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A Diagnostic Tool for Estimating the Incidence of Subsidies Delivered by Water Utilities in Low- and Medium-Income Countries, with Illustrative Calculations

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Abstract

It is conventional wisdom that poor households use less water than rich households, and intuition suggests that an increasing block tariff with a lifeline block will target subsidies to poor households. In this paper, we provide a simple diagnostic tool that a water utility can use to estimate the distribution of subsidies to households in different income quintiles and to check whether this intuition about the incidence of subsidies is correct in a specific local service area. The results of our illustrative calculations show that subsidies delivered through the most common tariff structures are very poorly targeted to poor households. This finding holds regardless of the specific characteristics of the tariff structure used to calculate households' water bills. We also find that the higher the correlation between household income and water use, the lower the proportion of total subsidies received by poor households.

Key Words: developing countries, households, subsidy targeting, water tariffs;,water utilities

JEL Codes: Q25, L95, D63

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1. Introduction

Most water utilities in developing countries charge all their customers – households, industries, and government agencies – less for water than the average total cost of service. Every unit of water delivered by the water utility is thus sold below cost and must be subsidized, typically by a combination of donor funds, fiscal transfers from central governments (taxpayers), and deferred maintenance and capital expansion (future customers). It is widely believed that poor households would not be able to afford piped water services if water were priced to recover costs. In addition, the majority of water utilities in developing countries now use an increasing block tariff structure (IBT) to calculate their customers' water bills. These two decisions – to utilize an IBT structure and to sell water to all customers below average total cost – determine the magnitude and distribution of subsidies to different income groups and customer classes.

However, water utilities rarely know the incidence of the subsidies they deliver because they do not have data on the income (or wealth) of their customers. More important, it is conventional wisdom that poor households use less water than rich households, and intuition suggests that an IBT with a lifeline block will target subsidies to poor households. In this paper, we provide a simple diagnostic tool that a water utility can use to estimate the distribution of subsidies to households in different income quintiles and to check whether this intuition about the incidence of subsidies is correct in a specific local service area. This diagnostic protocol is designed to calculate the incidence of subsidies to households with metered private connections, not to households using public taps or unmetered connections, or to industries or other users. But the protocol could be adapted to cover such situations.

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We use our diagnostic protocol to model baseline (status quo) conditions and typical tariff structures common in many water utilities and their associated service areas in cities in developing countries. The results show that only a small percentage of the total subsidies reach low-income households. This finding holds regardless of the specific characteristics of the tariff structure used to calculate households' water bills. We also find that the higher the correlation between household income and water use, the lower the proportion of total subsidies received by poor households. This contrasts sharply with common intuition that IBTs will effectively target subsidies to poor households if the poor use less water than the rich. We conclude that making small adjustments to water tariff structures in hopes of assisting poor households is misguided, and that water utilities need to focus on alternative subsidy targeting mechanisms, and in particular means testing, if they really want to assist poor households. Municipal water tariff structures should be designed to meet financial and economic objectives – and not attempt to achieve objectives related to poverty alleviation and income redistribution. If means testing is impractical or politically infeasible, then other policy instruments are required to achieve poverty alleviation.

The first section of the paper summarizes the types of water tariff structures currently used in developing countries, the rationales underpinning the widespread use of IBTs, and the findings from the existing literature on the incidence of subsidies in the water and sanitation sector. The second section presents the modeling strategy used to calculate the incidence of subsidies and the key assumptions needed. The third section of the paper discusses in more detail the data requirements for the use of the diagnostic protocol. The fourth section presents the results of the application of the diagnostic tool, assuming typical conditions of water utilities in low-income countries. The fifth, concluding section discusses what these findings mean for attempts to design water tariff structures to target subsidies to poor households.

2. Background

IBTs are now the tariff structure of choice in low- and middle-income countries. In 2013, Global Water Intelligence (GWI) surveyed 165 water utilities in 71 low- and middle-income countries and found that 74 percent were using IBTs (Table 1).

Table 1. Water tariffs in use in low- and middle-income countries.

Tariff structure	No. utilities	Percent
Decreasing block	1	1%
Fixed	6	4%
Increasing block	122	74%
Uniform volumetric	36	22%
Total	165	100%

Source: GWI (2013).

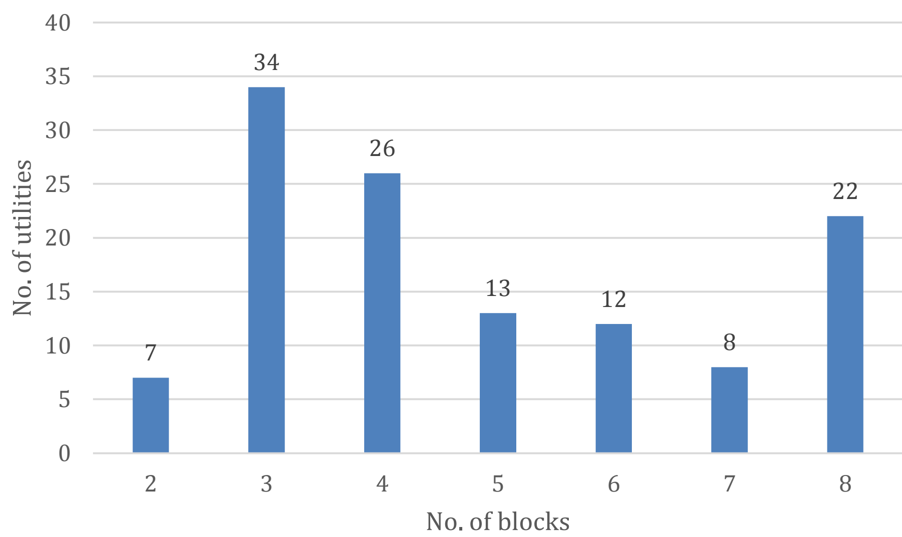
IBTs appear to have three appealing features. First, poor households can obtain water in the first (“lifeline”) block cheaply, or even for free. Thus, piped water services should be affordable to poor households if they do not use “excessive” quantities of water. Second, assuming rich households use more water than poor households, there is a potential for rich households to cross-subsidize poor households. Third, the price signals in the higher blocks provide an incentive to households to conserve water.

However, in order to increase their revenues, utilities have often made three modifications to the standard IBT, all of which diminish its simplicity and intuitive appeal. The first is to impose a minimum charge on a household’s monthly water bill. For example, this minimum charge is often set equal to the price in the first block times the size of the first block – i.e., households are charged for the entire first block regardless of how much water they use. The consequence of such a minimum charge is that the household has no incentive to use less water than the maximum quantity in the first block. Second, a positive fixed charge is often added to the volumetric component of households’ water bills. For households falling in the lifeline block, this can greatly increase the average cost per unit of water purchased.

The third modification is termed a “Volume Differentiated Tariff” (VDT), sometimes called a “ratchet” IBT. When a VDT is used to calculate a household’s water bill, households that use more than the lifeline block are charged the volumetric price in the highest block in which their water use falls for their entire water use. The VDT provides households a strong incentive to keep their water use just under the amount of the next highest priced block so that the higher prices do not kick in for all previously used units. It also provides a strong incentive for utilities to bill for water use just over the next highest priced block and for households to bribe a meter reader to record the household’s water use as just under the amount in the higher price block. VDTs thus induce a variety of socially inefficient and undesirable behaviors.

IBTs in their various forms are popular throughout the world, but the specific features of the IBT (i.e., the number of blocks, the average prices charged in each block, the size of the first ("lifeline") block, and the size of the positive fixed charge) vary widely from utility to utility. The majority of utilities with IBT structures in the GWI database used three or four blocks, but five, six, seven, or even eight blocks were not uncommon (Figure 1).

Figure 1. Characteristics of IBTs in practice – number of blocks. Source: GWI (2013).



The median size of the first block was ten cubic meters, surprisingly large (Table 2). Seventy percent of water utilities using IBTs added a positive fixed charge to the volumetric component of the tariff; the median size was US$4-5 per month in East Asia and Latin America and US$1 per month in South Asia and Sub-Saharan Africa.

Table 2. Characteristics of IBTs: size of first block (by region).

		Size of the first block (m3/mo.)		
Region	Obs.	Mean	Median	Std. Dev.
East Asia and Pacific	44	16.2	10.0	11.9
Latin America and Caribbean	32	12.1	10.0	7.6
Middle East and North Africa	17	18.1	8.3	18.1
South Asia	9	12.0	10.0	4.6
Sub-Saharan Africa	20	7.6	6.5	4.0
Total	122	13.7	10.0	11.2

Source: GWI (2013).

Looking at the subsample of 34 utilities in the GWI database that use a three-block IBT, the median price of water was US$0.35 per cubic meter in the first block, US$0.57 per cubic meter in the second block, and US$0.75 in the third block. In most utilities in developing countries, the average total cost of water services is in the US$1-2 per cubic meter range, so even water sold in the highest block is subsidized. Average household water use varies across households and by water utility, but in low-income and middle-income countries with such low average water prices, mean and median household water use typically falls in the range of 10-20 cubic meters per month. With the average lifeline block equal to 10 cubic meters, it is common for the majority of water sold to households to be billed at the lowest (lifeline) price.[1]

Over the past couple of decades, there has been growing interest among researchers as to how well different policy instruments perform with respect to delivering subsidies to the intended beneficiaries (Coady et al., 2004). In the water and sanitation sector, there have been several policy instruments used to target subsidies to poor households, including subsidizing the costs of connecting households to the piped network (Angel-Urdinola and Wodon, 2012); targeting geographic areas where predominantly poor households live (Foster et al., 2000; Gómez-Lobo and Contreras, 2003); offering free water from a system of public taps (Komives et al., 2005); and means testing to identify poor households eligible for subsidies to help pay their water bills (Gómez-Lobo and Contreras, 2003; Barde and Lehmann, 2014). But in most water utilities around the world, the principal policy instrument for assisting poor households has been the IBT.

Despite the popularity of IBTs, researchers have noted two reasons why they may not target subsidies effectively to low-income households in developing countries (Whittington, 1992, 2003; Boland and Whittington, 2000). First, only households with a piped water connection can receive subsidies delivered through the water tariff. In many developing countries, however, the poorest households often do not have piped water connections. Second, the underlying assumption that low-income households use less water than high-income households simply may not be accurate in many developing country contexts.

A number of studies have attempted to determine empirically the incidence of subsidies in the water and sanitation sector (for a summary, see Table A1 in Appendix A); most have focused on the question of how well the water tariff structure targets subsidies to poor

[1] This would not be true if a VDT were used.

households (e.g., Komives et al., 2005; Komives et al., 2006; Komives et al., 2007; Bardasi and Wodon, 2008; Banerjee et al., 2010).[2] Some researchers examine only quantity-based subsidies (Walker et al., 2000; Foster and Araujo, 2004); others compare the performance of quantity-based subsidy targeting with social tariffs applied via administrative selection (Foster, 2004; Barde and Lehmann, 2014). A few researchers explicitly compare the performance of quantity-based subsidies and connection subsidies (Angel-Urdinola and Wodon, 2012).

There is broad consensus in this literature that quantity-based subsidies delivered through the water tariff are poorly targeted in most developing country contexts. Indeed, all of the studies in the literature find that quantity-based subsidies delivered through the water tariff perform worse than if the subsidies were randomly distributed among the population. This finding is largely driven by the fact that low-income households in many countries do not have a piped connection to piped water and sanitation networks.

While there is broad consensus in the subsidy incidence literature regarding the poor performance of IBTs, analysts often do not have access to accurate data on both income and household water use. For example, nearly all of the studies in Table A1 use data from household income and expenditure surveys to estimate both income and water use. However, these surveys typically do not collect information on household water use. Rather, they ask households how much they spent on water the previous month. To obtain estimates of water use, studies in the literature back calculate water use from households' stated expenditure on water, using the official tariff and the households' level of service (e.g., piped water vs. piped water and sewer service). This can be problematic when households use multiple water sources or treatment technologies and thus provide an estimate of water expenditures that includes costs other than the household's water bill. When meters are shared, do not work, or are not read, a household's stated expenditure on water will be a poor proxy for water use. Stated expenditure will also be a poor proxy for water use when a household's water bill includes pro-rated connection charges, arrears, or credits.

Despite the general consensus in the empirical literature on subsidy incidence that IBTs do not effectively target subsidies to poor households, some researchers still argue that IBTs can

[2] Exceptions include Gómez-Lobo and Contreras (2003), who compare the performance of a geographic targeting subsidy scheme in Columbia and a means tested subsidy program in Chile, and Foster et al. (2000), who compare zonal and means tested subsidies in Panama.

be used to address concerns about equity, fairness, and affordability. For example, Hoque and Wichelns (2013, p. 489) state, “increasing block-rate tariffs are helpful in providing low-income consumers with essential water volumes at low prices while encouraging wealthier consumers to use water wisely.” Similarly, the Asian Development Bank’s Urban Water Supply and Sanitation in Southeast Asia: A Guide to Good Practice states, “[r]ising block tariffs are effective and fair. They are not perfect but they work well, are easy to implement, are easy to communicate to customers, and are a pragmatic solution to a complex issue” (ADB, 2014, p. 66).

The assertion that IBTs can be used to pursue equity or fairness typically stems from the assumption that low-income households use less water than high-income households. For example, describing the assumptions they used in a simulation model to derive efficient prices, Diakité et al. (2009) state, “it seems reasonable to assume that poor households that are connected to the water network will have their consumption level in the first pricing block. We therefore define a ‘poor’ household as one whose water consumption is below the upper bound of the social pricing block" (p. 267). Wichelns (2013, p. 320) makes a similar assumption in his tariff simulation model: "all of the water purchased by non-poor residents is [assumed to be] obtained from Block 2 or Block 3. We assume for simplicity that poor residents purchase water only in Block 1.” Both Diakité et al. (2009) and Wichelns (2013) not only assume that income and water use are highly correlated, but define income groups in their simulations by water use. The assumption that water use and income are highly correlated is intuitively appealing. (Table A2 in Appendix A provides additional examples from the literature of studies that implicitly or explicitly assume there is a strong correlation between income and water use.) However, the relationship between income and water use is an empirical question that may vary from one context to another.

The literature on municipal water pricing thus contains mixed messages regarding the extent to which IBTs can effectively deliver subsidies to low-income households. Therefore, it may be difficult for a water utility manager or policymaker to understand whether an IBT, or the water tariff more broadly, is an appropriate tool for delivering subsidies to low-income households with a piped connection, given the specific local realities in his or her city or service area. We have designed a diagnostic tool so that policymakers can estimate more precisely the incidence of subsidies delivered to households with metered connections in a situation more closely resembling their own local conditions. We then use this diagnostic tool to compare the subsidy targeting performance of a wide range of potential tariff structures.

A limited number of studies in the literature explicitly compare the targeting performance of multiple alternative tariff structures. This is in part due to the fact that studies often compare the performance of quantity-based subsidies delivered through the water tariff to alternative subsidy targeting mechanisms such as connection subsidies or means-tested subsidies. However, when studies in the literature do directly compare the targeting performance of quantity-based subsidies delivered through the water tariff, they often compare a small number of tariffs (e.g., Komives et al., 2005; Groom et al., 2008; Angel-Urdinola and Wodon, 2012; Wichelns, 2013; Barde and Lehmann, 2014). In general, studies do not systematically examine the extent to which changes to different components of the tariff have an impact on subsidy targeting. This paper seeks to address this gap in the literature. In the next section of the paper, we describe the analytical approach underpinning our diagnostic tool.

3. Analytical strategy

The diagnostic tool is designed to help a water utility manager answer the question, "What is the current incidence of subsidies to households with metered private connections in my service area?" To use this diagnostic tool, the user needs to know (or assume) the following five types of information:

1) Average total production (including both capital and operation and maintenance) cost of water services;
2) Distribution of water use for households with metered private connections;
3) Distribution of income (or wealth) of those households;
4) Correlation between household water use and income; and
5) Tariff structure used to calculate household water bills.

The diagnostic tool calculates the incidence of subsidies for an illustrative sample of 5,000 hypothetical households from the utility's service area. The results of the subsidy incidence calculations for these 5,000 households are assumed to be representative of the total population of households with metered private connections in the service area. The analytical strategy used to calculate the incidence of subsidies for these 5,000 hypothetical households involves five steps.

In the first step, for each of the 5,000 households, a value of household water use and income is drawn from the two assumed distributions (distribution of water use and distribution of income) to create 5,000 pairs of water use and income. These 5,000 pairs of household water use and income are drawn to achieve a pre-specified correlation between water use and income that the user thinks reflects local realities in his service area. To approximate the pre-specified correlation between water use and income, we use a procedure proposed by Johnson and Tenenbein (1981), which is described in Appendix B. These 5,000 households (each with an assigned value of water use and income) are divided into five groups based on their income. Each of these five income quintiles has 1,000 households, i.e., 20 percent of the hypothetical households.

In step 2, the water bill is calculated for each of the 5,000 households using the household's water use (Q_i) and the existing tariff structure. For example, if the water utility used a tariff structure with a uniform volumetric price P and no fixed charge, the water bill for household i (WB_i) would be

$$WB_i = P \times Q_i \quad (1)$$

Assuming the average total production cost per cubic meter is AC, then the subsidy received by household i (SUB_i) is

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

In step 3, 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 both calculated.

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

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

Step 4 is to calculate the share of the total subsidies received by households in each income quintile j ($ShareSUB_{IQj}$) …

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

In step 5, we repeat steps 1-4 a thousand times, and then calculate the average of the share of the total subsidies received by households in each income quintile j ($ShareSUB_{IQj}$) over the 1,000 replications. The result is our best estimate of the share of total subsidies received by households in each income quintile for the water utility's service area, given the assumptions made.

4. Data

Next, we discuss the data requirements of the diagnostic tool and where the user can obtain these data. Because capital costs are typically heavily subsidized and replacement costs are often unknown, many utilities do not have good estimates of their average total production costs per cubic meter. In most developing countries, average total production costs for piped water (not including sewerage collection and treatment) will probably be in the range of US$1.00-1.50 per cubic meter. These estimates can be used as a starting point in the subsidy incidence calculation.

The distribution of water use for households with metered private connections can be estimated from the utility's customer billing records. A log-normal functional form can be used to approximate this distribution. Figures 2 and 3 present examples of such a probability density function of household water use for two water utilities in low-income countries. A log-normal distribution can quite accurately approximate the probability density function of household water use in Figure 2 because the data suggest that this utility has working meters that are read regularly. In contrast, the probability density function in Figure 3 suggests that household water use is measured less accurately than in Figure 2, perhaps because water meters are not being read regularly, are not being read and recorded accurately, or are simply not functioning. In this case, a log-normal function can still be used to approximate the probability density function of household water use, but there will be more uncertainty about the actual shape (mean and standard deviation) of the function. The user will need to estimate the mean and standard deviation to fit the probability density function data for household water use to the assumed log-normal functional form.

Figure 2. Example of probability density function of household water use for a city in a low-income country.

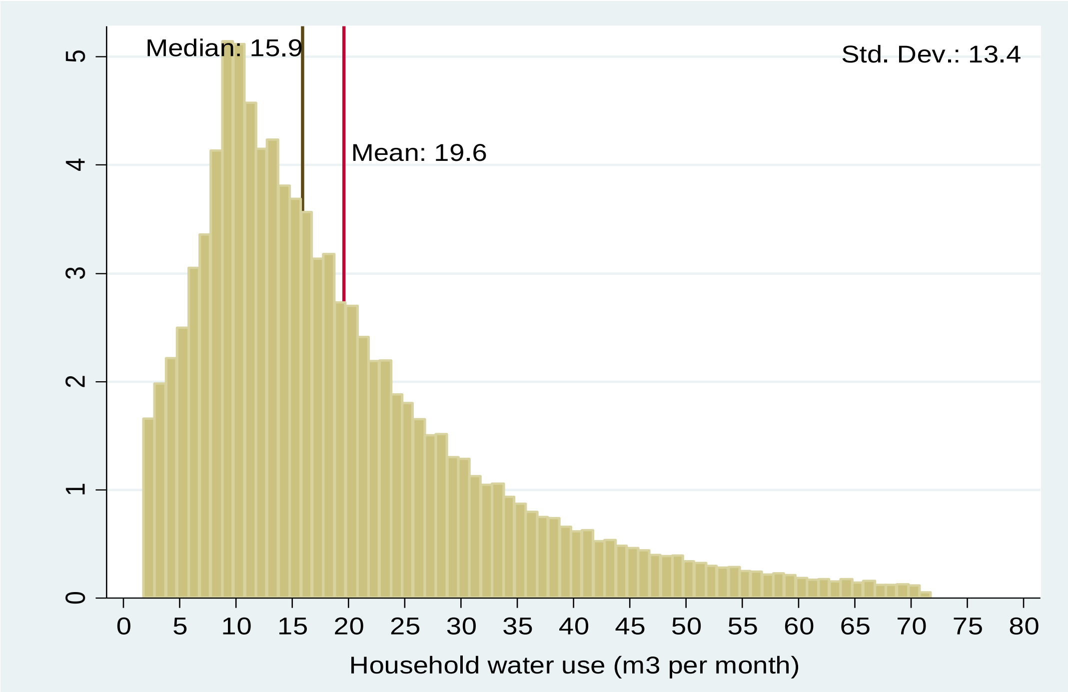
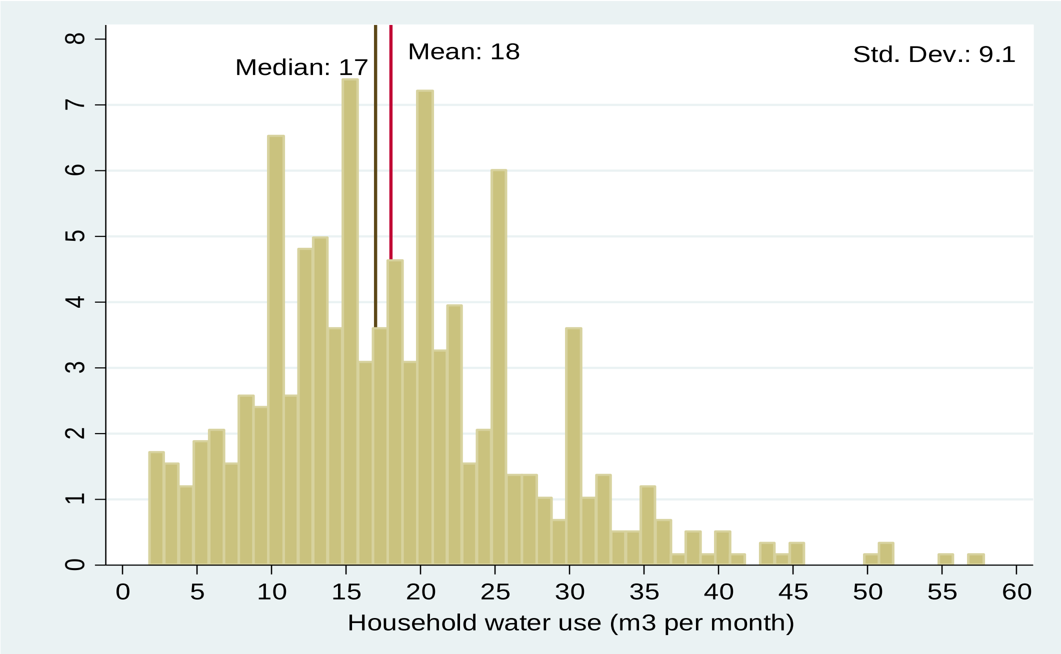


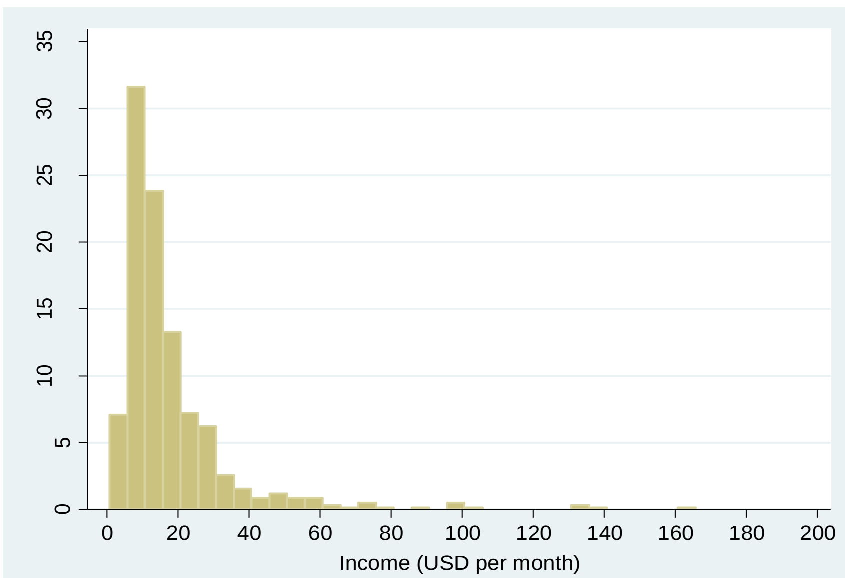
Figure 3. Example of a second probability density function of household water use for a city in a low-income country.



Some water utilities have not yet adopted electronic billing systems. In such cases, the user can abstract a sample of household water use data from paper records. Care will need to be taken to record household water use only for customers with working meters for the exclusive use of household members.

Data on household income, expenditures, or wealth usually can be obtained from existing or new household surveys. However, existing household surveys may not closely match the geographic service area of the water utility. Adjustments in the sample of general-purpose surveys will need to be made to include only households with metered private connections. Figure 4 presents the probability density function of household income for three cities in Sri Lanka. Similar to the probability density function for household water use, a log-normal function would provide a reasonably accurate fit for these household income data. As for the household water use data, the user will need to estimate the mean and standard deviation for the assumed log-normal function.

Figure 4. Example of a probability density function of household income – Three cities in Sri Lanka.



Data on the correlation between household water use and household income for a water utility's service area are much more difficult to come by. As noted, water utilities do not normally have household income information for their customers, and back calculating household water use from household surveys based on respondents' answers to questions about total water expenditures is problematic for the reasons noted above.

The best approach for estimating the correlation is to conduct a special survey to collect household income data for a sample of the utility's household customers so that the customer billing records can be matched with the household income data. Because such surveys can be expensive and time-consuming to organize and implement, most water utility managers will likely want to run the diagnostic tool without conducting a special survey to estimate the correlation between household water use and income. In the absence of data from the local service area, what is a reasonable value to assume for the correlation between household water use and income? There is surprisingly little data in the literature to answer this question. Table 3 presents estimates of this correlation coefficient for four data sets to which we have access that have data on both household water use and income.

Table 3. Correlation coefficients between water use and income – four studies.

Location	Study	Sample size	Correlation coefficient	Spearman's rank correlation
Sri Lanka (3 cities)	Nauges and van den Berg (2009)	590	0.22	0.28
El Salvador (3 cities)	Strand and Walker (2003)	398	0.08	0.13
Dakar, Senegal	Briand et al. (2010)	112	0.23	0.24
Nairobi, Kenya	Unpublished	648	0.14	0.34

The findings from these four studies (two from Africa, one from Latin America, and one from South Asia) all suggest that the correlation between household water use and income is quite low. Based on these results, in the absence of other information, we recommend that a user assume a Spearman rank correlation coefficient in the range of 0.1 to 0.3. Of course, the estimates of Spearman rank correlation coefficients in Table 3 are dependent on the tariff structure and any on subsidy schemes in place when the household water use and income data were collected. If tariffs were increased, the correlation coefficients could change as well.

The last information required is the tariff structure itself, which should be well known to the user. However, in our experience there may be a discrepancy between the official published water tariff and the tariff structure actually used to calculate households' water bills. The actual water tariff is the computer code used in the electronic billing system to calculate households' water bills. It happens that water utility managers may require increased revenues. One way to do this is to simply change the computer code in the customer billing system to increase the water bills households receive. A series of such "small" changes in the billing code may not be reflected in the official tariff. If the user wants to know the incidence of subsidies, the relevant status quo conditions include the tariff embedded in the billing code, not the official water tariff.

5. Results: An illustrative example

To illustrate the type of results that can be obtained from the implementation of this diagnostic protocol, we assume a set of baseline (status quo) conditions that are typical of water utilities in low and middle-income countries, and then report findings with regard to the incidence of subsidies. Results may differ somewhat for specific water utilities, but the general findings seem to be quite robust to changes in the main assumptions. The distributions of household water use and income have been calibrated using household data from two low-income countries. We consider two cases for the Spearman correlation coefficient between water use and income: a low-correlation case (0.2) and a high-correlation case (0.8). In both, the total amount of water used by the 5,000 households is the same, but the total and average water use in each income quintile varies. In the case of a low correlation (0.2), the average household water use varies from 16 m3 per month in the first quintile to 24 m3 per month in the fifth quintile (Table 4). In the case of a high correlation (0.8), the average household water use varies from 8 m3 per month in the first quintile to 39 m3 per month in the fifth quintile.[3]

Table 4. Average household water use (m3/mo.) by income quintile (IQ).

	IQ 1	IQ 2	IQ 3	IQ 4	IQ 5
Low correlation case (0.2)	16	18	20	21	24
High correlation case (0.8)	8	13	17	23	39
High correlation case (0.8)	8	13	17	23	39

We present findings for several different water tariff structures—uniform volumetric tariff and three variants of a two-block IBT (a "normal" IBT, an IBT with a minimum charge or free allotment,[4] and a Volume Differentiated IBT). We consider different levels of fixed charges (US$0, US$2, and US$4 per month) and two sizes of the lifeline block for IBT tariffs (10 and 15 cubic meters per month). For purposes of illustration, all of the tariff structures are assumed to generate the same revenues. The average cost is assumed to be US$1 per cubic meter in all

[3] The parameters of the log-normal distribution of monthly water use are: 2.75 for the mean and 0.70 for the standard deviation. The corresponding parameters for the log-normal distribution of monthly income are 7.41 (mean) and 0.88 (standard deviation). These correspond to an average household water use of 20 m3 per month and an average household income of about US$2,000 per year. Our results are found to be robust to changes in the mean and standard deviations of these two distributions.

[4] An IBT with free allotment means that water use in the first block is given for free.

scenarios and, as a consequence, the total amount of subsidies distributed to the 5,000 households is also the same for all tariff structures. The revenue target is based on the total household water use of the sample of 5,000 households and an assumed uniform volumetric charge of US$0.50 per cubic meter and no fixed charge. For other uniform volumetric tariff structures with different fixed charges, the volumetric price is adjusted up or down to achieve the same total revenue, assuming no quantity adjustment to the price change. For the IBT structures, the fixed charge and the size and volumetric price in the first block are set by assumption, and the price in the second block is adjusted to achieve the revenue target, again assuming no quantity adjustment to the price change. The characteristics of all the tariff structures considered in this section are summarized in Table 5.

Table 5. Characteristics of the tariff structures.

Tariff Code	Type of tariff	FC (US$/mo.)	LLB (m3/mo.)	Price in low block (US$/m3)	Price in upper block (US$/m3)	Bill for 15 m3 (US$)
UP-0	UP	0	0	0.50	0.50	7.5
UP-1	UP	2	0	0.40	0.40	8.0
UP-2	UP	4	0	0.30	0.30	8.5
IBT-0	normal IBT	0	10	0.25	0.71	6.1
IBT-1	normal IBT	2	10	0.25	0.53	7.1
IBT-2	IBT + MC	0	10	0.25	0.69	6.0
IBT-3	IBT + MC	2	10	0.25	0.51	7.0
IBT-4	IBT + FA	0	10	0.00	0.93	4.6
IBT-5	IBT + FA	2	10	0.00	0.74	5.7
IBT-6	normal IBT	4	10	0.25	0.34	8.2
IBT-7	IBT + MC	4	10	0.25	0.32	8.1
IBT-8	IBT + FA	4	10	0.00	0.56	6.8
IBT-9	normal IBT	2	15	0.25	0.64	5.8
IBT-10	IBT + MC	2	15	0.25	0.55	5.8
IBT-11	IBT + FA	2	15	0.00	1.04	2.0
VDT-0	normal VDT	0	10	0.25	0.52	7.9
VDT-1	normal VDT	2	10	0.25	0.41	8.2
VDT-2	VDT + MC	0	10	0.25	0.51	7.7
VDT-3	VDT + MC	2	10	0.25	0.40	8.1
VDT-4	normal VDT	4	10	0.25	0.30	8.6
VDT-5	VDT + MC	4	10	0.25	0.29	8.4
VDT-6	normal VDT	2	15	0.25	0.44	5.8
VDT-7	VDT + MC	2	15	0.25	0.40	5.8

Notes: UP (Uniform Pricing), IBT (Increasing Block Tariff), VDT (Volume Differentiated Tariff), MC (minimum charge), FA (free allotment), FC (fixed charge), LLB (lifeline block).

The way to compare results for different tariff structures is to consider each tariff structure as a possible example of status quo (baseline) conditions for a hypothetical water utility. We caution the reader that we have made no attempt to model the transition from one tariff structure to another.[5]

Figure 5 presents the results of the subsidy incidence calculations for six tariff structures, assuming a low correlation between household water use and income (a Spearman's rank correlation coefficient of 0.2). This is consistent with the correlations we report in Table 3. The six tariff structures are the following: uniform pricing with a monthly US$2 fixed charge (UP-lc1)[6] and five variants of a two-block IBT with a US$2 fixed charge and a 10 cubic meters lifeline block: a "normal" IBT (IBT-lc1), an IBT with a minimum charge (IBT-lc3), an IBT with free allotment (IBT-lc5), a Volume Differentiated IBT (VDT-lc1), and a Volume Differentiated IBT with minimum charge (VDT-lc3).[7] The vertical axis is the proportion of the total subsidy received by households in an income quintile. There are two striking results.

First, the proportion of the total subsidies received by households in the poorest income quintile is very low for all six tariff structures (about 0.15). Indeed, the subsidy targeting is worse than if the subsidy were randomly distributed to customers, which would provide 20 percent of the subsidies to each wealth quintile. Moreover, the share of total subsidies received by households in the five household income quintiles is the opposite of what one would want from a well-designed subsidy scheme. Households in the richest income quintiles receive higher proportions of the total subsidy than do households in the poorest quintiles. This occurs because all the water sold by the utility is subsidized, and the more water a household receives, the more subsidies it receives.

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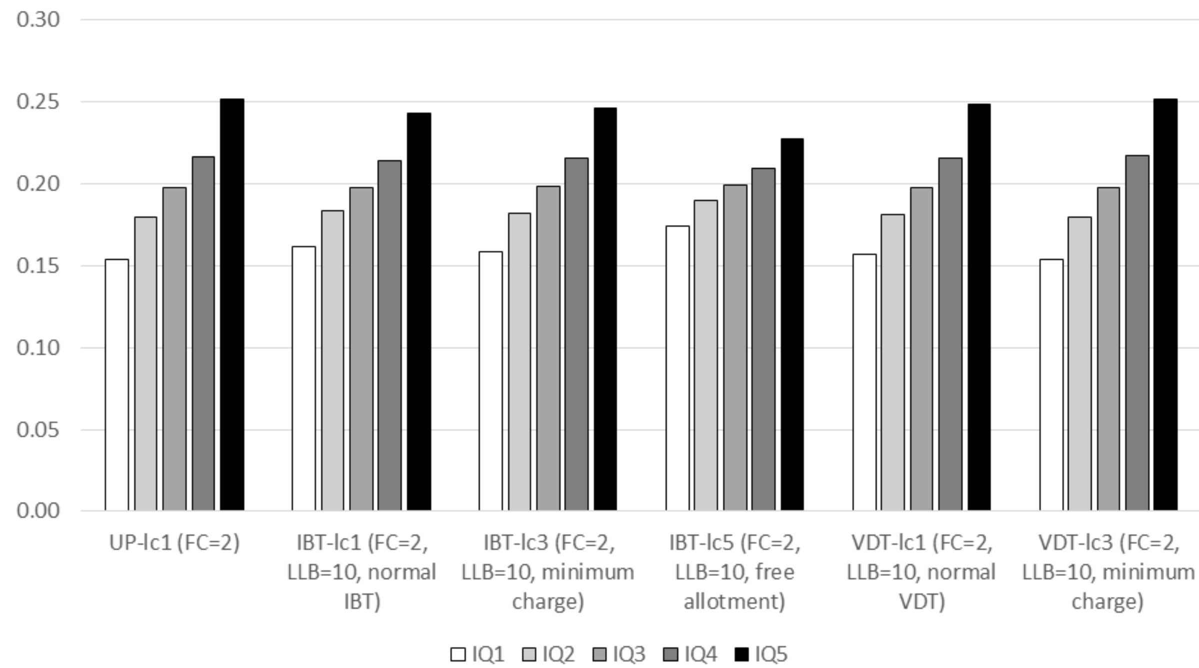
[5] The assumption of no quantity adjustment to price changes requires further explanation. The price elasticity of demand for residential water use is on the order of -0.1 to -0.30, not zero (Nauges and Whittington, 2010). In fact, the user of the diagnostic tool will not need to make this assumption to analyze status quo conditions in her service area. She will simply use the existing tariff structure in her service area that yielded the probability density function of household water use. Thus, each of these tariff structures is best conceptualized as an alternative status quo condition, not as a forecast of what would happen if a water utility manager changed his current tariff structure to one of the other structures simulated.

[6] The "lc" in the tariff code refers to the "low correlation" case (Spearman's correlation coefficient: 0.2). The "hc" in the tariff code refers to the "high correlation" case (Spearman's correlation coefficient: 0.8). The remainder of the tariff code follows Table 5.

[7] We do not show the results for a Volume Differentiated IBT with free allotment because, in the case of an IBT with two blocks, the Volume Differentiated IBT with free allotment is equivalent to an IBT with free allotment.

Figure 5. Subsidy incidence for six tariff structures (Spearman's correlation coefficient: 0.2) by income quintile (IQ).



Second, the results are essentially the same for all six tariff structures. In other words, all of the tweaking that water utilities and tariff consultants do to improve the targeting of subsidies is probably not helping poor households. Households in the richer quintiles receive a higher share of the total subsidies than do households in the poorer quintiles for all six tariff structures.

Figure 6 shows what happens if one assumes that the correlation between household water use and income is 0.8 (very high). This would be consistent with the widespread assumption that low-income households use less water than high-income households. Perhaps counterintuitively, given our assumptions, a high correlation between household water use and income only makes the subsidy incidence worse, i.e., households in the richest quintile receive an even larger share of the total subsidies. The total water use of the 5,000 households is fixed by the assumed distribution. A high correlation means rich households use more water and thus poor households must use less for the total water use to remain the same (see Table 4). Because all water is subsidized, the rich receive more subsidized water and a larger share of the total subsidies. Of course, both the income distribution and the tariff structure are embedded in the household water use distribution, so, for a given water utility, the user will want to choose a correlation coefficient that is consistent with local realities. The diagnostic tool is not designed to simulate the dynamic effects of a changing correlation between household water use and income.

Figure 6. Subsidy incidence for six tariff structures (Spearman's correlation coefficient: 0.8) by income quintile (IQ).

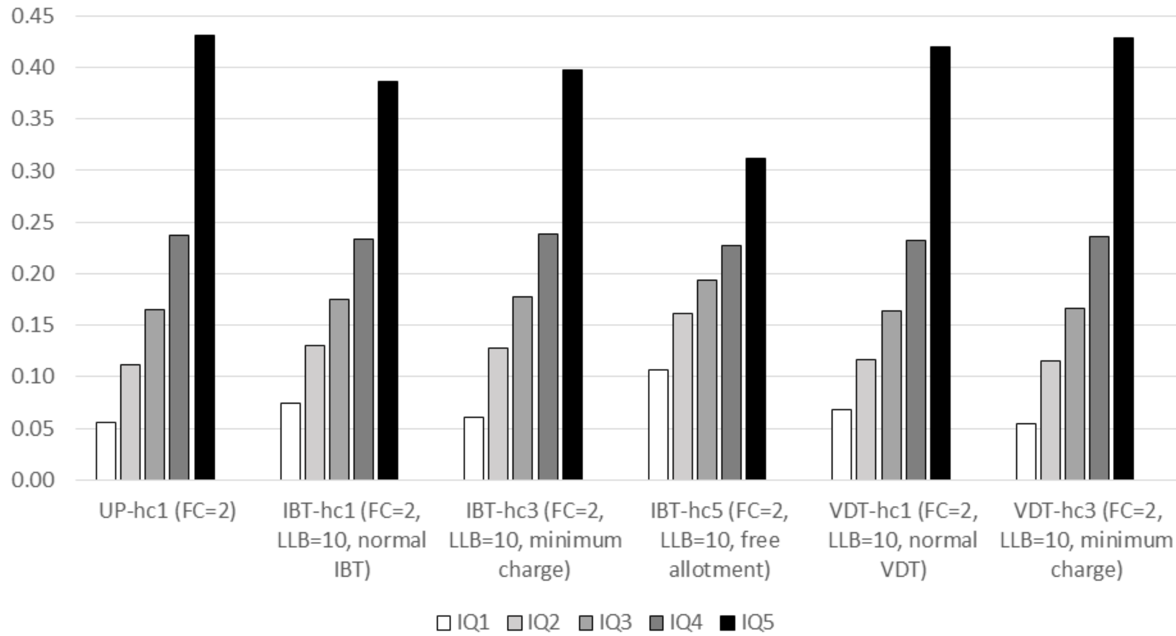


Figure 7 shows how the subsidy incidence is affected by changes in the positive fixed charge (US$0, US$2, and US$4) when a uniform volumetric tariff is used. As fixed charges are increased, the share of subsidies received by households in the poorest income quintiles falls. Increases in fixed charges are popular with water utilities because they stabilize the utilities' cash flows, but the burden falls disproportionately on poor households.

Figure 7. Subsidy incidence with uniform volumetric tariffs – Effects of changes in positive fixed charge (Spearman's correlation coefficient: 0.2).

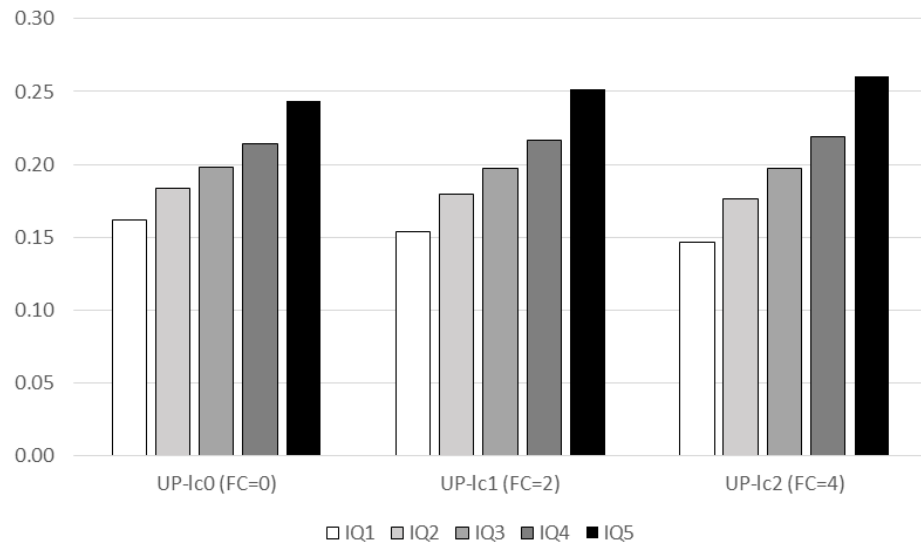
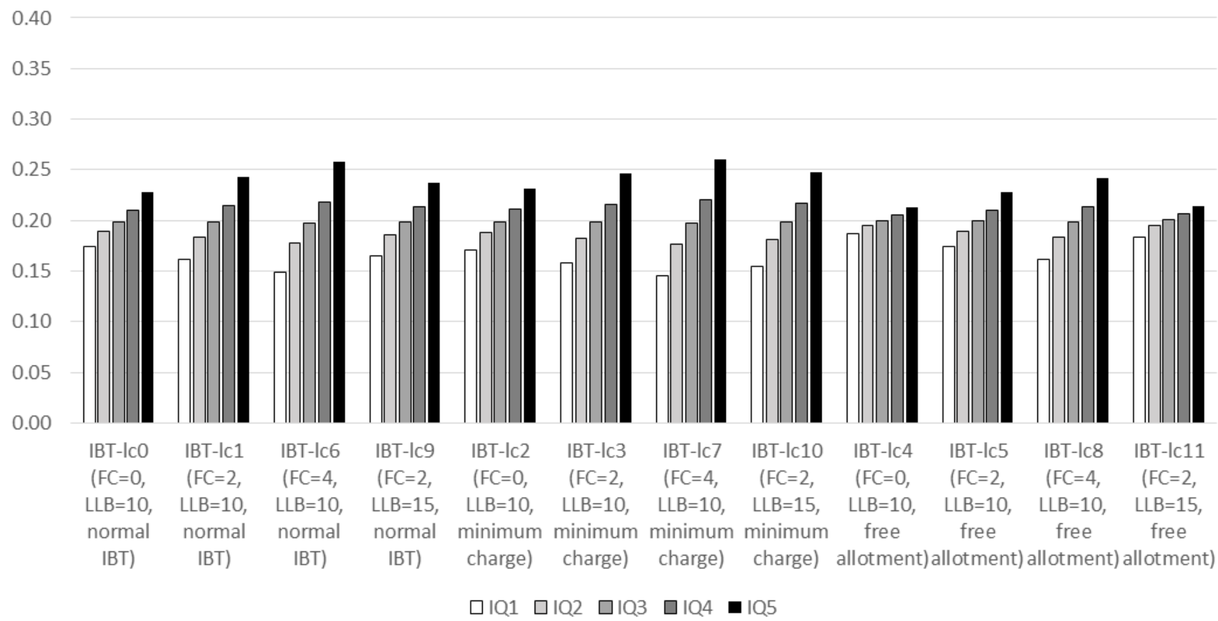


Figure 8 shows the subsidy incidence for three types of IBTs ("normal" IBT, IBT with minimum charge, and IBT with free allotment) and 12 specific IBT structures. These IBTs have different lifeline blocks (10 and 15 cubic meters per month) and different fixed charges (US$0, US$2, and US$4). All 12 IBTs perform worse than if the subsidies were evenly, or randomly, distributed among the income quintiles. This underscores the fact that, when water is sold below cost, as is the case in almost all low- and middle-income countries, seemingly significant changes to the tariff structure do not improve subsidy targeting.[8]

[8] Results for the Volume Differentiated IBT are similar. They are not shown here but are available upon request.

Figure 8. Subsidy incidence with different IBT tariffs (Spearman's correlation coefficient: 0.2).



6. Concluding remarks

In this paper, we provide a simple procedure that a water utility manager can use to check the incidence of subsidies to households with metered connections in a given service area. For baseline conditions that we believe are common in many low- and middle-income countries, the results of our illustrative calculations show that existing subsidies are very poorly targeted to poor households. Moreover, there is no easy fix: all of the tariff structures examined target subsidies poorly, i.e., households in richer income quintiles receive a higher proportion of the subsidies than do households in the poorer income quintiles.

We show that, contrary to conventional wisdom, the correlation between household water use and income is quite low, calling into question the fundamental assumption underpinning the popularity of the IBT. But if the correlation between household income and water use were high, the IBT would still not target subsidies effectively to poor households, given the types of IBT structures and block prices common in developing countries.

Our calculations suggest that water tariff structures cannot be easily designed to target subsidies to poor households when water is sold below the average total production cost. In our opinion, water tariffs should be designed to balance financial and economic objectives; other policy instruments are required to assist poor households. A means-tested subsidy program is an obvious candidate. As water utilities gradually become a part of the “big data” era, means testing should become increasingly feasible because estimating the income (or wealth) of a utility’s customers will become inexpensive and straightforward.

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Appendices

Appendix A.

Table A1. Summary of studies in the subsidy incidence literature.

Study	Country	Data source	Water use measure	Indicator(s)*	Tariffs compared	Performance of subsidy targeting**
Barde and Lehmann (2014)	Lima, Peru	Billing data, expenditure survey, tariff	Stated expenditure	Affordability; subsidy share; EOI; EOE; leakage rate	Status quo; 5 block IBT, 4 block means tested IBT ; means tested uniform price	Poor (non-means tested); excellent (means tested)
Angel-Urdinola and Wodon (2012)	Nicaragua	HH survey data and tariffs	Stated expenditure	Concentration coefficient and various targeting indicators	Status quo; variety of IBTs and VDTs	Poor
Banerjee and Morella (2011)	Multi-country - Africa	HH surveys and tariffs	Stated expenditure	Affordability (share of HH total expenditure); concentration coefficient	Status quo in utilities from 21 countries	Poor
Banerjee et al. (2010)	45 utilities in 23 African Countries	LSMS and tariffs	Stated expenditure	Affordability (share of HH total expenditure); concentration coefficient	Status quo in utilities from 23 countries	Poor
Garcia-Valinas et al. (2010)	Spain	Municipal surveys	Aggregate	Affordability	n.a.	n.a.
Diakité et al. (2009)	Cote d'Ivoire	HH panel data	Aggregate	Welfare gain/loss	Status quo; 3 block IBT; 3 block tariff with Ramsey prices	n.a.

* EOI=Errors of inclusion; EOE=Errors of exclusions.

** "Poor" refers to subsidies that perform worse than if subsidies were randomly distributed; "Moderate" refers to subsidies that perform on par with randomly distributed subsidies; "Good" refers to subsidies that perform better than if subsidies were randomly distributed.

Table A1. Summary of studies in the subsidy incidence literature (cont'd).

Study	Country	Data source	Water use measure	Indicator(s)*	Tariffs compared	Performance of subsidy targeting**
Ruijs (2009)	Sao Paolo, Brazil	HH data	Aggregate	Welfare gain/loss	Status quo; various 5 block IBTs; uniform price	n.a.
Ruijs et al. (2008)	Sao Paolo, Brazil	Aggregate panel data for demand est.	Aggregate	Affordability	Status quo; means tested IBT; IBT; uniform price	n.a.
Bardasi and Wodon (2008)	Niger	HH survey	Stated use	Average price	Status quo	n.a.
Groom et al. (2008)	Beijing China	HH income and expenditure survey - Panel 1987 2002	Stated expenditure	Welfare gain/loss	Status quo; IBT	Poor
Fankhauser and Tepic (2007)	Transition countries	LSMS	Stated expenditure	Affordability, % of HH expenditure	Status quo in 25 countries	n.a.
Angel-Urdinola and Wodon (2007)	Cape Verde, Sao Tome, Rwanda	Nationally rep HH surveys	Stated expenditure	Concentration coefficient	Status quo; VDT	Poor
Foster and Yepes (2006)	Multi-country Latin America	LSMS	Stated expenditure	Affordability	Status quo in 4 countries	Poor

* EOI=Errors of inclusion; EOE=Errors of exclusions.

** "Poor" refers to subsidies that perform worse than if subsidies were randomly distributed; "Moderate" refers to subsidies that perform on par with randomly distributed subsidies; "Good" refers to subsidies that perform better than if subsidies were randomly distributed.

Table A1. Summary of studies in the subsidy incidence literature (cont'd).

Study	Country	Data source	Water use measure	Indicator(s)*	Tariffs compared	Performance of subsidy targeting**
Komives et al. (2006)	Multi-country	Secondary literature	Stated expenditure	EOE; Concentration coefficient	Status quo in 4 countries	Poor
Komives et al. (2005)	Multi-country	LSMS	Stated expenditure	Omega; EOI, EOE; "Material impact"	Status quo and various IBTs in 4 countries	Poor
Foster and Araujo (2004)	Guatemala	LSMS style national survey (ENCOVI 2000)	Stated expenditure	EOE; EOI	Status quo	Poor
Foster (2004)	Argentina	Primary HH Survey (2500 HH)	Previous bill; Stated expenditure; Imputed using regression	Cumulative dist; Concentration coefficient; EOI, EOE	Status quo (means tested social tariff)	Good
Gómez-Lobo and Contreras (2003)	Chile and Columbia	National HH surveys (Chile - CASEN 1998; Columbia - 1997 NQLS)	Stated expenditure	Concentration curves; EOI; EOE	n.a.	n.a.
Foster et al. (2000)	Panama	LSMS	Stated expenditure	EOE, EOI	Status quo; administrative selection	n.a.
Walker et al. (2000)	Central America	Household survey	Previous bill	EOI; EOE; Average subsidy per HH per mo; Subsidy share	Status quo in 6 cities	Poor-moderate

* EOI=Errors of inclusion; EOE=Errors of exclusions.

** "Poor" refers to subsidies that perform worse than if subsidies were randomly distributed; "Moderate" refers to subsidies that perform on par with randomly distributed subsidies; "Good" refers to subsidies that perform better than if subsidies were randomly distributed.

Table A2. What researchers say about IBTs

Study	Quote
ADB (2014)	“[r]ising block tariffs are effective and fair. They are not perfect but they work well, are easy to implement, are easy to communicate to customers, and are a pragmatic solution to a complex issue." (p.66)
Khan (2014)	"Such [scarcity] pricing can inflict real costs on the poor. An increasing block tariff rate with a low bottom rate for households that consume a low level of electricity or water would allow them to afford basic necessities." (p.16)
Hoque and Wichelns (2013)	"Increasing block-rate tariffs are helpful in providing low-income consumers with essential water volumes at low prices while encouraging wealthier consumers to use water wisely … Cross-subsidy involving low water prices for low-income consumers and higher prices for wealthier consumers can be achieved using an increasing block-rate tariff.” (p.489)
Wichelns (2013)	"Volume-differentiated tariffs are generally more effective in targeting the intended subsidies of a pricing programme, and they provide opportunities for generating revenue to support investments in the delivery system." (p. 319)
Wichelns (2013)	"The volume-differentiated tariff provides a greater likelihood of success in achieving the goals of efficiency, equity and sustainability than does a typical increasing block-rate tariff. By disallowing non-poor residents the option of purchasing water in the lowest price block, the subsidy intended for poor households is delivered with greater accuracy and less slippage." (p. 232)
Diakite et al. (2009)	"The individual level analysis is not possible due to availability of only aggregate data, and we cannot adopt a definition of poverty based on observed individual income. However, it seems reasonable to assume that poor households that are connected to the water network will have their consumption level in the first pricing block. We therefore define as “poor” a household whose water consumption is below the upper bound of the social pricing block." (p. 267)
Ruijs (2009)	“[block tariffs] … are said to be better for income distribution as, in case of progressive block price systems, poor households who consume less, pay lower average prices.” (p. 161)
Groom et al. (2008)	“So, while a uniform tariff, despite its efficiency qualities, may have profoundly negative income effects on precisely those parts of the population least able to bear them, the IBT system is often thought to alleviate these problems by shifting the financial burden from low water consumers to high. In this way the equity– efficiency argument appears to be circumvented.” (p. 251)
World Bank (2007)	“…when an IBT is introduced, the poor, who are generally subsidized by such tariff structures, may become a lower priority for the water supplier.” (p. 20)

Appendix B. Description of procedure used to draw 5,000 pairs of household water use and income values from two log-normal distributions while maintaining a specified correlation coefficient

In order to generate pairs of random variables with some degree of dependence, we follow the procedure described in Johnson and Tenenbein (1981). The two random variables *Q* (household water use) and *W* (household income) are assumed to be log-normally distributed with respective distributions $F_q(q)$ and $F_w(w)$. Following Johnson and Tenenbein, let

$$U = U' \text{ and } V = cU' + (1-c)V'$$

where *U'* and *V'* are identically independently distributed random variables with any common density function *g(t)*, and *c* is a constant in the interval (0,1). The specification of the probability density function *g(t)* and the choice of the constant *c* determine the level of dependence (measured here by the Spearman's rank correlation coefficient, ρ) between the random variables of interest *Q* and *W*. For example, the Spearman's rank correlation coefficient ρ is equal to 0.2 if *g(t)* is normal and *c* is set at 0.176 (see Johnson and Tenenbein for Spearman's rank correlation coefficients corresponding to different specifications of *g(t)* and different values of *c*).

Let $Q' = H_1(U)$ and $W' = H_2(V)$, where $H_1(U)$ and $H_2(V)$ are the distribution functions of *U* and *V* respectively. It follows that

$$Q = F_q^{-1}(Q') = F_q^{-1}(H_1(U)) \text{ and } W = F_w^{-1}(W') = F_w^{-1}(H_1(V))$$

are positively correlated with Spearman's rank correlation coefficient ρ. In this article, we assume the probability density function *g(t)* to be normal.