Household Willingness to Pay for Piped Water Service Quality: Evidence from Zambia

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Abstract

Public utilities in developing countries are often characterized by poor supply quality and low levels of revenue collection. Poor supply quality may reduce water demand among households and revenue recovery by the water utility, which may impede efforts to expand access to water utilities. This paper estimates willingness to pay (WTP) for utility quality using both stated and revealed preference approaches. Revealed preference estimates of WTP for piped-water quality improvements may be biased due to endogeneity of quality and demand and are unable to distinguish between supply-side and demand-side reductions in water use when piped-water supply is intermittent. Therefore, I compare WTP estimates based on demand responses to quality with those derived from payment responses to quality. Because bill payments are made two months after consumption occurs, I am able to determine household payment responses to current period quality which are independent of current period consumption. Revealed preference estimates based on payments and demand both show that households are willing to pay for quality improvements when experiencing low chlorine and poor color, which likely indicates low pipe pressure observed by the household and an inadequate supply of water. I find that demand WTP estimates are smaller than payment WTP estimates, and both are generally smaller than stated preference results. Revealed and stated preference results show that households are willing to pay for higher piped-water supply quality but not more than an additional 1.40 USD per month, which represents 12 percent of the average bill.

Keywords: water utilities, water quality, willingness to pay, water demand

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1 Introduction

Piped-water provision in many developing countries is often unreliable, and the quality of water that households receive can be poor. Inadequate access to and provision of piped water has been shown to generate health consequences to households (Ashraf *et al.*, 2021), produce significant time costs through fetching water from other sources (Devoto *et al.*, 2012), and result in water storage costs for households (Baisa *et al.*, 2010). Improvements in piped-water supply in developing cities therefore have the potential to produce significant welfare gains for households. However, nonpayment of water bills among water customers in developing cities is often high. Previous research has argued that widespread nonpayment locks public utilities in a low-payment, low-quality equilibrium because utilities have neither the ability nor the incentive to upgrade the quality of service (McRae (2015); Burgess *et al.* (2020)). Infrastructure and water-quality improvements can be costly for water utilities, and much of these costs may be passed on to the consumer through higher water tariffs. Understanding the demand responses of households across the income distribution to piped-water quality improvements are therefore necessary to inform public policies in the water sector.

This study aims to estimate willingness to pay (WTP) for piped-water supply improvements among residential customers in Livingstone, Zambia. Commercial water utilities in Zambia are regulated nationally and are expected to meet standards for both service quality and cost recovery. However, water utilities in Zambia have shown negative performance trends in water losses and cost recovery in recent years (NWASCO, 2020). Water utilities in sub-Saharan Africa are furthermore expected to face significant external challenges due to fresh water supply variability in the region resulting from climate change (Serdeczny *et al.*, 2017) and rapid urbanization rates in African cities (Cobbinah *et al.*, 2015). Wealthy households in Zambia often drill private boreholes due to low service quality of piped water, which may generate environmental externalities through groundwater pollution and depletion. Unregulated drilling of boreholes in Lusaka, Zambia has been considered a primary contributor to over-abstraction in the region (Nussbaumer *et al.*, 2016). Another concern is that when the highest-income households exit the water network, it becomes more difficult for water utilities to recover costs from the customers that remain. Infrastructure improvements are therefore necessary for the efficient distribution of water resources and for keeping users with high WTP for supply quality connected to the piped-water network. However, if low-income households have low demand for quality improvements, higher water tariffs may reduce water access for households with limited willingness or ability to pay.

This paper presents several estimates of WTP for water supply quality improvements. Stated preference results have been widely used in the literature due to the difficulties in producing revealed preference estimates. Stated preference results are obtained from a randomized household survey of customers in Livingstone. Households were asked the amount that they would be willing to pay (above their current bill) for higher service quality on four metrics: consistent high-pressure, 24-hour service, water that is safe to drink, and water with a normal color and taste. Results show that households are willing to pay an additional 1.1 to 1.4 USD per month for improvements in service quality on average, however, the WTP for the median household is zero for all metrics except for water that is safe to drink, for which the median household is willing to pay an additional 0.5 USD per month. High-income households are willing to pay more in terms of the dollar amount and the percentage increase in their water bill, but low-income households are willing to pay a higher percentage of their income on quality improvements.

Estimating revealed preference WTP based on changes in household water demand is challenging due to the potential endogeneity of quality and demand. Quality measures produced from water tests or self-reported quality measures may be correlated with household demand. Another empirical problem, particularly in developing countries, is that households often experience intermittent supply of water, making it difficult to separately identify demand responses to water quality and supply reductions that affect water quality. Galaitsi *et al.* (2016) argues that intermittent water supply results in poor water quality for the customer, and customer payment responses may further reinforce supply intermittency.

To address this problem, I test whether household payments respond to current period quality. Because a household's current bill is for consumption that occurred two months prior, I am able to estimate payment responses to quality that are independent of changes in consumption. Nonpayment of water bills is common in Livingstone, and many households owe significant arrears to the water utility. The water utility will disconnect defaulting customers due to nonpayment, and therefore, payment responses to quality provide a measure of the long-run valuation of the water connection. I estimate payment responses to water tests that exceed the water utility regulator's water testing standards for low chlorine, high chlorine, high turbidity, and poor color. I find that nonpayment increases by approximately 0.5 USD per month when households are exposed to low chlorine. High-income and metered household have larger nonpayment response to low chlorine levels ranging from 0.5 to 1.5 USD per month. Household payment reductions may be primarily in responses to low pipe pressure which is highly correlated with low chlorine levels. Low-income households have a smaller nonpayment response to low chlorine levels but increase nonpayment by 1.2 USD per month when exposed to poor color and 0.6 USD per month when exposed to high turbidity. While a primary concern is that metered households may reduce payments in anticipation of future reductions in payment liabilities, there are significant reductions in payments among unmetered households, who pay a fixed fee, as well. The results suggest that high-income households are willing to pay for adequate pipe pressure, while low-income households are willing to pay for water with a normal color and appearance.

I compare revealed preference estimated derived from payment responses to quality to those derived from demand responses. I estimate household demand for quality using temporal variation in quality experienced at the customer level. Estimation results will be biased to the extent that local changes in demand affect local quality. However, due to the complexities of the piped-water network, quality is likely to be affected by a variety of exogenous and non-local factors including pipe bursts and changes in upstream demand. Water in Livingstone is priced according to an increasing block tariff (IBT) in which the marginal price that households pay depends on the amount that they consume. I address the endogeneity of prices and quantities using an instrumental variable (IV) approach in which the marginal price is instrumented using the household's expected marginal price, which is based on the prior year's consumption per consumer group and region. WTP for piped-water quality is estimated using the ratio of the quality elasticity to price elasticity coefficients multiplied by the mean observed marginal price. Revealed preference results derived from household demand responses show a similar result to estimates derived from payment responses — households are willing to pay for water quality improvements when experiencing low chlorine and poor color. Households are willing to pay an additional 0.1 to 0.4 USD per month for chlorine levels within standards when experiencing low chlorine and an additional 0.3 to 0.4 USD per month for color within standards when experiencing poor color. Because low chlorine and poor color may be an indicator of low pipe pressure, I am unable to distinguish between reductions in demand that occur when households experience poor quality and potential reductions in supply that may cause low pressure. Payment responses to quality are higher than demand responses to quality and more closely match the stated preference results. However, stated and revealed preference measures are not directly comparable because they do not measure identical quality improvements.

This paper primarily contributes to the growing literature on water demand estimation in low-income countries (see Szabo (2015); Diakité *et al.* (2009); Violette (2017); Nauges and Van Den Berg (2009)). There have been several previous studies that have estimated WTP for improvements in water service quality, but these studies have relied primarily on stated preference survey methods (see del Saz-Salazar *et al.* (2016); Akram and Olmstead (2011); Gunatilake *et al.* (2014); Ahsan *et al.* (2021)). Revealed preference estimates for improvements in water quality have been limited (Kremer *et al.* (2011); Ashraf *et al.* (2010)), and I am not aware of previous research that has estimated demand for piped-water quality improvements using a revealed preference approach. This paper also contributes to the well-established result from previous research that demand for improvements in health and environmental quality in low-income countries is generally low and highly income elastic (Kremer *et al.* (2011); Hall and Jones (2007); Greenstone and Jack (2015); Dupas and Miguel (2017)).

This paper proceeds as follows. Section 2 describes the institutional context of this study, the administrative and household survey data used, and the stated WTP estimates from household survey data. Section 3 presents the empirical strategy used to estimate revealed preference WTP and the IV approach which is used to estimate demand for piped-water quality. Section 4 presents the estimation results, and Section 5 concludes.

2 Research Setting and Data Description

This research project studies the WTP for piped-water supply quality in the context of a piped-water distribution network in Livingstone, Zambia. This research was conducted in partnership with the Southern Water & Sanitation Company (SWSC). SWSC is a private water utility company that is responsible for providing water and sewerage services to the entire Southern Province of Zambia. Water utilities in Zambia are regulated nationally by the National Water Supply and Sanitation Council (NWASCO), which approves major policy changes such as tariff increases. Tariff increases are accepted or rejected by NWASCO conditional on performance standards such as service hours, revenue collection efficiency, and the share of customers who are metered (NWASCO, 2020). A key challenge for SWSC is addressing non-revenue water losses from a combination of customer non-payment and water losses through leaks. Figure 1 shows the difference between total water produced at the treatment plant and water billed to the customer. Approximately half of the total water produced is lost through leaks in pipes before it is billed to the customer. It is estimated that national water utility companies in Zambia lost more than $500 million in technical and commercial losses between 2011 and 2017 (The World Bank, 2020).

2.1 Administrative Data

Administrative data was collected from SWSC from all residential, commercial, and institutional customers from December 2012 to June 2019. In June of 2019, there were 24,710 customers in Livingstone. Residential billing data include 1.6 million water bills over this period. Administrative billing data includes an itemized list of charges, total arrears to the company, an indicator for whether the customer is metered or unmetered, and an indicator for whether the customer's connection is currently active or disconnected due to nonpayment. Administrative data also include the total monthly payments made by each customer. Table 1 present summary statistics of the administrative data at both the billing level and the customer level. Households pay less than 90 percent of their bill on average and often accumulate large outstanding balances. By June of 2019, the average outstanding balance was over 500 ZMW (approximately 50 USD), which is approximately five times the average water bill. As a result of nonpayment, approximately 20 percent of households have disconnected accounts.[1] In the primary empirical analysis, disconnected customers and unmetered customers whose water consumption cannot be determined, are not included in the water demand estimation. Nonpayment of water bills results in insufficient cost recovery for the water utility. Figure 2 shows the average price of water, the marginal cost of supply, and the effective price of water (the price that households pay after accounting for non-payment). The average price of water is typically set above marginal cost, but the effective price of water is often insufficient to recover operating and management costs. Insufficient cost recovery limits the ability of the water utility to upgrade the quality of service and replace degrading infrastructure.

Panel (B) of Table 1 displays summary statistics at the customer level. Sixty-five percent of residential customers are Domestic Low households, which is a taxcode designation for

[1] See Spink (2022a) for an analysis of supply disconnections and payment enforcement in Livingstone.

the size of the household's plot.[2] Domestic Low households are generally lower income households in densely populated areas of the city (see Figure 3). Thirty-nine percent of households are connected to SWSC's sewer system, and these households are located geographically near the center of town (see Figure 4). Table 5 shows a comparison of several administrative and household survey variables for Domestic Low and Domestic Medium and High households. Domestic Low households consume less water, have a lower monthly bill, and make lower payments to the water utility than Domestic Medium and High households, however, Domestic Low households have similar arrears to Domestic Medium and High households. Domestic Low households are also more likely to be unmetered and disconnected. Domestic Low households have a household income that is approximately half of the average income of Domestic Medium and High households. Domestic Low households also spend an average of 12.6 percent of monthly income on water compared to 7.6 percent for Domestic Medium and High households. Domestic Low households are also less likely to have indoor plumbing, bathtubs or showers, septic tanks, and electricity connections.

2.2 Water Quality Data

I develop a measure of supply quality using water test data collected by SWSC. The water utility routinely monitors water quality on a weekly basis at several points throughout the city (see Figure 5). I average the water test values for each location over each billing month period. Figure 6 shows the distribution of the water test averages. The vertical lines in Figure 6 show the water quality standards. The primary quality measures used in this paper are indicator variables for whether the water test is out of compliance for that month for low chlorine, high chlorine, high turbidity, and poor color. There is significant bunching of chlorine values around the quality standards. As such, I define values exactly equal to the quality standard to be out of compliance. For color variables, the out of compliance value is

[2] Household plots that measure less than 540 square meters are classified as Domestic Low cost and households plots that measure between 540 and 1,350 square meters are classified as Domestic Medium cost. Household plots larger than 1,350 square meters are classifed as Domestic High cost plots (UN-Habitat, 2012).

15 cu, and no water tests achieve that value. Instead, I use the value of 5 cu or higher to be out of compliance for poor color. Scherer (2019) states that 5 cu is the lower bound of the point of customer complaint.

Water tests are linked to customers by geographically matching households to the nearest water test location. In the primary empirical analysis, observations that are more than 400 meters (approximately 0.25 miles) from the water test are excluded. Households in the same neighborhood typically draw water from the same main line (see Figure 7), and therefore, it is likely that households in the neighborhood of the water test location would experience similar quality. Table 2 show bivariate correlations of quality variables and network characteristics. Low chlorine and poor color a positively correlated with longer distances from production points and lower altitudes, and high chlorine and turbidity are positively correlated with higher altitudes and shorter distances from supply points.

2.3 Household Survey Data

To supplement the administrative and water quality data, a random sample of 808 households in Livingstone were surveyed in September of 2019. These households were sampled from SWSC's customer listing, and the sample was stratified by SWSC's administrative billing zones. If a household declined to respond or could not be reached after two attempts, it was replaced with a randomly drawn household from the unsampled population of the same stratum. Table 4 shows balance checks of relevant administrative data from 2019. The surveyed sample contains a higher share of older accounts and households that are connected to the sewer, but there are no other significant differences between the two groups for other administrative variables. The higher proportion of older accounts could be due to the fact that households that opened an account with SWSC after the network GIS mapping was completed in 2018 do not contain geographical coordinates and needed to be located using their home address, which was significantly more challenging for the enumerators. These newer accounts are often added in the periphery of the city, which are in areas not covered by the sewer network (see Figure 4). Households without GIS coordinates, however, are excluded from the primary empirical analysis of this paper due to the fact that they are unable to be matched to water quality data.

The first part of the household survey included demographic information about the household including household income, household size, the presence of indoor plumbing, the number of flush toilets and showers, and the number of additional household drawing water from their connection. Panel A of Table 3 presents summary statistics of household demographic variables. Household in Livingstone have an average income of 2,600 ZMW (or approximately 260 USD) per month. The median household spends approximately 7 percent of household income on water, which is above the commonly used affordability threshold of 5 percent of income (Banerjee *et al.*, 2011).[3] More than half of households do not have indoor plumbing or flush toilets, but 90 percent of households have an electricity connection.

2.4 Self-reported Quality Data

The second section of the survey contains questions about water sources and the quality of the piped water including the number of supply hours, the number of monthly outages, and whether the households have experienced any of the following in the past year: low pressure, bad taste, cloudy water, unusual color, or unexplained outages. Panel B of Table 3 shows summary statistics of these quality variables. Water source options for households in Livingstone include piped water, boreholes, public taps, and shallow wells. However, the nearly 98% of surveyed households (including both connected and disconnected households) responded that piped water from SWSC was their primary source of water, either through their own connection or a neighbor's connection.

Approximately one third of households report experiencing low pressure and water of unusual color and approximately 10 percent of household report experiencing cloudy water

[3]Previous research has argued that self-reported measures of income are likely to be underreported, and consumption or expenditure data in household surveys is often more reliable (Meyer and Sullivan (2003); Carletto *et al.* (2021)). The household survey asked respondents to estimate monthly household income, and therefore the water bill share of income measures are likely to be overstated. It is also possible that some respondents reported their own income instead of the household total.

and water with a bad taste. Households have 17 hours of water supply per day on average, but some households have as little as 6 hours of supply. Households report storing an average of 100 liters of water. Households report treating water before consumption approximately 10 percent of the time and boil water before consumption 20 percent of the time. Incidence of diarrheal diseases among children is high — one third of households with children reported that a child in the household became sick with diarrhea.

While these self-reported measures of service quality and water quality provide some information about the geographical distribution of quality, there could be biases in reporting of these subjective measures. Self-reported estimates of quality may be subject to frame-of-reference bias in which respondents of different socioeconomic statuses use different standards for scaling their welfare (Beegle *et al.* (2012); Ravallion and Lokshin (2001)).[4] Even in the absence of frame-of-reference bias, there is the concern that higher-income households may be better able to detect poor service quality. For example, households with indoor plumbing may be better able to detect issues with water pressure. Households with only a backyard tap generally fetch water in colored buckets, and households with indoor plumbing, in which water collects in porcelain sinks, may also be better able to detect changes in color. In Livingstone, less than half of the surveyed households have indoor plumbing, and these high-income areas are clustered in the center of town and the northern and western highlands (see Figure 3).

To test the correlation between reported and observed measures of quality, I estimate the following regression at the household level.

$$Q_{Reported,i} = \boldsymbol{Q}'_{WaterTest,i}\beta + \boldsymbol{X}'_i\rho + \varepsilon_i \qquad (1)$$

$Q_{Reported,i}$ is the reported quality estimate for household i from the household survey.

[4]Bertrand and Mullainathan (2001) further outlines other sources of bias that can be introduced from household surveys including cognitive problems and social desirability bias. Another concern among the survey enumerators was that households were reporting poor quality in the hopes that the water utility would address the problem. Households in this case were told to contact SWSC directly.

$\boldsymbol{Q}_{WaterTest,i}$ is the average of observed water tests from the last three years of the sample for each of the four indicators: low chlorine, high chlorine, high turbidity, and poor color. $\boldsymbol{X}_i$ is a vector of household characteristics that may affect reporting of quality including the natural log of household income and whether the household has indoor plumbing. The results of equation 1 identify off of spatial variation in both observed and self-reported quality measures.

Table 6 presents the results of equation 1. Observed low chlorine is positively correlated with reported low pressure but negatively correlated with self-reported bad tasting, cloudy, and unusually colored water. Poor color is positively correlated with self-reported low pressure and bad tasting water. High turbidity is negatively correlated with households reporting bad taste, unusual color, and interestingly, cloudy water as well. One potential explanation for this is that water tests with high turbidity are primarily observed during the end of the rainy season and may indicate high supply of water for those households during rainy season months. Households with indoor plumbing are significantly more likely to report low pressure but not other measures of poor quality. Households with indoor plumbing are likely to be located in the Domestic High areas of the city (see Figure 3). Household income does not significantly affect the reporting of poor quality.

2.5 Stated Preference WTP Estimates

The household survey included several WTP for improved quality questions using a contingent valuation (CV) approach (see Whittington (2010) for a review of CV methods in developing countries). While economists have long recognized the potential problems with estimating WTP from hypothetical scenarios using survey methods, CV estimates are widely used in situations in which revealed preference estimates are challenging Hanemann (1994). The household survey contained several hypothetical WTP questions of the form:

"If given the choice between your current piped water supply and a water supply with consistent high pressure but with a higher monthly water bill, which option would you choose? Assume that nothing else about the quality of the water, the water taste and color, or the frequency of outages would change."

Households were given a menu of prices ranging from a 5 ZMW higher water bill to a 50 ZMW higher water bill (in 5 ZMW increments) and were asked about each subsequent value number. If a household was willing to pay more than 50 ZMW, this value was stated directly by the respondent. Once a household claimed that they would not be willing to pay the given amount for higher quality, the enumerator proceeded to the next survey question. Since no actual monetary decisions were made, the stated preference WTP estimates are not incentive-compatible. The categories of WTP questions include consistent high pressure, 24-hour supply of water, water with a normal taste and color, and water that is safe to drink directly out of the tap. The order of the WTP questions were randomized for each survey. Table 3 shows summary statistics of the amount that households are willing to pay for improvements in supply quality. Households are on average willing to pay a 1.1 USD increase in their water bill for consistent high pressure, a 1.4 USD increase for 24-hour supply, a 1.5 USD increase for water that if safe to drink, and a 1.5 USD increase for water with normal taste and color. However, these averages may be driven largely by high-income users. The median amount that sampled households were willing to pay is zero for all categories except safe water, in which the median amount that households are willing to pay for water that is safe to drink is a 0.5 USD higher bill.

Figure 9 shows stated WTP estimates by income group. High-income households are defined as household with above the median income, and low-income households are those below the median income. High-income households are willing to pay more for quality improvements in Zambian Kwacha, total water bill, and in terms of the percentage increase in their water bill. Low-income households, however, are willing to pay more for quality improvements in terms of the percentage of monthly household income. High-income households are willing to pay a maximum monthly bill of 16.1 to 16.6 USD per month for water with quality improvements, and low-income households are willing to pay a maximum monthly bill of 13.6 to 13.8 USD per month for water with quality improvements. Stated preference results are higher than results found by Akram and Olmstead (2011). Akram and Olmstead (2011) find that households in Lahore, Pakistan are willing to pay between 7.5 and 9 USD per month for water that is safe to drink out of the tap, however, the average water bill in Lahore at the time of the survey was only 2.40 USD.

One concern with the use of stated preference results is that because households do not face actual monetary choices, stated preference results may be overstated Whittington (2010). In a comparison of stated and revealed preference estimates for improved non-piped water sources (protected wells) in rural Kenya, Kremer *et al.* (2011) finds that stated preference WTP estimates for improved water sources were twice as high as revealed preference estimates. Stated preference results in this study are approximately three to four times higher than revealed preference estimates, however the stated and revealed preference estimates cannot be directly comparable because they measure different improvements in quality. For example, the stated preference results ask household what they would be willing to pay for water that is safe to drink or of consistent high pressure, and the revealed preference estimates indicate what households are willing to pay for water quality that is within standards for chlorine, turbidity, and color.

3 Empirical Strategy

3.1 Nonpayment Responses to Quality

To estimate revealed preference WTP estimates, I first study nonpayment responses to changes in quality. As discussed in Section 2, households in Livingstone pay less than 90 percent of their water bill on average. Payments that occur in month t are for consumption that occurred in month $t-2$ (see Figure 10). Due to the delay in consumption and payments, I am able to test how current payments made to the water utility are affected by current period quality using the following regression.

$$NP_{it} = \boldsymbol{Q}'_{it}\beta + \boldsymbol{X}'_{it}\rho + \eta_i + \tau_t + \varepsilon_{it} \quad (2)$$

NP_{it} is nonpayment in period t for household i measured by $\text{Total Bill}_{i(t-2)} - \text{Total Payments}_{it}$. $\boldsymbol{Q}_{it}$ are indicators for water quality outside of standards for low chlorine, high chlorine, high turbidity, and poor color. Equation 2 controls for temporal changes in payments resulting from price changes or city wide policy or quality changes through month-by-year fixed effects, τ_t. I further control for household characteristics that may affect monthly payments using customer fixed effects, η_i. Spink (2022a) shows that the size of the administrative zone affects payment enforcement, and Spink (2022b) shows that household payments are highly responsive to becoming newly metered. I therefore control for size of the administrative zone and metering status of the customer in the matrix $\boldsymbol{X}_{it}$. I am therefore able to isolate payment responses of households resulting from idiosyncratic changes in quality that is observed by the household in period t.

Equation 2 may be biased if current period payments affect current period quality. There are several reasons why this is unlikely to be the case. First, 80 percent of payments are made after the 10th day of the billing cycle giving insufficient time for the water utility to invest in quality improvements. Second, water may take several days to reach the customer from supply points. Finally, billing and payment summaries are generally presented to the water utility after the billing cycle is complete.

Underpayment in the current period will increase a household's payment liability in the subsequent periods. Most households hold substantial arrears to the water utility. The average arrears of households in June of 2019 were 503 ZMW (approximately 50 USD). Metered households may respond to poor quality by both lowering demand in the current period (and subsequently lower their future payment liability) as well as lower current period payments, which will raise their future payment liability. Unmetered households, on the other hand, are charged the same fixed fee regardless of consumption and only alter payments through nonpayment on the current water bill. Nonpayment may increase a household's probability of being disconnected, which therefore provides a measure of the household's long-run valuation of the water connection.

3.2 Demand Responses to Quality

I next study household demand responses to changes in quality. Revealed preference estimates for demand for piped-water quality improvements are determined by estimating the following equation.

$$ln(w_{it}) = \alpha ln(p_{it}) + \boldsymbol{Q}'_{it}\beta + \boldsymbol{Z}'_{t}\gamma + \eta_i + \sigma_m + \varepsilon_{it} \quad (3)$$

In this demand equation, $ln(w_{it})$ is natural log of the monthly water consumption for household i in month t. The sample is restricted to metered and connected customers that consume a positive monthly quantity of water. I further exclude months of the sample in which there were a supply shortage (June of 2014 and October of 2018). Figure 1 shows that the shortage of water produced affected household consumption in these months. $ln(p_{it})$ is the natural log of the marginal price. $\boldsymbol{Q}_{it}$ is a matrix of quality indicators for poor water quality (water quality outside of standards) including low or high chlorine, high turbidity, or poor color. $\boldsymbol{Z}_t$ is a matrix of weather controls including monthly rainfall and temperature per month. σ_m are month fixed effects which additionally control for seasonal variation in demand. The term η_i are household-level fixed effects, which control for unobserved household characteristics that influence water demand, and ε_{it} is a random error term. Standard errors are clustered at the household level to adjust for serial correlation in water consumption at the household level.

Estimating demand for piped water under an IBT is challenging due to two primary sources of endogeneity that may bias ordinary least squares (OLS) demand estimates: (i) simultaneity of demand and supply equations, and (ii) consumption directly influencing marginal prices. Simultaneity bias in the context of water utilities is less of a concern than when estimating demand for typical market goods because prices are set administratively and may not reflect the marginal cost of supply. Olmstead (2009) argues that because water prices are changed infrequently at the administrative level, that price instruments would not be necessary if water prices were linear and budget constraints unkinked. Water pricing in Livingstone follows an IBT tariff structure with four pricing blocks (see equation 4 and 8). The price structure of the IBT itself creates a second source of endogeneity because the marginal price that a household pays is determined by a household's level of consumption. The IBT will therefore produce a positive correlation between the average price, p_{it}, and the error term, ε_{it}, and an upward bias of the regression coefficient on price in OLS estimates of equation 3.

$$p(w) = \begin{cases} p_1, & \text{if } w \in (0, \tilde{w}_1) \\ p_2, & \text{if } w \in [\tilde{w}_1, \tilde{w}_2) \\ p_3, & \text{if } w \in [\tilde{w}_2, \tilde{w}_3) \\ p_4, & \text{if } w \in [\tilde{w}_4, \infty) \end{cases} \tag{4}$$

3.3 Price Instruments

To address endogeneity of marginal prices under an IBT, instrumental variable (IV) methods have been widely used to estimate water and electricity demand. A common approach in the literature is to instrument actual marginal or average price with a linear combination of the full schedule of administrative marginal prices (Olmstead (2009); Szabo (2015); Hung and Huang (2015); Jia *et al.* (2021)).[5] Administrative prices are highly correlated with the observed marginal or average price that customers pay, but administrative price changes are unlikely to be correlated with unobserved portion of household demand for water, ε_{it}. If households stay within a consumption block and there is no bunching at the kink points, administrative price IVs should produce unbiased estimates of price elasticities.[6] However,

[5] Olmstead (2009) uses the full marginal price schedule and fixes fees as instruments for marginal price, and Szabo (2015) uses the full marginal price schedule as an instrument for average price. Hung and Huang (2015) and Jia *et al.* (2021) use a weighted average of marginal prices as an instrument for marginal price. Specifically, the instrument is the slope of a regression of total price calculated at uniform quantity bins on the bin quantities.

[6] Figure 12 shows a histogram of water quantities for metered and connected customers. There is little evidence of bunching at the kink points of the IBT. Rather, there is substantial bunching at multiples of 10, which is likely due to intentional or unintentional reporting errors on the part of the meter reader.

if household consumption shifts between consumption blocks, the problem of endogenous prices resulting from the IBT tariff structure remains. For example, if there are unobserved preference shocks that move households to a different tier of the IBT, these demand shocks will be correlated with the marginal price of consumption. In Livingstone, there are 4 consumption tiers in the water tariff, and significant within-household movement between tiers is likely to occur.[7]

Mansur and Olmstead (2012) attempt to address the problem of movement between IBT tiers by instrumenting marginal price with the expected marginal price. The expected marginal price is calculated seasonally for each household using structural demand parameters from Olmstead (2009). The authors note that this approach captures seasonal variation in the marginal prices paid resulting from movement between IBT tiers. There is significant seasonal variation in water demand in Livingstone, particularly for Domestic High households (see Figure 13).[8] McRae and Meeks (2016) adapt the process in Mansur and Olmstead (2012) by using a regression of pre-price reform demand to generate the expected marginal price per household in lieu of structural demand parameters. I follow a similar approach by calculating the household's expected marginal price using the following demand model.

$$ln(w_{it}) = \boldsymbol{X}'_{it}\beta + \tau_t + \lambda_r + \varepsilon_{it} \quad (5)$$

[7]Recent research has used discrete continuous choice (DCC) models to address the endogeneity of prices and demand under an IBT (Hewitt and Hanemann (1995); Olmstead (2009); Szabo (2015)). Olmstead (2009) argues that DCC models may have potential advantages over IV approaches because they theoretically can produce consistent and unbiased estimates and are also consistent with utility theory, however, they are more computationally intensive to estimate.

In a comparison of reduced form and structural approaches to estimating water demand, Olmstead (2009) finds DCC estimates of price elasticities which are larger in magnitude than IV estimates, and a similar result was found by Szabo (2015). Olmstead (2009) additionally conducts a Monte Carlo comparison of the bias of DCC and IV estimates and argues that the bias is substantial in both models. The bias in DCC models is smaller when the variation in consumer demand is primarily from household preferences, and neither model has an advantage when demand varies primarily through exogenous shocks.

[8]Seasons in Livingstone include a rainy season from mid-November to mid-March. No rain typically occurs during the dry season months of April to October. The months of May to July are typically cooler, but the warmest months of the year (September through November) occur during the end of the dry season. Peak water demand is therefore expected during these months (see Figure 13).

In equation 5, $\boldsymbol{X}_{it}$ is a matrix of binned household characteristics including an indicator for whether the household is Domestic Low, Domestic High, and connected to the sewer network. λ_r are region fixed effects. τ_t are month-by-year fixed effects that absorb any variation in price or yearly or seasonal changes in demand. Equation 5 is estimated in order to obtain a predicted level of water consumption, $\widehat{ln(w_{it})}$ for each bin of $\boldsymbol{X}_{it}$ within region and within month-by-year. The predicted $\widehat{ln(w_{it})}$ and standard errors are used to calculate the probability of households in that bin and region consuming in each IBT block during that month. I use the predicted probabilities from the same month in the previous year to estimate the current year's expected marginal price by multiplying these probabilities by the respective current year's marginal prices. Specifically, the expected marginal price is calculated as follows.

$$E[MP] = \sum_{i=1}^{4} p_{it} P(w_{b,t-12} \in (\underline{w_i}, \overline{w_i})) \tag{6}$$

where $w_{b,t-12}$ is the predicted water consumption for the household bin group in the previous year. This approach using the previous year's consumption to generate an expected marginal price is likely consistent with how customers estimate their expected water bill for the current year for several reasons. First, prior research has demonstrated that customers are more responsive to the average price of consumption or an expected marginal price rather than the marginal price (Ito (2014); Borenstein (2009); Shin (1985)). Secondly, previous research has shown that customers in Livingstone have a low literacy of water bills. Jack *et al.* (2018) conducted a household survey of customers in Livingstone and find that only 10% to 14% of surveyed heads of households in Livingstone can correctly locate the water quantity consumed on their water bill.[9] Economic theory suggests that customers maximize utility under an IBT by first choosing the kink point or line segment to consume at and then choosing optimal

[9]Szabó and Ujhelyi (2015) similarly find that only 12% of surveyed households in Pretoria, South Africa can correctly state the water consumption on their water bill.

water quantities within that segment. When customers have limited understanding of the tiered tariff structure, optimization of this type is unlikely to occur in practice. Finally, marginal prices in Livingstone typically are raised once per year in February and announced to customers on their water bill (see Figure 8). Customers can therefore predict that average prices in the current year will be some percentage increase from the previous year's prices.

The primary results in this paper use the expected marginal price as an instrument for the observed marginal price. I further compare the expected marginal price instrument to an instrument using a linear combination of marginal prices following Szabo (2015), which I refer to as the linear IV in empirical results. In these regressions, I instrument for average price using the full set of administrative marginal prices. Average price is used in the demand equation in this case because of the same rationale as described in the previous paragraph.

3.4 Quality Measures

I incorporate measures of piped-water quality into equation 3 using data from water tests conducted by SWSC. The quality variables are indicators for poor water quality including low chlorine, high chlorine, high turbidity, and poor color. Specifically, the indicator is equal to one when the water test is out of compliance with standards.[10]

Because equation 3 includes customer-level fixed effects, any spatial variation in quality that is correlated with demand is controlled for.[11] I control for seasonal variation in demand using weather controls and month fixed effects. The model does not include month-by-year fixed effects because the identifying price variation (changes in administrative prices) occurs at this level. The model therefore identifies demand for quality using temporal changes in quality. A primary concern is that local changes in demand may affect local quality. High

[10]SWSC defines water tests to be out of compliance for color if the water is 15 cu or higher. No water tests collected exceed this threshold. I define any detectable color change (5 cu or higher) to indicate poor color.

[11]Figure 14 shows the geographical variation in water test data. Domestic High areas (see Figure 3) appear to have higher chlorine levels on average. Additional storage facilities are located in Domestic Medium and High areas as well (see Figure 15), which suggests that the water utility may prioritize service quality in these areas.

local usage may affect local pipe pressure and thus the value of the water test. Another concern is that these temporal changes in quality are correlated with changes in demand. For example, the estimation results would be biased if the water utility prioritized quality improvements to household with growing demand for water. In order to obtain unbiased estimates of demand for quality, changes in quality must be idiosyncratic, for example, resulting from leaks or non-local changes in demand.

There are several ways in which household's local water quality may be affected by factors that are uncorrelated with the household's demand. First, a household's supply of water depends on complex interactions of altitude, distance from supply points, and upstream or downstream demand for water. The composition of the water network has changed over time and over 7,000 new accounts were added between 2013 and mid-2019. Most of these new accounts were added in newly connected neighborhoods in peri-urban areas of the city, which requires the installation of new main line pipes and the diversion of water from previously connected areas. Second, high-altitude neighborhoods may alternate between periods of being gravity fed from a reservoir or being supplied through direct pumping from the supply station when the reservoir is low. Finally, leaks and pipe bursts are common in Livingstone. There were over 1,000 customer complaints of leaks and pipe bursts throughout the sample period.

Figure 11 shows temporal variation in quality measures separately for Domestic Low and Domestic Medium and High households. High turbidity is largely seasonal and occurs during the end of the rainy season. Periods of poor color only occurred during a four-month period in early 2018. Quality plots show greater variation in turbidity and color water tests, which is likely due to the fact that water tests of turbidity and color occurred less frequently than tests of chlorine. There is some evidence of more chlorine being used over time, but this appears to affect both Domestic Low and Domestic High households.

3.5 Willingness to Pay for Quality Improvements

Using the coefficient point estimates and standard errors from equation 3, I calculate the WTP for improvements in service quality as follows for each coefficient in the β vector.[12]

$$WTP = \frac{\beta}{\alpha}\overline{p} = \frac{\frac{\partial_w/w}{\partial_Q}}{\frac{\partial_w/w}{\partial_p/p}}\overline{p} = \frac{\partial_p}{\partial_Q} \tag{7}$$

where $\overline{p}$ is the average observed marginal price. This estimate is the ratio of the quality elasticity to the price elasticity multiplied by the average marginal price in the sample.

3.6 Self-Reported Quality Measures

I further test how demand responds to self-reported quality measures from the household survey. These self-reported quality measures may be subject to reporting bias as discussed in Section 2. I estimate the following adaptation of equation 3.

$$ln(w_{it}) = \alpha ln(p_{it}) + \boldsymbol{Q}'_{it}\beta + \boldsymbol{X}'_{it}\rho + \boldsymbol{Z}'_{it}\gamma + \lambda_r + \sigma_m + \varepsilon_{it} \tag{8}$$

The estimation is restricted to households that were surveyed. I further restrict the sample to only the three years prior to when the survey was conducted. Because the variation in quality occurs at the customer level, I am no longer able to control for customer-level fixed effects. Instead, I include a matrix of household characteristics that may affect water demand, $\boldsymbol{X}_{it}$. Importantly, the matrix $\boldsymbol{X}_{it}$ includes household income, from which I am able to estimate income elasticities of demand. Following Olmstead (2009), I use virtual income, $\overline{Y}_{it}$, instead of actual income, Y_{it}, to account for the implicit subsidy households receive as a result of the IBT structure when they consume above the kink point. The implicit subsidy for a household consuming in the kth tier is defined as the difference in marginal prices

[12] Standard errors for WTP estimates are calculated using the delta method:

$$Var(\delta) \approx \frac{\overline{p}}{\alpha^2}[Var(\beta) + \delta^2 Var(\alpha) - 2\delta Cov(\alpha, \beta)]$$

between the $k+1$ and kth consumption tier, multiplied by the water quantity cutoff of the kth tier. Virtual income is expressed as follows.

$$\overline{Y}_{it} = Y_{it} + w_k(p_{k+1} - p_k) \tag{9}$$

Equation 8 identifies changes in demand for quality primarily from geographical variation in the self-reported measures. The matrix $\boldsymbol{Q}_{it}$ includes the self-reported share of the time that households experience low-pressure, bad tasting water, cloudy water, and water of an unusual color. Water test data shows geographical variation in observed water quality (see Figure 14). If the water utility prioritizes quality to households with higher demand, the results identifying from geographical variation will be biased. To address some of this concern, I include region fixed effects, λ_r. To control for season variation in water demand, I again include month fixed effects, σ_m, and weather controls, $\boldsymbol{Z}_{it}$. Standard errors in equation 8 are clustered at the household level.

4 Revealed Preference Results

4.1 Payment Responses to Quality

Table 7 presents the results of estimating equation 2. Household nonpayment increases by 0.4 to 0.6 USD per month when exposed to low chlorine. As seen in Table 1, low chlorine levels are highly correlated with surveyed households reporting low pressure. Metered and high-income households appear more responsive to low chlorine and increase nonpayment between 0.5 and 1.5 USD. This pattern is not surprising because Domestic Medium and High households are more likely to be metered. 80 percent of Domestic Medium and High households are metered, compared to only 56 percent of Domestic Low households. Unmetered and Domestic Low households increase nonpayment when experiencing poor color by 1.2 to 2.1 USD and increase nonpayment when experiencing high turbidity by 0.5 to 0.7 USD. Nonpayment responses to high chlorine levels are negative across all regressions, but these results are not statistically significant.

Nonpayment in the current period should result in a higher bill in the following period through the accumulation of arrears. Metered households may lower current period consumption as well as lower current period payments in expectation of a lower future bill; this will not be the case for unmetered households whose consumption is independent of their bill. Higher arrears are likely to result in a higher probability of being disconnected due to nonpayment. Increases in nonpayment therefore provide a measure of the long-run valuation of the water connection. However, in some cases, customer complaints may result in the water utility issuing a credit adjustment on the customer's account, but I do not observe this in the billing data. Nonpayment estimate in this care would provide a measure of customer dissatisfaction with the quality of service.

4.2 Demand Responses to Quality

Table 8 provides results from estimating equation 3. Price elasticity estimates range from -0.24 to -0.10 across specifications. These estimates are much lower than those found in previous studies in low-income countries. Table 9 presents the average of price elasticity and income elasticity estimates from previous water demand studies. Price elasticities from studies in developing countries range from -0.98 to -0.3. Table 9 further shows that IV estimates are generally lower than structural demand estimates that have been presented in the literature.

Table 8 shows that demand estimates using the expected marginal price instrument and estimates using the full set of marginal prices as instruments produce very similar results for price and non-price independent variables. The expected marginal price IV attempts to address seasonal variation in demand that results in within-customer movement between IBT blocks. Importantly, neither IV addresses concerns of endogeneity of price and quantities for customers that consume in the neighborhood of the kink points. Because of this, Szabo (2015) argues that any instrument that is based on administrative prices under an IBT will not be valid.

Columns (3) and (7) of Table 11 include only chlorine quality indicators, and columns (4) and (8) additionally include indicators for turbidity and color. These results are presented separately because color and turbidity were not tested as frequently as chlorine. When low chlorine is experienced, water demand is reduced by 2.6 to 6.7 percent across specifications. High chlorine results in a 1.5 to 2.9 percent decrease in demand. When the household experiences high turbidity, demand increases by approximately 3.9 to 4.5 percent. Demand is reduced by 6.6 to 6.9 percent when the household experiences poor water color. A possible explanation for this is that high turbidity is seasonal and occurs during the end of the rainy season (see Figure 13). While the estimation in equation 3 controls for month fixed effects and weather controls, positive demand responses to turbidity could be caused by higher supply either through higher pipe pressure or less service rationing during the rainy season.

There are several factors that can explain why the price and income elasticites are lower in magnitude than in previous literature. First, many households in Livingstone are not offered full 24 hours service. Table 3 shows that the average number of supply hours per day is 17 hours, and some households only receive 6 hours of supply per day. Service rationing may make it difficult for households to adjust consumption in response to price. Strand and Walker (2005) finds much lower in magnitude price elasticities of -0.1 for households with very low consumption who supplement their water supply with other sources of water. More worrisome is that service rationing may be correlated with quality indicators, particularly low chlorine and poor color. Low chlorine levels are highly correlated with low pipe pressure, and I am unable to distinguish between reductions in demand that occur when households experience low pressure and potential reductions in supply that may cause low pressure. Low chlorine and poor color are positively correlated with low pipe pressure, while high chlorine and high turbidity are negatively correlated with low pipe pressure (see Table 6).

Table 10 shows the results of equation 3 and equation 7. Panel A presents demand estimates of price and quality independent variables. Columns (1) and (2) present the results of equation 3. Columns (3) and (4) present the results using the linear IV. Columns (5) and (6) restrict the sample to Domestic Low households, and columns (7) and (8) restrict the sample to Domestic Medium and High households. Water demand is found to be more elastic for Domestic High households, and price elasticities for Domestic Low households was found to be zero. A possible explanation for this is that Domestic Low households may be unable to adjust consumption downward in response to price for two reasons. First, a higher percentage of Domestic Low households consume close to the basic water requirement for drinking, cooking, washing, and bathing, and thus have limited ability to adjust consumption in response to price. Second, service rationing, which more commonly occurs in Domestic Low areas, may further limit consumption responses. A final explanation is that Domestic Low households are less aware of price changes and IBT pricing structures. However, Table 7 does show consumption responses for Domestic Low households when experiencing poor color. As mentioned above, a primary concern is that poor quality, particularly on low chlorine and poor color metrics, may be correlated with service rationing.

Panel B of Table 10 shows that households are willing to pay 0.12 to 0.40 USD per month for water quality within standards when experiencing low chlorine, and 0.07 to 0.16 USD per month when experiencing high chlorine. Households are willing to pay 0.35 to 0.42 USD per month for water within standards when experiencing poor color. WTP for water quality within standards are negative when households experience high turbidity and range from -0.27 to -0.20. As discussed above, this may be a result of higher supply of water during the rainy season rather than actual demand for turbidity. As discussed in section 3.4, there are additional concerns that quality variables are correlated with demand, either because the volume of water supplied affects water quality tests or because local demand influences local quality. Table 10 shows no significant estimates of WTP for quality for either Domestic Low or Domestic Medium and High households. The results in Table 7 produce similar results to nonpayment responses to quality presented in Table 2. Both estimates show that households are willing to pay for water within standards when experiencing low chlorine and water within standards when experiencing poor color. Demand WTP estimates are smaller than payment WTP estimates, and both are generally smaller than stated preference results.

4.3 Demand Responses to Quality: Self-Reported Quality Data

Table 11 shows the results of estimating equation 8, which is restricted to surveyed households. Column (1) presents results from equation 3 for the subset of surveyed households. Column (2) present the results of equation 8 using region fixed effects instead of customer fixed effects and household demographic controls. Column(3) additionally includes quality variables. Table 11 shows an income elasticity of demand of 0.72 to 0.82. This estimate is generally lower than what is presented in the literature (see Table 9). Table 11 presents similar results to Table 10 in that low-income households have a lower elasticity of demand than high-income households. Low-income households also have a higher income elasticity of 0.29, while high-income households have a negative income elasticity of -0.06. This may be a result of the highest-income households in Livingstone consuming water primarily from boreholes.

As mentioned in section 2.4, there are significant concerns with the use of self-reported quality variables, particularly that households with a higher demand for quality may report lower quality. Additionally, because equation 8 identifies off of spatial and temporal variation, quality estimates will be biased if the water utility prioritizes quality to households with higher demand for quality. Results show positive WTP for water of normal pressure and color of 0.19 and 0.14 per month, respectively. Similar to the results of equation 3, I find negative WTP for cloudy water of -0.30 per month. As discussed in section 4.2, much of the observed findings could result from supply-side factors. That is, higher chlorine and turbidity may be associated with higher pipe pressure and lower intermittency, and low pressure and poor color may be associated with higher intermittency.

5 Conclusion

Public utilities in developing countries are often characterized by poor supply quality and low levels of revenue collection. A primary concern is that poor supply quality may further reduce water demand among households and revenue collection by the water utility. The combined threat of climate change and urbanization in developing cities is expected to put further stress on freshwater resources. An important area of research is therefore to understand customer demand responses to poor utility quality. However, deriving estimates of WTP for quality is challenging. Stated preference results are widely used but are often considered controversial because they are not incentive compatible. Revealed preference results of WTP for piped-water quality improvements present additional concerns of endogeneity of quality and demand and the inability to distinguish supply and demand factors in the presence of intermittent water supply. For this reason, I study payment responses to quality that are independent of current period demand and find that nonpayment increases in response to poor supply quality.

Despite the endogeneity concerns surrounding revealed preference estimates based on demand, WTP estimates using water test data and estimates using self-reported measures of quality produce similar results to revealed preference estimates based on payment responses to quality. Revealed preference estimates show that households are willing to pay for quality improvements when experiencing low chlorine and poor color, both of which are positively correlated with low pipe pressure. WTP estimates using demand responses to quality are therefore likely to incorporate the effect of reductions in supply that cause low pipe pressure. I find that demand WTP estimates are smaller than payment WTP estimates, and both are generally smaller than stated preference results. Revealed and stated preference results show that households are willing to pay for higher piped-water supply quality but less than an additional 1.4 USD per month, which represents 12 percent of the average bill.

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Appendices

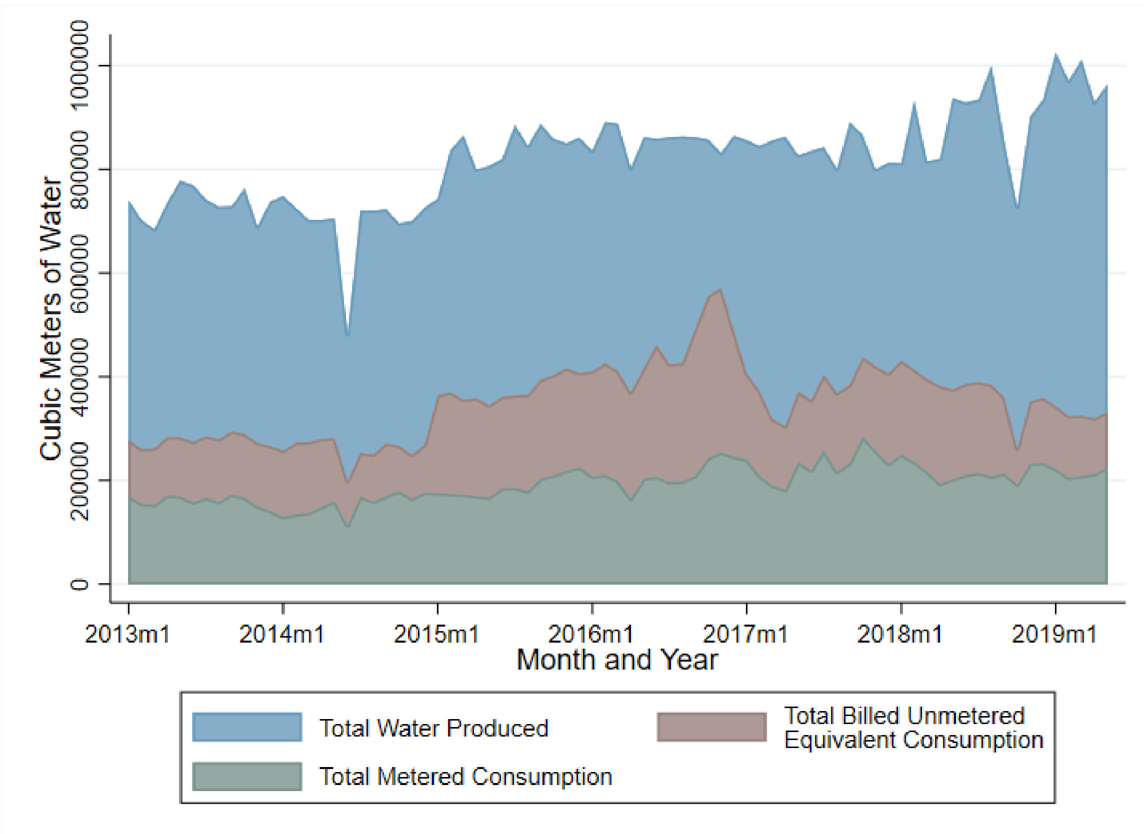
A Data Quality and Treatment of Outliers

There are several data anomalies in the billing data that I address. Data on the customer's outstanding balance is only complete for the last month of the sample. I am unable to iterate these values backwards to calculate outstanding data in previous periods because there are credit and debit adjustments that are not included in the billing data. These credit and debit adjustments occur when there are data entry errors that need to be addressed later by the water utility. The outstanding balance data is therefore only accurate in June of 2019, and I do not include outstanding balance data in the primary analysis for this reason.

There were several instances of unusually high payments and consumption values that are inconsistent with a residential household's consumption of water. In some instances, commercial properties may have been miscoded as residential, or a residential property was converted to a commercial property during the sample period. For example, some households are converted to guest homes. It is not known whether these high-valued payments are data entry errors or actual payments from high paying households. Therefore, if a customer makes a payment that is greater than the 99.9th percentile of the total bill including arrears (7,760 ZMW) from June of 2019, the customer is removed from the sample. There are several data quality concerns in the consumption data as well. I remove observations in which the customer consumed above the 99.9th percentile of residential water consumption (187 cubic meters) because these values are likely to be entry errors or miscoded properties.

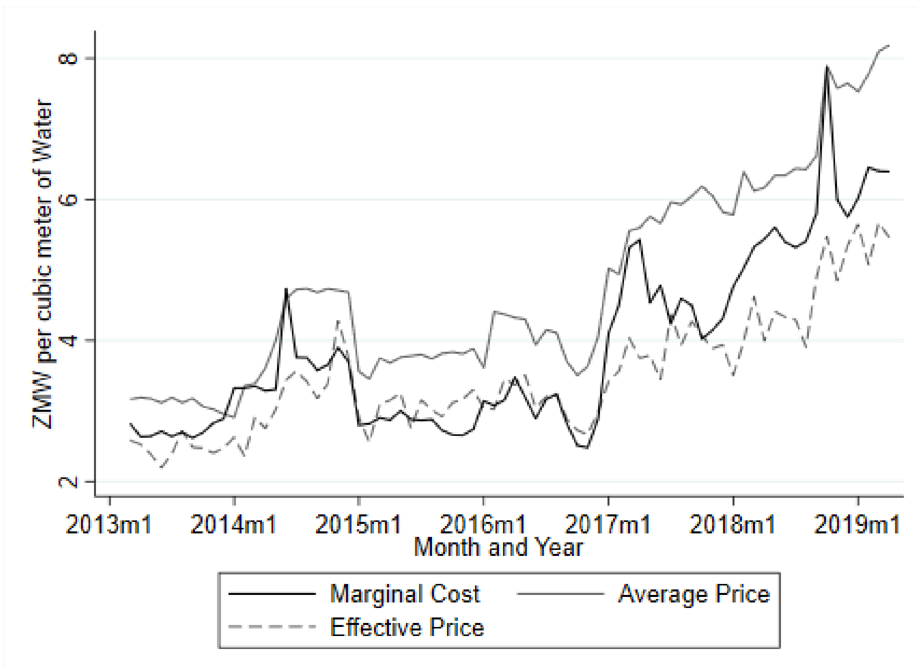
B Figures and Tables

Figure 1: Total water production, metered quantity consumed, and estimated unmetered quantity consumed



Notes: Total production data are obtained from bulk meters at the treatment plant on a monthly level. The total metered consumption is the aggregate metered quantity from both commercial and residential customers. Billed unmetered equivalent consumption represents the metered quantity that would result in the same monthly bill as the unmetered monthly tariff. The total billed unmetered equivalent consumption is the sum of the estimated unmetered quantity for all residential and commercial unmetered customers. The difference between total water produced and the sum of total unmetered and metered consumption represents non-revenue water that is lost through a combination of leaks, theft, and unbilled overuse of water.

Figure 2: Marginal Cost, Average Price, and Effective Price of Water



Notes: This figure presents the average price paid per cubic meter of water across all customers (metered and unmetered) and the marginal cost of production from 2013 to mid-2019. The effective price of water is the average price that consumers face after accounting for nonpayment. Marginal cost data are from the NWASCO Urban and Peri-Urban Water Supply and Sanitation Sector Reports from 2001-2020.

Figure 3: Locations of Domestic Low, Medium, and High Households in Livingstone

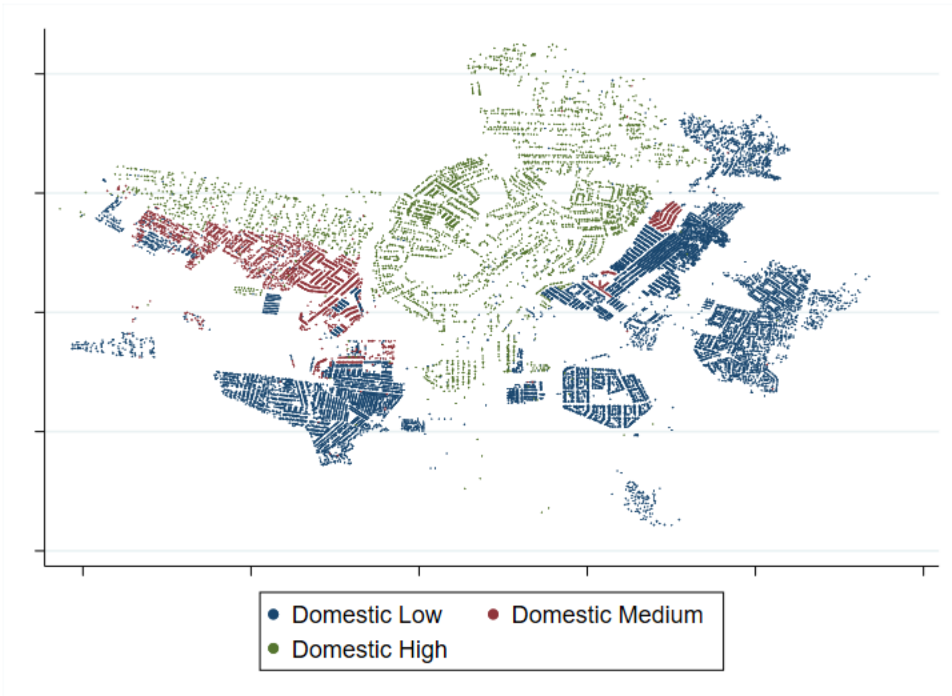


Figure 4: SWSC Sewer Network, May 2019

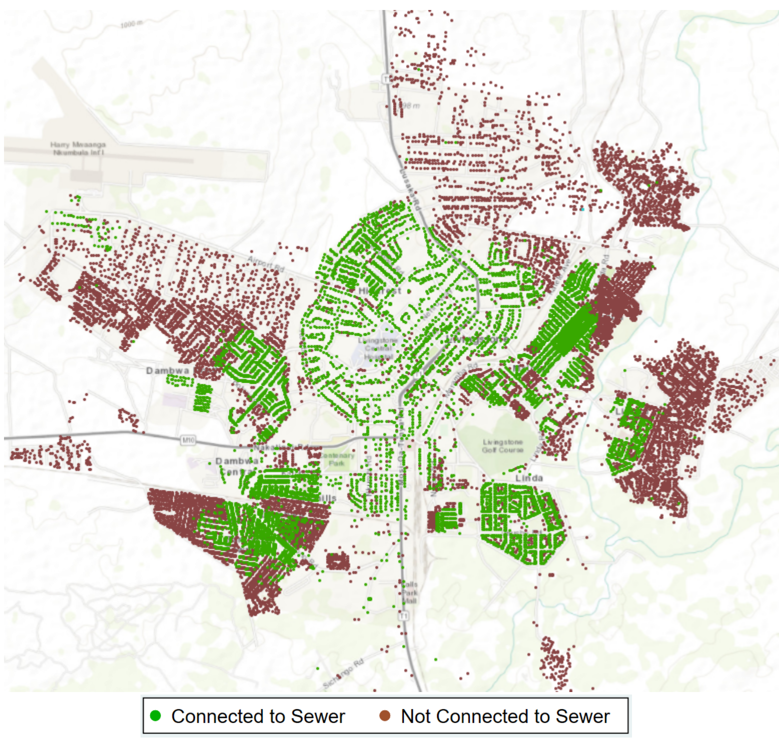
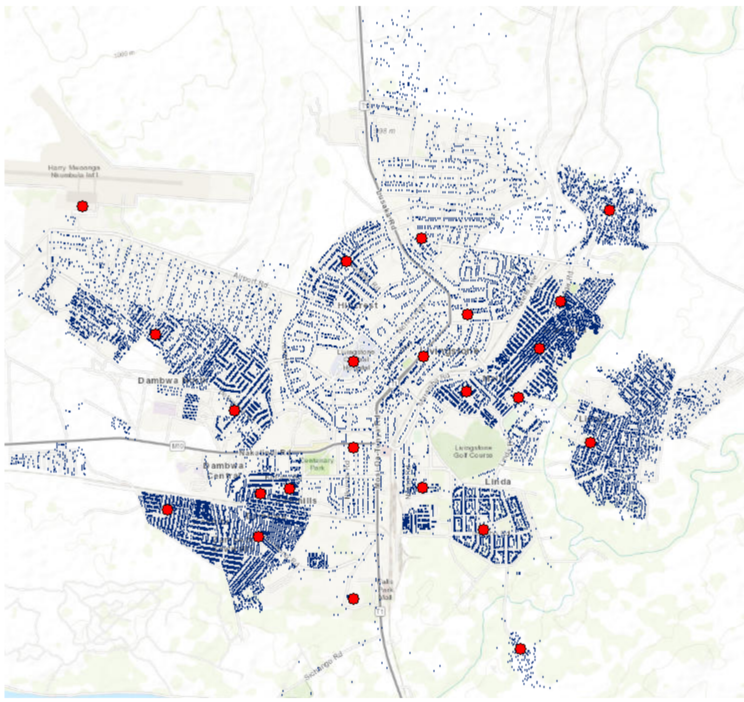
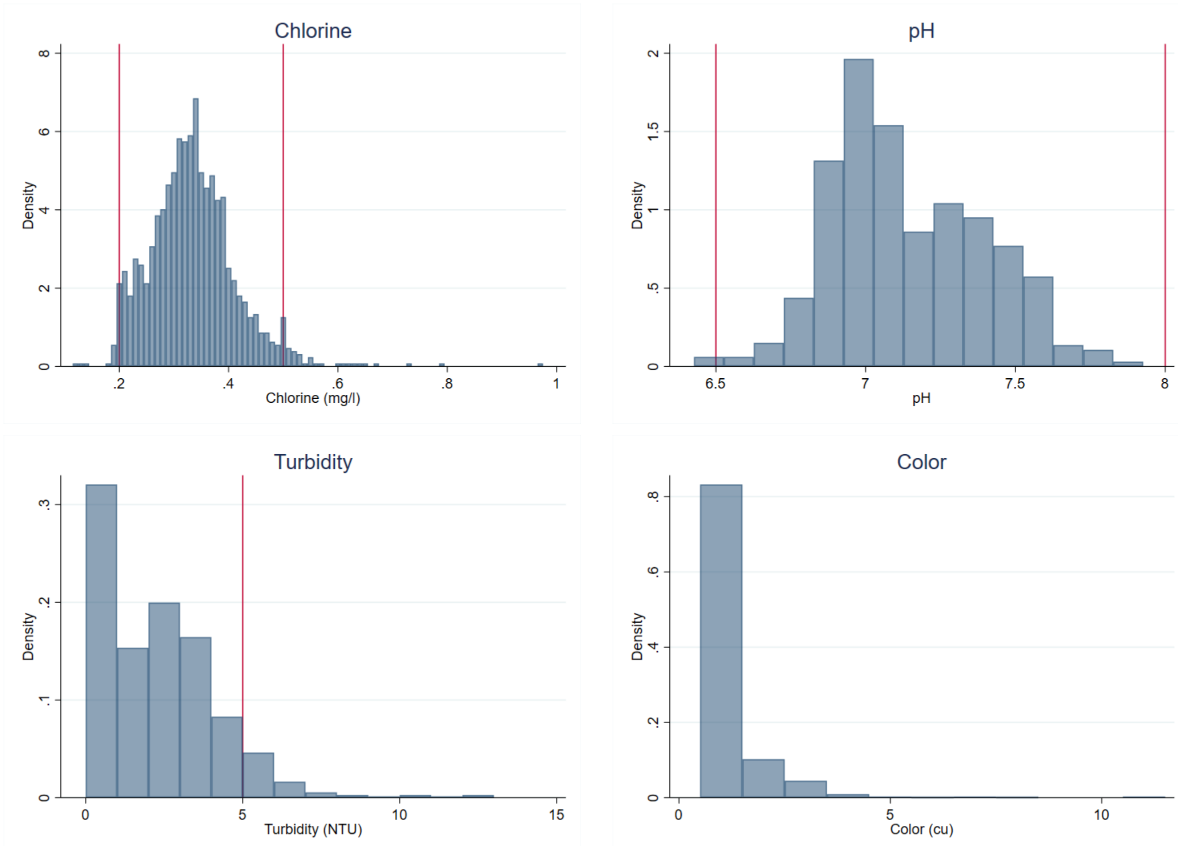


Figure 5: Water Test Locations



Notes: This figure shows the locations where the water tests were collected by the water utility. Households in the neighborhood of the water test are assigned the value of the monthly test.

Figure 6: Water Test Histograms



Notes: Data are monthly averages of weekly water tests conducted by SWSC between January 2014 and June 2019. Red vertical lines represent water quality standards. Due to bunching at the quality standards, I define water tests equal to the quality standards to be out of compliance. The compliance level for water color is 15 cu. I define any detectable change in water color (a value of 2 cu or higher) to be out of compliance in the empirical analysis.

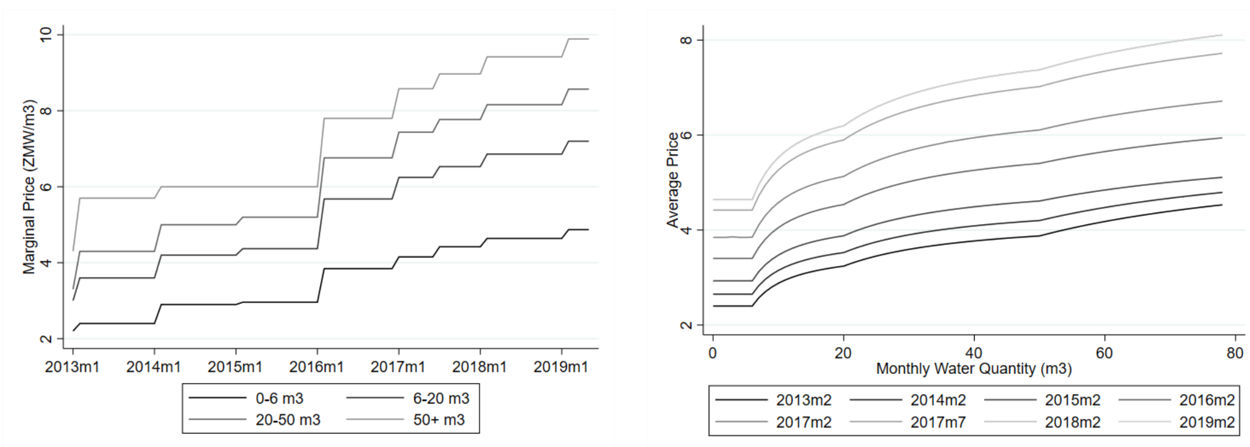
Figure 7: Mapped water network

Notes: This figure shows the GIS mapping of the water network and pipes in Livingstone. Pink lines are main water pipes, and blue lines are the service lines to individual connections.

Figure 8: Water Tariffs for Metered and Unmetered Households

(a) Metered Price Schedule

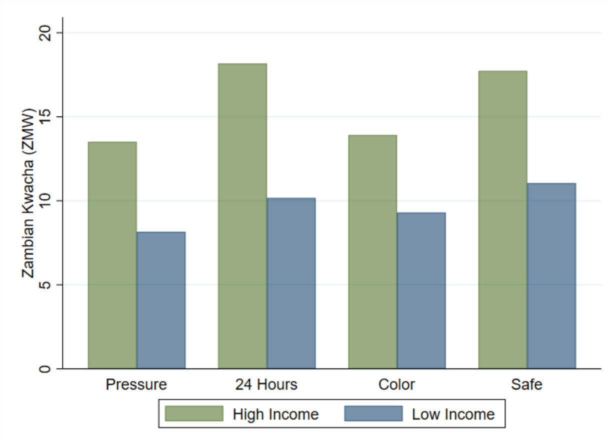
(b) Average Price per Quantity



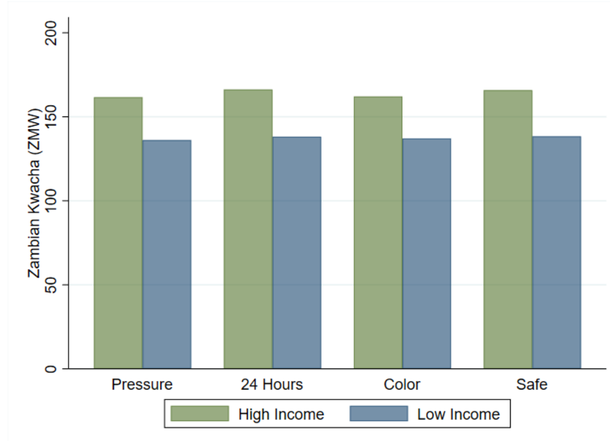
Notes: This figure presents the increasing block tariff price structure for metered households from 2013 to mid-2019 in sub-figure (a) and the average price of water per quantity consumed in sub-figure (b). Metered households are charged by the cubic meter at different marginal rates for each consumption tier: 0-6 cubic meters, 6-20 cubic meters, 20-50 cubic meters, and more than 50 cubic meters.

Figure 9: Stated Willingness to Pay by Income Category

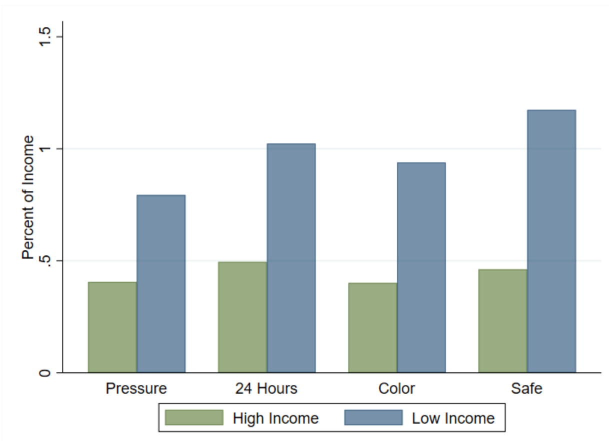
(a) WTP (Additional Amount (ZMW))



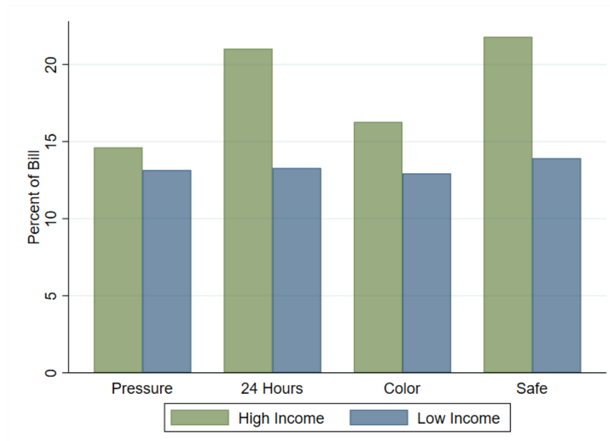
(b) WTP (Hypothetical Bill (ZMW))



(c) WTP (Percent of Income)



(d) WTP (Percent of Bill)



Notes: The bar graphs show the stated WTP for quality improvements in (a) Zambian Kwacha, (b) Hypothetical maximum bill, (c) Percent of income, and (d) Percent of water bill. Low-income households are defined as households with below the median income, and high-income households are those with above the median income. WTP categories include consistent high pressure, 24-hour service, water of a normal color and taste, and water that is safe to drink out of the tap. Percent of income was calculated using the stated WTP amount divided by the survey reported monthly household income. The WTP in percent of bill was calculated as the WTP amount divided by the average of all monthly water bills in 2018 and 2019 in which the customer was connected to the water network.

Figure 10: Timeline of Billing, Payments, and Disconnections

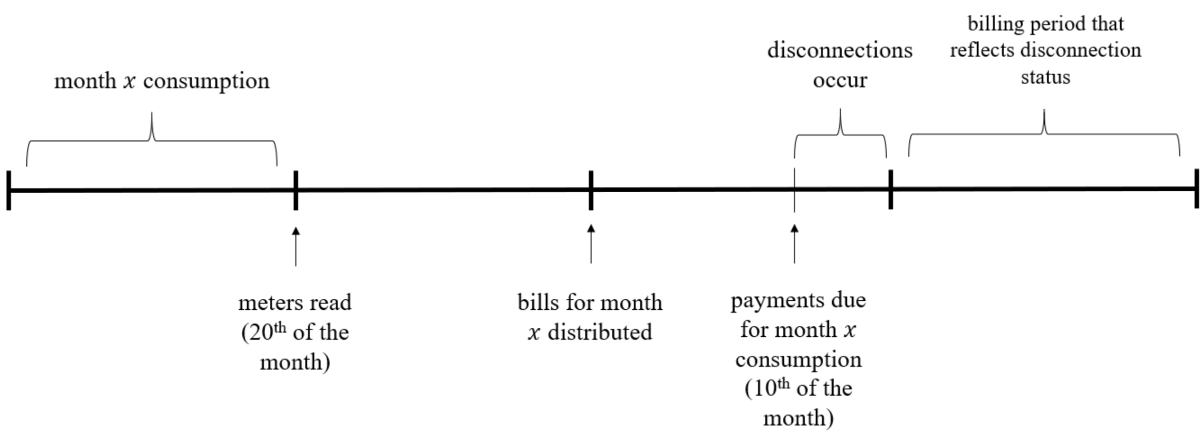
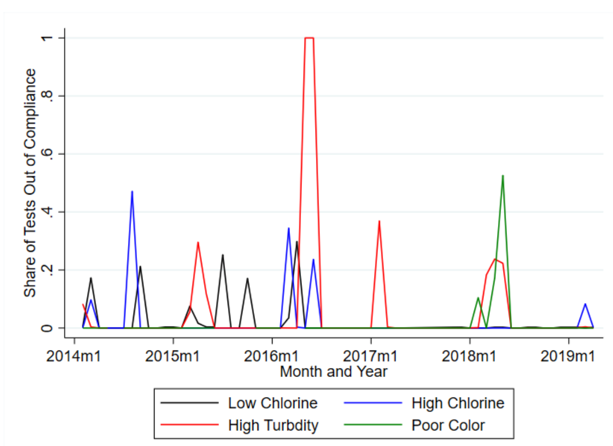
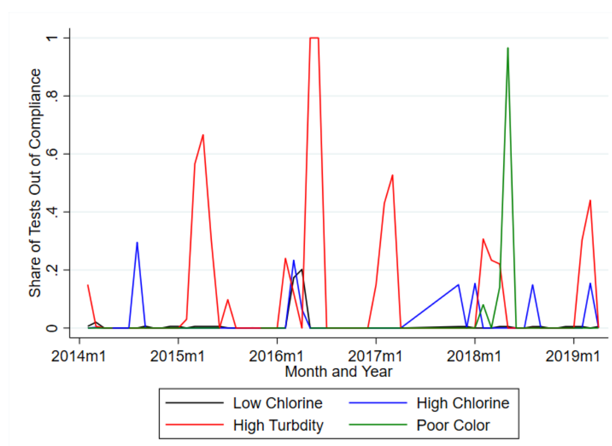


Figure 11: Temporal Variation in Quality Variables by Taxcode Designation

(a) Domestic Low

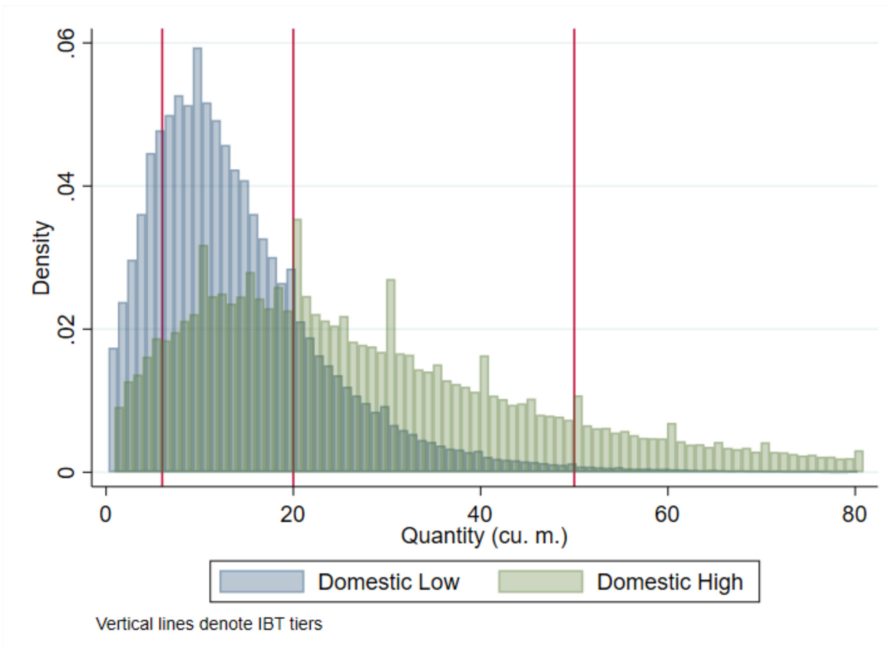


(b) Domestic Medium/High



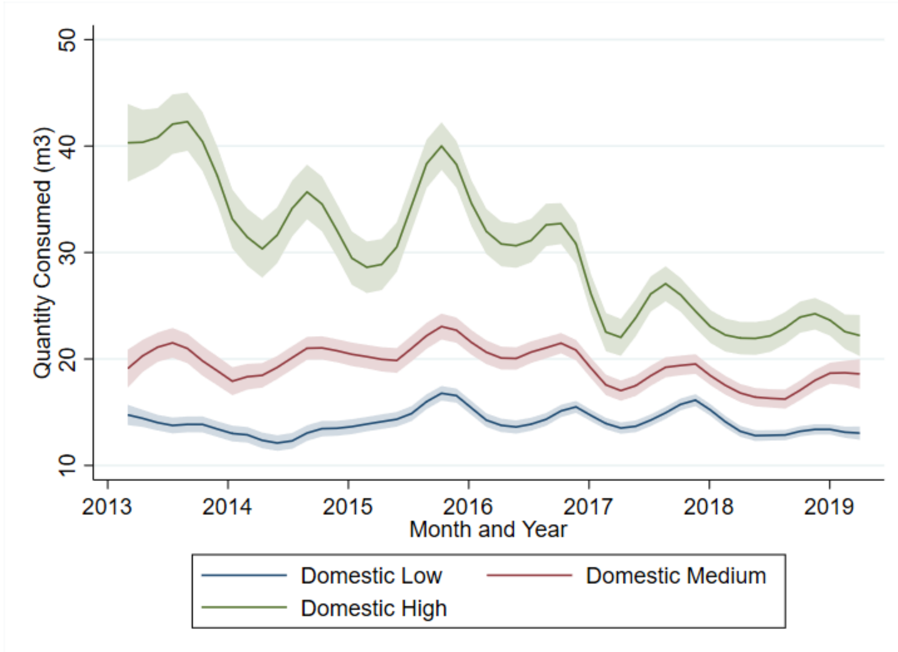
Notes: This figure presents variation in the share of tests that were recorded as out of compliance with water quality standards over time separately for Domestic Low and Domestic Medium and High households. Water test data was not collected before February of 2014 and between May and October of 2017. Water tests were conducted for turbidity and color less frequently than water tests for chlorine levels, which may explain the large variation in the share of out of compliant water tests for those quality variables.

Figure 12: Quantity histograms for metered households, Domestic Low and Domestic High



Notes: This figure shows histograms for the monthly Quantity consumed for metered customers separately for Domestic Low and Domestic High households. Vertical lines indicate the IBT cutoffs. Bunching at multiples of 10 may be due to meter readers recording rounded results either due to difficulties in reading the meter or intentionally as a form of collusion with the household.

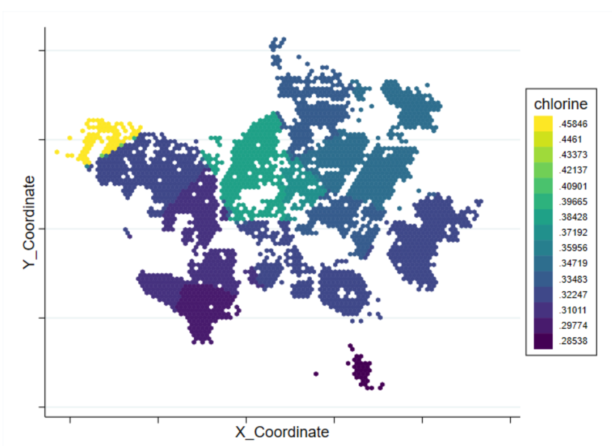
Figure 13: Seasonal Variation in Water Consumption



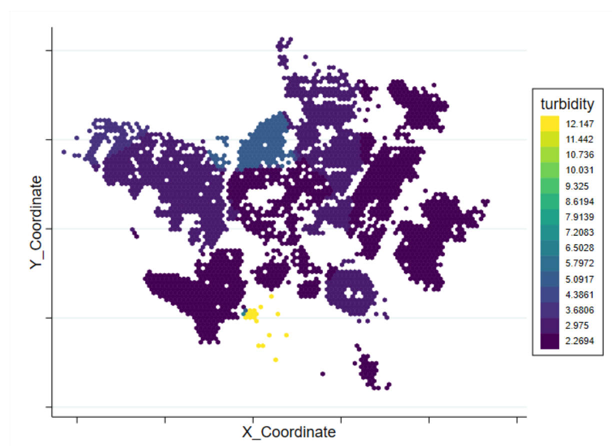
Notes: This figure presents a kernel-weighted local polynomial smoothing estimate of the mean water consumption separately for Domestic Low, Medium, and High households. The sample is restricted to households that are metered, connected, and consume a positive quantity of water. Estimation uses a Epanechnikov kernel with a bandwidth of 1.5. Plotted areas corresponds to the 95 percent confidence bands for the estimate of the local mean.

Figure 14: Geographical Averages of Water Test Data

(a) Chlorine

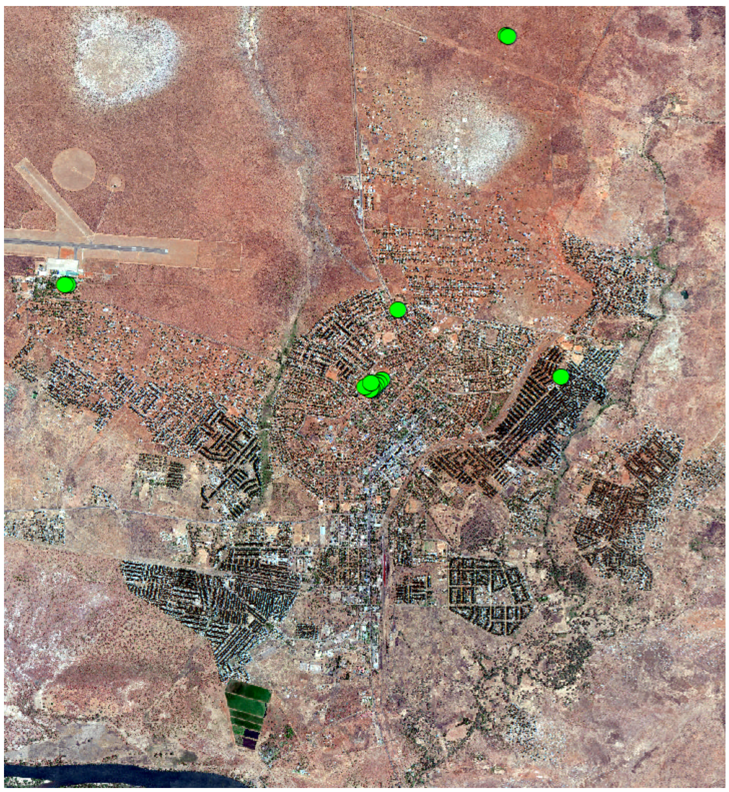


(b) Turbidity



Notes: This figure shows the geographical averages of water tests for chlorine in panel (a) and for turbidity in panel (b). Households are assigned the value of the closest water test. The graph indicates that chlorine and turbidity are lower at farther distances from the treatment plant or storage facilities.

Figure 15: Treatment Plant and Storage Facilities



Notes: This graph shows the location of water storage facilities. The collection of points in the center indicates the treatment plant. Additional storage tanks are located in high altitude areas.

Table 1: Summary Statistics: Administrative Data

Variable	Mean	Std. Dev.	10%	90%
Panel A: Administrative Data (Billing level)				
Consumption (m^3)	15.7	24.04	0	33
Total Current Charges	96.29	114.89	0	205.53
Consumption$\|$Connected (m^3)	20.31	25.57	6	36.93
Total Current Charges$\|$Connected	115.25	183	19.51	222.43
Outstanding Balance	503.12	757.13	44.5	1304.43
Total Payments	84.92	135.36	0	210
Unmetered	.37	-	-	-
Disconnected	.2	-	-	-
Panel B: Administrative Data (Customer level)				
Domestic Low	.65	-	-	-
Domestic High	.21	-	-	-
Connected to Sewer	.39	-	-	-
Distance to a Pay Station (km)	1.11	.72	.34	1.94
Age of Account (months)	65.8	20.78	30	78
Has a Private Borehole	.01	-	-	-

Notes: Panel A presents summary statistics of the administrative data at the billing level of residential customers from December 2012 to June 2019. Panel B presents summary statistics of the 23,719 residential customers of SWSC as of June 2019.

Table 2: Quality Variables Correlations: Water Quality Tests

Variables	Low Chlorine	High Chlorine	High Turbidity	Poor Color	Altitude	Distance
Low Chlorine	1.000					
High Chlorine	-0.019***	1.000				
High Turbidity	-0.015***	0.014***	1.000			
Poor Color	-0.011***	-0.014***	-0.029***	1.000		
Altitude (10m)	-0.090***	0.060***	0.169***	-0.059***	1.000	
Distance to Water Storage Reservoir (km)	0.070***	-0.090***	-0.036***	0.082***	-0.620***	1.000

Notes: This table presents bivariate correlations between quality and network variables. Only households within 400 meters of the water test are included.

Table 3: Summary Statistics: Household Survey Data

Variable	Obs	Mean	Std. Dev.	P10	P50	P90
Panel A: Household Demographics						
Monthly Income	741	2624.16	3001.82	500	2000	6000
Water Bill Share of Income	741	.1	.08	.02	.07	.27
HH size	792	4.81	2.04	2	5	7
Rooms in Household	793	4.71	2.3	2	5	8
Years of Schooling (HH Head)	777	12.25	2.38	9	12	14
Number of Sharing HHs	795	.29	1.14	0	0	1
Number of Flush Toilets	793	.6	.75	0	0	2
Number of Bathtubs/Showers	792	.6	.75	0	0	2
Indoor plumbing	793	.46	-	-	-	-
Has a Septic Tank	782	.41	-	-	-	-
Electricity Connection	793	.89	-	-	-	-
Panel B: Quality Variables						
Piped Water Primary Source	792	.98	-	-	-	-
Experienced Low Pressure	745	.37	-	-	-	-
Experienced Bad Taste	745	.1	-	-	-	-
Experienced Cloudy Water	745	.11	-	-	-	-
Experienced Unusual Color	745	.33	-	-	-	-
Experienced Outages	745	.24	-	-	-	-
Supply Hours	724	17.15	7.46	6	20	24
Liters of Water Stored	792	101.05	310.58	20	50	150
Share of Time Treating Drinking Water	791	.1	.24	0	0	.25
Share of Time Boiling Drinking Water	791	.21	.33	0	0	.75
Child had Diarrhea (last month)	377	.23	-	-	-	-
Child had Diarrhea (last 6 months)	377	.33	-	-	-	-
Ave. Time Fetching Water (per week)	777	28.21	70.2	0	1.33	70
Panel C: Stated Willingness to Pay						
WTP High Pressure	795	11.16	25.69	0	0	30
WTP 24 Hour Service	795	14.31	33.68	0	0	50
WTP Safe for Drinking	795	14.47	29.09	0	5	50
WTP Normal Color/Taste	795	11.51	24.73	0	0	40

Notes: Panel A displays household characteristics. The water bill share of income was calculated by taking the average water bill for connected customers in 2018 through 2019 and dividing it by the reported household income. Panel B shows summary statistics of self-reported quality measures that are equal to one if the household reported experiencing the problem in the last year. Supply hours indicate the average daily hours of water supply for the household. The share of time that households reported treating and boiling water was equal to 1 if a household reported "always", 0.75 if "most of the time", 0.5 if "half of the time", 0.25 if "sometimes", and 0 if "never". The average time spent fetching water indicates the average number of minutes spent for all household members. Panel (c) presents the stated WTP measures as described in Section 2.5.

Table 4: Household Survey Balance Checks

Variable	(1) Unsurveyed Mean/SD	(2) Surveyed Mean/SD	(3) t-test difference (2)-(1)
Total Current Charges (ZMW)	141	139	-1.68
	[122]	[96.1]	(5)
Outstanding Balance (ZMW)	494	493	-1.57
	[894]	[966]	(32.7)
Total Payments (ZMW)	95.3	94.7	-.658
	[109]	[91.2]	(4.12)
Domestic Low	.652	.663	.0108
	[.476]	[.473]	(.0183)
Unmetered	.295	.286	-.0081
	[.456]	[.452]	(.0133)
Disconnected	.226	.213	-.0135
	[.418]	[.41]	(.0153)
Connected to Sewer	.397	.467	.0705***
	[.489]	[.499]	(.0171)
Age of Account (months)	65	68	3***
	[21.3]	[18.3]	(.71)
Has a Private Borehole	.018	.0107	-.00729
	[.133]	[.103]	(.00481)
Observations	20,616	747	21,363

Standard errors in parentheses
*p<0.1, **p<0.05, ***p<0.01

Notes: Columns (1) and (2) present the means and standard deviations (in brackets) for relevant administrative data for unsurveyed and surveyed customers from January, 2019 to June, 2019. Outstanding balance represents the remaining unpaid balance for customers at the end of the survey period (June, 2019). Column (3) presents the difference in means between the unsurveyed and surveyed population and the standard error of this difference. Standard errors are clustered at the randomization stratification variable level, the administrative billing zone. All income, charges, outstanding balance, and payment variables are expressed in Zambian Kwacha (ZMW). 10 ZMW $\approx$ 1 USD.

Table 5: Comparison of Domestic Low and Domestic Medium and High Households

Variable	(1) Domestic Low Mean/SD	(2) Domestic Medium/High Mean/SD	(3) t-test difference (1)-(2)
Panel A: Administrative Data			
Comsumption (cubic meters)	16	27	-11***
	[14.5]	[32.2]	(1.58)
Total Current Charges (ZMW)	71.6	153	-81.7***
	[78.4]	[176]	(10.9)
Outstanding Balance (ZMW)	462	555	-93.2
	[644]	[1236]	(57.1)
Total Payments (ZMW)	60.8	140	-79.1***
	[111]	[265]	(9.87)
Unmetered	.434	.186	.249***
	[.496]	[.389]	(.0406)
Disconnected	.226	.0968	.129***
	[.418]	[.296]	(.0236)
Connected to Sewer	.376	.442	-.0662
	[.484]	[.497]	(.115)
Distance to a Pay Station (km)	1.12	1.08	.0449
	[.71]	[.757]	(.164)
Age of Account (months)	65.3	64.8	.5
	[20.6]	[22.3]	(3.04)
Panel B: Household Survey Data			
Monthly Income (ZMW)	1986	4054	-2068***
	[1628]	[4537]	(328)
Water Bill Share of Income	.126	.076	.0499***
	[.087]	[.0713]	(.00948)
Household Owns Property	.572	.508	.0638
	[.495]	[.501]	(.0472)
Household Size	4.88	4.73	.152
	[2.03]	[2.07]	(.168)
Rooms in Household	3.92	6.34	-2.42***
	[1.98]	[2.03]	(.227)
Number of Sharing Households	.316	.25	.0663
	[1.09]	[1.3]	(.119)
Number of Bathtubs/Showers	.3	1.21	-.907***
	[.563]	[.729]	(.0757)
Indoor Plumbing	.254	.877	-.623***
	[.436]	[.329]	(.0494)
Septic Tank	.312	.598	-.287***
	[.464]	[.491]	(.0573)
Electricity Connection	.861	.964	-.104***
	[.347]	[.186]	(.0267)

Standard errors in parentheses
*p<0.1, **p<0.05, ***p<0.01

Notes: Columns (1) and (2) present the means and standard deviations (in brackets) for relevant administrative and household survey variables for Domestic Low households and Domestic Medium and High households. Column (3) presents the difference in means between Domestic Medium and High households and Domestic Low households and the standard error of this difference. All monetary values are expressed in Zambian Kwacha (ZMW) (10 ZMW $\approx$ 1 USD).

Table 6: Correlations Between Stated and Observed Quality Measures

	Low Pressure			Bad Taste			Cloudy Water			Unusual Color		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Low Chlorine	1.979***	2.064***	2.094***		-0.290***	-0.282***		-0.486***	-0.469***		-0.976***	-0.794***
	(0.076)	(0.147)	(0.189)		(0.088)	(0.102)		(0.112)	(0.120)		(0.144)	(0.175)
High Chlorine		-0.422	-0.503	-0.060	0.790	0.821		0.720	0.776		0.461	0.558
		(0.918)	(0.967)	(0.378)	(0.481)	(0.522)		(0.597)	(0.663)		(0.956)	(0.971)
High Turbidity		-0.145	-0.374		-0.367***	-0.457**	-0.393***	-0.512***	-0.583**		-0.505*	-0.735**
		(0.316)	(0.366)		(0.140)	(0.178)	(0.139)	(0.197)	(0.232)		(0.291)	(0.328)
Poor Color		1.453*	0.642		1.130**	0.722		-0.422	-0.716	0.472	0.283	-0.125
		(0.771)	(0.844)		(0.555)	(0.569)		(0.481)	(0.504)	(0.721)	(0.747)	(0.808)
Ln(Income)			-0.014			-0.000			0.012			0.051
			(0.037)			(0.020)			(0.024)			(0.039)
Indoor Plumbing			0.147**			0.042			0.008			0.079
			(0.066)			(0.038)			(0.043)			(0.066)
Constant	0.318***	0.303***	0.295***	0.078***	0.073***	0.069**	0.133***	0.143***	0.135***	0.286***	0.321***	0.255***
	(0.026)	(0.036)	(0.055)	(0.016)	(0.020)	(0.028)	(0.023)	(0.027)	(0.036)	(0.029)	(0.037)	(0.058)
Observations	322	322	300	322	322	300	322	322	300	322	322	300
R Squared	0.007	0.023	0.039	0.000	0.039	0.034	0.013	0.019	0.025	0.001	0.011	0.028

* $p < .10$, ** $p < .05$, *** $p < .01$

Notes: This table presents the results of estimating equation 1. The dependent variables are indicators for whether the household reported low pressure (columns (1) - (3)), bad taste (columns (4) - (6)), cloudy water (columns (7) - (9)), and water of an unusual color (columns (10) - (12)). The independent variables include the average of the indicators for poor quality (low chlorine, high chlorine, high turbidity, and poor color outside of standards) for the last three years of the sample period. Independent variables for quality are derived from the water test data collected by SWSC. Columns (1), (4), (7), and (10) include only the water test indicators commonly associated with the reported quality indicator. Columns (2) - (3), (5) - (6), (8) - (9), and (11) - (12) include all observed quality variables in the same regression. Columns (3), (6), (9), and (12) additionally include controls for the natural log of income and an indicator for whether the households has indoor plumbing.

Table 7: Nonpayment Responses to Quality

	All		Metered		Unmetered		Domestic Low		Domestic Medium/High	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Low Chlorine	3.966***	5.905***	4.793***	11.379***	1.110	0.958	3.627***	2.854	5.099	15.609*
	(1.236)	(2.267)	(1.636)	(4.058)	(1.796)	(2.511)	(1.351)	(2.345)	(3.422)	(8.287)
High Chlorine	-0.650	-3.047	-1.456	-3.629	2.597	-2.627	-0.975	-2.532	-0.869	-7.914
	(1.680)	(2.239)	(2.033)	(2.594)	(2.677)	(4.460)	(1.071)	(1.573)	(4.097)	(6.324)
High Turbidity		1.740		0.688		5.184*		6.530***		1.550
		(1.650)		(1.941)		(2.991)		(1.588)		(3.031)
Poor Color		4.363		-0.295		21.171***		12.146***		-6.431
		(2.928)		(3.202)		(7.340)		(2.858)		(8.076)
Customer FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-by-year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	336560	179065	257232	135843	78944	42769	231318	126106	105242	52959
Y Mean	6.463	7.216	5.070	5.472	10.938	12.639	6.493	7.471	6.399	6.610

* $p < .10$, ** $p < .05$, *** $p < .01$

Notes: The dependent variable in all regressions is current period nonpayments, which is defined as the bill for consumption that occurred in period $t-2$ amount minus the current payments made. Quality variables are indicators for water tests being outside of standards. Additional independent variables include an indicator for whether the household is unmetered in the current period and the size of the household's administrative zone. The sample is restricted to connected households and households that were connected in the $t-2$ period. The sample includes only customers that are within 400 meters of the water test location. Months of supply shortages (June, 2014 and October, 2018) are excluded from the analysis. Columns (1) - (2) are all customers, columns (3) - (4) include only customers that are metered in the current period, and columns (5) - (6) include only customers that are unmetered in the current period. Columns (7) - (8) restrict the sample to Domestic Low customers and columns (9) - (10) restrict the sample to Domestic Medium or High households. All regressions include customer fixed effects and month-by-year fixed effects. Standard errors are clustered at the customer level. All payment variables are expressed in Zambian Kwacha (10 ZMW $\approx$ 1 USD).

Table 8: Quality Demand Estimates: Water Test Data

	Expected Marginal Price IV				Linear IV			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln(Marginal Price)	-0.235***	-0.177***	-0.115***	-0.095***				
	(0.013)	(0.013)	(0.017)	(0.019)				
ln(Average Price)					-0.215***	-0.181***	-0.126***	-0.109***
					(0.011)	(0.011)	(0.017)	(0.019)
Low Chlorine			-0.028**	-0.067**			-0.026**	-0.061**
			(0.011)	(0.029)			(0.011)	(0.028)
High Chlorine			-0.015*	-0.027**			-0.015*	-0.029**
			(0.009)	(0.013)			(0.009)	(0.013)
High Turbidity				0.045***				0.039***
				(0.008)				(0.007)
Poor Color				-0.069***				-0.066***
				(0.013)				(0.013)
Rainfall (100mm)		-0.038***	-0.035***	-0.040***		-0.048***	-0.034***	-0.036***
		(0.002)	(0.002)	(0.003)		(0.002)	(0.002)	(0.003)
Temperature (C)		0.063***	0.082***	0.097***		0.064***	0.080***	0.093***
		(0.003)	(0.004)	(0.006)		(0.003)	(0.004)	(0.006)
Customer FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FEs	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Observations	609521	609071	251437	130676	705112	697341	256904	135166
Y Mean	2.639	2.639	2.592	2.553	2.650	2.650	2.595	2.556
First Stage F Statistic	142719	140091	75000	60822	90367	87072	37313	31969

* $p < .10$, ** $p < .05$, *** $p < .01$

Notes: This table presents the results of estimating equation 3. The dependent variable in all regressions is the natural log of the monthly water consumption measured in cubic meters. The sample is restricted to metered and connected customers that are located within 400 meters from the water test. Columns (1) through (4) are estimated using the natural log of the expected marginal price as an instrument for natural log of the observed marginal price. Columns (5) through (8) use a linear combination of the natural log of the full schedule of marginal prices as an instrument for the natural log of the average price. Columns (1) and (5) presents regression results with only the price term and customer fixed effects. Columns (2) - (4) and (6) - (8) additionally include weather controls and month fixed effects. Columns (3) - (4) and (7) - (8) include indicators for low and high chlorine levels outside of standards. Columns (4) and (8) additionally include indicators for high turbidity and poor color outside of standards. Months of supply shortages (June, 2014 and October, 2018) are excluded from the analysis. Standard errors are clustered at the customer level.

Table 9: Estimates of Water Price and Income Elasticites from Previous Studies

	Price Elasticity	Income Elasticity	Estimation Method	Location
Panel A: Low- and Middle-Income Countries				
Szabo (2015)	-0.98	-	Structural	Pretoria, South Africa
Szabo (2015)	-0.38	-	IV	Pretoria, South Africa
Strand and Walker (2005)	-0.30	0.08	IV	17 Central American cities
Diakité *et al.* (2009)	-0.82	-	Structural	Côte d'Ivoire
Violette (2017)	-0.52	-	Structural	Manila, Philippines
Nauges and Van Den Berg (2009)	-0.37	0.14	IV	Southwest Sri Lanka
Nauges and Strand (2007)	-0.66	0.23	Structural	El Salvador
Basani *et al.* (2008)	-0.46	0.19	IV	Cambodia
Klassert *et al.* (2018)	-0.45	0.22	Structural	Jordan
Panel B: High-Income Countries				
Olmstead (2009)	-0.64	0.20	Structural	US and Canada
Olmstead (2009)	-0.29	0.68	IV	US and Canada
Mansur and Olmstead (2012)	-0.33	0.15	IV	11 North American cities

Notes: This table presents price elasticities and income elasticites of demand for water from previous studies. The value provided indicates the average estimate for piped water demand presented in the paper.

Table 10: Willingness to Pay for Quality

	Expected MP		Linear IV		Domestic Low		Domestic Med/High	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Demand Estimates								
ln(Price)	-0.115***	-0.095***	-0.126***	-0.109***	-0.004	0.048	-0.163***	-0.195***
	(0.017)	(0.019)	(0.017)	(0.019)	(0.038)	(0.041)	(0.050)	(0.059)
Low Chlorine	-0.028**	-0.067**	-0.026**	-0.061**	-0.005	-0.004	-0.106*	-0.198
	(0.011)	(0.029)	(0.011)	(0.028)	(0.020)	(0.049)	(0.057)	(0.579)
High Chlorine	-0.015*	-0.027**	-0.015*	-0.029**	-0.027	-0.022	-0.030	0.007
	(0.009)	(0.013)	(0.009)	(0.013)	(0.021)	(0.032)	(0.023)	(0.045)
High Turbidity		0.045***		0.039***		0.019		0.056***
		(0.008)		(0.007)		(0.023)		(0.021)
Poor Color		-0.069***		-0.066***		-0.082***		-0.006
		(0.013)		(0.013)		(0.025)		(0.037)
Panel B: WTP Estimates								
Low Chlorine to	1.397**	4.048**	1.204**	3.161**	6.522	-0.413	3.927	6.069
Within Standards	(0.612)	(1.909)	(0.546)	(1.550)	(61.567)	(5.794)	(2.475)	(17.809)
High Chlorine to	0.780*	1.614*	0.697*	1.518**	35.470	-2.606	1.110	-0.209
Within Standards	(0.456)	(0.856)	(0.410)	(0.730)	(314.015)	(4.407)	(0.985)	(1.366)
High Turbidity to		-2.717***		-2.033***		2.175		-1.711
Within Standards		(0.689)		(0.514)		(3.267)		(0.773)
Poor Color to		4.158***		3.462***		-9.628		0.196
Within Standards		(1.158)		(0.932)		(8.675)		(1.143)
Customer FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	251437	130676	256904	135166	48270	25386	25362	12171
Y Mean	2.592	2.553	2.595	2.556	2.460	2.416	2.843	2.828
First Stage F Statistic	75000	60822	37313	31969	13451	10894	10185	7168

$^{*}\ p < .10$, $^{**}\ p < .05$, $^{***}\ p < .01$

Notes: This table presents the results of estimating equation 3 and equation 7. The dependent variable in all regressions is the natural log of the monthly water consumption measured in cubic meters. The sample is restricted to metered and connected customers that are located within 400 meters of the water test location. Months of supply shortages (June, 2014 and October, 2018) are excluded from the analysis. Panel (A) presents demand estimates for the price and quality variables. The price independent variable is the natural log of the observed marginal price instrumented with the natural log of the expected marginal price for columns (1) - (2) and (5) - (8). The price independent variable is the natural log of the average price instrumented by a linear combination of the natural log of the marginal prices for columns (3) - (4). Quality variables are indicators for water tests being outside of standards. Columns (5) - (6) include only Domestic Low households, and columns (7) - (8) include only Domestic Medium and High households. Standard errors are clustered at the customer level. Panel B presents willingness to pay estimates for low quality determined by equation 7. Standard errors for WTP estimates are calculated using the delta method. All price variables are expressed in Zambian Kwacha (10 ZMW $\approx$ 1 USD).

Table 11: Quality Demand Estimates: Self-Reported Quality Data

	All Surveyed Customers			Low Income	High Income
	(1)	(2)	(3)	(4)	(5)
Panel A: Demand Estimates					
ln(Marginal Price)	-0.198***	-0.173***	-0.149***	-0.085*	-0.178***
	(0.031)	(0.030)	(0.032)	(0.051)	(0.039)
ln(Virtual Income)		0.072***	0.082***	0.287***	-0.063***
		(0.007)	(0.008)	(0.024)	(0.015)
Low Pressure			-0.046***	-0.085***	-0.052***
			(0.013)	(0.022)	(0.017)
Bad Taste			-0.020	-0.078***	0.033*
			(0.015)	(0.025)	(0.019)
Cloudy Water			0.075***	0.085***	0.048***
			(0.014)	(0.025)	(0.017)
Unusual Color			-0.033***	-0.024	-0.016
			(0.013)	(0.021)	(0.016)
Household Size		0.045***	0.037***	0.017***	0.052***
		(0.003)	(0.003)	(0.004)	(0.004)
Indoor Plumbing		-0.000	0.007	-0.091**	0.015
		(0.021)	(0.023)	(0.045)	(0.028)
Number of Bathtubs/Showers		0.154***	0.173***	0.319***	0.190***
		(0.013)	(0.013)	(0.035)	(0.015)
Rainfall (100mm)	-0.032***	-0.032***	-0.028***	-0.008	-0.040***
	(0.010)	(0.010)	(0.011)	(0.017)	(0.014)
Temperature (C)	0.072***	0.071***	0.071***	0.079***	0.066***
	(0.013)	(0.012)	(0.013)	(0.021)	(0.017)
Panel B: WTP Estimates					
Low Pressure to Normal			1.869***	5.813	1.783***
			(0.659)	(3.773)	(0.688)
Bad Taste to Normal			0.821	5.350	-1.146*
			(0.628)	(3.559)	(0.682)
Cloudy Water to Normal			-3.040***	-5.787	-1.669**
			(0.852)	(3.780)	(0.705)
Unusual Color to Normal			1.350**	1.610	0.537
			(0.575)	(1.692)	(0.549)
Customer FEs	Yes	No	No	No	No
Region FEs	No	Yes	Yes	Yes	Yes
Month FEs	Yes	Yes	Yes	Yes	Yes
Observations	20801	20742	18120	6807	11313
Y Mean	2.645	2.643	2.655	2.467	2.768
First Stage F Statistic	22509	23228	20335	6751	14176

* $p < .10$, ** $p < .05$, *** $p < .01$

Notes: The dependent variable in all regressions is the natural log of the monthly water consumption measured in cubic meters. The sample is restricted to metered and connected customers. Months of supply shortages (June, 2014 and October, 2018) are excluded from the analysis. ln(Marginal Price) is instrumented by the natural log of the customer's expected marginal price determined by equation 5. Quality variable are an indicator for whether the household reported to observe the supply problem. Column (1) presents regression results from equation 3 using only the sample of surveyed customers. Column (2) provides the results of estimating equation 8. Columns (3)-(5) include self-reported quality variables from the household survey data. Column (4) is restricted to households with income less than the median surveyed income, and column (5) restricts the sample to households with income higher than the median surveyed income. WTP is estimated using equation 7. Standard errors are clustered at the customer level.