Model Extensions

There are numerous directions in which our calculations could be extended. Perhaps the three most important are: 1) to explore the implications of changing our assumption that households respond to marginal instead of average prices; 2) to explore the implications of our assumption that the utility operates under constant returns to scale; and 3) to report the performance of the alternative tariff structures for additional criteria, such as water conservation.

What happens if households respond to marginal instead of average prices?

All 36 scenarios have been run under the assumption that households react to changes in marginal price. The full set of results is shown in Tables 9 and 10. If households respond to marginal prices, both the percentage of subsidies received by households in the poorest quintile and the average subsidy are similar to the scenarios presented in Tables 7 and 8, in which households react to average price. What differs is the change in consumer surplus and deadweight loss. In most scenarios in Tables 9 and 10, the magnitude of the change in consumer surplus is larger under the marginal price assumption. This is because the marginal price creates more distortion with respect to the constant volumetric price under UP, i.e., the difference

between the price the household faces under the IBT and the constant volumetric price the household faced under the UP tariff is larger when households respond to marginal price. The change in price experienced by the households is thus always larger under the assumption that households react to changes in the marginal price. So the performance of different tariffs in terms of economic efficiency is quite different depending on whether households respond to average or marginal prices. In some scenarios in Tables 9 and 10, the overall change in surplus is even positive.

Under the 100% cost recovery assumption, the relative ranking of the nine tariffs in terms of deadweight loss is similar under the average price and marginal price assumptions. For example, the IBT-15-5 (fixed charge set at US\$15 and lifeline block set at 5m^3 per month) provides the smallest deadweight loss (the change in welfare is even positive under the marginal price assumption). On the contrary, the IBT-0-15 (no fixed charge and 15m^3 lifeline block) leads to the largest deadweight loss, whether households respond to average or marginal prices.

Under the 100% cost recovery scenario, the following relationships hold whether households respond to average or marginal prices: i) for a given lifeline block, an increase in the fixed charge always decreases deadweight loss; and ii) for a given fixed charge, an increase in the size of the lifeline block always increases the deadweight loss. Thus, in the 100% cost recovery case, a large fixed charge combined with a small lifeline block produces the smallest deadweight loss. This is because a small lifeline block and a large fixed charge produce an average price and a marginal price that are quite close to the UP tariff of US\$5 per m^3 . Figure 5 provides a graphic illustration under a 100% cost recovery assumption: SC1 is the IBT-0-10 (US\$0 fixed charge and 10m^3 lifeline block) while SC15 is the IBT-15-5 (US\$15 fixed charge and 5m^3 lifeline block). Both the average and marginal prices under the IBT-15-5 are close to US\$5, so the change in prices when moving from UP to IBT is very small and, hence, the loss in welfare is small. However, this is the worst scenario for households in the poorest quintile because they receive the lowest proportion of subsidies under this particular tariff structure (15% of the total subsidies under a +0.1 correlation between water use and income, and less than 1% of the total subsidies under a +0.8 correlation).

Under the 50% cost recovery assumption, the picture is different. The deadweight loss is about the same under all IBTs when households are assumed to respond to average price (around US\$22,000 in total and US\$4.5 per household). This is not the case if households respond to marginal prices. The deadweight loss varies significantly across the marginal price scenarios in Tables 9 and 10. A positive change in welfare occurs for an IBT-15-5 and IBT-15-10, although the magnitude of the societal welfare gain is small (US\$3 and US\$1 per household, respectively).

Does the utility operate under constant returns to scale?

If the utility operated under increasing returns to scale, then the average cost of production would be higher than the marginal cost. For example, if we assumed that the marginal cost is still US\$5 per m³ but that the average cost is a specified amount above that, this would have implications for the calculation of the subsidies distributed to each quintile (but not for the proportion of total subsidies received by each quintile). The calculation of the deadweight loss would be unchanged.

One could refine the calculations further by specifying a cost function that more precisely describes the relationship between the cost and the quantity of water produced. One would then adjust the marginal cost and average cost depending on the total amount of water produced.

Are additional criteria needed?

Another extension of our modelling would be to add criteria. An obvious candidate for non-economists would be “water conservation.” This would require reporting the total water use under the different scenarios. The total water use varies across scenarios because the price elasticity of demand is assumed to be positive. For example, under the benchmark (UP) case, the total water sold to the 5,000 households amounts to about 115,000 m³. Scenarios with IBTs with a zero fixed charge under 100% cost recovery assumption have the largest differences in total water use compared to the benchmark case (about 15% lower).

6. Discussion

The results presented in this paper suggest that the trade-offs between the criteria of equity and economic efficiency in the design of water tariffs are different than generally assumed by water utility managers. Water tariff consultants spend much time and effort tinkering with the details of new IBT designs without recognizing how little such changes matter to the effective targeting of subsidies to poor households in most circumstances.

On the other hand, if households are responding to average rather than marginal prices, water resources economists may be overly concerned with the economic efficiency consequences of alternative tariff designs. More efficient use of water will likely require that water utilities initiate information campaigns to focus the attention of their customers on how marginal changes in their water use will affect their water bills. If marginal prices become more salient to customers as a consequence of increasing tariffs and information campaigns, these welfare losses from IBT designs may be quite large depending on the relationship between average and marginal costs.

In the past, poorly performing water tariffs have not been perceived to be a large societal problem, but this is changing with growing water scarcity and climate change. Our results show how the performance of alternative tariff designs depends on a set of assumptions that require empirical verification in a specific local setting and emphasize the importance of understanding local realities before launching into the design of new water tariffs. It is especially important to obtain accurate estimates of the correlation between household water use and income, the relationship between average and marginal prices, the price (average or marginal) to which households are responding, and the target level of cost recovery.

More careful modelling of the consequences of water tariff reforms is needed to counter the global conventional wisdom that IBTs are a sound, effective approach for balancing financial self-sufficiency, equity, and economic efficiency criteria. Our results show that, for a given level of cost recovery, IBTs can easily lead to worse outcomes in terms of economic efficiency, especially if households respond to marginal prices, and do little to increase equity.

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Tables and Figures

Table 1. Empirical Evidence on the Correlation between Water Use and Income

Location	Study in which dataset is described	Sample size	Spearman's rho
<i>OECD countries</i>			
Australia	Grafton et al. (2011)	154	0.12 (n.s.)
Canada	Grafton et al. (2011)	47	0.27
France	Grafton et al. (2011)	326	0.15
Italy	Grafton et al. (2011)	249	-0.05 (n.s.)
Korea	Grafton et al. (2011)	109	-0.10 (n.s.)
Netherlands	Grafton et al. (2011)	191	0.12
Norway	Grafton et al. (2011)	57	0.32
Portugal	Correia et al. (2015)	1575	0.18
Sweden	Grafton et al. (2011)	88	0.05 (n.s.)
<i>Developing countries</i>			
Sri Lanka (3 cities)	Nauges and van den Berg (2009)	590	0.28
El Salvador (3 cities)	Strand and Walker (2003)	398	0.13
Dakar, Senegal	Briand et al. (2010)	112	0.24
Nairobi, Kenya	Fuente et al. (2015)	648	0.34

Note: n.s. = non-significant at 95%.

Table 2. Descriptive Statistics on Household Water Use and Income (Source: 2008 OECD EPIC survey)

	Nb. of obs.	Mean water use (m ³ /month)	Median water use (m ³ /month)	Mean Income (US\$/month)
Canada	52	41	16	4746
Netherlands	198	15	9	3512
France	338	11	8	3994
Italy	256	34	17	3804
Sweden	91	18	11	3518
Norway	57	15	12	7199
Australia	163	37	16	4316
Korea	111	42	18	3051

Table 3. Nine Alternative IBT Tariff Designs + Status Quo UP Tariff

Tariff Code	Type of tariff	FC (US\$/mo.)	LLB (m ³ /mo.)
UP-0	UP	0	0
IBT-0-5	IBT	0	5
IBT-0-10	IBT	0	10
IBT-0-15	IBT	0	15
IBT-10-5	IBT	10	5
IBT-10-10	IBT	10	10
IBT-10-15	IBT	10	15
IBT-15-5	IBT	15	5
IBT-15-10	IBT	15	10
IBT-15-15	IBT	15	15

Notes: UP = Uniform Pricing, IBT = Increasing Block Tariff, FC =fixed charge, LLB = lifeline block

Table 4. Model Assumptions

Assumptions that are varied ...	Parameter value
Correlation between household income and water use	+0.1, +0.8
Percent cost recovery	50%, 100%
Price to which households respond	Average, marginal
Size of lifeline block	5 m ³ , 10 m ³ , 15 m ³
Size of fixed charge	0, US\$10, US\$15
Assumptions that are not varied ...	
All households have metered, piped connections	
Status quo tariff structure	Uniform volumetric tariff with price set equal to marginal cost = average cost
Average cost of water and wastewater services	US\$5 per m ³
Price elasticity of demand	-0.2
Income elasticity	0.0
IBT has two blocks	
Relationship between volumetric price in the first block (P ₁) and price in the second block (P ₂)	$P_1 = \frac{1}{2} P_2$
Lower limit on household water use	5 m ³
Household demand function for water	log-log

Table 5. Results for Benchmark Case: 50% Cost Recovery; Correlation between Water Use and Income = 0.1; IBT No Fixed Charge; LLB=10m³/mo.

<i>By income quintile (Q1 to Q5) and in total</i>	Q1	Q2	Q3	Q4	Q5	Total
In total						
Total number of households	1000	1000	1000	1000	1000	5000
Total water use (m3)	20,060	21,639	22,848	24,005	25,867	114,419
Total revenue from bills (US\$)	48,717	53,453	57,082	60,569	66,223	286,043
Total cost (US\$)	100,300	108,194	114,240	120,025	129,336	572,095
Total revenue - total cost (US\$)	-51,583	-54,741	-57,158	-59,456	-63,113	-286,051
Total change in surplus with respect to UP (US\$)	47,249	50,264	52,571	54,766	58,263	263,113
Cost recovery (%)	49	49	50	50	51	50
For households receiving subsidies (price is below cost)						
Number of hh receiving subsidies	1000	1000	1000	1000	1000	5000
Total subsidies distributed (US\$)	51583	54741	57158	59456	63113	286051
Total subsidies distributed (%)	18	19	20	21	22	100
Total change in surplus with respect to UP (US\$)	47,249	50,264	52,571	54,766	58,263	263,113
Total water use (m3)	20,060	21,639	22,848	24,005	25,867	114,419
Total revenue from bills (US\$)	48,717	53,453	57,082	60,569	66,223	286,043
Average subsidy per household (US\$)	51.6	54.7	57.2	59.5	63.1	57.2
Average subsidy per m3 (US\$)	2.6	2.5	2.5	2.5	2.4	2.5
Average water bill per household (US\$)	49	53	57	61	66	57
Average water use per household (m3)	20	22	23	24	26	23
For households making payments (price is above cost)						
Number of hh making payments	0	0	0	0	0	0
Total payments made (US\$)	0	0	0	0	0	0
Total payments made (%)	0	0	0	0	0	0
Total change in surplus with respect to UP (US\$)	0	0	0	0	0	0
Total water use (m3)	0	0	0	0	0	0
Total revenue from bills (US\$)	0	0	0	0	0	0
Average payment per household (US\$)	0	0	0	0	0	0
Average payment per m3 (US\$)	0	0	0	0	0	0
Average water bill per household (US\$)	0	0	0	0	0	0

Table 6. Scenario 1: 100% Cost Recovery; Correlation between Water Use and Income = 0.1; IBT No Fixed charge; LLB = 10m³/mo.

<i>By income quintile (Q1 to Q5) and in total</i>	Q1	Q2	Q3	Q4	Q5	Total
In total						
Total number of households	1000	1000	1000	1000	1000	5000
Total water use (m3)	18,266	19,696	20,468	21,712	23,400	103,543
Total revenue from bills (US\$)	88,686	97,320	102,017	109,670	120,018	517,711
Total cost (US\$)	91,331	98,480	102,342	108,561	117,000	517,714
Total revenue - total cost (US\$)	-2645	-1160	-325	1109	3018	-3
Total change in surplus with respect to UP (US\$)	2232	748	-89	-1528	-3443	-2080
Cost recovery (%)	97	99	100	101	103	100
For households receiving subsidies (price is below cost)						
Number of hh receiving subsidies	770	742	727	703	673	3614
Total subsidies distributed (US\$)	8783	8439	8256	7935	7553	40,965
Total subsidies distributed (%)	21	21	20	19	18	100
Total change in surplus with respect to UP (US\$)	8459	8133	7960	7653	7290	39,495
Total water use (m3)	8414	8354	8309	8188	8043	41,308
Total revenue from bills (US\$)	33,287	33,333	33,289	33,004	32,663	165,576
Average subsidy per household (US\$)	11.4	11.4	11.4	11.3	11.2	11.3
Average subsidy per m3 (US\$)	1.0	1.0	1.0	1.0	0.9	1.0
Average water bill per household (US\$)	43	45	46	47	49	46
Average water use per household (m3)	11	11	11	12	12	11
For households making payments (price is above cost)						
Number of hh making payments	230	258	273	297	327	1386
Total payments made (US\$)	6137	7278	7931	9044	10,571	40,962
Total payments made (%)	15	18	19	22	26	100
Total change in surplus with respect to UP (US\$)	-6227	-7386	-8049	-9181	-10,733	-41,575
Total water use (m3)	9852	11,342	12,159	13,524	15,357	62,235
Total revenue from bills (US\$)	55,399	63,987	68,728	76,666	87,355	352,135
Average payment per household (US\$)	26.6	28.2	29.1	30.5	32.3	29.6
Average payment per m3 (US\$)	0.6	0.6	0.7	0.7	0.7	0.7
Average water bill per household (US\$)	241	248	252	258	267	254
Average water use per household (m3)	43	44	45	46	47	45

**Table 7. Alternatives-by-criteria Decision Matrix (Correlation between Household Income and Water Use = +0.1);
Household Responds to Average Price**

Criteria	IBT-0-5*	IBT-0-10	IBT-0-15	IBT-10-5	IBT-10-10	IBT-10-15	IBT-15-5	IBT-15-10	IBT-15-15
Cost recovery	50%	50%	50%	50%	50%	50%	50%	50%	50%
Equity									
% of subsidies to poorest quintile	18%	18%	18%	17%	18%	18%	17%	17%	17%
Average subsidy in poorest quintile	US\$51	US\$52	US\$52	US\$50	US\$50	US\$50	US\$49	US\$49	US\$49
Economic efficiency (deadweight loss)	-US\$21,810 (US\$4.4/hh)	-US\$22,938 (US\$4.6/hh)	-US\$23,546 (US\$4.7/hh)	-US\$21,276 (US\$4.3/hh)	-US\$21,133 (US\$4.2/hh)	-US\$21,419 (US\$4.3/hh)	-US\$22,216 (US\$4.4/hh)	-US\$21,827 (US\$4.4/hh)	-US\$21,903 (US\$4.4/hh)
Cost recovery	100%	100%	100%	100%	100%	100%	100%	100%	100%
Equity									
% of subsidies to poorest quintile	22%	21%	21%	22%	21%	20%	15%	20%	19%
Average subsidy in poorest quintile	US\$7	US\$11	US\$13	US\$2	US\$5	US\$9	US\$3	US\$5	US\$8
Economic efficiency (deadweight loss)	-US\$920 (US\$0.2/hh)	-US\$2080 (US\$0.4/hh)	-US\$2596 (US\$0.5/hh)	-US\$197 (US\$0.0/hh)	-US\$519 (US\$0.10/hh)	-US\$951 (US\$0.2/hh)	-US\$26 (US\$0.0/hh)	-US\$272 (US\$0.1/hh)	-US\$646 (US\$0.1/hh)

* IBT-0-5 stands for an IBT design with a US\$0 fixed charge and a 5m³ lifeline block.

**Table 8. Alternatives-by-criteria Decision Matrix (Correlation between Household Income and Water Use = +0.8);
Household Responds to Average Price**

Criteria	IBT-0-5*	IBT-0-10	IBT-0-15	IBT-10-5	IBT-10-10	IBT-10-15	IBT-15-5	IBT-15-10	IBT-15-15
Cost recovery	50%	50%	50%	50%	50%	50%	50%	50%	50%
Equity									
% of subsidies to poorest quintile	8%	9%	9%	5%	6%	6%	4%	4%	4%
Average subsidy in poorest quintile	US\$24	US\$25	US\$25	US\$16	US\$17	US\$16	US\$11	US\$12	US\$12
Economic efficiency (deadweight loss)	-US\$21,775 (US\$4.4/hh)	-US\$22,913 (US\$4.6/hh)	-US\$23,540 (US\$4.7/hh)	-US\$21,250 (US\$4.3/hh)	-US\$21,229 (US\$4.2/hh)	-US\$21,419 (US\$4.3/hh)	-US\$22,202 (US\$4.4/hh)	-US\$21,794 (US\$4.4/hh)	-US\$21,903 (US\$4.4/hh)
Cost recovery	100%	100%	100%	100%	100%	100%	100%	100%	100%
Equity									
% of subsidies to poorest quintile	39%	28%	21%	40%	16%	9%	<1%	11%	7%
Average subsidy in poorest quintile	US\$9	US\$12	US\$10	US\$2	US\$3	US\$6	US\$1	US\$5	US\$6
Economic efficiency (deadweight loss)	-US\$870 (US\$0.2/hh)	-US\$2102 (US\$0.4/hh)	-US\$2658 (US\$0.5/hh)	-US\$204 (US\$0.0/hh)	-US\$454 (US\$0.1/hh)	-US\$970 (US\$0.2/hh)	-US\$34 (US\$0.0/hh)	-US\$233 (US\$0.0/hh)	-US\$626 (US\$0.1/hh)

* IBT-0-5 stands for an IBT design with a US\$0 fixed charge and a 5m³ lifeline block.

Table 9. Alternatives-by-criteria Decision Matrix (Correlation between Household Income and Water Use = +0.1); Household Responds to Marginal Price

Criteria	IBT-0-5*	IBT-0-10	IBT-0-15	IBT-10-5	IBT-10-10	IBT-10-15	IBT-15-5	IBT-15-10	IBT-15-15
Cost recovery	50%	50%	50%	50%	50%	50%	50%	50%	50%
Equity									
% of subsidies to poorest quintile	18%	18%	18%	17%	18%	18%	17%	17%	17%
Average subsidy in poorest quintile	US\$50	US\$51	US\$51	US\$50	US\$50	US\$50	US\$50	US\$50	US\$50
Economic efficiency (deadweight loss)	-US\$50,176 (US\$10/hh)	-US\$67,555 (US\$14/hh)	-US\$79,475 (US\$16/hh)	-US\$4319 (US\$1/hh)	-US\$18,008 (US\$4/hh)	-US\$27,256 (US\$5/hh)	US\$16,885 (-US\$3/hh)	US\$5091 (-US\$1/hh)	-US\$3214 (US\$1/hh)
Cost recovery	100%	100%	100%	100%	100%	100%	100%	100%	100%
Equity									
% of subsidies to poorest quintile	22%	21%	21%	22%	21%	20%	15%	20%	20%
Average subsidy in poorest quintile	US\$7	US\$12	US\$13	US\$2	US\$6	US\$9	US\$3	US\$5	US\$9
Economic efficiency (deadweight loss)	-US\$71,716 (US\$14/hh)	-US\$106,413 (US\$21/hh)	-US\$124,411 (US\$25/hh)	-US\$14,296 (US\$3/hh)	-US\$46,595 (US\$9/hh)	-US\$64,636 (US\$13/hh)	US\$14,455 (-US\$3/hh)	-US\$17,120 (US\$3/hh)	-US\$35,397 (US\$7/hh)

* IBT-0-5 stands for an IBT design with a US\$0 fixed charge and a 5m³ lifeline block.

Table 10. Alternatives-by-criteria Decision Matrix (Correlation between Household Income and Water Use = +0.8); Household Responds to Marginal Price

Criteria	IBT-0-5*	IBT-0-10	IBT-0-15	IBT-10-5	IBT-10-10	IBT-10-15	IBT-15-5	IBT-15-10	IBT-15-15
Cost recovery	50%	50%	50%	50%	50%	50%	50%	50%	50%
Equity									
% of subsidies to poorest quintile	8%	9%	9%	6%	6%	6%	4%	5%	5%
Average subsidy in poorest quintile	US\$23	US\$25	US\$25	US\$16	US\$18	US\$18	US\$13	US\$14	US\$14
Economic efficiency (deadweight loss)	-US\$50,146 (US\$10/hh)	-US\$67,610 (US\$14/hh)	-US\$79,303 (US\$16/hh)	-US\$4250 (US\$1/hh)	-US\$18,078 (US\$4/hh)	-US\$27,487 (US\$6/hh)	US\$17,042 (-US\$3/hh)	US\$5141 (-US\$1/hh)	-US\$3024 (US\$1/hh)
Cost recovery	100%	100%	100%	100%	100%	100%	100%	100%	100%
Equity									
% of subsidies to poorest quintile	39%	27%	19%	39%	18%	9%	<1%	12%	7%
Average subsidy in poorest quintile	US\$10	US\$11	US\$10	US\$2	US\$4	US\$6	US\$1	US\$5	US\$6
Economic efficiency (deadweight loss)	-US\$71,769 (US\$14/hh)	-US\$106,274 (US\$21/hh)	-US\$124,411 (US\$25/hh)	-US\$14,296 (US\$3/hh)	-US\$46,595 (US\$9/hh)	-US\$64,636 (US\$13/hh)	US\$14,455 (-US\$3/hh)	-US\$17,120 (US\$3/hh)	-US\$35,397 (US\$7/hh)

* IBT-0-5 stands for an IBT design with a US\$0 fixed charge and a 5m³ lifeline block.

Figure 1. Average Water Price (US\$/m³) vs. Monthly Water Use (m³) Under Three IBT Tariffs with US\$0 Fixed Charge (FC) and Three Sizes of the Lifeline Block (5m³, 10m³, and 15m³ Per Month)

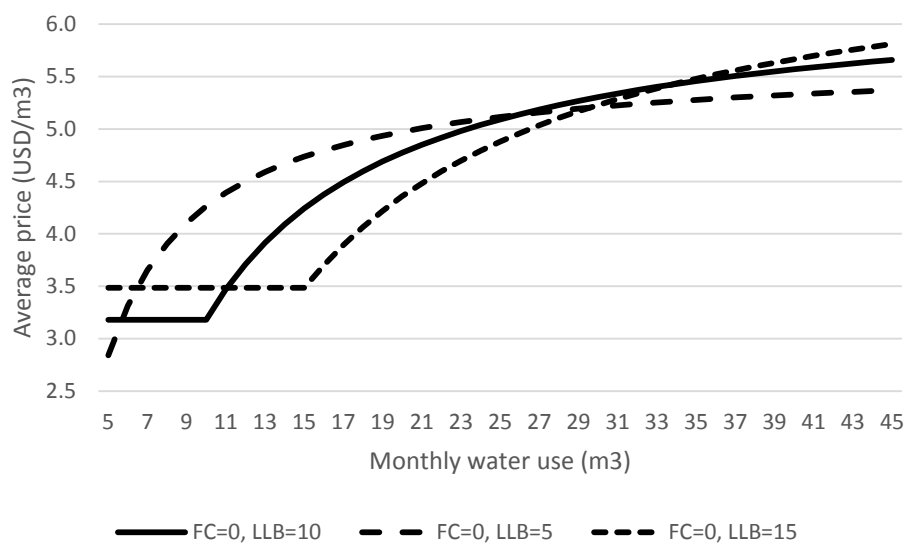


Figure 2. Average Water Price (US\$/m³) as a Function of Monthly Water Use (m³) under Three IBT Tariffs with Non-zero Fixed Charge (FC) and Two Sizes of the Lifeline Block (LLB): 5m³ and 10m³ Per Month

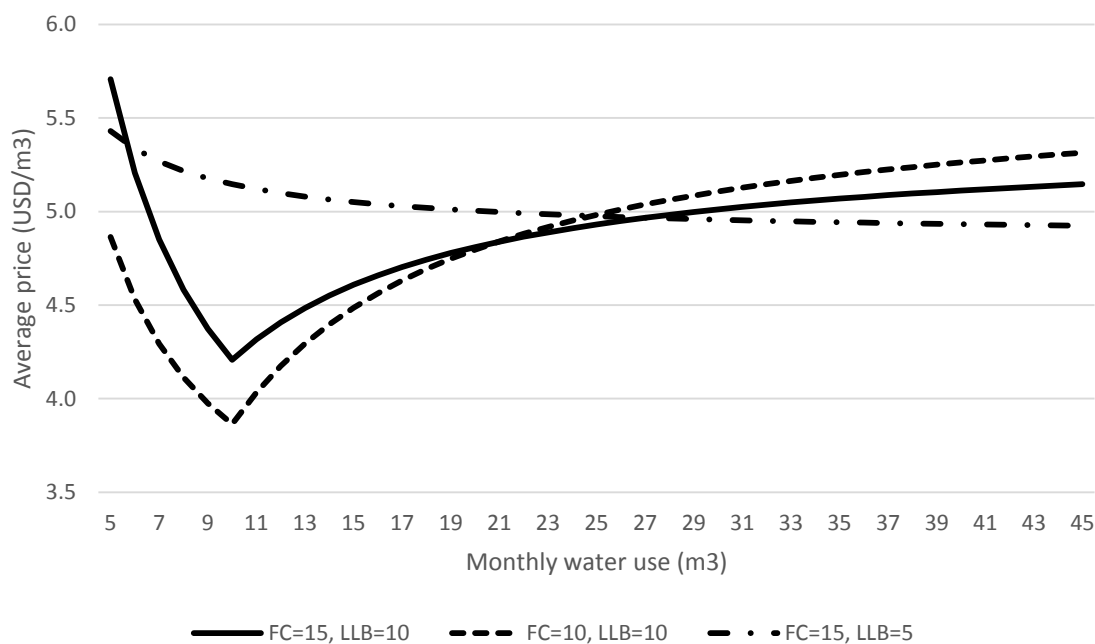


Figure 3. Distribution of Subsidies across Quintiles (Q1 to Q5) under Four Different Scenarios (IBT with US\$0 Fixed Charge and 10m³ Lifeline Block)

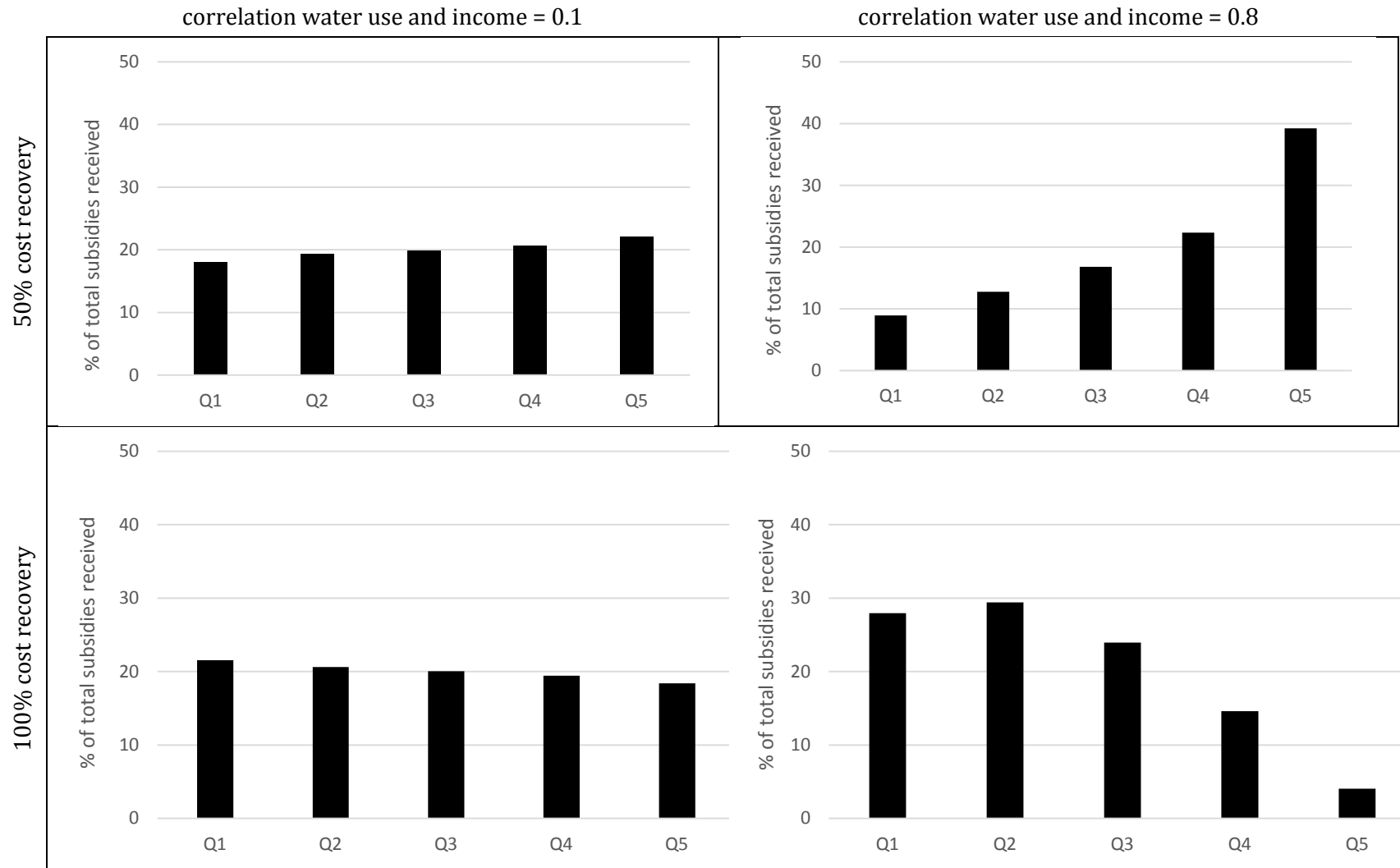


Figure 4. Cumulative Distribution of Subsidies vs. Household Income Percentile; Two Levels of Cost Recovery (50%, 100%) and Two Levels of Correlation (+0.1, +0.8)

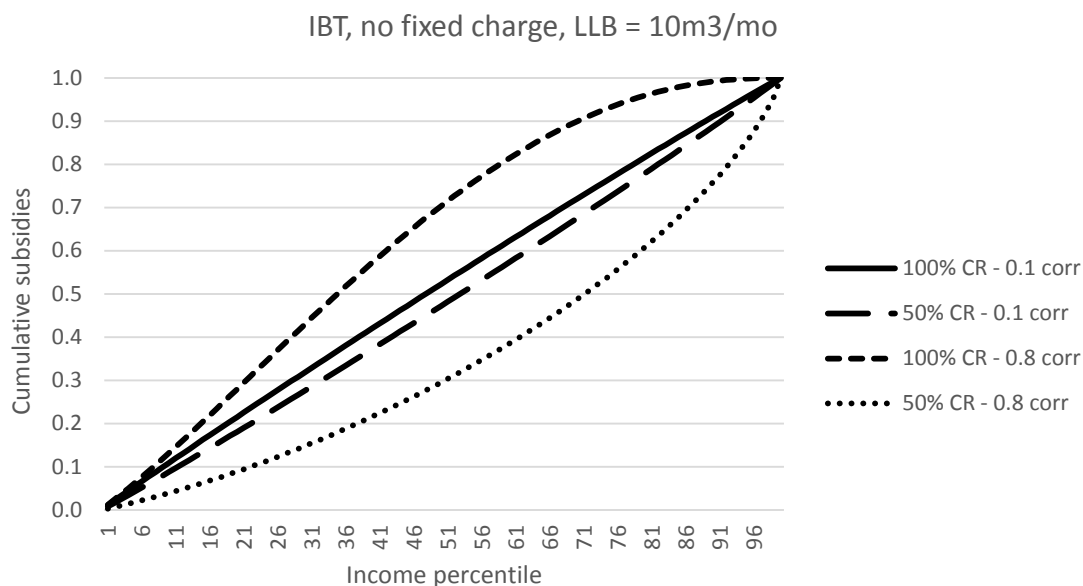
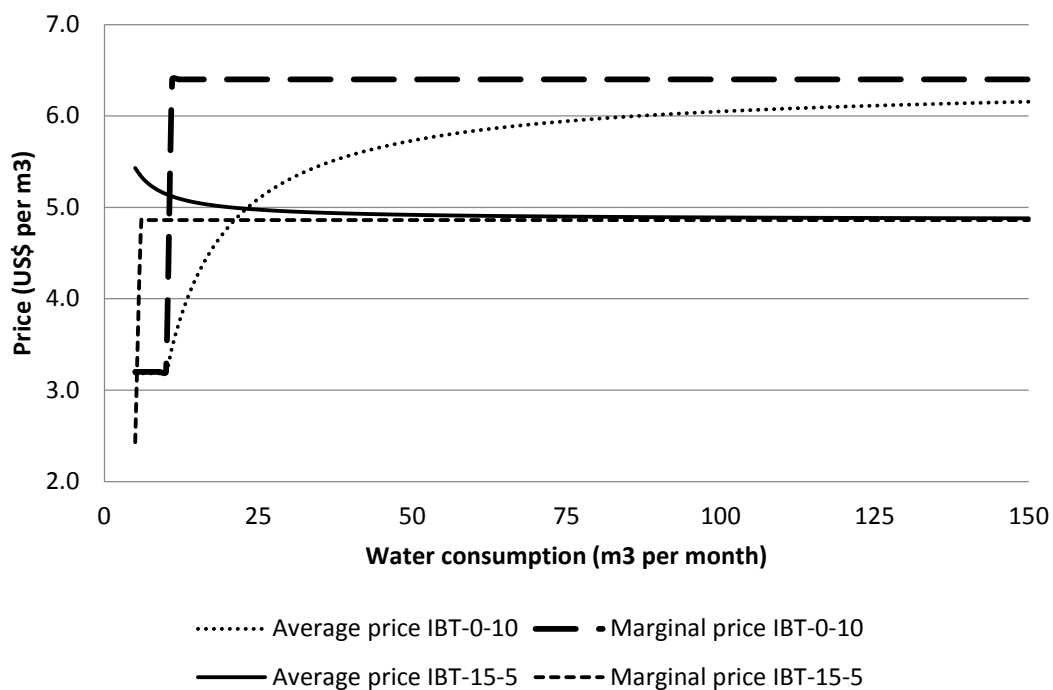


Figure 5. Average and Marginal Prices under IBT-0-10 (US\$0 Fixed Charge and 10m³ Lifeline Block) and IBT-15-5 (US\$15 Fixed Charge and 5m³ Lifeline Block), 100% Cost Recovery



Appendix

Table A1. List and Description of the 36 Scenarios

Scenario	Cost recovery	Correlation water use & income	Fixed charge (US\$/mo.)	Lifeline block (m ³ /mo.)
1	100%	0.1	0	10
2	100%	0.8	0	10
3	100%	0.1	0	5
4	100%	0.8	0	5
5	100%	0.1	0	15
6	100%	0.8	0	15
7	100%	0.1	10	10
8	100%	0.8	10	10
9	100%	0.1	10	5
10	100%	0.8	10	5
11	100%	0.1	10	15
12	100%	0.8	10	15
13	100%	0.1	15	10
14	100%	0.8	15	10
15	100%	0.1	15	5
16	100%	0.8	15	5
17	100%	0.1	15	15
18	100%	0.8	15	15
19	50%	0.1	0	10
20	50%	0.8	0	10
21	50%	0.1	0	5
22	50%	0.8	0	5
23	50%	0.1	0	15
24	50%	0.8	0	15
25	50%	0.1	10	10
26	50%	0.8	10	10
27	50%	0.1	10	5
28	50%	0.8	10	5
29	50%	0.1	10	15
30	50%	0.8	10	15
31	50%	0.1	15	10
32	50%	0.8	15	10
33	50%	0.1	15	5
34	50%	0.8	15	5
35	50%	0.1	15	15
36	50%	0.8	15	15