Environment for Development

Discussion Paper Series December 2017 ■ EfD DP 17-21 REV

Assessing the Performance of Alternative Water and Sanitation Tariffs

The Case of Nairobi, Kenya

David Fuente, Jane Kabubo-Mariara, Peter Kimuyu, Mbutu Mwaura, and Dale Whittington

Sida

EfD Environment for Development

RESOURCES FOR THE FUTURE

Environment for Development Centers

Central America
Research Program in Economics and Environment for Development in Central America Tropical Agricultural Research and Higher Education Center (CATIE)

Chile
Research Nucleus on Environmental and Natural Resource Economics (NENRE)
Universidad de Concepción

China
Environmental Economics Program in China (EEPC)
Peking University

Colombia
The Research Group on Environmental, Natural Resource and Applied Economics Studies (REES-CEDE), Universidad de los Andes, Colombia

Ethiopia
Environment and Climate Research Center (ECRC)
Ethiopian Development Research Institute (EDRI)

India
Centre for Research on the Economics of Climate, Food, Energy, and Environment, (CECFEE), at Indian Statistical Institute, New Delhi, India

Kenya
School of Economics
University of Nairobi

South Africa
Environmental Economics Policy Research Unit (EPRU)
University of Cape Town

Sweden
Environmental Economics Unit
University of Gothenburg

Tanzania
Environment for Development Tanzania
University of Dar es Salaam

USA (Washington, DC)
Resources for the Future (RFF)

Vietnam
University of Economics
Ho Chi Minh City, Vietnam

The Environment for Development (EfD) initiative is an environmental economics program focused on international research collaboration, policy advice, and academic training. Financial support is provided by the Swedish International Development Cooperation Agency (Sida). Learn more at www.efdinitiative.org or contact info@efdinitiative.org.

Assessing the Performance of Alternative Water and Sanitation Tariffs: The Case of Nairobi, Kenya

David Fuente, Jane Kabubo-Mariara, Peter Kimuyu, Mbutu Mwaura, and Dale Whittington

Abstract

Policy makers and utility managers can use a variety of tariff structures to calculate customers' bills for water and sanitation services, ranging from a simple flat monthly fee to complicated multipart tariffs with seasonal pricing based on metered water use. This paper examines the performance of alternative tariff structures for water and wastewater services in Nairobi, Kenya. In particular, we evaluate the performance of alternative tariffs relative to several criteria: the overall quantity of water sold (i.e., conservation), the magnitude of the total subsidy delivered through the tariff, subsidy incidence, change in customer welfare, and change in social welfare. To accomplish this, we develop a dynamic tariff simulation model and use a complete set of billing records from Nairobi City Water and Sewer Company to model the performance of alternative tariff structures. Contrary to conventional wisdom, we find that tariff alternatives with a uniform volumetric price perform as well as or better than increasing block tariff alternatives across nearly all policy-relevant metrics of tariff performance. These findings hold at the three levels of cost recovery that we consider and are robust to a wide range of assumptions about consumer behavior. This finding stands in stark contrast to the widespread use of increasing block tariffs (IBTs) in low and middle-income countries and to current perceptions of best practice in tariff design. Additionally, we find that neither the size of the lifeline block nor the number of blocks affects the relative performance of the IBT tariff alternatives in a policy-relevant manner. Finally, our simulations underscore the benefits of getting utilities on a path to improved cost recovery. This will be essential to ensuring governments have the resources to invest in climate resilient infrastructure and to meet the Sustainable Development Goals' aspiration of ensuring universal access to safe water and sanitation services.

Key Words: tariff simulation, water pricing, sanitation, increasing block tariff, Kenya, Africa

JEL Codes: Q25, L95, D63

Contents

Assessing the Performance of Alternative Water and Sanitation Tariffs: The Case of Nairobi, Kenya

David Fuente, Jane Kabubo-Mariara, Peter Kimuyu, Mbutu Mwaura, and Dale Whittington*

1. Introduction

Policy makers and utility managers can use a variety of tariff structures to calculate customers' bills for water and sanitation services, ranging from a simple fixed monthly fee to complicated multipart tariffs with seasonal pricing based on metered water use. Faced with such a wide range of options, what tariff should policy makers use? Further, once they have decided on a particular tariff structure, how should they set water prices? Economists and development practitioners have debated these questions for decades. However, the issue of pricing municipal water and sanitation services has renewed significance given the aspiration of the Sustainable Development Goals (SDGs) to ensure universal access to safe and affordable water and sanitation services, as well as the challenges posed by climate change. Indeed, tariff reform in many developing countries will play a central role in determining whether or not utilities are able to generate the revenue and acquire the financing necessary to achieve universal access to resilient water and sanitation services.

In this paper, we develop a framework for simulating the performance of water and sanitation tariffs with respect to several policy-relevant criteria. We then apply this framework to the case of Nairobi, Kenya, a rapidly growing city with conditions similar to those of many large cities in low- and middle-income countries. In particular, we examine the performance of five alternative tariff structures relative to the current tariff implemented by Nairobi City Water and Sewer Company (NCWSC) at three different levels of cost recovery. We then evaluate the performance of alternative tariffs relative to

* Corresponding author: David Fuente, The School of Earth, Ocean and Environment, University of South Carolina, 701 Sumter Street, EWS 617, Columbia SC 29208, USA, email: fuente@seoe.sc.edu. Jane Kabubo-Mariara, Partnership for Economic Policy (PEP), Kenya, School of Economics, University of Nairobi, Kenya. Peter Kimuyu, Commission for Revenue Allocation, Kenya. Mbutu Mwaura, Nairobi City Water and Sewer Company, Kenya. Dale Whittington, Department of City and Regional Planning, UNC-CH, USA, Department of Environmental Sciences and Engineering - Gillings School of Global Public Health, UNC-CH, USA, Manchester Business School, University of Manchester, UK.

The authors gratefully acknowledge funding from the Swedish International Development Cooperation Agency through the Environment for Development initiative at the Environmental Economics Unit of the University of Gothenburg, Sweden.

several criteria associated with tariff performance, including the overall quantity of water sold (i.e., conservation), the magnitude of the total subsidy delivered through the tariff, subsidy incidence, and changes in social welfare.

Our analysis extends the literature on tariff performance in several ways. First, the majority of studies in the literature focus on industrialized countries and examine one or two indicators of tariff performance. To our knowledge, this is the first study to examine the performance of water and sanitation tariffs relative to a broad portfolio of policy-relevant criteria in a low- or middle-income country context. Second, we explicitly compare the performance of a suite of increasing block tariffs (IBTs) to tariffs that implement a uniform volumetric price. Finally, in contrast to many studies in the literature, we simulate the performance of tariff alternatives over a five-year planning horizon and consider the performance of tariffs under uncertainty about consumer behavior.

Contrary to conventional wisdom, we find that tariff alternatives with a uniform volumetric price perform at least as well as IBT tariff alternatives at the three levels of cost recovery we consider. The uniform pricing alternatives include both a two-part tariff long promoted by economists (i.e., a uniform price with rebate) as well as a simple tariff in which customers face a uniform volumetric price. These findings are robust to assumptions about whether customers respond to average or marginal price. Overall, our findings add to a growing body of evidence that challenges commonly held perceptions about IBTs and suggest that considerable gains can be realized by getting utilities on a path to improved cost recovery.

2. Background and Literature

A water tariff is a set of rules by which a utility calculates how much customers need to pay on a regular basis (monthly, bi-monthly, etc.) in exchange for a specified level of service. A wide variety of tariff structures can be used to charge customers for water and sanitation services. Tariffs used to calculate the volumetric portion of customers' water and wastewater bills include increasing block tariffs (IBTs), decreasing block tariffs, and uniform price tariffs. Despite the diversity of tariff structures at policy makers' disposal, the IBT is the most widely implemented tariff among water utilities in low- and middle-income countries (GWI 2013). The IBT has widespread appeal due to the perception that it can subsidize water use for low-income households, while simultaneously recovering costs and promoting conservation among high-income customers (Whittington et al. 2015; Fuente et al. 2016).

The popularity of the IBT reflects the fact that policy makers often try to use the tariff to achieve, and balance, a wide range of policy objectives. Bonbright (1961) presented an early articulation of eight core objectives of tariff setting: simplicity and public acceptability, freedom from controversy, revenue stability, revenue sufficiency, rate (price) stability, fairness in apportionment of costs, avoidance of undue rate discrimination, and encouragement of efficiency.[1] The task of setting water tariffs might be relatively easy if these objectives were mutually reinforcing. However, many objectives associated with tariff design often conflict with one another. For example, the objectives of full cost recovery and affordability are often believed to be contradictory and economic efficiency can also be at odds with cost recovery and revenue stability.

Overall, the empirical literature on the performance of water and sanitation tariffs is relatively thin, fragmented, and dominated by studies that examine tariff performance in industrialized countries. The two best-developed threads in the literature include studies that estimate the price elasticity of demand or examine how well tariffs target subsidies to low-income households. The former category of studies estimate the price – and sometimes the income – elasticity of demand to derive second-best prices[2] to improve economic efficiency (e.g., Renzetti 1992b; Garcia-Valinas 2005; Diakite et al. 2009; Garcia-Valinas et al. 2010; Rinaudo et al. 2012; Reynaud 2016). These studies provide insight into customer behavior and offer concrete examples of how prices can be set to improve economic efficiency subject to a cost recovery constraint. However, these studies have two principal limitations with respect to the design of water and sanitation tariffs. First, economic efficiency is only one of several criteria that policy makers may consider when setting water tariffs; tariffs that improve economic efficiency may perform poorly with respect to other criteria. Second, policy makers typically do not have the

---

[1] See Berg and Tschirhart (1989), Hanemann (1997), and Whittington (2011) for detailed overviews of the various objectives of tariff setting.

[2] Examples of second best prices include Ramsey-Boiteux and Feldstein pricing. The basic aim of Ramsey-Boiteux pricing is to minimize the welfare losses associated with deviations from marginal cost pricing. To accomplish this, Ramsey-Boiteux pricing applies the inverse elasticity rule, in which customers who are less sensitive to price changes face higher marginal prices than those who are more sensitive to price changes. A common critique of Ramsey-Boiteux pricing is that it may be regressive if low-income customers are less sensitive to price changes than high-income customers. To address this, Feldstein (1972) proposed a pricing strategy that effectively weights the Ramsey-Boiteux price by the marginal utility of income, which is assumed to be decreasing in income.

necessary information (e.g., local estimates of the price elasticity of demand among different customer classes) to implement second-best pricing strategies. Policy makers could, of course, obtain this information, but it can be expensive to do so and it may not be possible to econometrically estimate these parameters in a credible manner.

The second well-developed thread in the literature examines the extent to which IBTs target subsidies to low-income households. Researchers have long questioned the extent to which IBTs effectively target subsidies to low-income households in low- and middle-income countries (e.g., Whittington 1992). Two decades of research using a range of data sources and methods across several countries has largely confirmed that IBTs do not effectively target subsidies to low-income households (Whittington et al. 2015; Fuente et al. 2016). However, like economic efficiency, subsidy targeting is one of several factors policy makers consider when setting water tariffs.

Overall, it is difficult to distill general insight from studies in the literature on the performance of water and sanitation tariffs. These studies often lack a common approach to simulating tariff performance, do not employ a common set of indicators of tariff performance, and typically simulate a small set of tariff alternatives. Many studies also focus on one or two dimensions of tariff performance. While studies in the literature provide insight into how a set of tariffs performs with respect to a particular objective, they often do not evaluate tariff performance relative to a portfolio of indicators.

A recent exception to this is Nauges and Whittington (2017), who use hypothetical data on residential customer water use to simulate the performance of nine alternative tariffs. In particular, they simulate a transition from a uniform price tariff to an IBT and examine how different IBT alternatives perform with respect to subsidy incidence and economic efficiency at two levels of cost recovery. Consistent with other studies in the literature, they find that the tariff alternatives they simulate do not effectively target subsidies to low-income customers at low levels of cost recovery and that subsidy targeting is worse when the correlation between income and water use is high. Additionally, they find that the efficiency losses associated with a shift from a uniform price tariff to an IBT are relatively small, particularly when customers respond to average, rather than marginal, price.

This paper seeks to make several contributions to the literature on tariff design. In particular, we extend previous work by Whittington et al. (2015) and Fuente et al. (2016) by expanding the scope of our analysis beyond subsidy incidence. This paper also extends the recent work of Nauges and Whittington (2017) in several ways. First, we simulate tariff performance using a complete set of billing records from a utility in a non-industrialized country. Thus, in addition to being one of a few studies to examine the performance of tariffs in a low or middle-income country context, our simulations include both residential and non-residential customers. Second, we examine a broader range of indicators of tariff performance than other studies in the literature. In particular, we expand the criteria of tariff performance to include both conservation and the trade-off between improving cost recovery (i.e., the magnitude of the subsidy delivered through the tariff) and the welfare effects associated with different tariffs.

3. Empirical Strategy

To assess the relative performance of alternative tariff structures in Nairobi, we develop a simulation model to forecast changes in customer water use, the utility's revenue, and the cost of providing water and wastewater services. We use this simulation model to examine the performance of five tariff alternatives relative to several policy-relevant criteria at three different levels of cost recovery. The simulation model runs in annual time steps over a five-year planning horizon, an interval at which tariff reviews are often conducted by regulators and over which a utility might seek to achieve full cost recovery. We then measure the performance of alternative tariff structures relative to a dynamic baseline – i.e., forecasts of the status quo tariff over the same planning horizon.

3.1. Description of Tariff Simulation Model

The total quantity of water used by customers and the total quantity of wastewater produced is determined by several factors, including the size of the service population, the composition of the service population (i.e., fraction of customers with water service only and fraction with both water and wastewater service), the tariff, climatic conditions, the wealth and other attributes of the service population, and service substitutes (e.g., private wells, water vendors, septic tanks). Our simulation model forecasts customer water use as a function of the water use in the prior period, customers' price elasticity of demand, the change in price customers face, customers' income elasticity of demand, and the change in income (Equation 1).

$$WUSE_{j,t} = WUSE_{j,t-1} * \left[1 + (\beta_{j,t} * \Delta P_{j,t-1} + \varepsilon_Y * \Delta Y_t * I_{j,R})\right] \tag{1}$$

where….

- $WUSE_{j,t}$ is the average monthly water use for a customer j in year t;
- $WUSE_{j,t-1}$ is the average monthly water use for customer j in year t-1;

- $\beta_{j,t}$ is the price elasticity of demand for customer j in year t;
- $\Delta P_{j,t-1}$ is the percent change in price from year t-1 to t-2 for customer j;
- ε_Y is the income elasticity of demand for residential customers;
- ΔI_t is the percent change in income from year t-1 to t; and
- I_R is an indicator variable that takes the value 1 if customer j is a residential customer and 0 otherwise.

In our base case scenario, we assume that that the income elasticity of demand for residential customers is +0.1 and that the annual change in income for residential customers is equal to 5%. (See Appendix 1 for a summary of parameter values used in our base case simulations.)

Economic theory assumes that consumers are well informed about the price schedules they face and that they respond to marginal prices. However, in the face of complex price schedules, consumers may not be well informed about the marginal price they face.[3] Additional factors that may influence whether customers respond to marginal price, average price, or some other price signal (e.g., an increase in the bill, expected marginal or average price, etc.) include the salience of customers' water bills, individual customer characteristics, water use, billing frequency, and payment method (e.g., automatic withdrawal, payment center, mobile money). Field work conducted for Fuente at al. (2016) suggested that customers in Nairobi were not well informed about the tariff they faced. Thus, in our base case simulations we assume that customers respond to changes in average, rather than marginal, price.

Because we do not have estimates of the price elasticity of demand for piped water services in Nairobi, we use estimates of the price elasticity of demand from the

[3] Since the issue was raised by Howe and Linaweaver (1967) and later discussed by Taylor (1975) and Nordin (1976), the extent to which customers respond to average or marginal price has been widely explored in the applied economics literature, particularly in the context of income tax (e.g., Saez 1999; Saez 2003; Saez 2010; Chetty et al. 2011), electricity tariffs (e.g., Ito 2014; Borenstein 2009), and to a lesser extent water tariffs (e.g., Foster and Beatie 1981; Ruijs et al. 2008; Nataraj and Hanemann 2011; Binet et al. 2013; Ito 2013). To our knowledge, only Binet et al. (2013) have explored whether water utility customers respond to average or marginal price in a developing country context; they found that customers' response indicated that customers underestimated both average and marginal price.

literature. In our base case, we assume that residential customers who use above 5 m^3/mo. have a price elasticity of demand of -0.2 (Arbues et al. 2003; Dalhuisen et al. 2003; Espey et al. 1997; Nauges and Whittington 2010). We also assume that residential customers who use less than 5 m^3/mo. are insensitive to price changes.[4] Because customers are unlikely to immediately adjust their water use in response to changes in price, we assume that residential customers respond to a one-year lagged change in price.

Because we do not have estimates of the price elasticity of demand for piped water services in Nairobi, we use estimates of the price elasticity of demand from the literature. In our base case, we assume that residential customers who use above 5 m^3/mo. have a price elasticity of demand of -0.2 (Arbues et al. 2003; Dalhuisen et al. 2003; Espey et al. 2007; Nauges and Whittington 2010). We also assume that residential customers who use less than 5 m^3/mo. are insensitive to price changes.[5] Because customers are unlikely to immediately adjust their water use in response to changes in price, we assume that residential customers respond to a one-year lagged change in price.

The literature on the demand for water among non-residential customers (e.g., commercial, industrial, and bulk customers) is quite thin, but suggests that non-residential customers are typically more responsive than residential customers to price changes (Renzetti 1992a; Renzetti 1992b; Reynaud 2003; Garcia and Reynaud 2004; Worthington 2010). However, in our simulations we assume that non-residential customers in Nairobi are insensitive to price changes. As discussed in more detail below, we make this assumption to allow us to estimate the economic impact of price changes on non-residential customers. While we believe this assumption is plausible in Nairobi given the low prices of water and the relatively short duration of our simulation period, it may result in our simulations overestimating the total amount of water used by non-residential customers.

We calculate customers' average monthly bill as a function of their water use and the tariff alternative simulated. The utility's average monthly revenue is the sum of all customers' bills multiplied by the utility's collection efficiency – i.e., the percent of total billings the utility collects as revenue. The total amount of water the utility must produce

[4] This is supported by empirical studies that use a Stone-Geary demand function to estimate what portion of water use is insensitive to price control (Madhoo 2009; Martinez-Espineira and Nauges 2004; Nauges et al. 2009).

and the total quantity of wastewater it must treat in each year of the simulation are a function of customer water use and the fraction of customers with a wastewater connection (Equations 2 and 3). The amount of water the utility must produce in each year of the simulation is also a function of the level of non-revenue water,[5] which may vary over time.

$$Q_{w,t} = \left[\sum_{j=1}^{N_t} \left(WUSE_{j,t}\right)\right] \Big/ \left(1 - NRW_t\right) \qquad (2)$$

where…

- $Q_{w,t}$ is the average amount of water that must be produced by the utility in year t;
- N_t is the total number of customers in year t;
- $WUSE_{j,t}$ is the average monthly water use for customer j in year t (Equation 1); and
- NRW_t is the level of non-revenue water in year t.

$$Q_{ww,t} = \left[\sum_{j=1}^{N_t} \left(WUSE_{j,t} \cdot Iww_j\right)\right] \qquad (3)$$

where…

- $Q_{ww,t}$ is the average amount of water that must be treated by the utility in year t;
- N_t is the total number of customers in year t;
- $WUSE_{j,t}$ is the average monthly water use for customer j at time t (Equation 1); and
- $Iww_{j,}$ is a dummy variable that takes the value of 1 if customer j has a wastewater connection and 0 if she does not.

As indicated in Equations 2 and 3, the simulation model accommodates annual changes in the size of the customer base (Nt). In our base case, we assume that the customer base increases 5% per year and that the relative composition of the customer

[5] We define non-revenue water as the volume of water produced by the utility minus the amount of water billed to customers, divided by the volume of water produced by the utility.

base remains constant throughout the five-year planning period (e.g., the proportion of residential and non-residential customers remains constant, as well as the proportion of customers who receive wastewater service).

A water utility needs financial resources to pay for three broad categories of costs: routine operations and maintenance costs (O&M costs), the repair and replacement of the existing capital stock, and the expansion of the water and wastewater network to meet increased demand for these services (expansion costs). Privately owned utilities also need revenue to pay dividends or retained profits. We assume that full cost recovery tariffs are tariffs that would allow the utility to raise sufficient revenue to cover O&M and capital costs without subsidies or without running down the capital stock. Based on our previous work, we assume that the full cost of water service and wastewater service in Nairobi is 0.94 USD/m3 and 0.98 USD/m3, respectively (Fuente et al. 2016). We also assume that the utility operates at constant returns to scale.

3.2. Performance Criteria

We evaluate the performance of alternative tariffs relative to five criteria: aggregate water use (i.e., conservation), the magnitude of the total subsidy delivery through the tariff, subsidy incidence, change in customer welfare, and change in social welfare (e.g., the deadweight loss to society). We have selected these criteria because they represent issues about which various stakeholders (policy makers, utility managers, economists, etc.) often express concern.[6]

We define aggregate water use under each tariff alternative as the total amount of water sold to customers. We compare aggregate water use under each tariff alternative at the end of the five-year planning period to a dynamic baseline of forecasts of aggregate water use under the current tariff at the end of the five-year planning period at status quo levels of cost recovery.

We define the magnitude of the subsidy delivered through the tariff as the difference between the utility's revenue and the cost of providing services. We calculate the subsidies delivered through the tariff alternatives each year and report the net present value of the stream of subsidies over the five-year simulation period.[7] We also examine

[6] These are positive indicators of tariff performance and we do not ex-ante assign a normative weighting to them.

[7] All net present value calculations use a real discount rate of 10%.

the distributional incidence of subsidies delivered through the tariff, which we define as the share of total subsidies delivered to low-income residential customers (Equation 4).

$$S_t = \frac{\sum_{j=1}^{N_t}\left(\left(WUSE_{j,t} \cdot COST_{j,t} - BILL_{j,t}\right) \cdot L_j\right)}{SUB_t} \tag{4}$$

where:

- S_t is the share of subsidies delivered to residential customers in low-income areas in year t;
- SUB_t is the average monthly subsidies delivered through the tariff in year t;
- N_t is the total number of customers at time t;
- $WUSE_{j,t}$ is the average monthly water use for customer j in year t (Equation 1);
- $COST_{j,t}$ is the average cost of serving customer j in year t;
- $BILL_{j,t}$ is the average monthly bill for residential customer j in year t; and
- L_j is a dummy variable that takes the value of 1 if customer j is a low-income residential customer and 0 otherwise.

NCWSC sells water to both residential and non-residential customers. We approximate the change in welfare for residential customers by calculating the change in consumer surplus that accompanies the transition to a new tariff. In particular, we use Equation 5 to calculate the change in consumer surplus for each customer and sum over the customer base to obtain the aggregate change in consumer surplus for each period in the simulation (Nauges and Whittington 2017).

$$\Delta CS_{j,t}^{T} = -\left(\frac{Q_{j,t}}{P_{j,t}^{\beta_{j,t}}\left(1+\beta_{j,t}\right)}\right)\left({P_{j,t}^{T}}^{(1+\beta_{j.t})} - P_{j,t}^{(1+\beta_{j.t})}\right) \tag{5}$$

where:

- $\Delta CS_{j,t}^{T}$ is the change in consumer surplus for residential customer j under tariff alternative T in year t;
- $Q_{j,t}$ is the quantity of water customer j would use under the status quo tariff in year t;

- $P_{j,t}$ is the price[8] faced by customer j at time t under the status quo tariff in year t;
- $\beta_{j,t}$ is the price elasticity of demand for customer j in year t; and
- $P_{j,t}^{T}$ is the price faced by customer j under tariff alternative T in year t.

The water use of non-residential customers reflects a producer's demand for an input (Renzetti 1992a; Reynaud 2003). We assume that non-residential customers are producers that select their use of inputs, including water, to minimize the cost of producing a certain level of output. We do not have information on non-residential customers' use of other inputs or their underlying production functions. Thus, we assume that their water demands are separable from other input demands (Renzetti 1992b; Garcia and Reynaud 2004)[9] and estimate welfare effects of price changes on non-residential customers as the change in their profits. Relying on our assumption that non-residential customers are insensitive to price changes, we approximate the change in profits for non-residential customers as the difference between the water bills they face under the status quo tariff and the different tariff alternatives we consider.[10]

As noted by Renzetti (1992b), a change in the water tariff can affect residential customers through two distinct channels. A change in tariff will affect residential customers directly through the price they face for water and sanitation services. We approximate this effect by the change in consumer surplus as described above. A change in tariff may also affect residential customers indirectly via the impact of price changes on non-residential customers' outputs. This effect is not included in our estimates of the change in customer welfare.[11]

In our base case, we assume that customers respond to changes in average, rather than marginal, price. As noted by Nauges and Whittington (2017), if customers respond to changes in marginal price, Equation 5 will not accurately measure the change in

---

[8] This is either the average or marginal price facing the customer, depending on whether the model assumes that customers respond to changes in average or marginal prices.

[9] We do not have data to confirm whether this assumption holds in Nairobi. However, both Renzetti (1992b) and Garcia and Reynaud (2004) cite examples that suggest this assumption may be reasonable in some industrialized countries.

[10] We acknowledge that this is a rough approximation of the impact of price changes on non-residential customers. However, additional information on the structure of firms' production functions would be required to develop more accurate estimates of the impact of price changes on non-residential customers.

[11] The indirect effect of the change in prices for non-residential customers on residential customers will be reflected in our estimates of the change in welfare if the following two conditions hold: 1) households' demand for water are independent of non-residential outputs, and 2) the output markets for non-residential customers are perfectly competitive or face linear demand (Renzetti 1992b; Brown and Sibley 1986).

consumer surplus under IBTs. Appendix 2 discusses this in more detail and describes how we calculate changes in consumer surplus when we assume that customers respond to marginal price.

Finally, we track changes in the deadweight loss to society as a result of the transition from the status quo tariff to different tariff alternatives. We calculate the change in deadweight loss as the difference between the change in the magnitude of subsidies associated with a shift to a new tariff and the change in change in customer welfare that accompanies this transition.

4. Data and Tariff Alternatives

We simulate the performance of alternative tariffs using the case of the Nairobi Water and Sewer Company. According to Kenya's most recent census, approximately 25% of Nairobi's population indicated that their primary drinking water source was a piped water connection into their dwelling (KNBS 2009). This is a private piped connection connected to indoor plumbing. An additional 50% indicated that their primary drinking water source was a piped connection that was not piped into their dwelling, suggesting that in 2009 half the population in Nairobi obtained water from a shared connection or public tap. Seventeen percent of households indicated that water vendors were their primary source for drinking water.

We populate our simulation model with information on customer water use from a complete set of 21 months of NCWSC's billing records. This includes households in Nairobi with a private piped connection to the network, households with a shared connection that are served by the utility, and households that obtain water from public kiosks. The billing data cover the period from August 2012 to May 2014 and contain information on the water use of NCWSC's approximately 200,000 customer accounts. We calculate customers' average monthly water use over this period from actual meter readings in the billing data (see Fuente et al. 2016 for additional detail).

NCWSC does not have socioeconomic or demographic information about its customers. In the absence of household-level data on income or socioeconomic status, we use the geographic location of customer accounts as a proxy for socioeconomic status. In particular, we use the GIS location of customer accounts to identify which accounts are located in low-income areas. We obtain information on the location and extent of low-income areas in Nairobi from the MajiData project of Kenya's Ministry of Water and Irrigation (MWI) and Water Services Trust Fund. (See Fuente et al. 2016 for more information about these data). Using this approach, we find that approximately 20% of the accounts in the billing records are residential customers located in low-income areas.

We compare the performance of five tariffs relative to the tariff that was in place during the period represented by the billing data that we use in our simulations (Table 1). This status quo tariff is an IBT with four usage blocks (IBT4): 0-10 m3/mo., 11-30 m3/mo., 31-60 m3/mo., and greater than 60 m3/mo. The tariff alternatives we simulate include an IBT with three usage blocks and a lifeline block of 10 m3/mo. per account (IBT3); an IBT with two usage blocks and a lifeline block of 5 m3/mo. per account (IBT2-5); an IBT with two usage blocks and a lifeline block of 10 m3/mo. per account (IBT2-10); a uniform price tariff (UP); and a uniform price tariff with a fixed charge or rebate (UP+R), in which we set the uniform volumetric price equal to the long-run marginal cost of service delivery.[12] The IBT3 tariff alternative represents the tariff for which NCWSC applied in its most recent tariff review. The IBT2-5 and IBT2-10 tariff alternatives provide an opportunity to examine how reducing the number of blocks and the size of the lifeline block would affect tariff performance. The UP tariff allows us to examine how a simple uniform price tariff performs relative to IBTs. The UP+R tariff alternative provides an opportunity to examine the performance of a tariff promoted by economists to simultaneously promote economic efficiency and cost recovery.

We simulate the performance of these five tariff alternatives under three cost recovery scenarios: status quo cost recovery (31%), an intermediate level of cost recovery (65%), and full cost recovery (100%). These cost recovery scenarios reflect cost recovery under our base case assumption that NCWSC has 30% non-revenue water and 85% collection efficiency, which reflects NCWSC's current level of operational efficiency.

In our base case scenario, the tariff alternatives share several common features. For example, we assume that the monthly meter rent is constant across all tariff scenarios (0.68 USD/mo. at baseline) and that the volumetric price applied to bulk and kiosk customers is the same across tariff alternatives for a given level of cost recovery. With the exception of the UP+R tariff scenario, we assume that the sewerage surcharge is 75% for all tariffs, the same surcharge currently assessed by NCWSC. Under the UP+R tariff scenario, we set the volumetric rate for sewer service equal to the long-run marginal cost of sewer service.

[12] For the purposes of our analysis, we assume that the long-run marginal cost is equal to the average O&M and capital costs for water and sewerage service in Nairobi. (See Saunders et al. (1977) for a detailed discussion of alternative conceptions of marginal cost pricing for water and sanitation services.)

For the status quo level of cost recovery, we set the volumetric prices in each tariff to ensure the tariff alternatives reach the same level of cost recovery as the baseline tariff (31%). The prices for each tariff in this scenario remain constant throughout the five-year planning horizon. For the IBT tariff alternatives, there is an infinite combination of volumetric prices in each block that could achieve a particular level of cost recovery. We use the following tariff design guidelines to set the tariffs for our base case analysis. In each cost recovery scenario, we assume that the price in the lifeline block of the IBT tariff alternatives is the same. For example, in the status quo cost recovery scenario (31%), we assume that the volumetric price in the lifeline block is 0.22 USD/m^3 in all IBT tariff alternatives. In the IBT3 tariff scenario, we set the prices in the second and third usage blocks so that the volumetric prices in each usage block are proportional to the prices in NCWSC's most recent application for a new tariff. In the IBT2-5 and IBT2-10 tariff scenarios, we set the price in the upper usage block to meet the target level of cost recovery. For the UP tariff, we set the uniform volumetric price to achieve the target level of cost recovery given our assumptions about the magnitude of the meter rent and sewerage surcharge.

Finally, under the UP+R tariff, we set the volumetric price for water and sewerage service equal to the long-run marginal cost of service delivery and apply a positive fixed charge or a rebate to meet the appropriate cost recovery level in each year.[13] For example, if revenue exceeds the amount necessary to meet a particular level of cost recovery, customers receive a rebate. Conversely, when revenue is not sufficient to meet a particular level of cost recovery, customers are assessed a positive fixed charge. We assume the fixed charge or rebate is applied in a lump sum manner – i.e., the fixed charge or rebate allocated to each customer is calculated by dividing the amount needed to achieve the target level of cost recovery by the total number of customer accounts. We also assume that the fixed charge or rebate does not affect customers' decisions to connect to, or disconnect from, the piped water and sewer network.

For the intermediate level of cost recovery and full cost recovery scenarios, we follow the same tariff-setting guidelines described above, but increase the volumetric prices in each tariff alternative by a fixed percent (in real terms) every year to reach the

[13] We set the rebate or fixed charge each year to ensure that the UP+R tariff alternative provides the same annual level of cost recovery as the UP tariff alternative over the five-year planning period.

target level of cost recovery in the final year of the planning horizon.[14] Many tariff design alternatives can achieve the same level of cost recovery. For example, in our intermediate and full cost recovery scenarios we assume that the meter rent is increased by the same percentage as the volumetric prices throughout the planning period. Alternatively, we could have opted to leave the meter rent at the current level and set the required annual price increase to meet the specified level of cost recovery. We also could have opted not to increase the volumetric price in the lifeline block over the simulation period and increased the prices in the upper blocks to meet the specified cost recovery objective. While these are potentially important considerations for tariff design for a particular utility, they do not affect the relative performance of the tariff alternatives we simulate, which is the primary objective of this paper.

5. Results

The NCWSC billing data used in our simulations contain approximately 200,000 accounts. Residential customers constitute nearly 95% of customer accounts in NCWSC's billing records and account for approximately 60% of water sold (Table 2). Although non-residential customers represent a small share (5%) of the total number of accounts, they account for 35% of total water use and 40% of total revenue under the baseline tariff. Mean water use among residential customers is 31 m^3/mo. compared to 347 m^3/mo. among non-residential customers. The high standard deviation in water use between residential and non-residential customers suggests there is considerable heterogeneity in water use within each customer class.

Over 70% of customer accounts receive both water and sewer service. Under the baseline tariff, residential customers with only water service pay an average price of 0.57 USD/m^3. Residential customers with both water and wastewater service pay an average of 0.80 USD/m^3 for both services, which reflects the 75% surcharge NCWSC assesses for wastewater service.

[14] There are several potential "paths" to achieve a target level of cost recovery by a specified date. For example, a utility could increase prices rapidly in the early years of a planning horizon and less dramatically in the later years. Alternatively, they could raise prices slowly in the initial years and increase them more dramatically in the latter years of the planning horizon. Both approaches could meet a cost recovery target by the end of the specified planning period, but have different implications with respect to the temporal allocation of costs and benefits as well as the political economy of the tariff reform process. We abstract from this in our simulations and increase prices the same percent each year because it does not affect the relative performance of the tariff alternatives we consider.

Under the status quo tariff, NCWSC achieves a simulated 31% level of cost recovery in Year 5 of the planning period and would sell approximately 12.6 million m^3/mo. of water per month under our base case assumptions. Under the status quo tariff, residential customers in low-income areas receive 13% of the total subsidy delivered through the tariff, which is proportional to their share of water use, but less than the share of total accounts they represent (20%).

5.1. Status Quo Cost Recovery (31%)

Table 3 summarizes the results of our simulation at status quo levels of cost recovery under our base case assumptions. The IBT3 and IBT2-10 tariffs result in similar levels of water use as the baseline tariff (IBT4). The IBT2-5 and UP tariffs produce a small (2%) decrease in total water use relative to the baseline tariff. In contrast to the similar levels of total water use simulated under the IBT and UP tariffs, the UP+R tariff yields a 19% reduction in water use relative to the baseline tariff. This simulated reduction in water use is driven by the fact that the volumetric price for water service under the UP+R tariff is four times larger than the volumetric price in the first block of the baseline tariff and one and half times larger than the price in the highest block of the baseline tariff (Table 4). The magnitude of the simulated reduction in water use under the UP+R tariff must be viewed with caution because the elasticities used in the simulation model represent customers' response to small (marginal) changes in price.

All customers are subsidized at status quo levels of cost recovery. The magnitude of the subsidy delivered through the tariff is quite large, approximately 150% of the total revenue received by the utility. The IBT and UP tariff alternatives result in small changes in the net present value of subsidies delivered through the tariff over the simulation period. This reflects the fact that all the tariff alternatives produce the same level of cost recovery by design and that water use is largely unchanged under each of these tariff alternatives relative to the baseline tariff. In contrast, the UP+R tariff alternative results in 17% reduction in the net present value of the subsidies delivered through the tariff, which accompanies the simulated reduction in water use. Under the UP+R tariff, customers receive subsidies as a rebate rather than through the volumetric prices in the tariff. At the status quo level of cost recovery, customers receive a rebate of 35 USD/mo. per account.

The IBT and UP tariff alternatives perform similarly to the baseline tariff with respect to subsidy incidence, delivering 12-13% of the total subsidies to residential customers in low-income areas. This reflects the low correlation between income and water use in Nairobi (Fuente et al. 2016) as well as the fact that we do not impose different behavioral assumptions on low-income customers and other residential customers. Only the UP+R shows a marked improvement in subsidy incidence relative to the baseline tariff, delivering 20% of the subsidies to customers in low-income areas. This improvement in subsidy targeting occurs because all accounts receive the same rebate under the UP+R tariff. While the UP+R tariff performs better than the other tariff alternatives with respect to subsidy incidence, subsidies remain poorly targeted because nearly 80% of the subsidies do not reach the intended beneficiaries. This finding is consistent with other research showing that a water tariff is an ineffective means of delivering subsidies to low-income customers (Komives et al. 2005; Whittington et al. 2015; Fuente et al. 2016; Nauges and Whittington 2017).

Prices are far below the long-run marginal cost of service delivery at the status quo level of cost recovery. At such low prices, customers enjoy considerable welfare gains relative to efficient pricing. Under the baseline tariff, we estimate that the consumer surplus for residential customers relative to efficient prices is approximately 4.7 million USD/mo. in Year 5 of the simulation.[15] Overall, each tariff alternative produces a small increase in the net present value in customer welfare at status quo levels of cost recovery relative to the baseline tariff. The UP tariff alternative results in a slightly larger increase in customer welfare than the IBT tariff alternatives, which reflects the decrease in the average price facing high-volume customers under this tariff.

Customers experience the largest simulated gains (6%) under the UP+R tariff. Though customers experience a reduction in welfare associated with reduced water use, they receive a rebate from the utility under the UP+R tariff. At status quo levels of cost recovery, the net present value of the rebate over the simulation period is larger than the net present value of the decreases in welfare associated with the UP+R tariff.

---

[15] The average surplus received by residential customers is 20 USD/mo. account. This may appear large, particularly in the context of Nairobi. However, there are several factors that must be considered when interpreting the magnitude of these surplus gains. First, we measure consumer surplus from a hypothetical baseline of long-run marginal cost pricing in which the volumetric price is much higher than the price facing customers at status quo levels of cost recovery. The elasticities used in our welfare calculations describe customer response to small price changes and may not accurately describe consumer response to large price changes. Second, the magnitude of the consumer surplus enjoyed by customers relative to efficient prices at status quo cost recovery is much lower than the subsidy delivered through the tariff (~75 USD/mo. per account). Finally, 20 USD/mo. per account may appear large compared to perceptions of household incomes in Nairobi. However, we estimate the surplus for a household with a private connection consuming 15 m^3/mo. facing the status quo tariff to be approximately 5.76 USD/mo. This is larger than their bill (5.16 USD/mo.), but smaller than the subsidy associated their water use (~9 USD/mo.). It is also important to recall that only the relatively well-off have private piped connections in Nairobi.

All of the tariff alternatives result in net losses to society at status quo levels of cost recovery because the magnitude of the subsidy delivered through the tariff is larger than the welfare gain customers experience from the low volumetric prices at this level of cost recovery. Table 3 shows the change in deadweight loss associated with the shift from the baseline tariff to each of the tariff alternatives at status quo levels of cost recovery. Though all of the tariff alternatives produce some reduction in the deadweight loss to society, the IBT3 tariff results in the smallest reduction in the deadweight loss to society. The IBT2-5 and UP tariffs produce similar reductions in the deadweight loss to society, which reflects the fact that the magnitude of the subsidy remains unchanged while customers experience small increases in welfare under these tariffs. The UP+R tariff produces the largest reduction (35%) in the net present value of losses over the simulation period relative to efficient pricing, which reflects the simulated decrease in subsidies under the UP+R tariff and the fact that customers experience slightly larger increases in welfare compared to the other tariff alternatives.

5.2. Intermediate Cost Recovery (65%)

At status quo levels of cost recovery, customers experience considerable welfare gains relative to efficient pricing. However, this results in a large deadweight loss to society, highlighting potential gains that can be achieved by improving cost recovery. To achieve our intermediate level of cost recovery (65%) by the end of the five-year simulation period, prices must be increased 16% annually in real terms (Table 4). This results in prices in the IBT and UP tariffs more than doubling over the five-year simulation period. For example, the price in the lifeline block of the IBT tariffs increases from 0.22 USD/m^3 to 0.47 USD/m^3 in Year 5. Similarly, the volumetric price in the UP tariff increases from 0.47 USD/m^3 to 0.99 USD/m^3, slightly more than our estimates of the long-run marginal cost of water supply in Nairobi. Though the volumetric price in the UP+R tariff does not change, the rebate customers receive under this tariff decreases from 35 USD/mo. per account to 4 USD/mo. per account.

At 65% cost recovery, the performance of the tariff alternatives relative to one another is similar to what we observe at status quo levels of cost recovery (Table 5). For example, as prices increase to improve cost recovery, the IBT and UP tariff alternatives produce similar decreases in the overall water use (8-10%) relative to the baseline tariff. The UP+R tariff produces the same simulated reduction (19%) in water use as the status quo level of cost recovery because the volumetric price does not change under the UP+R tariff.

The increase in prices necessary to meet the intermediate level cost recovery, and the simulated decrease in water use that accompanies this increase, result in a reduction in customer welfare relative to the baseline tariff. The net present value of the change in customer welfare over the simulation period ranges from approximately -11 million USD/mo. (UP+R) to -13.5 million USD/mo. (IBT3). This corresponds to a 39% (UP+R) to 48% (IBT3) decrease in the welfare gains customers experience under the baseline tariff relative to efficient prices. As we observe at status quo levels of cost recovery, in the aggregate customers experience smaller reductions in welfare under the UP tariff than the IBT tariff alternatives.

Relative to the low prices they face at status quo levels of cost recovery, customers are worse off when the utility increases prices to reach the intermediate level of cost recovery. However, this increase in prices results in a decrease in the magnitude of the subsidies delivered through the tariff and all of the tariff alternatives result in simulated reductions in the deadweight loss to society. The reduction in simulated losses ranges from -4.5 million USD/mo. under IBT3 to -12.6 million USD/mo. under UP+R. The UP and IBT2-5 tariffs result in a slightly larger reduction in the deadweight loss to society than the IBT2-10 and IBT3 tariff alternatives. This reflects the fact that the IBT and UP tariff alternatives produce the same reduction in subsidies delivered through the tariff, while the UP and IBT2-5 tariffs result in smaller decreases in customer welfare.

5.3. Full Cost Recovery

Substantial subsidies are still delivered through the tariff at intermediate levels of cost recovery. To reach full cost recovery by the end of the simulation period, the utility would need to increase prices 27% annually (Table 4). Under these price increases, the price in the lifeline block of the IBT tariff alternatives would increase from 0.22 USD/m^3 to 0.72 USD/m^3. Similarly, the volumetric price in the UP tariff increases from 0.47 USD/m^3 to 1.51 USD/m^3, well above our estimate of the long-run marginal cost of water supply in Nairobi. At the status quo and intermediate levels of cost recovery, customers receive a rebate under the UP+R tariff. However, to reach full cost recovery, customers must be assessed a fixed charge of 26.50 USD/mo. per account.

As shown in Table 6, we observe a similar pattern in the relative performance of the tariff alternatives as in the status quo and intermediate levels of cost recovery. In particular, the IBT and UP tariff alternatives perform similarly to one another and the UP+R tariff appears to outperform the other tariff alternatives across all of the criteria we consider.

Although the tariff alternatives exhibit similar relative performance as in the status quo and intermediate levels of cost recovery, the full cost recovery scenario provides insight into the implications of the utility moving toward financial self-sufficiency. At full cost recovery, the IBT and UP tariff alternatives result in a 13 to 19% reduction in aggregate water use in Year 5 of the simulation period, relative to the status quo tariff. As we caution above in the context of the UP+R tariff, however, the price increases required to achieve full cost recovery are quite large and the magnitude of these simulated reductions in water use must be interpreted with caution.

Customers continue to receive subsidies as the utility increases prices annually to reach full cost recovery in the final year of the simulation. However, all of the tariff alternatives result in a 50% or larger reduction in the net present value of the subsidies delivered through the tariff over the simulation period. This decrease in the net present value of subsidies, and the price increases required to achieve full cost recovery, are accompanied by substantial reductions in customer welfare (Table 6) across all tariff alternatives.

5.4. Trade-Offs along the Path to Cost Recovery

Thus far we have focused primarily on the relative performance of the tariff alternatives at the three levels of cost recovery, yet there are tradeoffs along the path to recovery that warrant additional attention. Figure 1 highlights the dynamics of the trade-off between customer welfare, the magnitude of the subsidy delivered through the tariff, and deadweight loss as the utility transitions from status quo levels of cost recovery to full cost recovery under the UP tariff.[16] At the beginning of the simulation period, the utility is at status quo levels of cost recovery. At such low prices, customers experience considerable welfare gains relative to efficient pricing, but a large amount of subsidies are delivered through the tariff. Because the magnitude of the subsidy delivered through the tariff is larger than the gains in customer welfare, the status quo level of cost recovery results in a deadweight loss to society.

As the utility increases prices to improve cost recovery, the magnitude of the subsidy delivered through the tariff decreases and customers experience a decrease in welfare relative to status quo levels of cost recovery. This results in a decrease in the deadweight loss to society as the utility moves along the path to full cost recovery.

[16] The deadweight loss and customer welfare in Figure 1 start from baseline welfare and deadweight loss under the status quo tariff relative to efficient prices.

At approximately 70% cost recovery, customers face efficient prices (i.e., the long-run marginal cost) and thus do not experience welfare gains relative to efficient prices. However, the utility does not achieve full cost recovery when customers face efficient prices because it operates at 30% non-revenue water. When customers face efficient prices, the deadweight loss to society is equal to the magnitude of the subsidy delivered through the tariff.

To reach full cost recovery, the utility must increase prices above efficient prices. While this reduces and eventually eliminates the subsidy delivered through the tariff, it results in customers experiencing a decrease in welfare relative to efficient prices. Thus, at full cost recovery there is still a deadweight loss to society, which equals the decrease in welfare customers experience relative to efficient prices. It is interesting to note that, at approximately 80% cost recovery, deadweight loss to society is comprised equally of the subsidy delivered through the tariff and the losses customers experience due to inefficient pricing.

6. Model Extensions and Additional Considerations

There are several ways to extend our analysis and issues that warrant further consideration. In this section, we examine the relative performance of the tariff alternatives when customers respond to marginal, rather than average, price, and we discuss several issues associated with the implementation of a UP+R tariff in practice. We also highlight the limitations of our analysis and identify areas for additional research.

6.1. What Happens When Customers Respond to Marginal Price?

In our base case simulations, we assume that customers respond to average rather than marginal price. Thus, it is not surprising that the IBT and UP tariff alternatives perform similarly to one another when customers respond to average price. We think it is reasonable to assume that customers in Nairobi respond to average price because water prices are currently very low in Nairobi and customers face a complicated IBT. However, it is plausible that customers might respond to marginal price under a less complicated tariff (e.g., an IBT with fewer blocks or a uniform price tariff) or as prices increase and become more salient. Thus, in this section we present the results of our simulations assuming that customers respond to marginal price.

Our simulations indicate that the prices required to reach the three levels of cost recovery are similar irrespective of whether customers respond to average or marginal price (Appendix 3). For example, prices must be increased 16% and 27% annually to reach intermediate and full cost recovery, respectively, when customers respond to marginal price. This is the same as the price increases required to reach these levels of cost recovery when customers respond to average price.

In general, all of the tariff alternatives result in smaller simulated reductions in water use than when customers respond to average price (Table 7). For example, the UP+R tariff produces a 13% simulated reduction in water use, compared to 19% when customers respond to average price. These smaller reductions in water use are accompanied by smaller decreases in customer welfare as the utility increases prices to improve cost recovery, particularly for the IBT tariffs. Finally, with the exception of the UP+R tariff, all tariff alternatives produce larger reductions in the deadweight loss to society when customer respond to marginal price.

Whether customers respond to average or marginal price affects the magnitude of the outcomes we simulate. This has implications for infrastructure planning as well as the magnitude of the welfare effects associated in the transition to new tariff structures and improved levels of cost recovery. However, the extent to which customers respond to average or marginal price also has implications for the performance of the tariff alternatives relative to one another.

When customers respond to average price, our simulations indicate that the UP tariff alternatives (UP and UP+R) perform equally as well as, or better than, the IBT tariff alternatives across all of the criteria we consider. When customers respond to marginal price, however, the UP performs similarly to the IBT tariffs, but no longer dominates the IBT tariff alternatives (Table 7). For example, at intermediate and full cost recovery, the UP tariff produces reductions in total water use that are similar to the IBT tariff alternatives. However, the UP tariff produces slightly larger reductions in customer welfare than either the IBT2-5 or IBT2-10 tariff. As a result, the UP tariff also leads to smaller deadweight loss reductions than the IBT2 tariff.

Finally, we observe a narrowing of the performance gap between the UP+R tariffs and other tariff alternatives when customers respond to marginal price. For example, in our base case simulations, there is a five to six percentage point difference in the reduction in water use between the UP+R and other tariff alternatives at full cost recovery. When customers respond to marginal price, this gap narrows to one to two percentage points. Unlike in our base case simulations, we find that the UP+R tariff produces similar reductions in welfare as the IBT2 tariff alternatives, as prices increase to reach full cost recovery.

6.2. Reconsidering the Uniform Price with Rebate (UP+R) Tariff

Economists have long recommended the UP+R tariff on the grounds of promoting economic efficiency (Coase 1946; Saunders et al. 1977). Our simulations show that the UP+R outperforms the IBT and UP tariff alternatives with respect to not only economic efficiency, but also equity (i.e., subsidy incidence), the welfare effects on customers, and conservation at all levels of cost recovery. This finding holds regardless of whether customers respond to average or marginal price. These results could be interpreted as providing a convincing case that the UP+R tariff should be implemented more widely in the sector. However, we caution against that interpretation for several reasons discussed below.

First, utilities may find the UP+R tariff administratively or politically difficult to implement. In weak institutional contexts, or where the public has a low level of confidence in public institutions, it may not be politically feasible or advisable for utilities to collect revenues that would later be returned to customers in the form of a rebate. The implementation of the UP+R tariff also requires a credible and politically acceptable means of calculating the magnitude of the fixed charge (or rebate) required to meet the utility's target level of cost recovery. This raises practical questions about how a utility might implement a UP+R tariff.

For example, should the fixed charge or rebate be determined ex ante based on forecasts of customer water use and input costs or ex post once customer water and input costs have been observed? If the utility (or regulator) determines the fixed charge ex ante, they risk under or overestimating the magnitude of the fixed charge (or rebate) to reach a particular level of cost recovery. However, the utility may have limited incentive to contain costs if the fixed charge (or rebate) is determined ex post.

Additionally, our simulations indicate that the magnitude of the fixed charge or rebate under UP+R pricing can be quite large. This can occur when the utility operates at low levels of cost recovery, when it exhibits a high level of non-revenue water, or when the marginal cost is substantially different than the average cost. The efficiency-promoting properties of the UP+R tariff require the rebate or fixed charge to be applied in a lump sum manner. This means that the utility would need to administer the rebate in a manner that did not affect customers' decisions about how much water to use or their decision about whether to connect or disconnect from the network. This raises important questions about both how and when the fixed charge is assessed or the rebate is delivered.

It is possible that the rebate or fixed charge would be less likely to influence customers' monthly water use if it were applied on an annual basis. However, this may not be politically acceptable or desirable for the reasons discussed above. Additionally, if the fixed charge or rebate were applied on an annual basis, should it be applied at the beginning, middle, or end of the fiscal year? The decision about when to apply the fixed charge or rebate may have implications for how customers respond to it.

There may also be behavioral implications related to how the fixed charge or rebate is implemented. For example, a rebate could be applied as credit on customers' utility bills, as a one-time cash transfer (e.g., an annual payment), or as a credit against income or property tax (e.g., if the utility was run by a municipality). It seems plausible that customers would respond differently to each of these modes of rebate delivery and that there may be considerable heterogeneity in customer responses associated with the timing and mode of delivery of the fixed charge or rebate.

The magnitude of the fixed charge or rebate under the UP+R tariff may impact customers' decisions about whether to connect or disconnect from the network. This may be not be a serious concern in industrialized countries where incomes are relatively high and self-supply options are often limited. However, entry-exit issues may be important in low- and middle-income countries where groundwater use is often poorly regulated (or unregulated), the market for vendors (e.g., tanker trucks) is better developed, and many households have already invested in above and below ground storage. The extent to which the magnitude of a fixed charge or rebate might affect customers' entry-exit decisions is an empirical question that must be considered to fully characterize the economic and financial implications of implementing a UP+R tariff.

Finally, in a low- or middle-income country context, the magnitude of the fixed charge or rebate may be economically salient for some customers. If a rebate or fixed charge is a non-negligible fraction of a customer's income, it may affect her water use via an income effect. We do not have information on customers' income and therefore do not address this in our simulations. However, the extent to which a fixed charge or rebate influences customer water use may have implications for the performance of the UP+R tariff relative to other tariff alternatives.

6.3. Limitations and Opportunities for Additional Research

While our results have several implications for the pricing of water and sanitation services in low- and middle-income countries, there are caveats that warrant mention, as well as areas for future work.

First, our simulations used water use data from a particular location in a particular point in time. While we believe conditions in Nairobi reflect conditions in many large, fast-growing cities in low- and middle-income countries, tariff design requires careful consideration of, and attention to, local conditions.

Second, we simulated an illustrative set of tariffs to examine the relative performance of alternative tariff structures. Given the central aim of this paper, we hold several factors constant across the tariff alternatives, including the magnitude of the meter rent, the price in the lifeline block for block tariffs, the sewerage surcharge, and pricing for kiosks and bulk customers. There is clearly scope for additional work to examine how each of these factors affects tariff performance.

Third, we constructed a set of tariffs to compare the performance of alternative tariff structures. These tariff alternatives were not designed to optimize a particular objective or set of objectives. Tariff design using multi-objective optimization techniques represents another clear area of expansion for this work.

Fourth, customers face large price increases under both the UP+R tariff and our full cost recovery scenario. The elasticities we use in our simulation represent customers' response to small changes in price and there is considerable uncertainty about how customers would respond to such large price increases. While this would not affect the relative performance of the tariffs we simulate, how customers respond to large price increases may have important implications for infrastructure planning and is an area for future research.

Fifth, our simulations assume that non-residential customers are insensitive to price changes. This assumption may be valid at low prices, but may not hold if prices are increased dramatically. Additional information on the extent to which price changes affect non-residential customers' water use, production, and profits would be necessary to more accurately estimate the impact of price changes on non-residential customers. The literature on the demand for municipal water and sanitation services among non-residential customers is quite thin (Worthington 2010) and represents a clear area for future research.

Finally, we examined the performance of alternative tariff structures relative to a modest set of performance criteria. There are several objectives that policy makers must balance when setting water and sanitation tariffs and careful attention must be paid to the political economy of tariff reform, including local perceptions of fairness and equity, the capacity of utilities to implement complex tariffs, and the incentives that tariffs create for both utilities and customers.

7. Summary and Conclusions

Our simulations provide several insights with respect to the performance of alternative tariff structures in Nairobi and for the design and evaluation of water and sanitation tariffs in low- and middle-income countries more broadly. Our findings suggest that the IBT tariff alternatives perform similarly to one another with respect to the portfolio of criteria we consider. This echoes the findings of Nauges and Whittington (2017) and suggests that policy makers and tariff consultants may be misdirecting their efforts when they focus on determining the appropriate size of the lifeline block, the number of blocks in an IBT, and the relative prices between blocks.

Additionally, economists have long recommended the UP+R tariff on the grounds of promoting economic efficiency (Coase 1946; Saunders et al. 1977). Our simulations indicate that the UP+R outperforms the IBT and UP tariff alternatives with respect to not only economic efficiency, but also equity (i.e., subsidy incidence) and several other policy-relevant indicators of tariff performance. These findings are robust to assumptions about whether customers respond to average or marginal price. Some utilities may find the UP+R tariff administratively or politically difficult to implement and there are several issues associated with how a utility might implement this tariff and, in turn, how this might affect customers' response to a UP+R tariff in practice. Nevertheless, our simulations raise interesting questions about how customers might respond to large price increases, the extent to which a large fixed charge (or rebate) impacts customers' entry-exit decisions, and whether the timing and mechanism for administering the fixed charge (or rebate) affects customer behavior. While these questions must be answered to determine whether a UP+R tariff can outperform other tariffs in a given context, our simulations suggest a UP+R tariff may warrant further consideration.

Contrary to conventional wisdom, we also find that a simple tariff with a uniform volumetric price (i.e., the UP tariff) performs equally well, or better, compared to the IBT tariff alternatives across all of the criteria we consider. While a UP tariff does not have the efficiency-promoting properties of a UP+R tariff, a UP tariff is easier to explain to customers and sends a clearer signal than IBTs about the cost of delivering water and sanitation services. Thus, our findings suggest that a tariff with a uniform volumetric price may perform as well as or better than the IBTs that many utilities are implementing in low- and middle-income countries. This finding stands in stark contrast to current perceptions of best practice in tariff design among utility managers, regulators, and the consultants who provide tariff-setting advice.

Utilities in low- and middle-income countries often implement tariffs that are not sufficient to cover the cost of providing water and sanitation services. Our findings reinforce the benefits of getting utilities on the path to full cost recovery. Improving cost recovery can promote more efficient water use, improve the financial viability of utilities, and deliver net social benefits. At low levels of cost recovery, existing customers of the utility experience relatively large welfare gains relative to efficient pricing. However, this comes at the expense of the utility and taxpayers (who may also be customers) with resulting net losses to society. Low levels of cost recovery also lead to well-documented deteriorating levels of service quality and hinder governments' ability to extend services to households that lack access to the piped water and sanitation network.

Overall, our findings add to a growing body of literature that questions the widespread use of IBTs in low- and middle-income countries. However, with the exception of the UP+R tariff, we find that there is surprisingly little difference in the performance of the tariff alternatives we simulate at a given level of cost recovery. This is particularly true when we consider uncertainty about customer behavior. Taken together, our findings suggest that when tariffs are not sufficient to cover the cost of water and sanitation service delivery, utilities and governments have more to gain by improving cost recovery than focusing narrowly on the structure of the tariff used to charge customers for water and sanitation services.

References

Arbués, F., Garcia-Valiñas, M.A., and Martínez-Espiñeira, R. 2003. Estimation of residential water demand: A state-of-the-art review. *Journal of Socio-Economics* 32 (1): 81–102.

Berg, S. and Tschirhart, J. 1989. *Natural Monopoly Regulation*. Cambridge: Cambridge University Press.

Binet, M., Carlevaro, F., and Paul, M. 2013. Estimation of residential water demand with imperfect price perception. *Environmental and Resource Economics* doi: 10.1007/s10640-013-9750-z.

Bonbright, J.C. 1961. *Principles of Public Utility Rates*. New York: Columbia University Press.

Borenstein, S. 2009. To what electricity price do consumers respond? Residential demand elasticity under increasing-block pricing. *Preliminary Draft April* 30. http://faculty.haas.berkeley.edu/borenste/download/NBER_SI_2009.pdf

Brown, S. and D. Sibley. 1986. *The Theory of Public Utility Pricing*. Cambridge University Press: Cambridge.

Chetty, R., Friedman, J.N., Olsen, T., and Pistaferri, L. 2011. Adjustment costs, firm responses, and micro vs. macro labor supply elasticities: Evidence from Danish tax records. *Quarterly Journal of Economics* 126 (2): 749-804.

Coase, R. H. 1946. The marginal cost controversy. *Economica* 13: 169-182.

Dalhuisen, J.M., Florax, R., de Groot, H. and Nijkamp, P. 2003. Price and income elasticities of residential water demand: A meta-analysis. *Land Economics* 79 (2): 292–308.

Diakité, D., Semenov, A. and Thomas, A. 2009. A proposal for social pricing of water supply in Côte d'Ivoire. *Journal of Development Economics* 88 (2): 258–268.

Espey, M., Espey, J. and Shaw, W. 1997. Price elasticity of residential demand for water: A meta-analysis. *Water Resources Research* 33 (6): 1369–74.

Feldstein, M. 1972. Equity and efficiency in public sector pricing: The optimal two-part tariff. *Quarterly Journal of Economics* 86 (2): 175-187.

Foster, H. S., Jr. and B. R. Beattie. 1981. Urban residential demand for water in the United States: Reply. *Land Economics* 57 (2): 257–65.

Fuente, D., J. Gakii Gatua, M. Ikiara, J. Kabubo-Mariara, M. Mwaura, and Whittington. D. 2016. Water and sanitation service delivery, pricing, and the poor: An empirical estimate of subsidy incidence in Nairobi, Kenya. *Water Resources Research* 52, doi:10.1002/2015WR018375.

Garcia, S. and Reynaud, A. 2004. Estimating the benefits of efficient water pricing in France. *Resource and Energy Economics* 26: 1-25.

Garcia-Valinas, M. 2005. Efficiency and equity in natural resources pricing: A proposal for urban water distribution service. *Environmental and Resource Economics* 32 (2): 183–204. doi:10.1007/s10640-005-3363-0.

Garcia-Valinas, M., Martínez-Espineira, R., and González-Gómez, F. 2010. Affordability of residential water tariffs: Alternative measurement and explanatory factors in Southern Spain." *Journal of Environmental Management* 91 (12): 2696–2706.

Global Water Intelligence (GWI). 2013. Global Water Tariff Survey, Oxford, U. K. [Available at http://www.globalwaterintel.com/global-water-intelligence-magazine/tariff-survey/.]

Hanemann, M. 1997. Price and Rate Structures. In *Urban Water Demand Management and Planning*, edited by D. Baumann, J. Boland, and M. Hanemann. New York: McGraw Hill.

Howe, C. and Linaweaver, H. 1967. The impact of price on residential water demand and its relationship to system design and price structure. *Water Resources Research* 3 (1): 13–32.

Ito, K. 2013. How do consumers respond to nonlinear pricing? Evidence from household water demand. *Working Paper*. http://people.bu.edu/ito/Ito_Water_Irvine.pdf

Ito, K. 2014. Do consumers respond to marginal or average price? Evidence from nonlinear electricity pricing. *American Economic Review* 104 (2):537-63.

Kenya National Bureau of Statistics (KNBS). 2009. Population and Housing Census 2009, Nairobi, Kenya.

Komives, K., Halpern, J., Foster, V., Wodon, Q. and Abdullah, R. 2005. *Water, Electricity, and the Poor: Who Benefits From Utility Subsidies?* Washington, DC: World Bank.

Madhoo, Y.N. 2009. Policy and nonpolicy determinants of progressivity of block residential water rates – a case study of Mauritius. *Applied Economic Letters* 16 (2): 211-215.

Martínez-Espiñeira, R. and Nauges, C. 2004. Is all domestic water consumption sensitive to price control? *Applied Economics* 36 (15): 1697–1703.

Ministry of Water and Irrigation (MoWI) and Athi Water Services Board (AWSB). 2014. *Feasibility Study and Master Plan for Nairobi and Satellite Towns*. November 2012.

Nataraj, S.and Hanemann, M. 2011. Does marginal price matter? A regression discontinuity approach to estimating water demand. *Journal of Environmental Economics and Management* 61 (2): 198–212.

Nauges, C. and Whittington, D. 2010. Estimation of water demand in developing countries: An overview. *The World Bank Research Observer* 25 (2): 263-94.

Nauges, C. and Whittington, D. 2017. Evaluating the performance of alternative municipal water tariff designs: Quantifying the trade-offs between cost recovery, equity, and economic Efficiency. *World Development* 91:125-143

Nauges, C., Strand, J. and Walker, I. 2009. The value of water connections in Central American cities: A revealed preference study. *Environment and Development Economics* 14 (3): 349–70.

Nordin, J. A. 1976. A proposed modification of Taylor's demand analysis: Comment. *The Bell Journal of Economic Management and Science* 7: 719-21.

Renzetti, S., 1992a. Estimating the structure of industrial water demand: the case of Canadian manufacturing. *Land Economics* 68: 396–404.

Renzetti, S., 1992b. Evaluating the welfare effects of reforming municipal water prices. *Journal of Environmental Economics and Management* 22: 147–192.

Reynaud, A. 2003. An econometric estimation of industrial water demand in France. *Environmental and Resource Economics* 25: 213–232.

Reynaud, A. 2016. Assessing the impact of full cost recovery of water services on European households. *Water Resources and Economics* 14: 65-78.

Rinaudo, J., Neverre, N. and Montginoul, M. 2012. Simulating the impact of pricing policies on residential water demand: A Southern France case study. *Water Resources Management* 26 (7): 2057–68. doi:10.1007/s11269-012-9998-z.

Ruijs, A., Zimmermann, A. and van den Berg, M. 2008. Demand and distributional effects of water pricing policies. *Ecological Economics* 66 (2-3): 506–516.

Saez. E. 1999. Do taxpayers bunch at kink points? *NBER Working Paper*. Vol. 7366. Cambridge, MA: National Bureau of Economic Research.

Saez, E. 2003. The effect of marginal tax rates on income: a panel study of 'bracket creep'. *Journal of Public Economics* 87: 1231-1258.

Saez, E. 2010. Do taxpayers bunch at kink points? *American Economic Journal: Economic Policy* 2 (3): 180–212.

Saunders. R., Warford, J., and Mann, P. 1977. Alternative concepts of marginal cost for public utility pricing: Problems of application in the water supply sector. *World Bank Staff Working Paper No. 259*. Washington, D.C.: The World Bank.

Taylor, L. 1975. The demand for electricity: A survey. *The Bell Journal of Economics* 6 (1): 74-110.

Worthington, A. 2010. Commercial and industrial water demand estimation: Theoretical and methodological guidelines for applied economic research. *Griffin Business School Discussion Paper* 2010-2011: 1-25.

Whittington, D. 1992. Possible adverse effects of increasing block water tariffs in developing countries. *Economic Development and Cultural Change* 41 (1): 75-87.

Whittington, D. 2011. Pricing water and sanitation services. In *Treatise on Water Science* 1: 79-95.

Whittington, D., Nauges, C., Fuente, D., and Wu., X. 2015. A diagnostic tool for estimating the incidence of subsidies delivered by water utilities in low- and medium-income countries, with illustrative simulations. *Utilities Policy* 34: 70-81.

Tables and Figures

Table 1. Summary of the Tariff Alternatives

Tariff Alternative	Tariff Type	No. Blocks	Lifeline Block *(m3/ac./mo.)*
IBT4 (baseline)	IBT	4	10
IBT3	IBT	3	6
IBT2-5	IBT	2	5
IBT2-10	IBT	2	10
UP	Uniform price	n.a.	n.a.
UP+R	Uniform price w/ rebate	n.a.	n.a.

Table 2. Summary Statistics from the NCWSC Customer Base

	Unit	Residential	Non-residential	Kiosk	Bulk
Water Use					
% total	%	57%	35%	3%	4%
Mean (*s.d.*)	m3/mo.	31	347	192	11,301
		(194)	*(1,927)*	*(942)*	*(47,609)*
Accounts	%	94%	5%	1%	<1%
Total Revenue	%	56%	41%	1%	2%

Table 3. Summary of Status Quo Cost Recovery Simulation Results

Criteria	Units	Status Quo	Status Quo Cost Recovery (31%) IBT3	IBT2-10	IBT2-5	UP	UP+R
Water Use (t=5)	m3/mo.	12,586,418	12,546,144	12,463,506	12,361,515	12,372,133	10,184,194
% change	*%*	*n.a.*	*0%*	*-1%*	*-2%*	*-2%*	*-19%*
Subsidy (NPV[a])	USD/mo.	-64,176,442	-64,259,346	-63,928,548	-63,002,367	-63,286,002	-53,372,468
% change	*%*	*n.a.*	*0%*	*0%*	*-2%*	*-1%*	*-17%*
Subsidy Incidence (t=5)	%	13%	13%	13%	12%	12%	20%
Change in Customer Welfare (NPV[a])	USD/mo.	n.a.	660,356	937,804	789,208	1,047,355	1,829,944
% status quo[b]	*%*	*n.a.*	*2%*	*3%*	*3%*	*4%*	*6%*
Change in Deadweight Loss (NPV[a])	USD/mo.	n.a.	-577,452	-1,185,698	-1,963,283	-1,937,795	-12,633,918
% status quo[b]	*%*	*n.a.*	*-2%*	*-3%*	*-5%*	*-5%*	*-35%*

[a] All NPV calculations use a 10% discount rate.

[b] Percent change measured relative to customer welfare and deadweight loss under the status quo tariff relative to efficient prices.

Table 4. Summary of Tariff Alternatives Simulated under Base Case Conditions (t=5)

		Cost Recovery Scenario		
		31%	**65%**	**100%**
Common Components		t=5	t=5	t=5
Meter rent	USD/mo.	0.68	1.44	2.22
Sewer surcharge*	%	75%	75%	75%
Annual price increase	%	0%	16%	27%
4-Block IBT (IBT4 - status quo)				
0 to 10	USD/m3	0.22	0.22	0.22
11 to 30	USD/m3	0.45	0.45	0.45
31 to 60	USD/m3	0.50	0.50	0.50
> 60	USD/m3	0.63	0.63	0.63
Kiosk	USD/m3	0.17	0.17	0.17
Bulk	USD/m3	0.30	0.30	0.30
3-block IBT (IBT3)				
Block 1 UB	m3/mo.	6	6	6
Block 2 UB	m3/mo.	60	60	60
P Block 1	USD/m3	0.22	0.47	0.72
P Block 2	USD/m3	0.37	0.78	1.21
P Block 3	USD/m3	0.59	1.26	1.94
Kiosk	USD/m3	0.17	0.36	0.56
Bulk	USD/m3	0.30	0.64	0.98
2-Block IBT: 10 m3/mo. block 1 (IBT2-10)				
Size of LLB	m3/mo.	10	10	10
Price in LLB	USD/m3	0.22	0.47	0.72
Price in UB	USD/m3	0.52	1.10	1.70
Kiosk	USD/m3	0.17	0.36	0.56
Bulk	USD/m3	0.30	0.64	0.98
2-Block IBT: 5 m3/mo. block 1 (IBT2-5)				
Size of LLB	m3/mo.	5	5	5
Price in LLB	USD/m3	0.22	0.47	0.72
Price in UB	USD/m3	0.51	1.07	1.65
Kiosk	USD/m3	0.17	0.36	0.56
Bulk	USD/m3	0.30	0.64	0.98
Uniform Price (UP)				
Volumetric price	USD/m3	0.47	0.99	1.51
Uniform Price w/ Rebate (UP+R)				
Vol. price (water only)	USD/m3	0.94	0.94	0.94
Vol. price (water + wastewater)	USD/m3	1.93	1.93	1.93
Vol price (wastewater only)	USD/m3	0.98	0.98	0.98
Rebate (+)/Fixed Chard (-)	USD/ac/mo.	35	4	-26.50

** Except the UP+R tariff*

Table 5. Summary of Intermediate Cost Recovery Simulation Results

			Intermediate Cost Recovery (65%)				
Criteria	**Units**	**Status Quo**	**IBT3**	**IBT2-10**	**IBT2-5**	**UP**	**UP+R**
Water Use (t=5)	m3/mo.	12,586,418	11,551,921	11,474,577	11,378,184	11,384,305	10,184,194
% change	*%*	*n.a.*	*-8%*	*-9%*	*-10%*	*-10%*	*-19%*
Subsidy (NPV[a])	USD/mo.	-64,176,442	-46,121,476	-45,734,727	-45,147,390	-45,435,421	-40,451,553
% change	*%*	*n.a.*	*-28%*	*-29%*	*-30%*	*-29%*	*-37%*
Subsidy Incidence (t=5)	%	13%	14%	12%	12%	12%	20%
Change in Customer Welfare (NPV[a])	USD/mo.	n.a.	-13,532,599	-13,200,968	-13,031,142	-12,733,580	-11,090,970
% status quo[b]	*%*	*n.a.*	*-48%*	*-47%*	*-46%*	*-45%*	*-39%*
Change in Deadweight Loss (NPV[a])	USD/mo.	n.a.	-4,522,366	-5,240,747	-5,997,910	-6,007,441	-12,633,918
% status quo[b]	*%*	*n.a.*	*-13%*	*-15%*	*-17%*	*-17%*	*-35%*

[a] All NPV calculations use a 10% discount rate.

[b] Percent change measured relative to customer welfare and deadweight loss under the status quo tariff relative to efficient prices.

Table 6. Summary of Full Cost Recovery Simulation Results

			Full Cost Recovery (100%)				
Criteria	**Units**	**Status Quo**	**IBT3**	**IBT2-10**	**IBT2-5**	**UP**	**UP+R**
Water Use (t=5)	m3/mo.	12,586,418	10,954,546	10,885,809	10,789,277	10,799,428	10,184,194
% change	*%*	*n.a.*	*-13%*	*-14%*	*-14%*	*-14%*	*-19%*
Subsidy (NPV[a])	USD/mo.	-64,176,442	-31,845,107	-31,437,491	-30,962,315	-31,442,092	-28,531,027
% change	*%*	*n.a.*	*-50%*	*-51%*	*-52%*	*-51%*	*-56%*
Subsidy Incidence (t=5)	%	13%	n.a.	n.a.	n.a.	n.a.	n.a.
Change in Customer Welfare (NPV[a])	USD/mo.	n.a.	-25,521,990	-25,141,093	-24,857,603	-24,371,607	-23,011,497
% status quo[b]	*%*	*n.a.*	*-90%*	*-89%*	*-88%*	*-86%*	*-81%*
Change in Deadweight Loss (NPV[a])	USD/mo.	n.a.	-6,809,345	-7,597,858	-8,356,524	-8,362,742	-12,633,918
% status quo[b]	*%*	*n.a.*	*-19%*	*-21%*	*-23%*	*-23%*	*-35%*

[a] All NPV calculations use a 10% discount rate.

[b] Percent change measured relative to customer welfare and deadweight loss under the status quo tariff relative to efficient prices.

Table 7. Summary of Simulation Results When Customers Respond to Marginal Price

			Status Quo Cost Recovery (31%)				
Criteria	**Units**	**Status Quo**	**IBT3**	**IBT2-10**	**IBT2-5**	**UP**	**UP+R**
Water Use (t=5)	m3/mo.	12,571,600	12,698,432	12,679,173	12,619,545	12,752,211	10,884,020
% change	*%*	*n.a.*	*1%*	*1%*	*0%*	*1%*	*-13%*
Subsidy (NPV[a])	USD/mo.	-64,079,718	-64,978,987	-64,897,409	-64,446,098	-65,506,362	-56,694,684
% change	*%*	*n.a.*	*1%*	*1%*	*1%*	*2%*	*-12%*
Subsidy Incidence (t=5)	%	13%	13%	13%	13%	13%	20%
Change in Customer Welfare (NPV[a])	USD/mo.	n.a.	1,697,188	2,506,501	2,023,042	1,724,366	3,504,766
% status quo[b]	*%*	*n.a.*	*6%*	*9%*	*7%*	*6%*	*12%*
Change in Deadweight Loss (NPV[a])	USD/mo.	n.a.	-797,919	-1,688,810	-1,656,663	-297,722	-10,889,800
% status quo[b]	*%*	*n.a.*	*-2%*	*-5%*	*-5%*	*-1%*	*-31%*

			Intermediate Cost Recovery (65%)				
Criteria	**Units**	**Status Quo**	**IBT3**	**IBT2-10**	**IBT2-5**	**UP**	**UP+R**
Water Use (t=5)	m3/mo.	12,571,600	11,718,436	11,702,025	11,653,294	11,775,603	10,884,020
% change	*%*	*n.a.*	*-7%*	*-7%*	*-7%*	*-6%*	*-13%*
Subsidy (NPV[a])	USD/mo.	-64,079,718	-46,550,568	-46,387,038	-46,374,551	-46,995,136	-43,070,624
% change	*%*	*n.a.*	*-27%*	*-28%*	*-28%*	*-27%*	*-33%*
Subsidy Incidence (t=5)	%	13%	14%	12%	12%	12%	20%
Change in Customer Welfare (NPV[a])	USD/mo.	n.a.	-11,959,821	-10,621,233	-10,901,058	-11,987,101	-10,115,411
% status quo[b]	*%*	*n.a.*	*-42%*	*-37%*	*-38%*	*-42%*	*-36%*
Change in Deadweight Loss (NPV[a])	USD/mo.	n.a.	-5,569,328	-7,071,448	-6,804,109	-5,097,481	-10,893,684
% status quo[b]	*%*	*n.a.*	*-16%*	*-20%*	*-19%*	*-14%*	*-31%*

[a] All NPV calculations use a 10% discount rate.

[b] Percent change measured relative to customer welfare and deadweight loss under the status quo tariff relative to efficient prices.

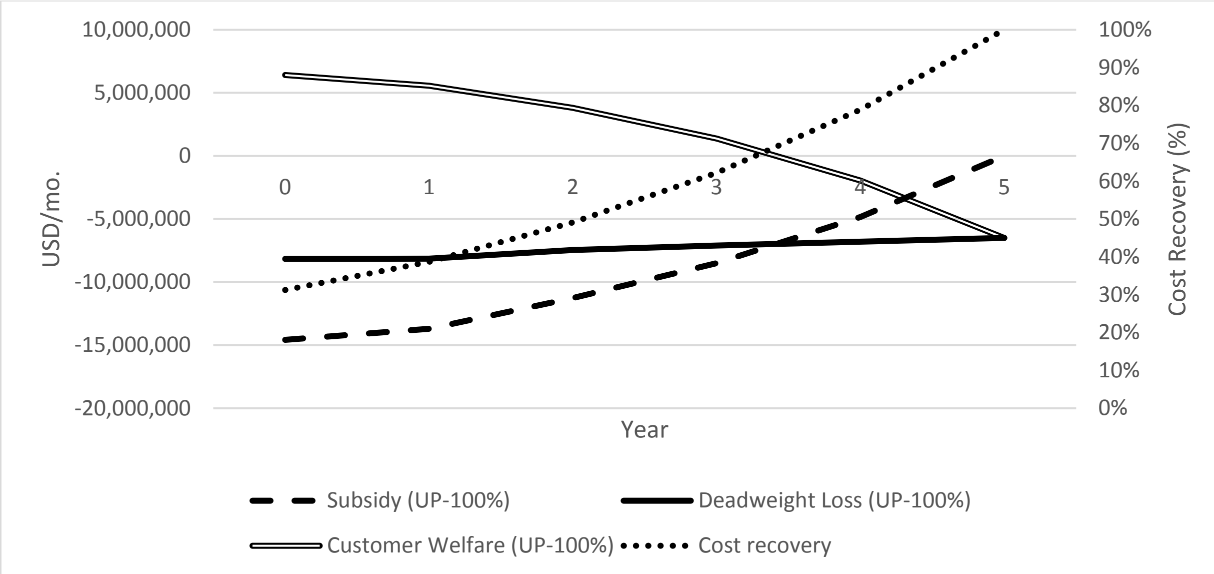
Table 7 (cont.'d). Summary of Simulation Results When Customers Respond to Marginal Price

			Full Cost Recovery (100%)				
Criteria	**Units**	**Status Quo**	**IBT3**	**IBT2-10**	**IBT2-5**	**UP**	**UP+R**
Water Use (t=5)	m3/mo.	12,571,600	11,144,977	11,111,075	11,072,336	11,197,165	10,884,020
% change	*%*	*n.a.*	*-11%*	*-12%*	*-12%*	*-11%*	*-13%*
Subsidy (NPV[a])	USD/mo.	-64,079,718	-31,997,088	-32,216,801	-31,874,950	-32,311,800	-29,953,075
% change	*%*	*n.a.*	*-50%*	*-50%*	*-50%*	*-50%*	*-53%*
Subsidy Incidence (t=5)	%	13%	n.a.	n.a.	n.a.	n.a.	n.a.
Change in Customer Welfare (NPV[a])	USD/mo.	n.a.	-23,455,021	-21,304,146	-21,861,420	-23,585,104	-23,230,451
% status quo[b]	*%*	*n.a.*	*-83%*	*-75%*	*-77%*	*-83%*	*-82%*
Change in Deadweight Loss (NPV[a])	USD/mo.	n.a.	-8,627,609	-10,558,772	-10,343,348	-8,182,814	-10,896,193
% status quo[b]	%	*n.a.*	*-24%*	*-30%*	*-29%*	*-23%*	*-31%*

[a] All NPV calculations use a 10% discount rate.

[b] Percent change measured relative to customer welfare and deadweight loss under the status quo tariff relative to efficient prices.

Figure 1. Dynamics of the Subsidy, Customer Welfare, Deadweight Loss, and Cost Recovery for the UP Tariff Alternative



Appendix 1. Simulation Model Parameters for the Base Case Scenario

Model Parameter	Unit	Model
EXOGENOUS FACTORS		
Customer growth	%	5%
Economic growth	%	5%
Exchange rate	KSH/USD	90
Discount rate	%	10%
CUSTOMER BEHAVIOR		
Average vs. marginal price	n.a.	Average price
Residential IED	n.a.	0.1
Residential PED		
Usage threshold	m3/mo.	5
Upper PED	n.a.	-0.2
Lower PED	n.a.	0
Non-residential PED	n.a.	0
OPERATIONAL EFFICIENCY		
NRW	%	30%
Collection efficiency	%	85%
COST		
Operations & Maintenance		
Water	USD/m3	0.23
Wastewater	USD/m3	0.23
Capital Costs		
Water	USD/m3	0.71
Wastewater	USD/m3	0.75

PED = Price elasticity of demand
IED = Income elasticity of demand

Appendix 2. Calculation of Consumer Surplus under Increasing Block Tariffs when Customers Respond to Marginal Price

As indicated in the main text, Equation 3.5 will not correctly measure the change in consumer surplus for increasing block tariffs when customers respond to marginal rather than average price. To address this, we measure the change in consumer surplus under each tariff alternative in a two-step process. In the first step, we calculate the change in consumer surplus under each tariff alternative, relative to a hypothetical baseline in which customers face efficient prices, which we assume is the long-run marginal cost of service delivery. In the second step, we calculate the change in consumer surplus associated with moving from the baseline tariff to a new tariff as the difference in consumer surplus that customers enjoy under the baseline tariff and the new tariff, relative to efficient prices. We describe this two-step process in more detail below.

<u>Step 1</u>: Adjust estimates of consumer surplus to reflect surplus gained under increasing block tariffs.

Figure A2-1 depicts a scenario in which a customer's water use falls in the second block of a two block IBT with a 10 m^3/mo. lifeline block (IBT2-10). When customers respond to marginal price, Equation 3.5 measures the area A+B as the change in consumer surplus relative to efficient pricing. However, the customer also receives area D under IBT2-10. To address this in our calculations of consumer surplus, we add area D to the consumer surplus calculated in Equation 3.5. Figure A2-2 depicts a scenario in which a customer's water use falls in the first block of IBT2-10. When customers respond to marginal price, Equation 3.5 measures the area H+I as the gain in consumer surplus under IBT2-10 relative to efficient pricing. In this instance, Equation 3.5 measures the correct change in consumer surplus and no adjustment is required.

Figure A2-1. Customer Water Use in Block 2 of IBT2-10 Relative to Efficient Pricing

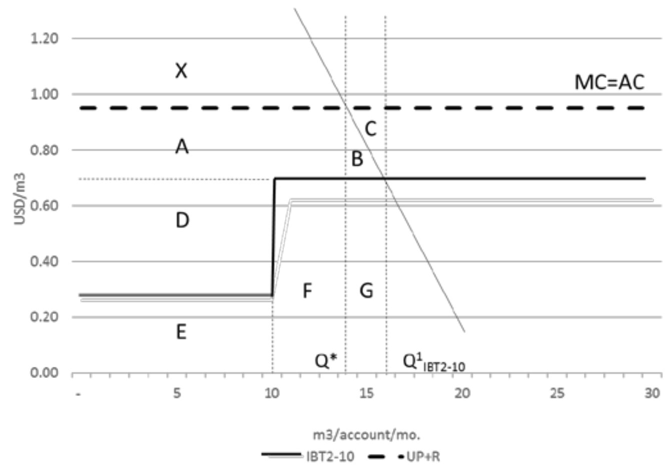
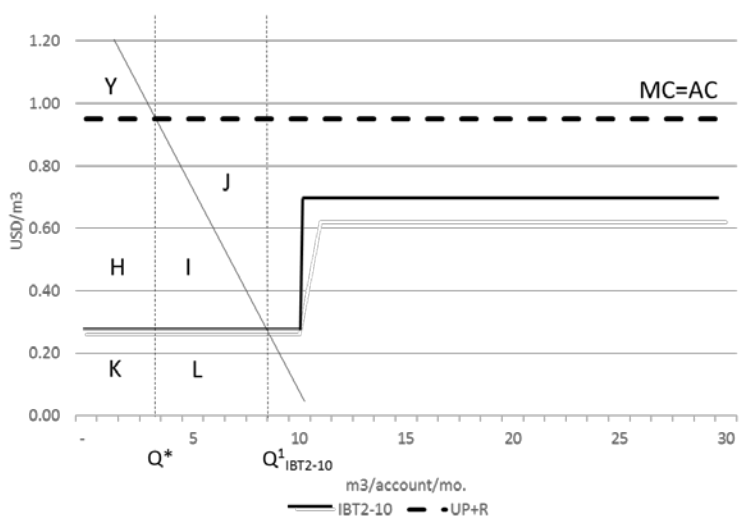


Figure A2-2. Customer Water Use in Block 1 of IBT2-10 Relative to Efficient Pricing



When customers respond to marginal price, we adjust the consumer surplus measured in Equation 3.5 to reflect the change in surplus associated with the usage blocks of the IBT tariff alternatives. The procedure we use to do this for the IBT2-10 tariff alternative is described in Equation A1 below.

$$\Delta CSmp_{j,t}^{IBT2-10} = \begin{cases} \Delta CS_{j,t}^{IBT2-10} & if \max\left(Q_{j,t}^{*}, Q_{j,t}^{IBT2-10}\right) \leq B1 \\ \Delta CS_{j,t}^{IBT2-10} + \left(P_{2,t}^{IBT2-10} - P_{1,t}^{IBT2-10}\right) \cdot B1 & if \max\left(Q_{j,t}^{*}, Q_{j,t}^{IBT2-10}\right) > B1 \end{cases} \quad \text{(A1)}$$

where,

- $\Delta CSmp_{j,t}^{IBT2-10}$ is the change in consumer surplus for customer j in year t under IBT2-10 when customer j responds to marginal price;
- $\Delta CS_{j,t}^{IBT2-10}$ is the change in consumer surplus for customer j in year t under IBT2-10 when customer j responds to average price (Equation 3.5);
- $Q_{j,t}^{*}$ is customer j's projected water use under efficient pricing in year t;
- $Q_{j,t}^{IBT2-10}$ is customer j's water use under IBT2-10 in year t;
- $B1$ is the size of the lifeline block under IBT2-10; and
- $P_{i,t}^{IBT2-10}$ is the volumetric price in block i under IBT2-10 in year t (i=1,2).

Step 2: Calculate the change in consumer surplus associated with the transition from the baseline tariff to a new tariff.

In the second step, we calculate the change in consumer surplus that results from a shift from the status quo tariff, a 4-block IBT (IBT4), to a variety of different tariffs as described in Equation A2.

$$\Delta CS_{t}^{IBT4\rightarrow T} = \Delta CS_{t}^{T} - \Delta CS_{t}^{IBT4} \quad \text{(A2)}$$

where $\Delta CS_t^{IBT4 \rightarrow T}$ is the change in consumer surplus associated with the shift from the status quo tariff to tariff alternative T in year t and ΔCS_t^{T} and ΔCS_t^{IBT4} are the change in consumer surplus under tariff alternative T and IBT4, respectively, relative to efficient pricing in year t.

Appendix 3. Summary of Tariffs and Prices When Customers Respond to Marginal Price

		Cost Recovery Scenario		
		31%	**65%**	**100%**
Common Components				
Meter Rent	USD/mo.	0.68	1.44	2.25
Sewer surcharge*	%	75%	75%	75%
Annual price increase	%	0%	16%	27%
4-Block IBT (IBT4 - status quo)				
0 to 10	USD/m3	0.22	0.22	0.22
11 to 30	USD/m3	0.45	0.45	0.45
31 to 60	USD/m3	0.50	0.50	0.50
> 60	USD/m3	0.63	0.63	0.63
Kiosk	USD/m3	0.17	0.17	0.17
Bulk	USD/m3	0.30	0.30	0.30
3-block IBT (IBT3)				
Block 1 UB	m3/mo.	6	6	6
Block 2 UB	m3/mo.	60	60	60
P Block 1	USD/m3	0.22	0.47	0.72
P Block 2	USD/m3	0.37	0.78	1.21
P Block 3	USD/m3	0.59	1.26	1.94
Kiosk	USD/m3	0.17	0.36	0.56
Bulk	USD/m3	0.30	0.64	0.98
2-Block IBT: 10 m3/mo. block 1 (IBT2-10)				
Size of LLB	m3/mo.	10	10	10
Price in LLB	USD/m3	0.22	0.47	0.72
Price in UB	USD/m3	0.52	1.10	1.68
Kiosk	USD/m3	0.17	0.36	0.56
Bulk	USD/m3	0.30	0.64	0.98
2-Block IBT: 5 m3/mo. block 1 (IBT2-5)				
Size of LLB	m3/mo.	5	5	5
Price in LLB	USD/m3	0.22	0.47	0.72
Price in UB	USD/m3	0.51	1.06	1.64
Kiosk	USD/m3	0.17	0.36	0.56
Bulk	USD/m3	0.3	0.64	0.98
Uniform Price (UP)				
Volumetric price	USD/m3	0.46	0.98	1.51
Uniform Price w/ Rebate (UP+R)				
Vol. price (water only)	USD/m3	0.94	0.94	0.94
Vol. price (water + wastewater)	USD/m3	1.93	1.93	1.93
Vol price (wastewater only)	USD/m3	0.98	0.98	0.98
Rebate	USD/ac/mo.	37	5	-29

* Except the UP+R tariff