ESSAYS ON WATER AND SANITATION SERVICE DELIVERY IN SUB-SAHARAN AFRICA

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A dissertation submitted to the faculty at the University of North Carolina at Chapel Hill in partial fulfillment of the requirements of the degree of Doctor of Philosophy in the Department of City and Regional Planning in the College of Arts and Sciences.

Chapel Hill
2017

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ABSTRACT

David Fuente: Essays on Water and Sanitation Service Deliver in Sub-Saharan Africa
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Tariffs (i.e., user fees) will play a critical role in financing the Sustainable Development Goals' aspiration to ensure universal access to water and sanitation services by 2030. This dissertation is comprised of three essays that examine the pricing of water and sanitation services in sub-Saharan Africa, focusing specifically on the case of Nairobi, Kenya. The first essay examines the extent to which the increasing block tariff (IBT) implemented in Nairobi effectively targets subsidies to low-income households, one of the primary objectives of the IBT implemented by Nairobi City Water and Sewer Company (NCWSC) and the majority of utilities in Sub-Saharan Africa. Contrary to conventional wisdom, I find that high-income residential and nonresidential customers receive a disproportionate share of subsidies and that subsidy targeting is poor even among households with a private metered connection.

Subsidy incidence is, however, only one of several criteria that policy makers consider when designing tariffs. The second essay provides a systemic review of the literature on pricing water and sanitation services, identifying the ways in which the literature might inform tariff design and areas for future research. I find that the literature is diverse, fragmented, and focused primarily on industrialized countries. The majority of studies in the literature also examine two or fewer criteria, limiting the extent to which the literature characterizes the actual tradeoffs policy makers face when designing tariffs.

The third essay develops a framework for simulating the performance of water and sanitation tariffs. I apply this framework to the case of Nairobi to examine the performance of five alternative tariff structures relative to the IBT implemented by NCWSC. I find that tariff alternatives with a uniform volumetric price perform equally well or better than IBT tariff alternatives at three levels of cost recovery. These findings add to a growing body of evidence that challenges commonly held perceptions about IBTs. These findings also underscore the benefits of getting utilities on path to full cost recovery, an essential component of financing the global aspiration to ensure universal access to high quality water and sanitation services.

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LIST OF ABBREVIATIONS

ABM	Agent Based Model
ASCE	American Society for Civil Engineers
AWSB	Athi Water Services Board
CGE	Computable General Equilibrium
GIS	Geographic Information System
GPS	Global Positioning System
GWI	Global Water Intelligence
IBT	Increasing Block Tariff
IED	Income Elasticity of Demand
KSH	Kenyan Shilling
LSMS	Living Standards Measurement Study
MoWI	Ministry of Water and Irrigation
NCWSC	Nairobi City Water and Sewer Company, Ltd.
O&M	Operations and Maintenance
OECD	Organization of Economic Co-operation and Development
PED	Price Elasticity of Demand
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SDG	Sustainable Development Goal
SDM	System Dynamic Model
UNC	University of North Carolina
USD	United States Dollars
WHO	World Health Organization
WSTF	Water Services Trust Fund

INTRODUCTION

In September 2015, global leaders met at the United Nations Sustainable Development Summit to adopt the Sustainable Development Goals (SDGs), an ambitious set of goals aimed at ending poverty, improving human health and well-being, and addressing climate change. The SDG for water and sanitation (Goals 6.1 and 6.2) seek to ensure access to safe and affordable water and sanitation services for all by 2030. This represents a major shift in global ambition both with respect to the scope of the goals – universal access – as well as the target level of service. The SDGs defines “safe” services as service that is safely managed, available on premise, when needed. The World Bank estimates that it will cost approximately 100 billion USD per year between now and 2030 to meet the SDGs for water and sanitation (Hutton and Varughese 2016). This estimate does not include the cost of maintaining, repairing, or replacing countries’ existing water and sanitation infrastructure, or the cost of investing in infrastructure that is resilience to climate change.

While many low and middle income countries face the challenge of investing in their first generation of water and sanitation infrastructure, the water and sanitation infrastructure in many industrialized countries is reaching, or has reached, the end of its useful life and is in many cases failing. In the United States, the American Society of Civil Engineering have given the nation’s water and sanitation infrastructure a D+ rating, indicating that the infrastructure is in poor condition. According to the American Water Works Association and American Society for Civil

Engineers, it will cost approximately one trillion dollars to replace the United States' water infrastructure network and 300 billion dollars to meet the United States' wastewater and storm water capital requirements (ASCE 2013). These estimates also do not include the cost of investing in climate-resilient water and sanitation infrastructure.

Financing the next generation of water and sanitation infrastructure in both developing and industrialized countries will require the mobilization of substantial resources. There are three general ways in which governments can finance this infrastructure transition: taxes, tariffs (i.e., user fees), and transfers (e.g., from international donors). Given the magnitude of the infrastructure challenge, governments will need to deploy each of these sources of finance to ensure their citizens have access to high quality water and sanitation services. To date, tariffs have largely been under-utilized by governments and service providers as source of domestic finance for water and sanitation service delivery, particularly in low and middle-income countries. The International Monetary Fund estimated that in 2012 nearly 500 billion USD in subsidies were delivered through water and sanitation tariffs as a result of prices that were insufficient to cover the full cost of services (Kochar et al. 2015). This may seem counterintuitive because tariffs – and a stable revenue stream – directly affect utilities' ability to attract finance from domestic and international capital markets.

This dissertation is comprised of three essays that examine water and sanitation service delivery in sub-Saharan Africa, focusing specifically on the pricing of water and sanitation services in one of the region's largest cities, Nairobi, Kenya. Sub-Saharan Africa was one of only two regions[1] not to meet the Millennium Development Goal of halving the population without

[1] The other region is Oceania, which includes many small nations in the Pacific Islands.

access to improved water and sanitation facilities by 2015 (UNICEF and WHO 2015). It is also the region where the investment needed to meet the SDG aspiration of ensuring universal access to safely managed water and sanitation services is greatest.

The first and third essays in the dissertation examine issues related to the pricing of municipal water and sanitation services using the case of Nairobi, Kenya, a city widely regarded as the economic hub of East Africa. In particular, these essays examine the performance of the existing increasing block tariff (IBT) implemented by the Nairobi City Water and Sewer Company (NCWSC) and a suite of potential alternative tariffs relative to several indicators of tariff performance. The IBT is among the most widely used tariffs by water utilities, particularly in developing countries. According to a recent survey of water utilities across the globe, 53% percent of utilities in the sample implement an IBT, with 74% percent of utilities in developing countries doing so (GWI 2013).

In a traditional IBT, the marginal price for water use increases from one usage block to the next and customers are charged the marginal price for water use in each block accordingly. The popularity of the IBT reflects two widely held perceptions about its potential merits. First, policy makers believe a low marginal price in the lowest usage block of an IBT, often referred to as a “lifeline block”, will ensure that low-income households have access to a certain quantity of water at a price deemed affordable. Second, they believe that higher prices in the upper block(s) of the IBT can both prevent wasteful or extravagant water use and provide an opportunity to improve cost recovery from households who use more water.

The first essay of the dissertation combines data on households’ socioeconomic status and metered water use to examine the distributional incidence of subsidies delivered through the IBT in Nairobi. Contrary to conventional wisdom, I find that high-income residential and non-residential customers receive a disproportionate share of subsidies and that subsidy targeting is poor even among households with a private metered connection. I also find that stated expenditure on water, a commonly used means of estimating water use, is a poor proxy for metered use and that previous studies on subsidy incidence underestimate the magnitude of the subsidy delivered through water tariffs. These findings have implications for both the design and evaluation of water tariffs in developing countries.

Subsidy targeting is, however, only one of several criteria that policy makers might consider when designing tariffs for water and sanitation services. Recognizing this, the second essay of the dissertation provides a systemic review of the literature pricing water and sanitation services, highlighting ways in which insights from the literature might inform water and sanitation service pricing and identifying areas for future research. I find that the empirical literature on pricing municipal water and sanitation services is diverse and fragmented. Studies identified through this systematic review are published in a wide range of journals and vary considerably with respect to their core aims, methods, number of tariffs examined, and the indicators of tariff performance considered. However, the majority of studies examine two or fewer objectives, limiting the extent to which the literature characterizes the tradeoffs policy makers often face when setting tariffs for municipal water and sanitation services. I also find that the majority of studies in the literature focus on water pricing in industrialized countries, highlighting an opportunity for research on water pricing in low and middle-income countries.

Informed by the second essay, the third essay develops a framework for simulating the performance of water and sanitation tariffs with respect to several policy-relevant criteria. I then apply this framework to the case of Nairobi. In particular, I examine the performance of five alternative tariff structures relative the current tariff implemented by Nairobi City Water and

Sewer Company (NCWSC) at three different levels of cost recovery. I then evaluate the performance of alternative tariffs relative to several indicators of 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 overall changes in social welfare. I also examine how the tariff alternatives perform under uncertainty about consumer behavior. Contrary to conventional wisdom, I find that tariff alternatives with a uniform volumetric price perform equally well or better than IBT tariff alternatives at the three levels of cost recovery we examine. This includes both a two-part tariff long promoted by economists (i.e., uniform price with rebate) as well as a simple tariff with a uniform volumetric price. These findings are robust to assumptions about whether customers respond to average or marginal price. Overall, these findings add to a growing body of evidence that challenges commonly held perceptions about IBTs and suggest that the attention policy makers and tariff consultants pay to selecting the size of the lifeline block and number of blocks in an IBT is misdirected. These findings also underscore the benefits of getting utilities on path to full cost recovery, a critically important component of financing the global infrastructure transition required to ensure universal access to high quality water and sanitation services.

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CHAPTER 1: WATER AND SANITATION SERVICE DELIVERY, PRICING, AND THE POOR: AN EMPIRICAL ESTIMATE OF SUBSIDY INCIDENCE IN NAIROBI, KENYA[2]

1.1 Introduction

The increasing block tariff (IBT) is among the most widely used tariffs by water utilities, particularly in developing countries. According to a recent survey of water utilities across the globe, 53% percent of utilities in the sample implement an IBT, with 74% percent of utilities in developing countries doing so (GWI 2013). In a traditional IBT, the marginal price for water use increases from one usage block to the next and customers are charged the marginal price for water use in each block accordingly. The popularity of the IBT reflects two widely held perceptions about its potential merits. First, policy makers believe a low marginal price in the lowest usage block of an IBT, often referred to as a "lifeline block", will ensure that low-income households have access to a certain quantity of water at a price deemed affordable. Second, they believe that higher prices in the upper block(s) of the IBT can both prevent wasteful or extravagant water use and provide an opportunity to improve cost recovery from households who use more water. The intuitive appeal of the IBT rests on the implicit assumptions that all households have a private piped connection to the water network and that low-income households use less water than high-income households.

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[2] This chapter previously appeared as an article in Water Resources Research. The original citation is as follows: Fuente, D., Gakii Gatua, J., Ikiara, M., Kabubo-Mariara, J., Mwaura, M., 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.

Scholars have long questioned whether these assumptions are valid in low and middle-income countries (Whittington 1992; Boland and Whittington 2000; Komives et al. 2005). This has led to a body of empirical work that has challenged common intuition about the poor, access to water and sanitation services, and the relationship between household income and water use (e.g., Komives et al. 2006; Komives et al. 2007; Banerjee et al. 2008; Banerjee and Morella 2011; Barde and Lehman 2014). In this paper, we examine the distributional incidence of subsidies delivered through the increasing block water tariff in Nairobi, Kenya. We combine socioeconomic data from a household survey with household data on metered water use to estimate the distribution of subsidies among residential customers with a private metered connection in Nairobi. We then use a complete set of customer billing records from Nairobi City Water and Sewer Company (NCWSC) to estimate the distribution of subsidies among all residential customers, including those with shared connections. Finally, we expand the scope of our analysis and examine the distribution of subsidies among residential and nonresidential customers in Nairobi.

Our analysis departs from existing studies in the subsidy incidence literature in three ways. First, studies in the literature typically use stated expenditure on water from household interviews to estimate water use. To our knowledge, this study is the first to combine household-level socioeconomic data with data on metered water use to estimate subsidy incidence in the water sector. Second, unlike the majority of studies in the literature, we use empirical city-specific estimates of the cost of providing water and wastewater services to estimate subsidy incidence. Finally, all previous studies in the literature focus on the distribution of subsidies among residential customers. Our study extends the literature by examining the distribution of subsidies among all customer classes.

We find that the IBT implemented in Nairobi is not targeting subsidies to low-income households effectively. Among households with a private metered connection, households in the lowest wealth quintile receive less than 20% of the subsidies delivered to these customers. Subsidy targeting improves slightly when we examine subsidy incidence among all residential customers, but higher-income customers still receive a disproportionate share of subsidies. Our analysis of subsidy incidence among all customer classes indicates that non-residential (e.g., commercial, industrial, bulk water, etc.) customers, who constitute 5% of customer accounts, receive over a third of the subsidies delivered through the tariff. We also find that stated expenditure is a poor proxy for metered water and that the magnitude of the subsidy delivered through the water tariff is substantially larger than previous studies would suggest.

The remainder of the paper is organized as follows. The second section of the paper discusses the issue of subsidy incidence and provides a review of the subsidy incidence literature in the water sector. The third and fourth sections describe our empirical strategy and the data used in our analysis, respectively. The fifth section presents our results. The final section provides a discussion of our results and some concluding remarks.

1.2 Background and Literature Review

Despite the intuitive appeal of IBTs, there are a number of reasons why the IBT may not effectively target subsidies to low-income households in many low- and middle-income country contexts. For example, in order for a household to receive a subsidy that is delivered through the water tariff, it must have a piped connection. However, poor households often lack a piped water connection and are thus largely excluded from subsidies provided through low-priced water delivered through a piped connection. Similarly, low-income households are also often more likely than wealthier households to have a shared connection to the piped water network (e.g., a yard tap) and to live in multi-unit dwellings that are served by a single meter. Households that share a connection or live in a multi-unit dwelling served by a single meter pay a higher volumetric price for water than if they had an individual meter because the collective water use of those who share a connection falls in the upper, more expensive, blocks of the IBT. Finally, the extent to which household income and water use are highly correlated is an empirical question, even among households with a private piped connection. Indeed, the limited empirical evidence in the literature suggests that the correlation between household income and water use is much less than commonly assumed (Whittington et al. 2015).

Concerns about the extent to which the IBT, and utility tariffs more broadly, can be used to effectively target subsidies to low-income households has led to a body of empirical research on subsidy incidence. (See Appendix 1-1for a summary of studies that have been published on subsidy incidence since 2000.) To calculate the distributional incidence of subsidies delivered through the water tariff, the analyst needs information on the magnitude of the subsidy received by each household and the relative income or wealth of each household. The subsidy received by each household is the difference between what it costs to provide the particular household with a particular level of service (e.g., water or water and wastewater service) and what the household actually pays for this service.

The cost of serving each household is a function of households' water use, whether the household has only water or water and wastewater service (i.e., their "level of service"), and the unit cost of providing water and wastewater services. The amount households pay for water and sanitation service is a function of households' water use, their level of service, and the tariff the utility uses to calculate their monthly bill for water and sanitation services. Thus, in total the analyst must have five pieces of information to estimate subsidy incidence: households' water use, households' service level, the unit cost of providing water and wastewater services, the tariff, and some measure of households' wealth or socioeconomic status. Assembling this information can be quite difficult in practice. (See Gomez-Lobo et al. (2000) for an overview of information and modeling challenges associated with designing water and sanitation tariffs.)

For example, data on households' socioeconomic status and demographics are typically available in secondary household survey data, such as national income and expenditure surveys, World Bank Living Standards Measurement Study (LSMS) data, and some national censuses. However, these surveys typically do not contain information on household water use. Similarly, utility billing records contain information on household water use, provided customers are metered, the meters are working, and the utility regularly reads customers' meters. Due to confidentiality requirements, however, it is typically not possible to match household level socioeconomic data in nationally representative household income and expenditure surveys and customer data in utility billing records.

Because it can be difficult or not possible to obtain good measures of both socioeconomic status and water use for the same household, studies in the literature typically use a single data source to obtain information on both households' socioeconomic status and water use. In particular, most studies use households' stated expenditure on water to estimate households' water use. They collect this information either through primary household surveys (e.g., Foster 2004, Bardasi and Wodon 2008, and Angel-Urdinola and Wodon 2012) or from nationally representative household budget and expenditure surveys (e.g., World Bank LSMS data). (See Appendix 1-2 for a discussion of why stated expenditure may not be a good proxy for metered water use.)

Studies in the subsidy incidence literature (Appendix 1-1) address the issue of cost in three general ways. (Appendix 1-3 provides a summary of cost estimates used in the literature.) First, studies may use generic cost estimates, or international benchmarks, to calculate subsidy incidence (e.g., Komives et al. 2005, Komives et al. 2006, Foster and Yepes 2006). Common sources for generic cost estimates include GWI (2004) and Kingdom et al. (2004). Other studies use empirical, site-specific cost estimates (e.g., Groom et al. 2008, Banerjee and Morella 2011, Walker et al. 2000). However, these studies typically do not explicitly state what the cost estimates include or precisely how they were derived. Finally, studies may make ad hoc assumptions about the cost of providing water and wastewater services. For example, Barde and Lehmann (2014) assume that the average tariff currently implemented in Lima, Peru (approximately 0.64 USD/m^3) represents full cost recovery.

There is broad consensus in the literature that de facto subsidies delivered through the water tariff are poorly targeted and largely regressive (see Appendix 1-1). Indeed, many studies find that subsidies delivered through the water tariff perform worse than if the subsidies were equally distributed among the population. This is principally due to the fact that low-income households are less likely to have a private connection to the piped water network and, thus, do not receive subsidies delivered through the water tariff.

Studies that examine subsidy incidence only among households with a piped connection also find that subsidies are poorly targeted. This is primarily because income and water use are often not highly correlated and the tariff implemented by many utilities is not sufficient to cover the cost of providing service. These empirical results are supported by simulations conducted by Whittington et al. (2015) that suggest little can be done to improve subsidy targeting when tariffs are not sufficient to cover costs.

There are three main gaps in the water literature on subsidy incidence. First, studies in the literature either focus only on subsidies associated with the delivery of piped water service or do not explicitly state whether they include subsidies associated with wastewater service. Piped wastewater services are usually more expensive to provide than piped water services. To the extent that wastewater services are sold below cost and to the extent that higher-income households are more likely to have connections to the piped wastewater network, estimates in the literature may overestimate the performance of subsidies delivered through the tariff.

Second, nearly all of the studies in the literature use stated expenditure to estimate water use, which may be a poor proxy for metered water use. Thus, it is unclear whether the broad consensus in the literature is attributable to the fact that studies use the same, potentially flawed, measure of water use.

Finally, all of the studies in Appendix 1-1 focus on subsidy incidence only among residential customers. This is not surprising given that these studies use data from household surveys. As a result, however, the literature ignores the distributional issues between residential and non-residential (e.g., commercial, industrial, bulk, etc.) customers. Depending on the tariff applied to non-residential customers, failing to include non-residential customers may over or understate the magnitude of total subsidies delivered through the water tariff.

1.3 Empirical Strategy

This study was designed to fill these gaps in the subsidy incidence literature. Our empirical strategy proceeds in three analytical steps. In the first step of our analysis, we combine socioeconomic and demographic data from a survey of 656 households with data on metered water use from NCWSC billing records. We use these data to: 1) estimate the distribution of subsidies among households with a private metered connection, and 2) examine the extent to which stated expenditure is an accurate proxy of metered water use. We focus this first step of the analysis on households with a private metered connection to capture the relationship between household income and water use. Households who shared a connection with another household or family were excluded from our survey sample.

According to the most recent census, less than a quarter of households in Nairobi reported using a private connection to the piped water network as their primary drinking source (KNBS 2009). Approximately half of households used piped water that is not delivered into their dwelling (e.g. a shared tap) as their primary drinking water source. Thus, in the second step of our analysis, we examine the distribution of subsidies among all NCWSC's residential customers, which includes residential customers with shared connections. In the third, final, step we expand the scope of our analysis to examine the distribution of subsidies among residential and non-residential customers in Nairobi.

1.3.1 Subsidy Incidence

We obtained information on customer water use from 21 months of NCWSC's billing records. Like many utilities, NCWSC does not read each meter every month. (NCWSC reads approximately 75% of meters each month.) To address this, we calculate monthly water use directly from actual meter readings in the NCWSC billing data as described in Equation 1.1.

$$WUSE_{i,t} = \left[\frac{READING_{i,t} - READING_{i,t-1}}{RDATE_{i,t} - RDATE_{i,t-1}}\right] \cdot 30.5\ days \qquad (1.1)$$

where:

- $WUSE_{i,t}$ is the water use for household i in month t;
- $READING_{i,t}$ is the meter reading for household i in month t;
- $READING_{i,t-1}$ is the previous actual meter reading for household i;
- $RDATE_{i,t}$ is the date on which NCWSC read the meter for household i in month t; and
- $RDATE_{i,t-1}$ is the date of the previous actual meter reading for household i.

We then use the estimates of households' monthly water use obtained in Equation 1.1 to calculate households' average monthly water use over the period covered by the billing records.

We define the subsidy received by each customer as the difference between the cost to serve each household and what the households pay for service. Our analysis of NCWSC's billing records confirms that the utility implements the official tariff (Table 1.1) to calculate customers' water and sewer bills. Thus, we calculate how much a customer pays by applying NCWSC's official tariff to our estimates of customers' average monthly water use. (NCWSC implements an IBT with 4 usage blocks. In addition to the fixed charge for meter rent, NCWSC applies a minimum charge for 10 m^3/mo. Households that use less than 10 m^3/mo. are charged for 10 m^3/mo. NCWSC charges customers with a connection to the sewer network an additional 75% of the volumetric portion of their water bill for wastewater service.)

We define the cost of serving a particular customer as in Equation 1.2.

$$COST_i = WUSE_i \cdot WCOST + I_{ww,i} \cdot (WUSE_i \cdot WWCOST) \tag{1.2}$$

where:

- $COST_i$ is the average monthly cost of serving household i (USD/month);
- $WUSE_i$ is the average water use of household i from Equation 1.1 (m^3/month);
- WCOST is the average volumetric cost of providing water service (USD/m^3);
- WWCOST is the average volumetric cost of providing wastewater service (USD/m^3); and
- $I_{ww,i}$ is an indicator variable that takes the value 1 if a household has wastewater service and 0 otherwise.

We develop empirical estimates of the average cost of providing water and wastewater services. Our cost estimates include both operations and maintenance as well as capital costs. They do not include the opportunity cost of the raw water supply. We estimate subsidy shares, the share of subsidies received by different groups of customers, to assess subsidy incidence. (Note that we do not examine affordability because this requires making ad hoc assumptions about what is and is not "affordable".) Equation 1.3 defines the share of subsidies going to a particular group of customers.

$$S_j = \frac{\sum_{i=1}^{n_j} SUB_i}{\sum_{j=1}^{J} \sum_{i=1}^{n_j} SUB_i} \tag{1.3}$$

where:

- S_j is the share of subsidies received by customer group j (j=1…J), and
- SUB_i is the share of subsidies received by household i.

In the first step of our analysis, j indexes the five wealth quintiles of our survey sample. In the second step, j indexes accounts located in low income areas and accounts in non-low income areas. In the final step of our analysis, j indexes residential, non-residential, kiosk, and bulk customer classes.

1.3.2 Stated Expenditure as a Proxy for Water Use

We also examine whether stated expenditure is an accurate proxy for metered water use by estimating household water use from households' stated expenditure on water and comparing this to their metered water use. To do this, we ask households if they can recall the amount of their last bill from NCWSC and the number of months of service the bill covered. Equation 1.4 shows how we impute water use for customers with only piped water service. We use an analogous approach to impute water use for customers with both water and sewer service.

$$\begin{aligned} IMPUSE_i &= (EXPS_i - RENT)/p1 \; if \; EXPS_i > 0 \;\&\; EXPS_i \leq b1max_w \\ &= b1 + (EXPS_i - b1max_w)/p2 \; if \; EXPS_i > b1max_w \;\&\; EXPS_i \leq b2max_w \\ &= b2 + (EXPS_i - b2max_w)/p3 \; if \; EXPS_i > b2max_w \;\&\; EXPS_i \leq b3max_w \\ &= b3 + (EXPS_i - b3max_w)/p4 \; if \; EXPS_i > b3max_w \end{aligned} \tag{1.4}$$

where:

- $IMPUSE_i$ is the imputed water use for household i (m^3/mo.);
- $EXPS_i$ is the stated expenditure for household i (KSH/mo.);
- RENT is the monthly meter rent charged in the NCWSC tariff (Table 1.1);
- pX is the volumetric price for water in the Xth block in the NCWSC tariff (Table 1.1);

- bX is the volumetric upper bound for the Xth block in the NCWSC tariff (Table 1.1); and
- $bXmax_w$ is the amount a water customer would be charged for consuming the maximum amount in the Xth block of the NCWSC tariff.

1.4 Data

The first step of our analysis examines subsidy incidence among households with a private connection to the piped water network. For this analysis, we use data from a sample of 656 households that were randomly drawn from two of Nairobi's six service regions, which were purposefully selected to ensure income heterogeneity in our sample. (See Appendix 1-4 for a detailed description of the survey and sampling strategy.) The survey was conducted between November 2013 and January 2014 and collected a range of socioeconomic and demographic information from households, including data on monthly income, household expenditure, and asset ownership. Following Filmer and Pritchett (2001) and Filmer and Scott (2008), we use principal component analysis to construct an asset index to serve as a proxy for wealth (see Appendix 1-5). We use the asset index as our primary proxy for wealth because approximately 15% of respondents in our sample refused to provide information about their monthly household income. (Assets included in the index include: liquid propane gas (LPG) as a main cooking fuel, biomass or kerosene as a main cooking fuel, separate kitchen, security guard, connection to the electricity grid, mobile phone, internet connection, TV, radio, computer, private car, washing machine, refrigerator, borewell, and additional land in/out of Nairobi.)

We obtain information on customer water use from 21 months of NCWSC's billing records. The billing data cover the period from August 2012 to May 2014. The principal challenge in our empirical strategy was to identify households in our survey sample in the billing records. Like many cities in developing countries, Nairobi does not have a formal system of addresses. Thus, it was not possible to first construct our sample from the billing records and then locate households to conduct the household survey. To address this, we used households' account numbers to identify households in our sample in the billing records. Because households do not typically know their NCWSC account number, however, we obtained households' account numbers by matching the serial number on households' water meter with the account number on the NCWSC marketing assistant's itinerary. When possible we verified the the account number with a physical copy of a household's recent water bill. (Fifty-six percent of households in our sample were able to show enumerators a copy of their water bill. All account numbers matched the accounts associated with the meter serial numbers.)

We use data from five years of audited financial statements (FY 2007 to 2012) to estimate NCWSC's average operations and maintenance costs. We derive capital cost estimates from data in NCWSC's water master plan (MoWI & AWSB 2014) and interviews with senior water and sanitation engineers at NCWSC, Athi Water Services Board, and local engineering firms. Table 1.2 presents the cost estimates we use in our analysis. Assuming 35% non-revenue water, we estimate the full cost (O&M plus capital costs) of water service to be 1.40 USD/m^3 and 1.46 USD/m^3 for wastewater service. (Non-revenue water refers to water the utility produces but for which it does not receive revenue.) These estimates are higher than the cost estimates used in many studies, but of similar magnitude to the cost estimates in GWI (2004) and Kingdom et al. (2004) once non-revenue is accounted for (see Tables A1-3a and A1-3b in Appendix 1-3).

For the analysis of subsidy incidence among all residential customers and among all customer classes, we obtain information on the water use of NCWSC's approximately 180,000 residential customers from 21 months of NCWSC's billing records. NCWSC does not have socioeconomic or demographic information about its customers. In the absence of household-level data on income or socioeconomic status, one could potentially use household budget and expenditure survey data or recent census data to obtain aggregate data on household characteristics. This is not possible in Nairobi for two reasons. First, the most recent Kenya Integrated Household Budget and Expenditure Survey (2005-6) contains only 685 observations from Nairobi. Second, data from the most recent census are not publicly available.

To address this, we use the geographic location of customer accounts as a proxy for relative wealth. In particular, we use the GIS location of customer accounts to identify which accounts are located in low-income areas. Information on the GIS location of each account was collected by NCWSC as part of a pilot program to conduct meter reading with smartphones. As of May 2015, approximately 85% of the 180,000 residential customer accounts were geocoded.

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 (MoWI) and Water Services Trust Fund (WSTF) (MoWI & WSTF 2015). The MajiData project is a multi-year effort to create a database of information related to water and sanitation service provision in all of Kenya's urban low-income areas. As part of this process, the MajiData team identified and mapped low income areas in the service area of each Water Service Provider in Kenya using publicly available data, stakeholder consultations, and transect walks of each service area (MoWI & WSTF 2008). MajiData's classification of low-income areas includes informal settlements, planned areas with planned low income housing, and informal housing in planned residential areas. To our knowledge, this information is the most comprehensive, up to date mapping of low-income areas in Nairobi.

For our analysis of subsidy incidence among all customer classes, we obtain water use data from the same set of NCWSC billing records described above. NCWSC billing data include 13 different customer classes. We group these customer classes into four general types: residential, non-residential, bulk, and kiosk. Our non-residential customer type includes accounts classified as government, community, and industrial.

1.5 Results

1.5.1 Household Survey – Subsidy Incidence

Table 1.3 presents information on selected characteristics of households in our survey sample. The average household in our sample has four members, which is consistent with the average household size in Nairobi from the latest census. Approximately half of the households in our sample rent their home. Over ninety percent of households in our sample have a sewer connection. Seventy-eight percent of households in our survey report using their piped water connection as their primary drinking water source. The remaining 22% report using bottled water for their primary drinking water source. Over a quarter of households in our sample report purchasing water from a vendor in the previous year, which reflects the fact that NCWSC does not provide customers 24x7 water service.

Mean and median water use in our survey sample are 19 m^3/mo. and 13 m^3/mo., respectively (Figure 1.1). Average water use among all residential customers in the NCWSC billing data is 31 m^3/mo. However, the mean water use of households on meter-reader itineraries with 100% individual meters is 20 m^3/mo., similar to what we find in our sample of households. Nearly 40% of households in the sample fall in the lifeline block (0 to 10 m^3/mo.). Over 80% of the households in the sample have water use that falls in the first two usage blocks (below 30 m^3/mo.). Only 4% of the sample falls in the upper-most block of NCWSC's tariff (>60 m^3/mo.).

We find considerable heterogeneity in water use, both within and across wealth quintiles. (This heterogeneity persists if we examine only three wealth groups.) Figure 1.2 plots household water use versus the households' wealth index score. The correlation between a household's wealth index score and water use in our sample is 0.20. Mean water use is 16 m^3/hh/mo. for households in the first (lowest) wealth quintile and 30 m^3/hh/mo. for households in the fifth (highest) wealth quintile (Table 1.4).

Table 1.4 also shows the average monthly bill for households in the five wealth quintiles. The mean bill for households in the lowest quintile is 931 KSH/hh/mo. (approximately 10 USD/hh/mo.). The mean bill for households in the highest wealth quintile is 1509 KSH/hh/mo. (approximately 17 USD/hh/mo.). As a point of comparison, the mean water and sewer bill for households in the lowest quintile is only 60% of what these households report paying for electricity. For the wealthiest households in the sample, the mean bill is less than a quarter of what they report spending on electricity.

Table 1.4 presents the average price paid by households in each wealth quintile. For the full sample, the mean average price ranges from 79 KSH/m^3 (0.90 USD/m^3) to 50 KSH/m^3 (0.56 USD/m^3) across wealth quintiles. The mean average price for households in the lowest wealth quintile is 70 KSH/m^3 (0.79 USD/m^3) and 50 KSH/m^3 (0.56 USD/m^3) for households in the highest wealth quintile. Households in the lowest quintile face a higher average price than households in in the highest quintile because the tariff includes both a positive fixed and minimum charge (e.g., customers are charged for 10 m^3/mo. regardless of their water use). These average price estimates reflect the fact that over 90% of households in our sample have a sewer connection.

Figure 1.3 shows the distribution of subsidies across wealth quintiles. If the subsidy were evenly, or randomly, distributed among the population, each wealth quintile would receive 20% of the total subsidy. A well-targeted subsidy would deliver a substantial share of the total subsidies to low-income households. In our sample, households in the lowest quintile receive only 16% of the total subsidy. Households in the top three wealth quintiles receive nearly 70% of the total subsidy, with households in the highest wealth quintile receiving almost 30% of the total subsidy.

1.5.2 Household Survey – Stated Expenditure as a Proxy for Metered Water Use

During the survey, we asked households if they can recall the amount of their last bill from NCWSC. Nearly 85% of households in our sample indicated that they could, considerably higher than the 30% percent reported in Foster (2004). Figure 1.4 presents a scatter plot of metered versus imputed water use for households who could recall the amount of their previous water bill. The 45-degree line in Figure 1.4 traces a line of equality for which imputed and metered water use would be the same for each household. The scatter plot in Figure 1.4 displays a high degree of dispersion, indicating that stated expenditure does not provide an accurate proxy for metered water use in our sample.

We find that stated expenditure typically overestimates households' water use, often by a substantial amount. This is reflected in Table 1.5, which provides summary statistics of metered water use and imputed water use from households in our sample. Average metered water use among households who could recall the amount of their last water bill was approximately 19

m^3/mo. The average water use imputed from stated expenditure among the sample, however, was 27 m^3/mo. (42% higher).

1.5.3 Subsidy Incidence Among All Residential Customers

The results presented above examine subsidy incidence among our survey sample, all of whom had a private piped connection. In the second step of our analysis we expand the scope of our inquiry to examine subsidy incidence among all residential customers. This analysis includes households with a private piped connection as well as households served by a shared connection. NCWSC does not have information on whether accounts are served by shared or individual connections. Thus, the results below examine subsidy incidence among all residential customers and do not directly address water use or subsidy incidence among accounts with shared and individual connections.

Approximately 20% of residential customer accounts in NCWSCs billing records are located in low-income areas identified in the MajiData database. Table 1.6 provides a summary of water use among residential accounts of different income levels. The mean and median water use in accounts located in low-income areas is 30 m^3/mo. and 12 m^3/mo., respectively. This is only slightly lower than the mean (33 m^3/mo.) and median (14 m^3/mo.) water use of accounts that are not located in low-income areas.

Figure 1.5 provides a summary of subsidy incidence among all NCWSC's residential customers. Accounts located in low-income areas constitute 19% of residential accounts and receive 21% of the total subsidies delivered to residential customers. This is approximately the same amount of subsidies that low-income customers would receive if the subsidy were evenly distributed among residential customers.

1.5.4 Subsidy Incidence among all Customer Classes

We now turn to the results for subsidy incidence among all customer classes. Residential accounts constitute 94% of NCWSC customers (Table 1.7). Nonresidential accounts represent 5% of NCWSC customers. The remaining 1% of accounts are official public kiosks and bulk customers.

Despite the fact that residential accounts make up the vast majority of NCWSC customers, they account for only 57% of the overall water use and 56% of total billings (Table 1.7). Non-residential customers, on the other hand, account for 35% of the overall water use and 41% of total billings.

We find that non-residential customers receive 31% of the total subsidy. By contrast, residential customers receive 63% of the total subsidy delivered through the water tariff. Among residential customers, accounts in high-income itineraries represent 21% of accounts and receive 19% of the total subsidy. Accounts in low-income itineraries represent 14% of total accounts and receive only 9% of the total subsidies, far less than if subsidies were randomly distributed among customers.

1.6 Discussion and Conclusions

Our analysis of subsidy incidence among a sample of 656 households in Nairobi with a private metered connection indicates that households in the lowest wealth quintile receive only 15% of the total subsidies delivered to households in our sample. In contrast, households in the highest wealth quintile receive nearly 30% of the subsidies. Thus, among our sample of customers with a private metered connection, the current water tariff performs worse than if the subsidy was randomly distributed among households.

In Nairobi, the poor targeting of the subsidies even among households with a private metered connection is driven by a combination of three factors. First, very few customers' water use falls in the uppermost blocks of NCWSC's IBT (Figure 1.1). Indeed, over 80% of households in our sample fall in the first two blocks of NCWSC's tariff. Thus, irrespective of the prices in each block there is not a sufficient number of customers in the upper blocks to enable a meaningful level of cross-subsidy. Second, at current prices nearly all customers are being subsidized. The average price paid for water and sanitation services among the wealth quintiles in our sample ranges from 0.56 USD/m^3 to 0.90 USD/m^3. In contrast, we estimate the full cost of providing water and sanitation services in Nairobi to be approximately 2.86 USD/m^3. When nearly all customers are subsidized, it is not possible for a subsidy delivered through the tariff to effectively target subsidies to intended beneficiaries. Finally, contrary to common intuition, we find a low correlation between our wealth proxy and water use, which is consistent with the limited data that exist in the literature (Whittington et al. 2015).

We also find that stated expenditure is a poor proxy for metered water use. Despite the significant measurement error associated with using stated expenditure as a proxy for water use, we find that using stated expenditure to estimate subsidy incidence does not change the policy implications of our results. This is true in our sample because the majority of NCWSC customers have arrears or credits on their accounts, and we find a low correlation between income and whether customers have arrears or credits. This may not be true in other places. Thus, our findings suggest that researchers should exercise caution when using stated expenditure to estimate water use.

When we expand our analysis to the distribution of subsidies among all NCWSC's 180,000 residential customers, we find that subsidy incidence improves very slightly. Among all residential customers, customers located in low-income areas account for approximately 19% of total residential accounts and receive 21% of the total subsidies delivered to residential customers. This seemingly counterintuitive result can be explained by the fact that low-income customers are more likely to have shared connections, which register high levels of water use, and all water use is subsidized at current prices. While subsidy targeting among all residential customers is slightly better than subsidy incidence among only households with a private connection, errors of inclusion remain high and customers in low-income areas are no better off than if subsidies were randomly distributed among residential customers.

Finally, our analysis of subsidy incidence among all customer classes indicates that non-residential customers receive over one-third of the total subsidies delivered through NCWSC's tariff. Residential customers receive only 63% of the total subsidies. This is not surprising given that all customers are subsidized at current prices and non-residential customers account for nearly 40% of total water use. However, policy makers often implement an IBT with a lifeline block specifically to target subsidies to low-income, residential customers. We find that this is not occurring in Nairobi. Our results highlight the importance of examining subsidy incidence among all customer classes, which has largely been ignored in the literature.

In addition to our findings related to subsidy incidence, our analysis raises important issues about the magnitude of the subsidy delivered through the water tariff. Most studies on subsidy incidence focus on subsidies associated with piped water service among only residential customers. They do not examine subsidies associated with sewer service or subsidies delivered to non-residential customers. Our analysis suggests that limiting the scope of subsidy incidence in this manner would lead to a substantial underestimate of the magnitude of the subsidy delivered through the water tariff.

In Nairobi, examining subsidies associated with piped water service among residential customers would result in a total subsidy that is approximately 40% less than the subsidy associated with both piped water and sanitation services for residential customers. Similarly, we find that examining subsidies associated with both piped water and sewer services among only residential customers would underestimate the total subsidy delivered through the water tariff by 45%. In total, focusing only on subsidies associated with providing water service to residential customers would underestimate the magnitude of the subsidy delivered through the water tariff by 65%. We estimate that the total subsidy delivered through the tariff is approximately one and half times NCWSC's total billings.

Policy makers in the water sector often express concern about the affordability of water and wastewater services, especially for low-income households. This concern is often misplaced because the poorest residents in cities typically rely on vended water from public kiosks or private vendors. (For example, in Nairobi the price of vended water from public kiosks is 2 KSH/20L (1.11 USD/m^3), which is closer to full cost recovery for water supply (1.40 USD/m^3) than the volumetric price for water in the tariff applied to metered residential connections.) Nonetheless, policy makers' concern about affordability is often the primary justification for keeping water prices low and for implementing an IBT that includes a lifeline block. Our findings add to a growing body of empirical literature that suggests that IBTs implemented by many utilities do not effectively target subsidies to low-income households. In Nairobi, we find this is particularly true when examining subsidy incidence among all customer classes, but also when we restrict our analysis to households with private metered connections. This is striking given that the poorest households often lack access to piped water and sanitation services altogether. This growing body of evidence suggests that the IBT is an ineffective and often expensive means of delivering subsidies to low-income households. Thus, if policy makers want to subsidize water and sanitation services for low-income households, they should explore alternative subsidy delivery mechanisms, including both connection subsidies and means-tested subsidies (i.e., subsidies for which households must meet an income or wealth criteria).

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TABLES AND FIGURES

Table 1.1. Summary of the Tariff Implemented by Nairobi City Water and Sewerage Company.

Tariff Component	
Residential, Commercial, and Industrial	
0 to 10[b] m^3/mo.	0.22 USD/m^3
11 to 30 m^3/mo.	0.45 USD/m^3
31 to 60 m^3/mo.	0.50 USD/m^3
> 60 m^3/mo.	0.63 USD/m^3
Water Kiosk	
All units	0.18 USD/m^3
Bulk Supply	
All units	0.31 USD/m^3
Other Charges	
Sewerage[c]	75%
Meter Rent	0.59 USD/mo.
Connection Charges	29 USD

[a] Conversion rate = 90 KSH/USD.
[b] Customers charged for a minimum of 10 m^3/mo.
[c] Applied to the volumetric component of the water bill.

Table 1.2. Summary of Cost Estimates Used to Calculate Subsidy Incidence

Cost Component	USD/m^3 [a]
Water Service[b]	**1.40**
O&M	*0.30*
Capital Costs[c]	*1.10*
Wastewater Service[b]	**1.46**
Operations & Maintenance	*0.30*
Capital Costs[c]	*1.16*

[a] Conversion rate = 90 KSH/USD.
[b] Cost estimates assume 35% non-revenue water.
[c] 10% real discount rate; 30-year average useful life of capital.

Table 1.3. Basic Characteristics of Households Surveyed

Household Characteristic	**Value**
Household size *(s.d.)*[*]	4
	(1.78)
Home owner	51%
Primary drinking water source	
Piped water connection	78%
Bottled water	22%
Water vendor (previous year)	26%
Household water treatment	68%
Sewer connection	93%

[*]*Standard deviation*

Table 1.4. Water Use, Representative Bill, and Average Price among Wealth Quintiles

		Wealth Quintile					
	Unit	**1**	**2**	**3**	**4**	**5**	**Overall**
Mean water use (*s.d.*)[*]	m³/hh/mo.	16	14	14	24	30	19
		(30)	*(15)*	*(17)*	*(25)*	*(32)*	*(26)*
Representative water bill	USD/hh/mo.	10.35	8.39	8.19	14.18	16.76	11.58
Average price	USD/m³	0.79	0.90	0.83	0.62	0.56	0.74

[*]*Standard deviation*

Table 1.5. Summary Statistics for the Distributions of Metered and Imputed Water Use

Water Use	**Unit**	**Mean**	**Std. Dev.**	**Min**	**Max**
Metered	m³/mo.	19	24	0.7	292
Imputed	m³/mo.	27	34	0.3	436

Table 1.6. Summary of Water Use Among NCWSC Residential Customers

Residential Area Classification	Water Use (m^3/acct./mo.) Mean	Median	Std. Dev
Low income	33	14	220
Middle/high-income	30	12	127
All residential	**31**	**12**	**194**

Table 1.7. Summary of the Share of Accounts, Water Use, Billings, and Subsidies Among Four NCWSC Customer Classes

Customer Class	% Total Accounts	% Total Water Use	% Total Billings	% Total Subsidy
Residential	94%	57%	56%	63%
Non-residential	5%	35%	41%	31%
Kiosk	<1%	3%	1%	2%
Bulk	<1%	4%	2%	3%
Total	100%	100%	100%	100%

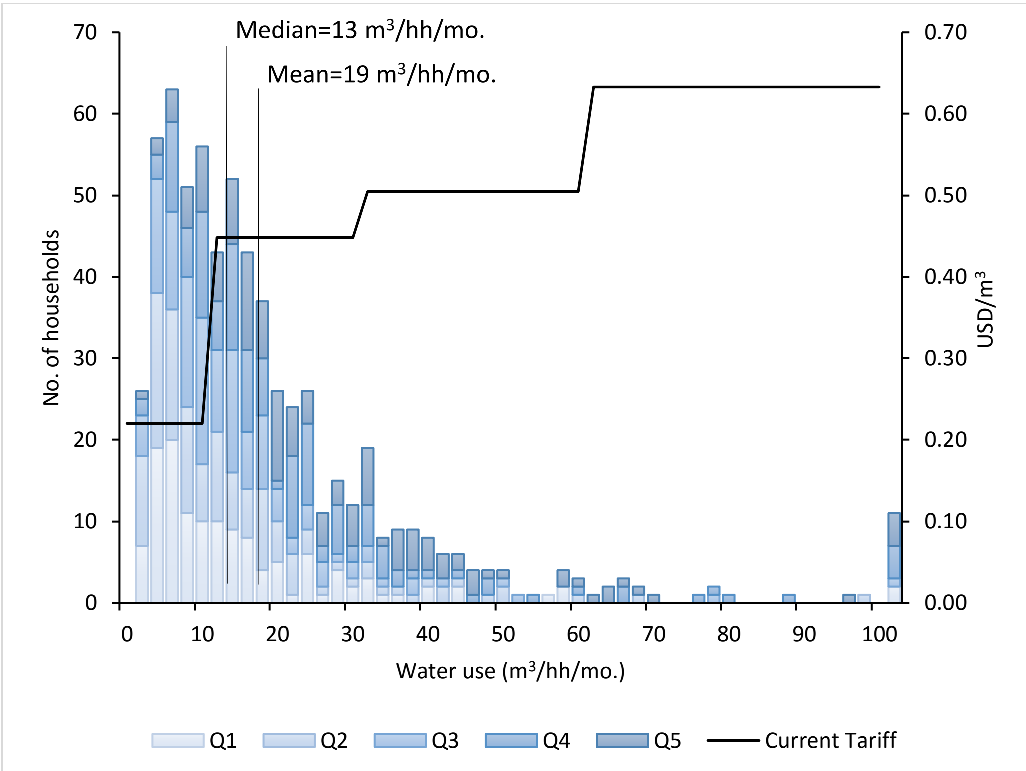

Figure 1.1. Distribution of Water Use among Survey Sample with NCWSC Tariff Blocks

* Nine observations with water use above 100 m^3/mo. not shown on the graph for scale purposes.

Figure 1.2. Scatter Plot of Monthly Household Water Use Versus Wealth.

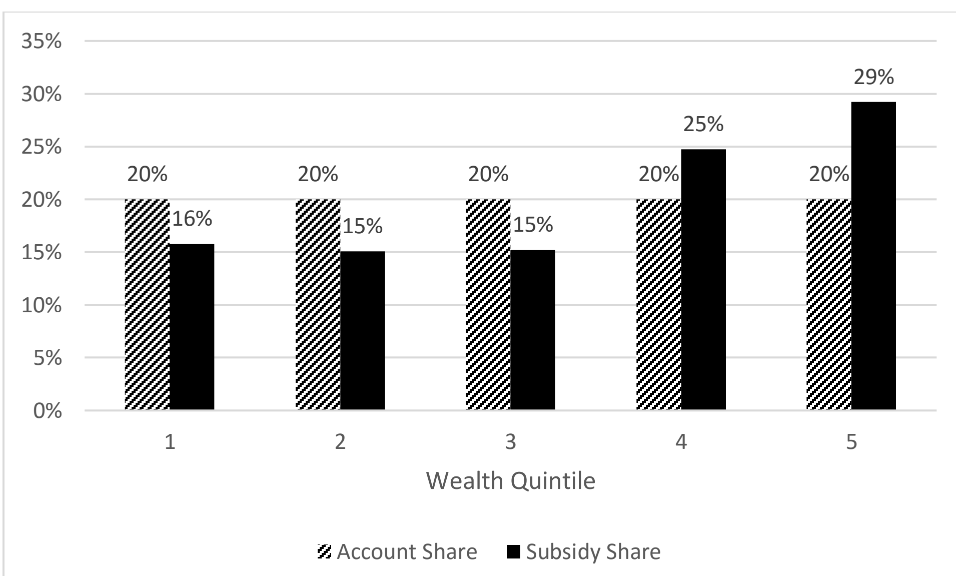

Figure 1.3. Share of Subsidies Received by Each Wealth Quintile.

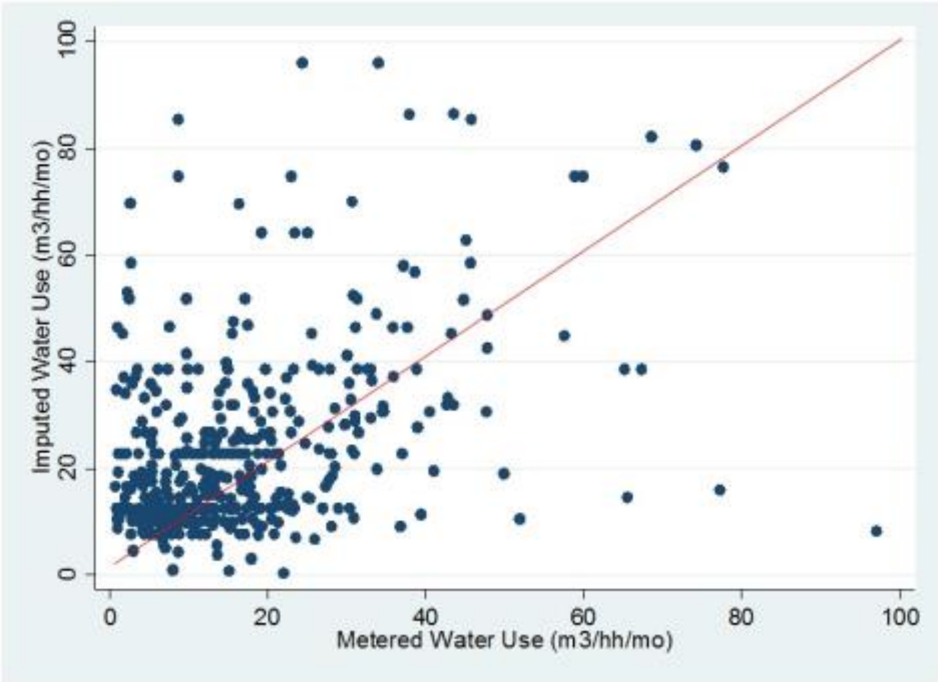

Figure 1.4. Imputed Versus Metered Water Use

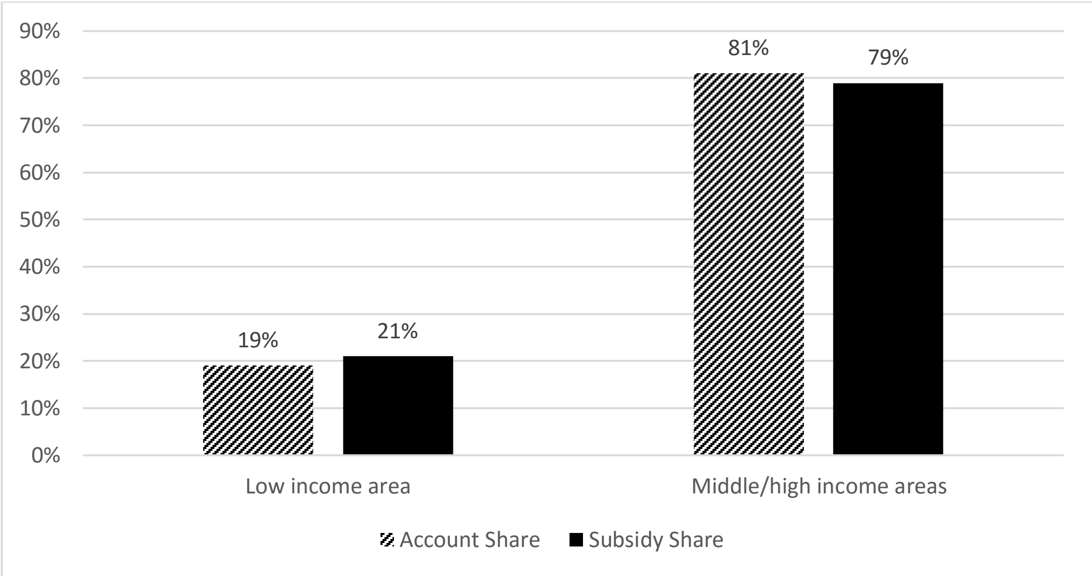

Figure 1.5. Share of Total Residential Accounts and Subsidies Received by Accounts in Low-income and Middle/High-income Areas

CHAPTER 2: ASSESSING THE PERFORMANCE OF TARIFFS FOR WATER AND SANITATION SERVICES – A SYSTEMATIC REVIEW

2.1 Introduction

The Sustainable Development Goals (SDG) for water and sanitation seek to ensure access to safe and affordable water and sanitation services for all by 2030. This represents a major shift in global ambition both with respect to the scope of the goals – universal access – as well as the target level of service. The SDGs defines "safe" service as service that is safely managed, available on premise, and there when needed. According to a recent study by the World Bank, it will cost approximately 100 billion USD per year to meet the SDGs for water and sanitation (Hutton and Varughese 2016). This estimate does not include the cost of maintaining, repairing, or replacing countries' existing infrastructure stock, or the cost of investing in infrastructure that is resilience to climate change.

While many low and middle income countries face the challenge of investing in their first generation of water and sanitation infrastructure, the water and sanitation infrastructure in many industrialized countries is reaching, or has reached, the end of its useful life and is now failing. In the United States, the American Society of Civil Engineering has given the nation's water and sanitation infrastructure a grade of D+, indicating that the infrastructure is in poor condition.

According to the American Water Works Association and American Society for Civil Engineers, it will cost approximately one trillion dollars to replace the United States' water infrastructure network and 300 billion dollars to meet the United States' wastewater and storm water capital requirements (ASCE 2013). These estimates also do not include the cost of investing in climate-resilient water and sanitation infrastructure.

There are three general ways in which governments can finance the infrastructure transition that is on the horizon in both less developed and industrialized countries in the coming decades: taxes, tariffs (i.e., user fees), and transfers from donors. Given the magnitude of the infrastructure challenge, governments will need to deploy each of these to ensure their citizens have access to high quality water and sanitation services. In this paper, we present the results of a systematic review of the empirical literature on the pricing of water and sanitation services, highlighting ways in which insights from the literature might inform water and sanitation service pricing and identifying areas for future research.

Overall, we find that the empirical literature on pricing municipal water and sanitation services is diverse and relatively fragmented. Studies identified through our systematic review are published in a wide range of journals and vary considerably with respect to their core aims, methods, number of tariffs examined, and the indicators of tariff performance considered. Studies typically examine a subset of objectives commonly associated with water pricing and tariff reform, including economic efficiency, cost recovery, affordability, and equity. We find that the majority of studies examine two or fewer objectives, limiting the extent to which the literature characterizes the tradeoffs policy makers often face when setting tariffs for municipal water and sanitation services. We also find that while several studies in the literature show that it is possible to design welfare-improving tariffs, the welfare gains from implementing these tariffs are relatively small. Finally, we find that the majority of studies focus on municipal water pricing in industrialized countries, highlighting an opportunity for additional research on municipal water pricing in low and middle-income countries.

The remainder of the paper proceeds as follows. The second section of the paper describes the methodology we employed to conduct the systematic literature review. The third section provides an overview of the papers identified in the systematic review, including the primary focus of the papers, methods employed, and indicators of tariff performance examined. The fourth section provides a discussion of main themes identified in our review. The fifth and final section highlights areas for future research and provides concluding remarks.

2.2 Methodology

Our systematic review of the empirical literature on the performance of water tariffs follows the methodology recommended by PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses)[3]. This approach to a systematic literature review consists of five basic steps. First, the researcher defines Boolean search terms. This is done by trial and error on select databases with two objectives in mind: 1) the search term must be broad enough to capture all the references the researcher has previously identified as relevant or essential based on their knowledge of the field, and 2) the search terms must also be specific enough to produce a manageable set of papers to review.[4]

[3] http://www.prisma-statement.org/

[4] What constitutes manageable is, of course, subjective.

In the second step, the researcher uses these search terms to query a defined set of publication databases. The researcher next compiles a list of non-duplicate references from these databases and then iteratively refines the list to obtain a core set of papers. Once the researcher has assembled a core set of studies, the researcher adds relevant literature identified through citations in the core literature, supplemental literature searches, and expert opinion.

Following this methodology, we defined and refined a key set of Boolean search terms related to the pricing of water and sanitation services.[5] We then used the Boolean search terms to query four academic search engines: Web of Science, SCOPUS, Academic Search Complete, and Business Search Complete. (Table 2.1 provides a summary of the number of references identified in each database.) We imported the citations from the respective search on each database into citation management software and then removed duplicate citations. In total, this search produced 939 unique references.

Next, we iteratively screened the 939 references to obtain a core set of relevant literature. (Figure 2.1 provides a schematic of the literature-screening process.) In particular, we reviewed the title of each reference to identify and remove references that did not focus on domestic or municipal water supply. During this process, we also removed studies that focused on hedonic valuation or energy as well as conference proceedings. This initial screening identified 513 references that were not relevant to this study.

We then re-examined the titles of the remaining 426 references to identify articles that specifically focused on municipal water and sanitation service pricing. During this step, we

[5] The final Boolean search terms used for this systematic literature review were "water AND (drinking OR residential OR municipal) AND (price OR pricing OR tariff) AND (model OR modeling OR simulation OR simulate OR estimate)".

excluded papers that focused on ground water management, river basin management, and general water resource management issues. We also excluded papers that solely focused on subsidy incidence because this literature has been reviewed elsewhere (see Whittington et al. 2015 and Fuente et al. 2016). We retained papers that focused on water conservation, tariff simulation, and the price elasticity of demand.[6] This screening step identified 292 papers that were not relevant to this study.

Finally, we reviewed the abstracts of the remaining 221 papers and assigned keywords to each study. Table 2.2 presents a summary of the keywords that emerged from this analysis as well as the number of papers associated with each term.[7] While reviewing the papers from the Boolean search of the four academic databases searched, we identified 27 additional studies in the references of the papers that were potentially relevant to this study. We reviewed these papers to determine whether they met the inclusion criteria for our review. Of the 27 additional studies identified during this process, 10 were added to the database of references. At this stage in the review process, we identified 66 papers that were potentially relevant to this review. We reviewed these papers to identify studies that focused specifically on water pricing, tariff simulation, and tariff performance. In total, we identified a set of 34 empirical papers to include in this review.

[6] There is a large literature that examines the price elasticity of demand for municipal water services. This review only considers studies that examine the price elasticity of demand if these estimates are used to simulate the performance of alternative tariffs.

[7] Note that some papers were assigned more than one keyword.

2.3 Results

Papers identified through our systematic review were published primarily in peer-reviewed journals that focus on water or economics (Table 2.3). Several papers, however, were published in more general peer-reviewed journals that focus on international development or policy, or as book chapters and working papers. Overall, the studies identified in our review appear in a range of journals with a limited number of journals publishing more than one of the studies, as illustrated in Table 2.3. For example, both *Utilities Policy* and *Water Resources Management* published four of the papers identified in our literature review. Similarly, *Water Resources Research* published three studies and *Water Resources and Economics*, which was only launched in 2013, published two of the studies identified in our review. Though several studies in the literature appear in economics journals, they are published in different journals that span the fields of environmental and resource economics, development economics, and industrial organization.

The rate of publication of studies that examine the performance of tariffs for municipal water and sanitation services has been relatively constant over the past two decades (Figure 2.2). The number of studies identified in our review ranges from one to three studies per year. This trend stands in contrast to Berg and Marques' (2011) broader review of quantitative studies on water and sanitation utilities in which they document an exponential increase the number of studies over time. In the remainder of this section, we discuss several dimensions of the literature, including: studies' primary objectives, location, methodology, the type and number of tariffs compared, and the indicators used to assess tariff performance.

2.3.1 Primary focus, location, and service Level

Nearly all of the studies identified in the systematic literature review explicitly compare the performance of more than one water tariff with respect to at least one indicator of tariff performance. Approximately one third of the studies identified through the systematic literature review focus primarily on modeling the outcomes and performance of different tariff structures (see Table 2.4). Studies that do not primarily focus on modeling different tariffs often attempt to derive efficient prices by estimating the price and income elasticities of demand for municipal water service (e.g. Diakité et al., 2009; Garcia-Valinas, 2006; Garcia-Valinas, 2005; and Garcia and Reynaud, 2004). Many of these studies then use empirical estimates of the price elasticity of demand to calculate the welfare effects of moving from the current tariff to another tariff. Studies that do not estimate the price elasticity of demand include Grafton and Kompas (2007), who use assumptions about the price elasticity of demand to calculate the price increases necessary to meet a minimum reservoir storage requirement and Yates et al. (2013), who estimate the welfare changes associated with a drought plan implemented in the El Dorado Irrigation District of California.

Utilities often provide both water and sanitation services. However, the empirical literature on pricing water and sanitation service delivery focuses primarily on the pricing of water services. As shown in Table 2.3, only four of the 34 studies explicitly include wastewater services in their analysis. The near exclusive focus on water services in the literature may be explained by several factors. Utilities commonly set the price for wastewater services as a fixed percentage of volumetric price for water services. Additionally, many studies in the literature use data that is aggregated at some geographic level (e.g., municipality, county, region), which may not include information on the fraction of households with a connection to the wastewater network or how water use differs among customers with and without access to the piped water network. Finally, wastewater services are often outside the primary scope of many studies. This is particularly true for studies that focus on estimating the price elasticity of demand for municipal water services.

The studies identified in the systematic review examine the pricing of municipal water services in 19 different countries.[8] The majority of studies examined tariffs in North America or Europe (Table 2.4). The majority of studies in Europe focused on France and Spain. We identified three studies that examine tariffs in Sub-Saharan Africa (Diakité et al. 2009; Briand 2006; and Cueva and Lauria 2001), one that focused on South Asia (Saleth and Dinar 2001), and one that focused on the Middle East (Rosenburg 2010). The prevalence of studies focusing on industrialized countries likely can be attributed to the fact that water pricing and tariff reforms have a longer history in these countries and, as a result, data are more readily available. In addition to studies that use data from particular countries, five studies use hypothetical data in their simulations (i.e., Hoffman and Du Plessis 2013; Wichelns 2013; Nauges and Whittington 2017; and Elnaboulsi 2001).

2.3.2 Number of tariffs compared

Although the primary objective of many of the studies we identified in our review is not modeling the performance of different tariff structures, most studies did compare different tariffs in some manner. For example, studies either compared a different tariff structure (e.g., an IBT with a uniform volumetric price) or variants of the same tariff structure (e.g., an IBT with two

[8] This includes Reynaud (2016) who uses data from nine European countries.

blocks and an IBT with four blocks, with different volumetric prices in each block). Overall, there is a wide range in the number of tariffs compared in each study. The number of tariffs compared in the studies identified in the systematic literature review ranged from two to 53.

Studies that compared only two tariffs fall into two general categories. The first category consists of studies that compared an existing tariff to price increases under the same tariff structure (e.g., Cueva and Lauria 2001; Cheeseman et al. 2008; and Di Cosmo 2011). For example, Cueva and Lauria (2001) compared the existing tariff in Dakar, Senegal to prices necessary to meet a particular cost recovery objective. Di Cosmo (2011) examined the impact of a one percent increase in the volumetric price on households in Italy.

The second category of studies that examined two tariffs includes studies that compared an existing tariff to an alternative tariff structure. This includes Barberán and Arbués (2009), who compared the existing tariff in Zaragoza, Spain to a tariff they derived to meet a particular equity criterion developed by the authors. Similarly, Garcia-Valinas (2005) compared the existing tariff in Seville, Spain to Feldstein prices[9] they derived from estimates of the price elasticity of demand and assumptions about marginal utility of income.

The remaining studies in the literature explicitly compared multiple tariff structures. For example, Renzetti (1992) examined four tariffs in Vancouver: the existing tariff, average cost pricing, seasonal pricing, and seasonal pricing with Ramsey prices. Diakité et al. (2009)

[9] Feldstein pricing was first proposed by Feldstein (1972) in the optimal pricing literature as a means to address concerns about the distributional impacts of Ramsey-Boiteux pricing, one approach to optimal pricing under a cost recovery constraint. The basic aim of Ramsey-Boiteux pricing is to minimize the welfare losses associated with deviating marginal cost pricing. To accomplish this, Ramsey-Boiteux pricing applies what is widely referred to as the inverse elasticity rule, wherein consumers who are less sensitive to price changes face higher marginal prices than those that are more sensitive to price changes. A common critique of Ramsey-Boiteux pricing is that it may be regressive if low-income households are less sensitive to price changes than high income households. To address this, Feldstein pricing effectively weights the Ramsey-Boiteux price by the marginal utility of income, which is assumed to be decreasing in income.

compared the existing tariff in Cote d'Ivoire with four different variants of IBTs derived using Ramsey pricing. Rinaudo et al. (2012) compared eight tariffs in their analysis of water pricing in southern France: a uniform price, seasonal pricing[10], and five variants of a three-block IBT. Using data from Sao Paolo, Brazil Ruijs et al. (2008) compared eight tariffs, including uniform and IBTs that incorporate means-tested discounts for low income users. More recently, Nauges and Whittington (2017) used hypothetical data to compare the performance of nine IBT tariff alternatives relative to a uniform price status quo tariff.

2.3.3 Modeling framework

Studies in the literature typically simulate a change from the status quo (the existing tariff) to a new state of the world (a new tariff) to assess the performance of various tariffs. There are a variety of ways researchers can model the transition from one tariff to another ranging from relatively simple models that forecast water use based on changes in a single parameter over a single time-step to more complex dynamic models that simulate tariff performance using systems of equations. The first category includes models that assume a relationship between water use and a particular parameter (often price) as well as models that estimate an empirical relationship between water use and the parameter(s) of interest in a particular population.

The second category of models include computable general equilibrium (CGE), agent based models (ABMs), and system dynamic models (SDMs) (House-Peters et al. 2011). Unlike the models described above, these models typically assume, rather than estimate, a functional

[10] The author does not state whether seasonal prices are modeled as an IBT or a uniform price tariff.

relationship between water use and a variety of parameters drawing upon empirical evidence from the literature. These models then simulate water use, revenues, and (sometimes) costs based on a range of factors, including but not limited to the size and characteristics of the service population (e.g. income, household size, appliance ownership, etc.), the behavior of the service population, and projected changes in temperature or precipitation. While these models can vary considerably with respect to geographic scale, they commonly simulate water use over a multiple rather than single time periods.

The studies identified through the systematic literature review employ the full range of models described above. The majority of studies in the literature use econometric techniques to estimate the demand for water service and then use this empirical relationship to predict customer water use under alternative tariff structures (e.g., Renzetti 1992; Garcia-Valinas 2005; Diakité et al. 2009; Garcia-Valinas 2010; Rinaudo et al. 2012[11]; Reynaud 2016). Approximately 40 percent of studies that estimate the price elasticity of demand use household or account level[12] data. The remaining studies that estimate the price elasticity of demand use aggregate[13] data.

The remaining studies identified in the systematic literature review employ various simulation techniques. This includes hypothetical models that simulate only changes in relative

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[11] Rinaudo et al. (2012) estimate the price elasticity of demand using aggregate data from southern France and then predict changes in water demand using a simple functional form ($C=kP^{\varepsilon}$), where C is the quantity of water, P is the marginal price, ε is the price elasticity of demand, and k is a constant calibrated on the aggregate data.

[12] Utilities typically bill accounts associated with a particular water meter. Accounts may include multiple households if each household does not have an individual meter. For example, a utility may use a single meter to measure the water use of a multi-unit apartment building.

[13] For example, Garcia and Reynaud (2004) estimate the price elasticity of demand using data from 50 water utilities in France. Each utility is treated as a unit of observation and data on water use, income, and demographics are average values from the utilities' service area.

price (Hoffman and du Plessis 2013) to more complex ABMs (Rosenberg 2010), SDMs (Ahmad and Prashar 2010), CGE (Briand 2006), and custom-developed software (Yates et al. 2013) that model the dynamic interaction between tariffs, water use, revenues, capacity expansion, costs of service, and other outcome variables. Three studies employ Monte Carlo analysis to simulate the performance of alternative tariffs (e.g., Cueva and Lauria 2001; Rosenberg 2010; Nauges and Whittington 2017). Wolak (2016) used an optimization routine to derive tariffs that meet a cost recovery objective subject to constraints on revenue stability.

2.3.4 Cost and capacity

Approximately half of the studies identified in the systematic literature review explicitly consider the costs of water and sanitation service delivery. Several studies that incorporate costs in their simulation models use cost estimates derived from cost functions estimated using operational and financial data from utilities[14] (e.g. Renzetti 1992; Kim 1995; Saleth and Dinar 2001; Garcia and Reynaud 2004; Garcia-Valinas 2005; Diakete et al. 2009). The remaining studies that incorporated costs in their analysis either use average costs from utility financial statements (Cuevea and Lauria 2001; Rosenburg 2010) or assume average costs (Elnaboulsi 2001; Krause et al. 2003; Briand 2006; Hall 2009; Wichelns 2013). A limited number of studies (e.g, Elnabousi 2001; Briand 2006; Ahmad and Prashar 2010; and Yates et al. 2013) explicitly incorporated capacity and capacity expansion in their simulation models.

[14] Renzetti (1992) and Garcia-Valinas (2005) estimate both a short-run and long-run marginal cost function. The remaining studies either estimate only short run costs.

2.3.5 Indicators of tariff performance

There are several criteria commonly used to assess the performance of water pricing and tariff reforms, including but not limited to: revenue sufficiency (i.e., cost recovery), revenue stability, economic efficiency, water conservation, equity, fairness, and simplicity and public acceptability.[15] Studies in the literature typically examined tariffs relative to four general objectives of tariff making: economic efficiency, conservation, cost recovery, and affordability (Table 2.5).[16] Over half of the studies in the literature addressed the issue of economic efficiency in some manner. Many studies that address economic efficiency used it to motivate the proposal of alternative tariff structures. For example, a number of studies derived Ramsey or Feldstein prices (Monteiro and Roseta-Palma 2011; Diakité et al. 2009; Garcia-Valinas 2005; and Renzetti 1992). Others attempted to derive tariffs that implement marginal cost pricing (e.g., Hall 2009; Grafton and Kompas 2007; Briand 2006; Garcia and Reynaud 2004; Kraus et al. 2003; and Cueva and Lauria 2001). In addition to using an economic efficiency criterion to motivate the design of alternative tariffs, nearly half of the studies identified in the systematic review calculated the welfare effects of households in the sample moving from the current tariff to a new tariff.[17]

Nearly half of the studies identified in the systematic literature review addressed the issue of cost recovery, and the majority of these studies addressed cost recovery by imposing it as a constraint in the simulation or optimization model, while defining alternative tariff measures

[15] See Bonbright (1961), Berg and Tschirhart (1989), and Hanemann (1997) for detailed discussions of objectives commonly associated with water pricing and tariff reform.

[16] Additional objectives discussed in this literature include total revenue, subsidy incidence, reservoir storage and hydro power generation, and total water use.

[17] Yates et al. (2013) and Rinaudo et al. (2012) do not use economic efficiency to derive alternative tariffs, but do examine the welfare effects of different policies.

(e.g. Wichelns 2013; Monteiro and Roseta-Palma 2011; Hall 2009; Diakité et al. 2009; and Garcia-Valinas 2005; Reynaud 2016; Wolak 2016; Nauges and Whittington 2017). Rosenberg (2010) and Cueva and Lauria (2001) explicitly compared the level of cost recovery achieved by different tariff alternatives.

Several authors addressed notions of equity or examined distributional issues in some way. The majority of studies addressed notions of equity by examining the distributional impacts of alternative tariffs. An exception to this is Barberán and Arbués (2009) who proposed a tariff to meet an equity criterion that they proposed. Olmstead and Mansur (2012) compared the welfare effects of different demand-side management tools on households with different lot sizes and incomes. Ruijs et al. (2008) examined the bill-to-income ratio under different tariffs for households in different income quintiles. And Hajispyrou et al. (2002) compared the marginal price, average price, and water use among households in different wealth quintiles under different tariff structures.

In addition to economic efficiency, cost recovery, and equity criteria, studies in the literature examine a number of other criteria commonly associated with tariff reform. For example, five studies in the literature assess tariff performance in terms of a criterion of affordability. As discussed in more detail below, the bill-to-income ratio is the most common indicator of affordability used in these studies (Ruijs et al. 2008; Cueva and Lauria 2001; Reynaud 2016). Nearly a quarter of the studies explicitly examined water conservation. This includes Baerenklau et al. (2014) who examined the effectiveness of water budget based tariffs in reducing water consumption and Reynaud (2016) who simulated the impact of full cost recovery pricing on customer water use in nine European countries. Finally, Wolak (2016) examines the use of tariffs derived using household characteristics to improve revenue stability.

Approximately three quarters of the studies in the literature examined two or fewer of the criteria discussed above (Table 2.5). Only two studies examined more than three criteria (e.g. Cueva and Lauria 2001; Reynaud 2016). This suggests that studies in the literature are typically focused on a single criterion, or a small set of criteria associated with tariff setting. Very few studies explicitly analyzed the trade-offs between the different criteria they examined.

2.4 Discussion

As noted above, the literature on water and sanitation service pricing is broad and relatively fragmented. Nevertheless, there are several common themes that emerge from our systematic review of this literature. Many studies in the literature estimate the demand for municipal water services and then use empirical estimates of demand to derive efficient pricing, forecast the extent to which different tariffs can be used to achieve water conservation targets, and examine the affordability of proposed tariffs. Several studies in the literature also seek to identify or address customer heterogeneity in some manner. We discuss each of these themes in more detail below.

2.4.1 Efficiency

Over half of the studies identified in the systematic literature review assess the performance of tariffs using an economic efficiency criterion. This includes studies that derived or examined efficient prices as well as studies that calculated the welfare gains or losses associated with alternative tariffs. Studies in the literature that derived efficient prices either examined some form of marginal cost pricing or derived second best prices (e.g., Ramsey or Feldstein prices). Studies that examined marginal cost pricing often used an assumption for what constitutes marginal cost. For example, Schoengold and Zilberman (2014) assumed that price in the upper block of the increasing block tariff used by four utilities in the western United States reflects the long-run marginal cost of supply. Grafton and Kompas (2007) used estimates of the long-run marginal cost of water supply in Sydney, Australia obtained from the local regulatory authority.

A limited number of studies used empirical estimates of marginal cost in their analysis of efficient pricing. For example, Hall (2009) calculated the long-run incremental cost of water supply in Los Angeles as an approximation of the long-run marginal cost. He found that the long run incremental cost was one and half times the historical average cost of water supply. Only Garcia and Reynaud (2004) estimated marginal costs econometrically. They then used this estimate to examine the implications of marginal cost pricing.[18] In particular, they estimated the short-run marginal cost of water supply for utilities in France and found that existing prices were relatively close to their estimates of the short-run marginal cost of water supply.

Several studies that examine efficient pricing derived second best prices using empirical estimates of demand. For example, Garcia-Valinas (2005) derived Feldstein prices using estimates of the price elasticity of demand for water among residential and non-residential customers in Seville, Spain and assumptions about the marginal utility of income. They found that Feldstein prices can achieve distributional outcomes without reducing social welfare. Diakité

[18] Diakite et al. (2009) use empirical estimates of marginal cost from previous work in their derivation of second best prices in Cote d'Ivore.

et al. (2009) combined estimates of the price elasticity of demand and a non-linear cost function to derive welfare-maximizing prices using a panel of data from 156 communities in Cote d'Ivore. In particular, they identified a non-linear optimal price schedule, which they used to develop several welfare-improving alternative increasing block tariff structures.

Studies that derived efficient prices primarily sought to demonstrate that it is possible to do so while meeting a utility's cost recovery objectives. These studies provide insight into consumer behavior in particular contexts, add to the body of literature on consumer response to price changes, and provide concrete examples of how prices can be set to improve economic efficiency. Overall, there appears to be an emerging consensus that, although it is possible to derive welfare-improving tariffs, the welfare gains from doing so are relatively modest (Groom et al. 2008; Garcia and Reynaud 2004; Diakité et al. 2009; and Nauges and Whittington 2017).

2.4.2 Customer heterogeneity

Several studies in the literature addressed the issue of customer heterogeneity in some manner. The studies that derived Ramsey or Feldstein prices discussed above explicitly exploited heterogeneity in customer response to price changes, including differences in how residential and non-residential customers respond and customers of different income levels respond to price changes. Other studies examined the use of socio-demographic information of customers to improve tariff design. For example, using data from two communities in the United States, Wolak (2016) combined empirical estimates of demand with household characteristics to derive non-linear tariffs to meet utilities' hypothetical revenue and conservation objectives. He found that knowledge of customer-level demographics can be used to design tariffs the reduce revenue uncertainty by 70 to 96 percent. Using data from the Eastern Municipal Water District in California, Baerenklau et al. (2014) examined the impact of introducing a revenue-neutral increasing block tariff in which the size of the lifeline block varies for each household based on household characteristics (e.g., household size). They estimated that the implementation of such a “water budget” increasing block tariff resulted in a 17 percent decrease in water use compared to a hypothetical uniform price tariff that generated the same revenue.

Studies that examine customer heterogeneity provide useful examples of how different types of information about customers can be used to improve the design of water tariffs to achieve a range of policy objectives (e.g., cost recovery, economic efficiency, revenue stability, and conservation). However, water utilities often do not have detailed information on their customers. For example, water utilities typically do not have the information necessary to implement second-best pricing strategies (i.e., local estimates of the price elasticity of demand among different customer classes and the marginal utility of income). In theory, policy makers could obtain this information, but it can be expensive to do so and it may not be possible to estimate these parameters for a particular service population in a credible manner. Similarly, it may be difficult or impossible for utilities to obtain and maintain accurate information on household characteristics necessary to implement “water budget rates” discussed in Baerenklau et al. (2014). Recognizing that it may be difficult for utilities to obtain accurate information on customers, several studies discussed, or explicitly examined, menu tariffs as an incentive compatible way to help utilities overcome information asymmetry (e.g., Barberán and Arbués 2009; Krause et al. 2003; Elnaboulsi 2001).

2.4.3 Affordability

Several studies in the literature examine the issue of affordability. Affordability is often measured as the ratio of a household's expenditure on water and their income. The extent to which water service is affordable is, of course, subjective. However, studies in the literature typically use an oft-cited rule of thumb that water service is affordable if households spend less than three to five percent of their income on water (OECD 2010).

Using household data from Dakar, Senegal Cueva and Lauria (2001) find that household expenditure on water for households with a connection to the piped water network is approximately 4% of households' monthly income. Using aggregate data from 39 municipalities that constitute the Metropolitan Region of Sao Paola, Brazil, Ruijs et al. (2008) find that under the current tariff households spend between 0.5% and 5% of their income on piped water service. In contrast to Cueva and Lauria (2001) and Ruijs et al. (2008) who examine the affordability of existing tariffs, Reynaud (2016) estimates demand for water using data from nine European countries to examine the impact of full cost recovery pricing. They find that, with the exception of Bulgaria, households in the first income decile would spend less than three percent of their income[19] on piped water service at the authors' estimates of full cost recovery pricing.

Departing from other studies in the literature, Garcia-Valinas (2010) argues that the commonly used measure of affordability, households' total expenditure on water, is flawed. In particular, They argue that only the fraction of households' water use necessary to meet basic needs should be considered when examining the affordability of water services. Using data from approximately 300 municipalities in southern Spain, Garcia-Valinas (2010) estimates a Stone-

[19] Reynaud (2016) uses "equalized disposable income" as an income proxy, which he defines as, "the total income of a household after tax and other deductions that is available to for spending or saving" (74).

Geary demand function for water service to identify the proportion of water use that is insensitive to changes in price. They then calculate how much households would pay for this quantity of water under existing tariffs and finds that this minimum level of water use would cost between 0.20 percent and 3 percent of average monthly income.[20] This level of expenditure was far lower than if households' total water use was used to estimate affordability.

Although a number of studies in the literature examine affordability, there does not appear to be a clear or consistent way of calculating the bill-to-income ratio that is used against the three-to-five percent rule of thumb referred to in the literature. For example, it is not clear whether the bill-to-income ratio includes only how much households pay for water service from a utility or whether it includes households' total expenditure on water, which may include the cost of bottled water or supplemental supply from water vendors. It is also not clear whether this threshold for affordability includes how much households spend on sanitation services.

2.4.4 Conservation

Water conservation is reflected in economists' definition of economic efficiency. Nevertheless, utility professionals and policy makers often express interest in promoting conservation in its own right as a means to address existing supply constraints or avoid the need to increase water supply. Several studies in the literature examined the extent to which different tariffs affected customers' water use. As discussed above, Baerenklau et al. (2014) find that the "water budget" increasing block rate implemented in the Eastern Municipal Water District in

[20] Garcia-Valinas (2010) indicates that more refined data on the income distribution in the municipalities included in her study were not available.

California resulted in 17 percent decrease in aggregate water use relative to a hypothetical counterfactual uniform price tariff that generates the same amount of revenue. Using data on household characteristics, Wolak (2016) computed price schedules that reduce aggregate water use by 25 percent while generating at least as much revenue as the existing tariffs. Using aggregate data from 300 municipalities in Southern France, Rinaudo et al. (2012) estimated that a 50 percent increase in the marginal price for water would result in nearly 3 million cubic meters of water savings, which they indicated is enough to postpone water supply expansion by six years.[21] They estimated that the majority of water savings (and welfare losses associated with the price increases) is a result of reduced water use among households with gardens. Finally, Mansur and Olmstead (2012) estimated the welfare implications of using water use restrictions in response to drought several utilities in the western United States. They argued that replacing rationing with drought pricing would generate welfare gains equal to approximately 30% of what households in their sample spend on water in each year.

2.5 Summary and Conclusions

This paper presented the results of a systematic review the literature on the performance of tariffs for water and sanitation services. Papers identified through our systematic review are published in a wide range of journals and vary considerably with respect to studies' core aims, methods, number of tariffs examined, and the indicators of tariff performance examined. Reflecting this heterogeneity, the studies identified in the systematic review often do not speak

[21] As noted by the authors, this projection needs to be interpreted with caution because the price elasticity of demand describes how customers respond to marginal (e.g., small) changes in price.

directly to, or build upon, one another to contribute to a cohesive body of knowledge that can directly inform water pricing and tariff reform efforts. This is not surprising given the individual aims of studies in the literature, but highlights an important opportunity given the potential role of tariffs in financing the infrastructure transition facing both developing and industrialized countries alike. Additionally, the empirical literature is largely silent on the public or political acceptability of different tariff alternatives. This is understandable for studies that examine variants of existing tariffs, but requires additional attention for tariffs that represent significant departures from current pricing practices, particularly if the literature seeks to inform policy.

Our review of the literature highlights a number of other promising areas for research. As discussed above, many studies examine customer heterogeneity in some manner. This includes studies that examine customer heterogeneity along a single dimension (e.g., residential vs. non-residential customers, income, etc.) as well as studies that seek to use more detailed socio-demographic data to improve the design of water and sanitation tariffs. Utilities often do not have the information required to implement second-best pricing or implement “water budget” rates described in Baerenklau et al. (2014) and it may be expensive or not possible for utilities to obtain and update this information on a regular basis. However, this may not be true in well-resourced contexts and may change with advances in big data and e-governance. As a result, there is an opportunity for additional research on customer heterogeneity and, in particular, heterogeneity in customer demand. Even if utilities cannot use this information directly in the tariff design process, additional insight into customer heterogeneity can inform infrastructure planning as well as the potential distributional impacts of tariff reform.

In addition to research that provides insight into heterogeneity in the demand for municipal water and sanitation services, we know relatively little about the extent to which customers respond to average price, marginal price, or some other price signal. With the exception of Nauges and Whittington (2017), studies in the literature often do not explicitly state whether they assume customers respond to average or marginal price. This assumption is important because it has implications for both forecasting customer response to price changes under alternative tariffs as well as the welfare implications associated with them. Several studies in the broader literature on the demand for municipal water services seek to identify whether customers respond to average, marginal, or some other price in a given context (Ito 2013; Nataraj and Hanemann 2011). However, there is not general consensus on whether customers respond to average or marginal price. Customer responses are also likely to be heterogeneous, context specific, and non-stationary. The extent to which customers respond to average or marginal price may vary with a range of factors, including the type of tariff, level of prices, salience of prices, and frequency of billing. Additional insight into this aspect of customer behavior will be useful for understanding the potential implications of implementing alternative tariffs in different contexts.

We also know relatively little about how customers respond to large price increases. Several studies examined forecast aggregate water use under different hypothetical tariffs using estimates of the price elasticity of demand. However, the price elasticity of demand describes how customers respond to marginal changes in price and may not be appropriate to predict customers' response to large price increases. Currently, the tariffs implemented by many utilities that provide water and sanitation services price do not generate sufficient revenue to cover the full cost of providing these services to their customers. According to the International Monetary Fund, tariffs that are not sufficient to cover the cost of service delivery resulted in nearly 500 billion dollars of implicit subsidies globally in 2012 (Kochar et al. 2015). If tariffs are to play a meaningful role in financing the water and sanitation infrastructure transition, utilities will need to move towards full cost recovery pricing. Understanding how customers respond to large price increases in both the short-run and long-run – including the extent to which price increases influence customers – decisions about whether to connect to, or disconnect from, piped water and sanitation networks – will help utilities better forecast future revenue and infrastructure needs.

The Sustainable Development Goals for water and sanitation explicitly call for universal access to safe and affordable water and sanitation services. Most studies in the literature measure affordability using the ratio of a households' water bill to their income and then apply the widely-cited rule of thumb that service is affordable if is below three to five percent of a households' income. This notion of affordability lacks an empirical basis, does not take into account household preferences, and ignores the reality that households without access to piped water and sanitation services often pay more for these services than those connected to the network. Additionally, there is currently a lack of clarity about whether the numerator in the bill-to-income ratio includes both water and sanitation services or reflects the fact that households often use multiple sources. Similarly, there is a lack of clarity on whether the "correct" denominator of the bill-to-income ratio is total expenditure or income. Assuming affordability will continue to play in important role in global dialogue about water and sanitation service delivery, there is a need for more focused attention to developing an empirically-informed definition of affordability and a consistent means of measuring it.

Finally, our systematic review indicates that the vast majority of studies in the literature examine the pricing of water and sanitation services in industrialized countries. This likely reflects the fact that data are more readily available from utilities in these countries. However, it highlights a clear opportunity for additional research on the pricing of water and sanitation services in low- and middle-income countries. Urban and peri-urban areas are growing rapidly in these countries and governments are struggling to provide high-quality water and sanitation services to an increasingly urban population. This presents an important and dynamic context for future research on pricing water and sanitation services.

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TABLES AND FIGURES

Search Engine	No. of References
Web of Science	338
SCOPUS	440
Academic Search Complete	180
Business Search Complete	214
Total	**1172**
Non-duplicate	**939**

Table 2.1. Summary of Boolean search results from four academic search engines.

Keywords	No. of References
Price elasticity of demand	93
Simulation	18
Tariff comparison	30
Misc.	46
Demand forecasting	16
Demand-side management	19
Welfare	8

Table 2.2. Summary of keywords assigned after abstract review.
(Note: Papers were assigned more than one keyword when applicable.)

Study	Journal	Water	Economics	Policy & Development	Other
Nauges and Whittington (2017)	World Development			X	
Wolak (2016)	n.a.				Working paper
Reynaud (2016)	Water Resources and Economics	X			
Whittington et al. (2015)	Utilities Policy			X	
Schoengold and Zilberman (2014)	Water Resources and Economics	X			
Renzetti et al. (2014)	Utilities Policy			X	
Baerenklau et al. (2014)	Land Economics		X		
Hoffman and du Plessis (2013)	Water Sa	X			
Wichelns (2013)	International Journal of Water Resources Development	X			
Yates et al. (2013)	Water Policy	X			
Rinaudo et al. (2012)	Water Resources Management	X			
Olmstead and Mansur (2012)	Journal of Urban Economics		X		
Monteiro and Roseta-Palma (2011)	Water Resources Research	X			
Di Cosmo (2011)	Water Resources Management	X			
Garcia-Valinas et al. (2010)	Journal of Environmental Management			X	
Rosenburg (2010)	Journal of Water Resources Planning and Management	X			
Ahmad and Prashar (2010)	Water Resources Management	X			
Hall (2009)	Contemporary Economic Policy		X		
Diakite et al. (2009)	Journal of Development Economics		X		
Barberan and Arbues (2009)	Water Resources Management	X			
Cheesman et al. (2008)	Water Resources Research	X			
Ruijs et al. (2008)	Ecological Economics		X		
Groom et al. (2008)	n.a.				Book chapter
Grafton and Kompas (2007)	Utilities Policy			X	
Briand (2006)	n.a.				Working paper
Garcia-Valinas (2005)	Environmental Resource Economics		X		
Garcia and Reynaud (2004)	Resource and Energy Economics		X		
Krause et al. (2003)	Journal of Regulatory Economics		X		
Hajispyrou et al. (2002)	Environment and Development Economics		X		
Saleth and Dinar (2001)	Water Resources Research	X			
Elnaboulsi (2001)	Water Resources Management	X			
Cueva and Lauria (2001)	n.a.				Book chapter
Kim (1995)	Review of Industrial Organization		X		
Renzetti (1992)	Utilities Policy			X	

Table 2.3. Publication outlets and types of journals for studies identified in the systematic review.

Study	Primary focus on tariff simulation?	Country	Region	Service
Nauges and Whittington (2017)	Yes	Hypothetical	n.a.	water
Wolak (2016)	No	United States	North America	water
Reynaud (2016)	No	9 European countries	Europe and Central Asia	water
Whittington et al. (2015)	Yes	Hypothetical	n.a.	water & wastewater
Schoengold and Zilberman (2014)	Yes	United States	North America	water
Renzetti et al. (2014)	Yes	Canada	North America	water
Baerenklau et al. (2014)	No	United States	North America	water
Hoffman and du Plessis (2013)	No	Hypothetical	n.a.	water
Wichelns (2013)	Yes	Hypothetical	n.a.	water
Yates et al. (2013)	No	United States	North America	water
Rinaudo et al. (2012)	Yes	France	Europe and Central Asia	water
Olmstead and Mansur (2012)	No	United States	North America	water
Monteiro and Roseta-Palma (2011)	No	Portugal	Europe and Central Asia	water & wastewater
Di Cosmo (2011)	No	Italy	Europe and Central Asia	water
Garcia-Valinas et al. (2010)	No	Spain	Europe and Central Asia	water & wastewater
Rosenburg (2010)	Yes	Jordan	Middle East and North Africa	water
Ahmad and Prashar (2010)	No	United States	North America	water
Hall (2009)	No	United States	North America	water
Diakite et al. (2009)	No	Cote d'Ivore	Sub-Saharan Africa	not stated
Barberan and Arbues (2009)	No	Spain	Europe and Central Asia	water
Cheesman et al. (2008)	No	Vietnam	East Asia Pacific	water
Ruijs et al. (2008)	No	Brazil	Latin American & Caribbean	water
Groom et al. (2008)	Yes	China	East Asia Pacific	water
Grafton and Kompas (2007)	No	Australia	East Asia Pacific	water
Briand (2006)	Yes	Senegal	Sub-Saharan Africa	water
Garcia-Valinas (2006)	No	Spain	Europe and Central Asia	water
Garcia and Reynaud (2004)	No	France	Europe and Central Asia	water
Krause et al. (2003)	No	United States	North America	water
Hajispyrou et al. (2002)	No	Cyprus	Europe and Central Asia	water
Saleth and Dinar (2001)	No	India	South Asia	water
Elnaboulsi (2001)	No	Hypothetical	n.a.	water & wastewater
Cueva and Lauria (2001)	Yes	Senegal	Sub-Saharan Africa	water
Kim (1995)	No	United States	North America	water
Renzetti (1992)	Yes	Canada	North America	water

Table 2.4. Summary of basic information from studies identified in the systematic literature review.

Study	Efficiency	Equity	Cost Recovery	Affordability	Revenue stability	Conservation	Other
Nauges and Whittington (2017)	X	X	X				
Wolak (2016)			X		X		
Reynaud (2016)	X		X	X		X	
Whittington et al. (2015)		X					
Schoengold and Zilberman (2014)	X	X	X				
Renzetti et al. (2014)		X					
Baerenklau et al. (2014)			X			X	
Hoffman and du Plessis (2013)						X	
Wichelns (2013)			X				
Yates et al. (2013)							reservoir storage
Rinaudo et al. (2012)						X	total revenue
Olmstead and Mansur (2012)	X	X				X	
Monteiro and Roseta-Palma (2011)	X		X				
Di Cosmo (2011)						X	
Garcia-Valinas et al. (2010)				X			
Rosenburg (2010)		X	X				
Ahmad and Prashar (2010)						X	
Hall (2009)	X		X				
Diakite et al. (2009)	X	X	X				
Barberan and Arbues (2009)		X		X			
Cheesman et al. (2008)						X	total revenue
Ruijs et al. (2008)		X		X			
Groom et al. (2008)		X	X				
Grafton and Kompas (2007)	X						
Briand (2006)	X						
Garcia-Valinas (2005)	X	X	X				
Garcia and Reynaud (2004)	X						
Krause et al. (2003)	X		X				
Hajispyrou et al. (2002)	X	X					
Saleth and Dinar (2001)		X					
Elnaboulsi (2001)	X		X				
Cueva and Lauria (2001)	X	X	X	X			
Kim (1995)	X						
Renzetti (1992)	X		X				

Table 2.5. Summary of policy objectives examined in studies identified in the systematic literature review.

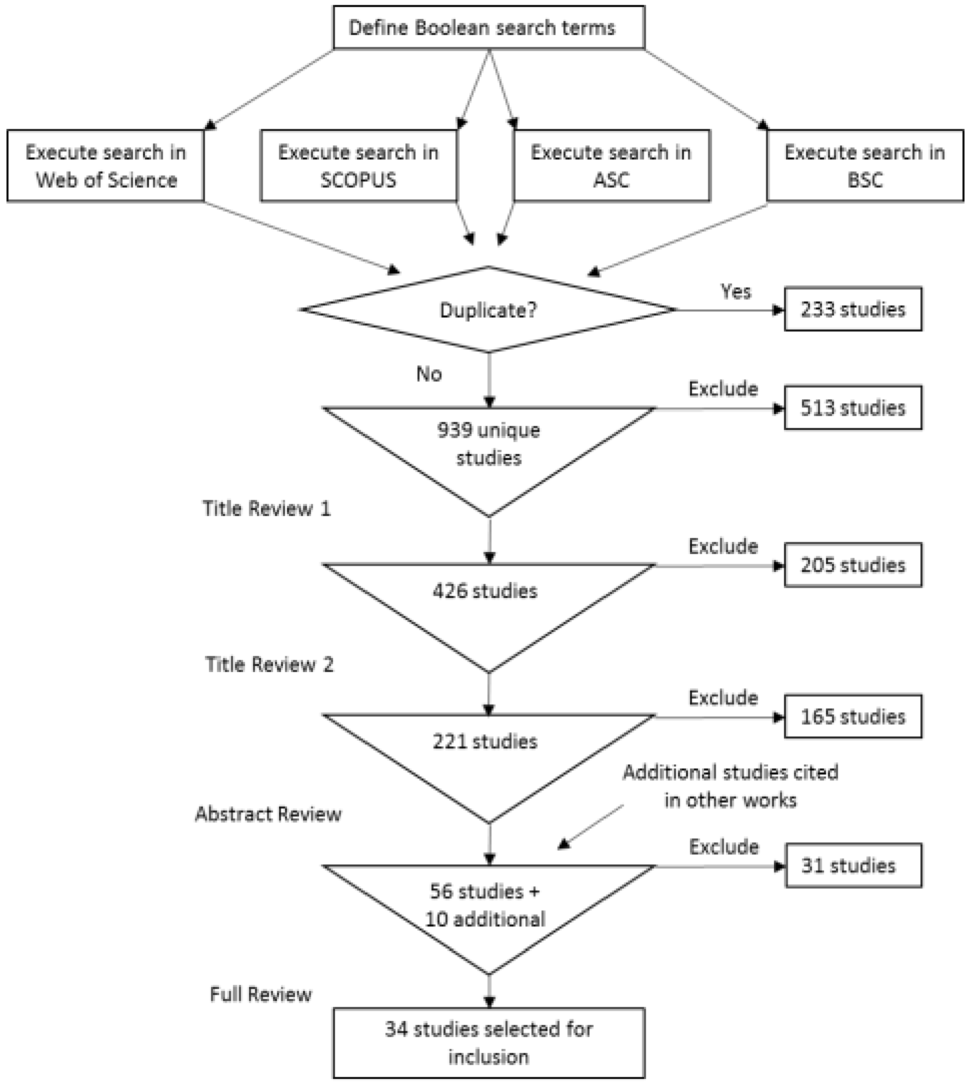

Figure 2.1. Schematic of the systematic literature review process.

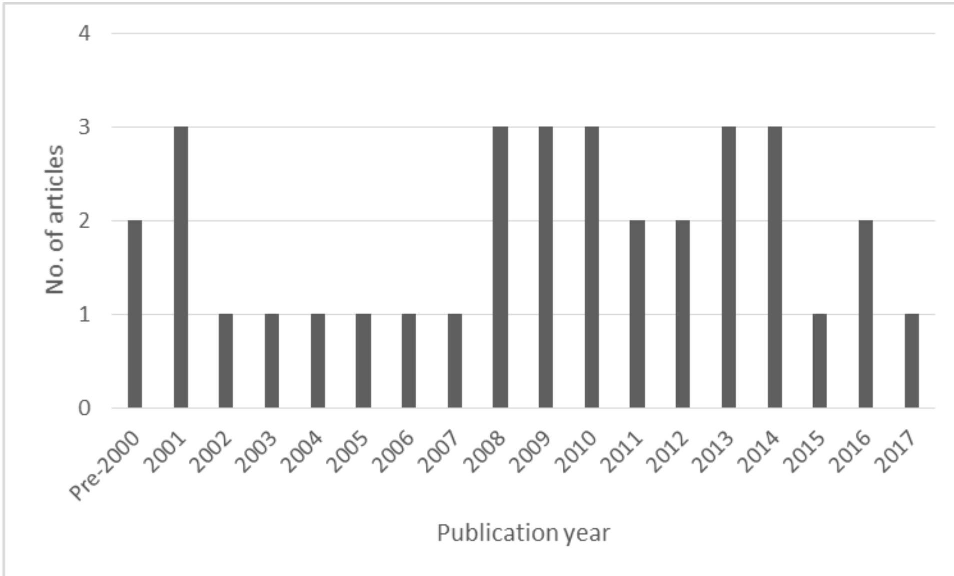

Figure 2.2. Annual distribution of publications identified in the systematic review.

CHAPTER 3: ASSESSING THE PERFORMANCE OF ALTERNATIVE WATER AND SANITATION TARIFFS: THE CASE OF NAIROBI, KENYA.

3.1 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 safely managed 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 that 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 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 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 5-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 equally well or better than IBT tariff alternatives at the three levels of cost recovery we consider. This includes 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.

3.2 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 (e.g., monthly, bi-monthly, etc.) in exchange for a specified level of service. Informed by this broad definition, there is a wide variety of tariff structures that can be used to charge customers for water and sanitation services. Tariffs that policy makers can use 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 be used to simultaneously subsidize water use for low-income households and recover costs and promote 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.[22] 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

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

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 most well-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[23] to improve economic efficiency (e.g., Renzetti 1992b; Garcia-Valinas 2005; Diakite et al. 2009; Garcia-Valinas 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 principle limitations with respect to the design of water and sanitation tariffs. First, economic efficiency is one of several criteria policy makers may consider when setting water tariffs and tariffs that improve economic efficiency may perform poorly with respect to other criteria. Second, policy makers typically do not have the information necessary to implement second-best pricing strategies (i.e., local estimates of the price elasticity of demand among different customer classes). Policy makers could of course

[23] 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 that 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.

obtain this information, but it can be expensive to do so and it may not be possible to estimate these parameters in a credible manner econometrically.

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. Studies in the literature 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 in the literature 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 conservation and the trade-off between improving cost recovery (i.e., the magnitude of the subsidy delivered through the tariff) and the welfare effects of associated with different tariffs.

3.3 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 5-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.

3.3.1 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 but not limited to: the size of the service population, the composition of the service population (i.e., fraction of customers with water service only and 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 3.1).

$$WUSE_{j,t} = WUSE_{j,t-1} * \left[1 + (\beta_{j,t} * \Delta P_{j,t-1} + \varepsilon_Y * \Delta Y_t * I_{j,R})\right] \tag{3.1}$$

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 3-1 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.[24] 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:

[24] 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 income tax (e.g., Saez 1999, Saez 2003, Saez 2010, Chetty et al. 2011), electricity tariffs (e.g., Ito 2014 and 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, and Ito 2013). To our knowledge, only Binet et al. (2013) has explored whether water utility customers respond to average or marginal price in a developing country context and found that customers' response indicated that customers underestimated both average and marginal price.

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, we assume that customers respond to changes in average, rather than marginal, price in our base case simulations.

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 that use above 5 m3/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 m3/mo. are insensitive to price changes.[25] 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 to price changes than residential customers (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 believe this assumption is

[25] This is supported by empirical studies in the literature 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).

plausible in Nairobi given the low prices of water in Nairobi 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 and the total quantity of wastewater it must treat in each year of the simulation is a function of customer water use and the fraction of customers with a wastewater connection (Equations 3.2 and 3.3). 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[26], which may vary over time.

$$Q_{w,t} = \left[\sum_{j=1}^{N_t}\left(WUSE_{j,t}\right)\right] \Big/ (1 - NRW_t) \qquad (3.2)$$

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 3.1); and
- NRW_t is the level of non-revenue water in year t.

[26] 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.

$$Q_{ww,t} = \left[\sum_{j=1}^{N_t} \left(WUSE_{j,t} \cdot Iww_j\right)\right] \tag{3.3}$$

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 3.1); and
- Iww_j, is dummy variable that takes the value of 1 if customer j has a wastewater connection and 0 if they do not.

As indicated in Equations 3.2 and 3.3, the simulation model accommodates annual changes in the size of the customer base (N_t). In our base case, we assume that the customer base increases 5% per year and that the relative composition of the customer 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.

3.3.2 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.[27]

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 relative 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

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

of subsidies over the five-year simulation period.[28] We also examine 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 3.4).

$$S_t = \frac{\sum_{j=1}^{N_t}\left(\left(WUSE_{j,t} \cdot COST_{j,t} - BILL_{j,t}\right) \cdot L_j\right)}{SUB_t} \tag{3.4}$$

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 3.1);
- $COST_{j,t}$ 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 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 calculate the change in consumer

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

surplus for each customer using Equation 3.5 and sum over the customer base to obtain the aggregate change in consumer surplus for each period in the simulation (Nauges and Whittington 2017).

$$\Delta CS_{j,t}^{T} = -\left(\frac{Q_{j,t}}{P_{j,t}^{\beta_{j,t}}\left(1+\beta_{j,t}\right)}\right)\left(P_{j,t}^{T\ (1+\beta_{j.t})} - P_{j,t}^{(1+\beta_{j.t})}\right) \quad (3.5)$$

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[29] 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 producers' 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

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

underlying production functions. Thus, we assume that their water demands are separable from other input demands (Renzetti 1992b; Garcia and Reynaud 2004)[30] 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.[31]

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.[32]

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 3.5 will not accurately measure the change in consumer surplus under IBTs. Appendix 3-2 discusses this in more detail and describes how we calculate changes in consumer surplus when we assume that customers respond to marginal price.

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[30] 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.

[31] We acknowledge that this is necessarily rough approximation of the impact of prices 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.

[32] 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 and the non-residential outputs are independent, and 2) the output markets for non-residential customers are perfectly competitive or face linear demand (Renzetti 1992b; Brown and Sibley 1986).

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.

3.4 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 socio-economic 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 we use in our simulations (Table 3.1). 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 3 usage blocks and a lifeline block of 10 m3/mo. per account (IBT3), an IBT with 2 usage blocks and a lifeline block of 5 m3/mo. per account (IBT2-5), an IBT with 2 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.[33] The IBT3 tariff alternative represents the tariff NCWSC applied for 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 affects tariff performance. The UP tariff allows us to examine how a simple uniform price tariff

[33] 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.)

performs relative to IBTs and 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.

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 5-year planning horizon. For the IBT tariff alternatives there are 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/m3 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.[34] 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 target level of cost recovery

[34] 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.

in the final year of the planning horizon.[35] 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 accordingly. We could have also 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, the primary objective of this paper.

3.5 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 3.2). 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

[35] 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 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.

residential customers is 31 m3/mo. compared to 347 m3/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/m3. Residential customers with both water and wastewater service pay an average of 0.80 USD/m3 for both services, which reflects the 75% surcharge NCWSC assesses for wastewater service.

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 m3/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%).

3.5.1 Status quo cost recovery (31%)

Table 3.3 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 3.4). 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 similar 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 that shows that the 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 the consumer surplus for residential customers relative to efficient prices is approximately 4.7 million USD/mo. in year 5 of the simulation.[36] 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

[36] 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 are 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 m3/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 to the network in Nairobi.

present value of the rebate over the simulation period is larger than the net present value of the decreases in welfare associated with UP+R tariff.

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 3.3 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.

3.5.2 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 potentials 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% (in real terms) annually (Table 3.4). 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/m3 to 0.47 USD/m3 in year 5. Similarly, the volumetric price in the UP tariff increases from 0.47 USD/m3 to 0.99 USD/m3, 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 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 3.5). 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 accompany 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 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.

3.5.3 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 3.4). Under these price increases, the price in the lifeline block of the IBT tariff alternatives increases from 0.22 USD/m3 to 0.72 USD/m3. Similarly, the volumetric price in the UP tariff increases from 0.47 USD/m3 to 1.51 USD/m3, 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 3.6, 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 similar 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 towards 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 five 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 3.6) across all tariff alternatives.

3.5.4 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 3.1 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.[37] 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.

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

[37] 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.

80% cost recovery, deadweight loss to society is compromised equally of the subsidy delivered through the tariff and the losses customers experience due to inefficient pricing.

3.6 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 tariffs alternatives we consider when customers respond to marginal, rather than average, price and 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.

3.6.1 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 necessarily 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 less 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 3-3). 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 3.7). 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 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 well 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 3.7). For example, at intermediate and full cost recovery, the UP tariff produces similar reductions in total water use as the IBT tariff alternatives and the magnitude of the subsidy delivered through the tariff. However, the UP tariff produces slightly larger reductions in customer welfare than both the IBT2-5 and IBT2-10 tariffs. As a result, the UP tariff also leads to smaller reductions in the deadweight loss to society than the IBT2 tariff alternatives.

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 also find that the UP+R tariff produces similar reductions in welfare as the IBT2 tariff alternatives as prices increase to reach full cost recovery.

3.6.2 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, exhibits a high level of non-revenue water, or when the marginal cost is substantially different than 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 is 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 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-exist issues may be important in low- and middle-income countries where groundwater use is often poorly (or not) regulated, the market for vendors (e.g., tanker trucks) is more well-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 customers' income, it may affect their 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.

3.6.3 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 tariffs 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 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 tariffs create for both utilities and customers.

3.7 Summary and Conclusions

Our simulations provide several insights with respect to the performance of the 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's (2017) and suggests that the time and resources policy makers and tariff consultants invest in determining the appropriate size of the lifeline block, the number of blocks in an IBT, and the relative prices between blocks may be misdirected.

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 than, 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, they are easier to explain to customers and send a clearer signal about the cost of delivering water and sanitation services than IBTs. Thus, our findings suggest that a tariff with a uniform volumetric price may perform as well as or better than the

IBTs 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 to society. 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, taxpayers (who may also be customers), and higher levels of government 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.

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TABLES AND FIGURES

Table 3.1. 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 3.2. 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 3.3. 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 3.4. 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 3.5. 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 3.6. 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 3.7. Summary of simulation results when customers respond to marginal price.

Criteria	Units	Status Quo	IBT3	IBT2-10	IBT2-5	UP	UP+R
			Status Quo Cost Recovery (31%)				
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%*

Criteria	Units	Status Quo	IBT3	IBT2-10	IBT2-5	UP	UP+R
			Intermediate Cost Recovery (65%)				
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 3.7 (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.

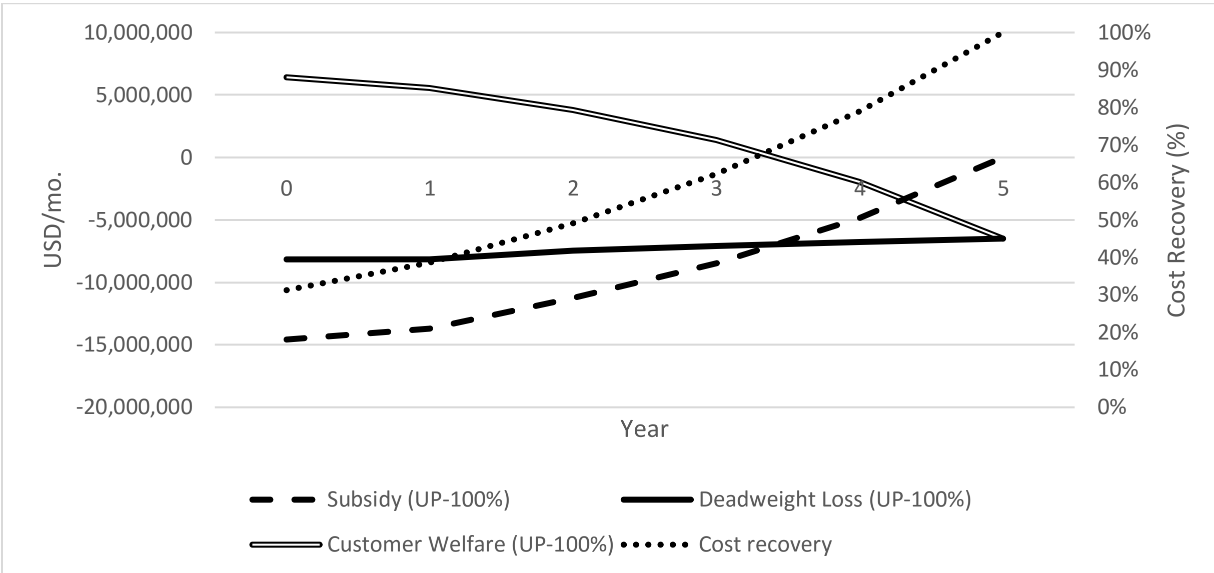


Figure 3.1. Dynamics of the subsidy, customer welfare, deadweight loss, and cost recovery for the UP tariff alternative.

CONCLUSION

Tariffs play an essential role in generating the revenue to pay for the day-to-day operation of utilities, repair and replace ageing infrastructure, and finance to expand the piped water and sanitation networks to meet increasing demand for these services. This dissertation examines the pricing of water and sanitation services in low- and middle-income countries using the case of Nairobi, Kenya – a fast growing, major metropolitan area with conditions similar to that of many cities in developing countries. In particular, this dissertation examines the performance of different tariff structures with respect to several criteria that policy makers consider when designing tariffs for water and sanitations services. The major findings of each chapter are summarized below.

Chapter 1 examines the extent to which the increasing block tariff (IBT) implemented in Nairobi effectively targets subsidies to low-income households. To accomplish this, I combine data on household socio-economic status and metered water use with empirical estimates of the cost of water and sanitation service delivery in Nairobi. I find that the magnitude of the subsidy delivered through the tariff is larger than the Nairobi City Water and Sewer Company's (NCWSC) annual revenue. This is much larger than previous studies, which consider only tariffs for water service, would suggest. I also find that stated expenditure on water, a commonly used means of estimating water use, is a poor proxy for metered use. This has implications for future efforts to assess the incidence of subsidies delivered through water and sanitation tariffs as well as other studies that use stated expenditure as a proxy for water use.

Consistent with previous studies in the literature, Chapter 1 also demonstrates that the IBT in Nairobi does not effectively target subsidies to low-income households. Indeed, I find that residential customers in low-income areas receive less than 10% of the subsidies delivered through the tariff. I also find that subsidies are poorly targeted even among households with a private connection to the piped water and sewer network. This is because all customers are subsidized at current prices and there is a low correlation between income and water use in Nairobi. These findings add to a growing body of literature that suggests that the IBTs implemented by many utilities do not effectively target subsidies to low-income households.

Subsidy incidence is, of course, one of several criteria that policy makers consider when designing tariffs for water and sanitation services. Recognizing this, Chapter 2 provides a systemic review of the peer-reviewed literature on pricing water and sanitation services, identifying ways in which the literature might inform water and sanitation service pricing and promising areas for future research. I find that the peer-reviewed literature on pricing municipal water and sanitation services is diverse, fragmented, and focused primarily on industrialized countries. I also find that the majority of studies examine two or fewer dimensions of tariff performance, limiting the extent to which the literature characterizes the actual tradeoffs policy makers face when designing tariffs. These findings suggest that there is considerable scope for additional research to better characterize the performance of tariffs for water and sanitation services in a range of economic and institutional contexts.

Informed by the findings in Chapter 2, Chapter 3 presents a framework for simulating the performance of water and sanitation tariffs with respect to several policy-relevant criteria. I then evaluate the performance of alternative tariffs relative to several indicators of 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 overall changes in social welfare. Contrary to conventional wisdom, I find that tariff alternatives with a uniform volumetric price perform equally well or better than IBT tariff alternatives at the three levels of cost recovery considered. This includes both a two-part tariff long promoted by economists (i.e., uniform price with rebate) as well as a simple tariff with a uniform volumetric price. These findings are robust to assumptions about whether customers respond to average or marginal price and 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.

Despite this, with the exception of the UP+R tariff, I find there is little difference in the performance of the tariff alternatives considered at a given level of cost recovery. This is surprising given the time and resources utilities and regulators typically invest in tariff design. Taken together these 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.

IBTs are among the most widely used tariffs by water utilities, particularly in low- and middle-income countries. This is due to the widespread perception that the IBT can simultaneously target subsidies to low-income households, recover costs from customers who use more water, and promote conservation. Overall, the findings presented in this dissertation call into question the rationale for implementing IBTs in low- and middle-income countries. Indeed, this dissertation reinforces the fact that water and sanitation tariffs are ineffective and inefficient means of delivering subsidies to low-income households. This suggests that if policy makers want to subsidize water and sanitation services for low-income households, they should explore alternative subsidy delivery mechanisms, including both connection subsidies and means-tested subsidies (i.e., subsidies for which households must meet an income or wealth criteria).

Utilities in low- and middle-income countries often implement tariffs that are not sufficient to cover the cost of providing water and sanitation services. As documented in the case of Nairobi, this can result in considerable subsidies being delivered through water and sanitation tariffs. Improving cost recovery can promote more efficient water use, improve the financial viability of utilities, and deliver net social benefits to society. While existing customers benefit from low prices for water and sanitation services in the short term, this comes at the expense of the utility, taxpayers (who may also be customers), and higher levels of government with resulting net losses to society. Low levels of cost recovery also lead to deteriorating levels of service quality and hinder governments' ability to extend services to households that lack access to the piped water and sanitation network. This dissertation reinforces the benefits of getting utilities on the path to full cost recovery, which will be essential to meet the global aspiration of achieving universal access to high quality water and sanitation services.

APPENDIX 1-1: SUMMARY OF SUBSIDY INCIDENCE LITERATURE

Table A1-1. Summary of Studies in the Subsidy Incidence Literature (Adapted from Whittington et al. 2015)

Study	Country	Data Source[a]	Data Year	Sample Size	Water Use Measure[a]	Indicator(s)[b]	Subsidy Targeting[c]
Whittington et al. (2015)	Hypothetical	Hypothetical	n.a.	n.a.	Hypothetical	Subsidy share	Poor
Barde and Lehmann (2014)	Lima, Peru	Billing data, expenditure survey, tariff	2010	2570	Stated expenditure	Affordability; subsidy share; EOI; EOE; leakage rate	Poor (non-means tested); Excellent (means tested)
Angel-Urdinola and Wodon (2012)	Nicaragua	HH survey data and tariffs	2001 & 2005	3641 (2001) 6102 (2005)	Stated expenditure	Concentration coefficient	Poor
Banerjee and Morella (2011)	Multi-country - Africa	HH surveys and tariffs	Varies	Varies	Stated expenditure	Affordability (share of HH total expenditure); concentration coefficient;	Poor
Banerjee et al 2010	45 utilities in 23 African Countries	LSMS and tariffs	Varies	Varies	Stated expenditure	Affordability (share of HH total expenditure); concentration coefficient;	Poor
Garcia-Valinas et al (2010)	Spain	Municipal surveys	2005	301 municpalities	Aggregate	Affordability	n.a.
Diakite et al (2008)	Cote d'Ivore	HH panel data	1998-2002	780 total in panel (aggregate data)	Aggregate	Welfare gain/loss	n.a.

[a] Aggregate refers to data averaged over a geographic area (e.g., service region, metropolitan area, county, etc.).
[b] EOE=Errors of exclusion. EOI=Errors of inclusion.
[c] "Poor" = worse than if subsidies were equally or randomly distributed; "Moderate" = slightly better than if subsidies were equally or randomly distributed; "Excellent" = large proportion of subsidies targeted to low-income households.

Table A1-1 (cont.'d). Summary of Studies in the Subsidy Incidence Literature (Adapted from Whittington et al. 2015)

Study	Country	Data Source[a]	Data Year	Sample Size	Water Use Measure[a]	Indicator(s)[b]	Subsidy Targeting[c]
Ruijs (2009)	Sao Paolo, Brazil	HH data	1997-2002	63 MRSP	Aggregate	Welfare gain/loss	n.a.
Ruijs et al (2008)	Sao Paolo, Brazil	Aggregate panel data for demand est.	1997-2002	Panel of 39 MRSPs (aggregate data)	Aggregate	Affordability	n.a.
Bardasi and Wodon (2008)	Niger	HH survey	1998	533	Stated use	Average price	n.a.
Groom et al (2008)	Beijing China	HH income and expenditure survey - Panel 1987 2002	1987-2002	645 HH plus aggregate data on quintiles	Stated expenditure	Welfare gain/loss	Poor
Fankhauser and Tepic (2007)	Transition countries	LSMS	Varies	Varies	Stated expenditure	Affordability (% of HH expenditure)	n.a.
Angel-Urdinola and Wodon (2007)	Cape Verde, Sao Tome, Rwanda	Nationally rep HH surveys	Varies 1999-2002	Varies	Stated expenditure	Concentration coefficient	Poor
Foster and Yepes (2006)	Multi-country Latin America	LSMS	Not stated	Not stated	Stated expenditure	Affordability (% of HH that would spend more than x% if tariffs were raised)	Poor

[a] Aggregate refers to data averaged over a geographic area (e.g., service region, metropolitan area, county, etc.).
[b] EOE=Errors of exclusion. EOI=Errors of inclusion.
[c] "Poor" = worse than if subsidies were equally or randomly distributed; "Moderate" = slightly better than if subsidies were equally or randomly distributed; "Excellent" = large proportion of subsidies targeted to low-income households.

Table A1-1 (cont'd). Summary of Studies in the Subsidy Incidence Literature (Adapted from Whittington et al. 2015)

Study	Country	Data Source[a]	Data Year	Sample Size	Water Use Measure[a]	Indicator(s)[b]	Subsidy Targeting[c]
Komives et al (2006)	Multi-country	Secondary literature	Varies	Varies	Stated expenditure	EOE; concentration coefficient	Poor
Komives et al (2005)	Multi-country	LSMS	varies	Varies	Stated expenditure	Concentration coefficient; EOI, EOE; "Material impact"	Poor
Foster and Araujo (2004)	Guatemala	LSMS style national survey (ENCOVI 2000)	2000	7,276	Stated expenditure	EOE; EOI	Poor
Foster (2004)	Argentina	Primary HH Survey (2500 HH)	2002	2,500	Previous bill; Stated expenditure; Imputed using regression	Cumulative dist; concentration coefficient; EOI, EOE	Moderate
Gomez-Lobo and Contreras (2003)	Chile and Columbia	National HH surveys (Chile - CASEN 1998; Columbia - 1997 NQLS)	1997/98	Chile 48,107; Columbia 4,094	Stated expenditure	Concentration curves; EOI; EOE	n.a.
Foster et al (2000)	Panama	LSMS	1997	n.a.	Stated expenditure	EOE, EOI	n.a.
Walker et al (2000)	Central America	Household survey	Varies 1995-1998	Varies	Previous bill	EOI; EOE; Average subsidy per HH per mo; subsidy share	Poor-moderate

[a] Aggregate refers to data averaged over a geographic area (e.g., service region, metropolitan area, county, etc.).
[b] EOE=Errors of exclusion. EOI=Errors of inclusion.
[c] "Poor" = worse than if subsidies were equally or randomly distributed; "Moderate" = slightly better than if subsidies were equally or randomly distributed; "Excellent" = large proportion of subsidies targeted to low-income households.

APPENDIX 1-2: DISCUSSION OF STATED EXPENDITURE AS A PROXY FOR METERED WATER USE

There are several reasons why imputed water use may not be a good proxy for metered water use. Households may not be able to accurately recall how much they spend on water and sanitation services. Households incur a variety of expenses each month and throughout the year and survey evidence suggests that water constitutes a very small portion of monthly household expenditure (often less than 3%) for households with piped connections (Appendix C.4 in Komives et al. 2005). Thus, it is possible that households may have difficulty recalling expenditure on water and sanitation services because they do not represent a major portion of their total expenditures. Indeed, in a 2,500 household survey conducted in Argentina, Foster (2004) reports that only 30% of the households were able to recall the amount of their most recent bill.

Even if households can perfectly recall their monthly expenditure on water and sanitation services, there are additional reasons why expenditure on these services might be a poor proxy for actual water use. For example, income and expenditure surveys often do not contain information on whether a household connection is metered. If households do have metered connections, the meters may not be working or the utility may not read them on a regular basis. Households may also have a shared connection. In these instances, households' water bills will not reflect their metered water use.

Additionally, household budget and expenditure surveys ask households how much they spent on water last month. They typically do not ask households specifically how much they spent on piped water services, nor do they ask households how much they spent on sanitation services. For example, the most recent Kenya Integrated Household Budget and Expenditure survey asks households “What was the total cost of water for your household last month?” (KNBS 2006). Thus, household recall of expenditure on water in these surveys may include the amount they spent on water from vendors and sewer services.

Water bills may also include fees that are unrelated to water consumption in the most recent billing period. This could include fees for other services (e.g., solid waste collection), pro-rated connection charges, arrears, or penalties for non-payment. Additionally, countries in Latin America and elsewhere are experimenting with including payment for environmental services in water bills to promote watershed protection (see Whittington and Pagiola 2012).

APPENDIX 1-3: COST ESTIMATES USED IN THE LITERATURE

Table A1-3a. Summary of Cost Estimates Used in the Literature.

Study	Location	Cost Estimates (USD/m3)	Service	Includes	Source
Foster and Araujo (2004)	Guatemala	0.30 - 0.40	Water	Indicates "full cost"	Cites "international benchmarks"
Komives et al. (2005)	Multi-country	See Table A1-3b	Water	Varies	Not stated
Komives et al. (2006)	Multi-country	See Table A1-3b	Water	Varies	Not stated
Foster and Yepes (2006)	Multi-country	0.30	Water	O&M	Kingdom et. al (2004)
Foster and Yepes (2006)	Multi-country	0.90	Water	O&M plus capital costs	Kingdom et. al (2004)
Groom et al. (2008)	China	0.85	Water	"Full financial" cost recovery	Not stated
Walker et al. (2000)	Multi-country	0.09 - 0.27	Water	O&M	Not stated
Walker et al. (2000)	Multi-country	0.17 - 0.47	Water	Capital costs including "financing charges plus depreciation"	Not stated
Barde and Lehman (2014)	Peru	0.64	Water	Not stated	Average tariff

Table A1-3b. Cost Estimates from GWI (2004).

	Developing country	**Industrialized countries**
<0.20 USD/m³	Tariff *insufficient* to cover basic operations and maintenance costs	Tariff *insufficient* to cover basic operations and maintenance costs
0.20 - 0.40 USD/m³	Tariff *sufficient* to cover operation and some maintenance costs	Tariff *insufficient* to cover basic operations and maintenance costs
0.40 - 1.00 USD/m³	Tariff *sufficient* to cover operations and maintenance costs and most investment needs	Tariff *sufficient* to cover basic operations and maintenance costs
>1.00 USD/m³	Tariff *sufficient* to cover operations and maintenance costs and most investment needs in the face of extreme supply shortage	Tariff *sufficient* to cover full cost of modern water systems in most high-income cities

Source: GWI (2004) in Komives et al (2005)

APPENDIX 1-4: SURVEY DESCRIPTION AND SAMPLING STRATEGY

This paper uses data collected through a survey of approximately 739 NCWSC customers conducted between November 2013 and January 2014. (The study received UNC IRB approval under Study No. 13-1932 as well as approval from Kenya's National Council for Science and Technology (Ref No. NACOSTU/P/13/8073/406.)

The survey was comprised of eight modules. The first module recorded basic logistical information about the survey, including informed consent, enumerator code, date, and start time. Importantly this module recorded each household's account number, which the enumerators recorded from the NCWSC meter readers' log books. The account number allows us to identify households in the NCWSC billing records.

The second module contained screening questions to ensure the households met the criteria for participation in the study and collected information related to the household's piped water connection. This module also contained questions related household recall about expenditure on water and sanitation services. The third module of the survey collected information about the households' composition and demographics. The fourth module contained questions related to their socioeconomic status, including questions about household expenditure, income and asset ownership. The fifth module asked households about additional water sources they might use, including private boreholes, water vendors, and bottled water. The sixth module contained a number of questions about the extent to which and under what circumstances households treated their drinking water. The seventh module collected information related to household sanitation facilities. Finally, the eighth module contained wrap up information about the survey, including the enumerators' perceptions of the quality of the survey and the GPS coordinates of the households' location.

In general, wealthier households are more likely to have a connection to the piped water and sewer network than lower income households. Because the objective of the household survey was to investigate the relationship between income and water use among NCWSC customers, the primary challenge for the survey was to ensure the sample had adequate income heterogeneity.

To address limitations of the NCWSC administrative data, our sampling strategy combined purposive and stratified random sampling. NSWCS service area consists of six regions. Each region consists of zones, which are further subdivided into itineraries. There are 26 zones in total and approximately 2000 itineraries. Each itinerary contains between 100 and 200 accounts. NCWSC marketing associates (meter readers) use these itineraries on their daily meter reading routes.

The project team and a committee from NCWSC first assigned an income category to each of the 25 zones based on the subjective, local knowledge of the project team and NCWSC staff members. Due to the fact that the primary sampling challenge was to ensure the sample had adequate income heterogeneity, the project team then identified the two regions with the highest representation of low income zones (Eastern and Northeastern) and randomly selected one of these regions (Northeastern). Similarly, we identified the two regions with the highest representation of high income zones (Southern and Western) and randomly selected one of these regions (Western).

Once the two regions were selected, the following sampling strategy was employed. Each day the project team, in collaboration with head of billing and metering from the appropriate regional office randomly assigned enumerators to marketing associates, with two enumerators paired with a single marketing associate. Each pair of enumerators would then shadow a marketing associate on their meter reading route for that day. Starting at the beginning of the itinerary the marketing associate was reading that day, the enumerators were instructed to select the tenth customer account as the first household. The marketing associate would then introduce one of the enumerators to the household and continue on their meter reading route. The second enumerator would select the twentieth account on the list and do the same.

Once the enumerators completed an interview, they would call the marketing associate and meet them where he/she was in their current meter reading route. The enumerator would then use the next account as a sample household. If nobody was at the household, enumerators were instructed to note the address and attempt two call backs. If someone from the household was home, but did not have time to complete the survey or the head of household or their spouse was not home, enumerators were instructed to take the contact information of the head of household and attempt to schedule a call back two times before replacing the household in the sample.

The survey included a number of quality control measures. First, each day the survey supervisor would collect and review completed questionnaires from the enumerators. If the supervisor identified problems with the questionnaire, enumerators were instructed to re-visit the households to verify or correct the information. Second, the project team conducted random spot checks on the enumerators to ensure they followed the prescribed sampling protocol and to ensure that they administered the survey instrument appropriately. This included spontaneously meeting enumerators in the field to observe interviews, conversations with the marketing associates about how the enumerators selected households, and visits or calls to households who had been surveyed to discuss the types of questions the enumerator asked them and how long they spent with them. We also employed double, independent data entry.

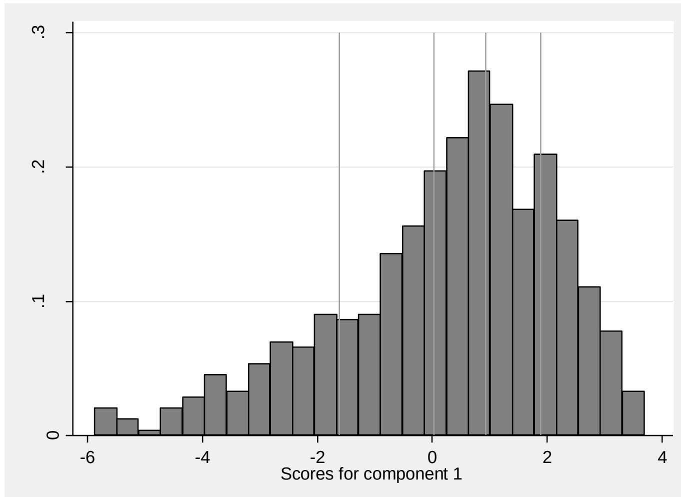
As described in the main text, our final sample consists of 656 households. Of the initial 741 households surveyed 83 households were dropped from the sample. One household was dropped due to a duplicate account number; 14 accounts could not be located in the NCWSC billing data; 30 accounts only did not have an actual meter reading during the billing period we observed; and 38 accounts had no non-zero meter readings during the billing period we observed.

APPENDIX 1-5. WEALTH INDEX

We constructed a wealth index using principle component analysis following Filmer and Pritchett (2001) and Filmer and Scott (2008). Table A1-5a presents the 28 variables we include in the wealth index. All variables were covnerted to indicator variables (0-1) or continuous variables as appropriate. The first column of Table A1-5a presents the first component (factor score) of the principle component analysis. The first component has an eignenvalue of 5.93 and explains 21.2% of variation in the 28 variables in our index. For binary variables the factor score can be interpreted as the marginal change in a household's wealth index score by going from not owning the asset to owning the asset. For example, cooking with biomass decreases a household's wealth index score by 0.243. Similarly, having a security guard on premise increases a household's wealth index score by 0.201.

The distribution of the wealth index scores is relatively smooth and skewed to the right (Figure A1-5a). The verticle lines in Figure A1-5a indicate the cutpoints for the wealth index that divide our sample into five quintiles. Each quintile in our sample has 131 or 132 househholds.

Figure A1-5a. Distribution of factor scores used to construct the wealth index with quintile cut points.



The second through sixth columns of Table A1-5a show the mean of each variable included in the index for households in each predicted wealth quintile. The final column in Table A1-5a presents the mean for each variable for the entire sample. The mean values for each variable across the wealth quintiles largely agree with our prior assumptions about the relationship between asset ownership and wealth. For example, one percent of households in the lowest wealth quintile report having an internet connection. In contrast, 71% of households in the highest wealth quintile report having an internet connextion. Similarly, less than 10% of households in the lowest wealth quintile report owning a car in contrast to 98% of households in the highest wealth quintile. Exceptions to this include the extent to which households own or rent their home and own land/property in or outside of Nairobi.

Table A1-5a. Factor scores and mean values of components of the wealth index by predicted wealth quintile.

	Factor Score	Lowest	Second	Third	Fourth	Highest	All
Cooks with LPG	0.234	0.39	0.87	0.99	0.98	0.98	0.84
Cooks with biomass	-0.243	0.60	0.11	0.00	0.01	0.00	0.14
Level of school completed	0.144	11.89	13.69	14.61	16.16	16.88	14.64
Own/rent	0.039	0.52	0.34	0.48	0.49	0.74	0.51
Separate kitchen in house	0.179	0.83	0.99	1.00	1.00	1.00	0.96
Security guard	0.201	0.21	0.56	0.80	0.98	0.98	0.71
Electric security fence	0.161	0.02	0.04	0.14	0.36	0.82	0.27
Electricity connection	0.147	0.90	0.99	1.00	1.00	1.00	0.98
Mobile phone	0.032	0.99	0.99	1.00	1.00	1.00	1.00
Phone with data plan	0.126	0.57	0.76	0.82	0.89	0.94	0.79
Internet connection	0.168	0.01	0.05	0.15	0.40	0.71	0.26
TV	0.126	0.89	0.98	0.99	1.00	1.00	0.97
Radio	0.104	0.70	0.82	0.89	0.84	0.83	0.81
Computer/laptop	0.264	0.17	0.42	0.68	0.85	0.98	0.62
Bicycle	0.214	0.12	0.24	0.20	0.37	0.50	0.29
Motorcycle	0.224	0.02	0.02	0.02	0.06	0.08	0.04
Car	0.277	0.08	0.31	0.56	0.85	0.98	0.56
Washing machine	0.244	0.02	0.07	0.11	0.13	0.72	0.21
Water heater	0.258	0.11	0.31	0.61	0.61	0.86	0.50
Refrigerator	0.258	0.39	0.88	0.97	0.99	0.99	0.84
Gas cooker	0.264	0.30	0.81	0.95	0.96	1.00	0.80
Meko (local stove)	0.086	0.48	0.52	0.36	0.31	0.19	0.37
Add.'l house in Nairobi	0.209	0.07	0.12	0.15	0.16	0.20	0.14
Add.'l house outside Nairobi	0.139	0.33	0.30	0.37	0.16	0.23	0.28
Land in Nairobi	0.203	0.09	0.09	0.12	0.11	0.04	0.09
Land outside Nairobi	0.091	0.48	0.51	0.56	0.34	0.18	0.42
Borehole on property	0.070	0.00	0.01	0.00	0.05	0.17	0.05
Toilet inside home	0.207	0.77	0.99	1.00	1.00	1.00	0.95

Notes: n=656. Each quintile has 131 or 132 households.

APPENDIX 3-1: 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 3-2: 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 customers enjoy under the baseline tariff and 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 m3/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.

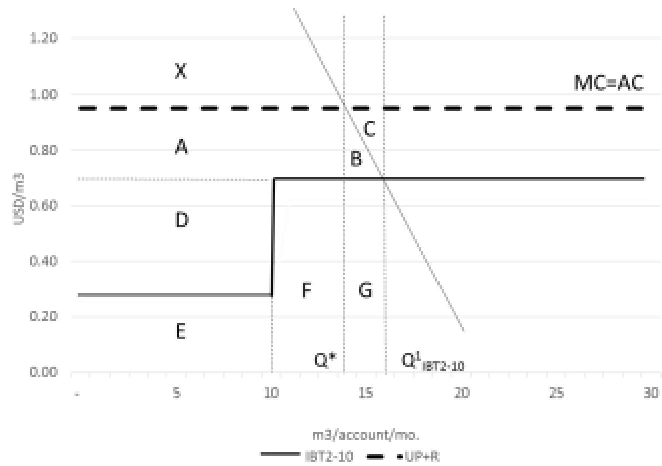


Figure A2-1. Customer water use in block 2 of IBT2-10 relative to efficient pricing.

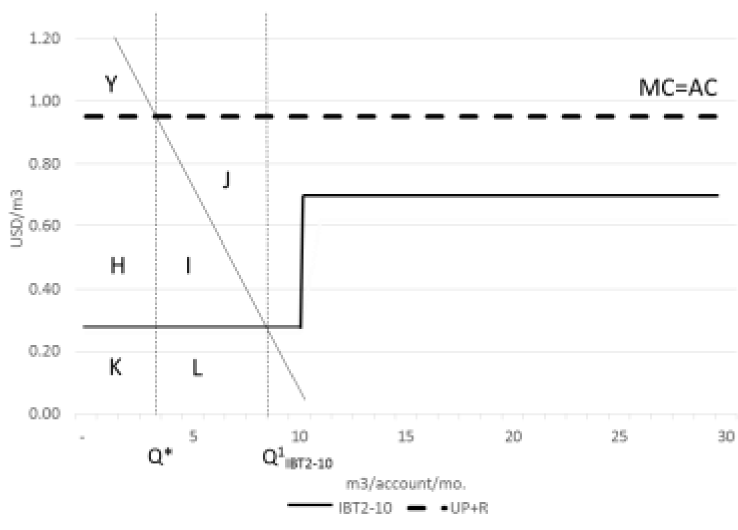


Figure A2-2. Customer water use in block 1 of IBT2-10 relative to efficient pricing.

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).

<u>Step 2</u>: 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.

$$\Delta CS_t^{IBT4 \rightarrow T} = \Delta CS_t^T - \Delta CS_t^{IBT4} \qquad \text{(A2)}$$

Where $\Delta CS_t^{IBT4 \rightarrow T}$ is the change 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 3-3: 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*