Water Sharing Under Increasing Block Pricing

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Abstract

Pricing of piped water in developing countries has been a topic of significant policy debate. Many low-income countries utilize an increasing block tariff (IBT) to promote efficient use of water and provide a subsidy to low-consumption households. However, low-income households in developing countries often share the same water connection, which undermines the subsidy objectives of the IBT. Water utilities are increasingly transitioning to full metering of water connections, but little empirical evidence exists on the effect of metering on water access and cost recovery, particularly in the context of widespread water sharing. I study the transition from unmetered to metered connections using an event study of large-scale metering campaigns in Livingstone, Zambia. Metering raises the marginal price that households pay for water but also raises the price of sharing by reducing the share of a household's neighbors that can provide free water through their unmetered connection. I find that metering produces significant revenue gains for the water utility. Revenue increases by more than 30 percent after metering events in areas that were metered. Metering events also result in re-connections for households that were disconnected due to non-payment. The share of households that are disconnected decreases by approximately 30 percent among low-income households after metering. This study provides suggestive evidence that sharing households transition to use of individual connections after metering. The welfare effects of metering for households, however, is not clear due to the simultaneous change in the price of an individual connection and the price of sharing.

Keywords: piped water access, utilities, metering, water sharing

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1 Introduction

Pricing of piped water in developing countries has been a topic of significant policy debate. The design of water prices must balance several conflicting policy objectives including recovering costs for the utility provider, ensuring access for low-income households, and encouraging conservation of water resources. The most common type of water tariff use in Africa is the increasing block tariff (IBT) (Banerjee *et al.*, 2011). Under increasing block pricing, low levels of consumption are priced at a lower marginal price, which allows for high-consumption households to cross-subsidize low-consumption households. If water use is an adequate proxy for income, the IBT should work well to provide water access to low-income households at a lower rate as well as discourage overuse of water. However, previous research has argued that the IBT does not necessarily achieve this cross-subsidy objective when multiple households share the same water connection (Whittington and Nauges (2020); Violette (2017);Whittington (1992)).

I study the transition between unmetered and metered pricing and the implications for water sharing in Livingstone, Zambia. Water utilities in Zambia are increasingly trying to meter all their customers in hopes of reducing non-revenue water resulting from overuse of unmetered connections. The share of customers metered is widely considered to be a performance indicator of water distribution systems (Van den Berg and Danilenko (2017); NWASCO (2020)). Overuse is expected because unmetered households face a zero marginal price for water. High-income households may overuse water from unmetered connections primarily for individual uses such as lawn care. Low-income households, however, may share water with neighbors who do not have an individual connection or have had their individual connection disconnected due to nonpayment. When connections are unmetered, households without a connection can often share with their neighbor at little or no cost. When connections become metered, sharing becomes considerably more expensive because the marginal price of water increases with consumption. Previous research has shown the importance of water sharing among low-income households for increasing access to improved water sources (Devoto *et al.* (2012); Violette (2017)). While both high-income and low-income households may benefit from having an unmetered connection, the monthly cost of an unmetered connections is high – households are charged above the 80th percentile of the metered monthly charges.

I study the effect of several large-scale metering campaigns on household payments, disconnections, and water consumption using event study framework. Water source options for households in Livingstone include primarily piped water use from an individual connection or through sharing with a neighbor's connection. Other alternatives such as shallow wells and boreholes are uncommon. Metering may encourage water connections by (i) lowering the monthly bill for individual consumption and (ii) making sharing more expensive. I find that metering produces significant revenue gains for the water utility. Revenue increases by more than 30 percent after metering events in areas that were metered. Metering events also result in re-connections for households that were disconnected due to non-payment. The share of households that are disconnected decreases by approximately 30 percent among low-income households after metering. Results show that the observed effect is primarily due to increases in payments and decrease in disconnections among households treated with meters, but revenue increases are also observed from households that were already metered. The welfare effects to households, however, is not clear due to the simultaneous change in the price of an individual connection and the price of sharing.

Estimating the effect of metering on water consumption is difficult to measure because unmetered consumption is never observed. Instead, I analyze consumption changes shortly after meter installation. Water bills are distributed two months after consumption occurs. Because of the delay in consumption and billing, it may take households several months to adjust consumption to their optimal metered consumption. I find that high-income households reduce their consumption by 23 percent by 10 months after metering events.

This research contributes to the growing literature on optimal tariff design of water and electric utilities. Previous studies have focused on both the design of the tariff structure (see Szabo (2015); Ito (2014); Violette (2017); McRae and Meeks (2016); Burgess *et al.* (2019)) and connection fees (see Devoto *et al.* (2012); Lee *et al.* (2020); Blimpo *et al.* (2018)). Previous literature on the effect of metering has been limited despite the frequent transitions from unmetered to metered connections among utilities in low-income countries. A notable exception is McRae (2015), who estimates the efficiency and welfare impacts of the transition from unmetered to metered electricity connections in Columbia and finds significant welfare benefits to low-consumption households. However, the findings of this study cannot be easily generalized to water utility contexts because interhousehold sharing of electricity connections may be more difficult. Jack and Smith (2020) study the transition from post-pay to pre-paid metering in South Africa and find net revenue gains for the water utility primarily from the poorest customers.

This paper proceeds as follows. Section 2 discusses the research setting and a description of water pricing in Livingstone. Section 3 presents the theoretical framework. Section 4 presents quasi-experimental results. Section 5 presents suggestions for future work.

2 Research Setting and Data Description

This research project was conducted in Livingstone, Zambia in cooperation with the Southern Water & Sanitation Company (SWSC). SWSC is a private water utility company that is responsible for providing water and sewerage services to Zambia's Southern Province. SWSC is one of eleven national utility companies, which are regulated nationally by the National Water Supply and Sanitation Council (NWASCO). Proposed tariff increases or policy changes by SWSC are accepted or rejected by NWASCO conditional on performance indicators such as new customers added, service hours, the share of customers who are metered, and revenue collection efficiency (NWASCO, 2020). Water utilities in Zambia face significant challenges when trying to service last mile customers, particularly those in peri-urban and rural areas. Expansion of water networks not only requires large infrastructure investments from utility companies, but often high connection fees from households, which have been shown to be a significant barrier to increasing connections to water and electricity grids (Lee *et al.* (2020); Devoto *et al.* (2012); Golumbeanu and Barnes (2013); Blimpo *et al.* (2018)). Urban and rural water coverage in Zambia remains below 88% and 44%, respectively (see Figure 1).

Administrative data was collected from SWSC from all 24,710 residential and commercial water customers in Livingstone from December 2012 to June 2019. Administrative data include customer billing and payment data as well as the locations of each connection. Billing data include an indicator for whether the household is metered and an indicator for whether the customer is disconnected (due to nonpayment) in that month. To supplement the administrative data, a random sample of 808 households in Livingstone were surveyed in September of 2019. The household survey gathered information about the customer demographics and water sharing between households. Table 1 presents summary statistics of the administrative data collected from SWSC of residential customers and the household survey data.

Nonpaying customers in Livingstone are frequently disconnected by the water utility, and households that remain disconnected often rely on the use of a neighbor's water connection to meet their daily water needs. In order to reconnect to their water connection, households must pay a reconnection fee as well as clear any debt with the water utility. An average of 18 percent of customers are disconnected per billing month. Customers in Livingstone have an average monthly income of 2,654 ZMW (approximately 65 USD). Sixty-five percent of residential customers are Domestic Low households, which is a taxcode designation for the size of the household's plot.[1] Domestic Low households are generally lower income households in densely populated areas of the city (see Figure 2). Figure 3 shows an example of a typical Domestic Low households in Livingstone. Because I only have income data for

[1] 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).

surveyed households, I use the indicator of whether the household is Domestic Low, Medium, or High as a proxy for income. Table 2 shows a comparison of administrative and household survey data between Domestic Low and Domestic Medium and High households. Domestic Low households on average consume less water, have a lower income, and are less likely to have indoor plumbing or an electricity connection.

2.1 Water Pricing

Water tariffs in Livingstone are dependent on whether the account is metered or unmetered. Unmetered accounts are charged a flat monthly bill regardless of monthly usage. The tariff structure for unmetered accounts is shown in Figure 4 (a). SWSC uses the taxcode designations Domestic Low, Domestic Medium, and Domestic High to determine the monthly tariff for unmetered accounts. Domestic High households, which have larger plots and are generally higher income households, are charged more per month than Domestic Medium and Domestic Low households. Table 2 shows that the average consumption for Domestic Low households is 16 cubic meters of water compared to 27 cubic meters of water for Domestic Medium and High households.

Metered accounts are billed according to an increasing block tariff (IBT). The IBT structure for metered accounts is shown in figure 4 (b). The IBT is a widely used pricing scheme for both water and electricity utilities in developing countries. Under an IBT, increasing marginal prices are set for each consumption tier. The general rationale for the use of this tariff structure is twofold: (i) to encourage water conservation by pricing larger quantities of water at a higher marginal price and (ii) to allow higher-quantity users, who are generally wealthier, to cross-subsidize the lower-quantity users who are generally poorer (Whittington and Nauges, 2020). For these reasons, the IBT is generally considered to be both pro-environment and pro-poor.

In practice, however, the IBT may not achieve these intended goals. First, the goal of conservation may not be achieved if households are sub-optimally responding to the price structure of the IBT. Ito (2014) provides evidence of customers responding to the average price of electricity rather than the marginal price and argues that this consumer behavior reduces the effectiveness of nonlinear pricing to encourage energy conservation. Second, consumers may have limited understanding of the price structure for water and electric utilities and/or low literacy of utility bills. Szabó and Ujhelyi (2015) find that only 12% of surveyed households in Pretoria, South Africa can correctly state the water consumption on their water bill. Similarly, Jack *et al.* (2018) find that both heads of household can only correctly locate the water consumed on the monthly bill in only 10% to 14% of surveyed households in Livingstone. Finally, the IBT can only provide a subsidy to poor households if they are in fact the lower quantity users, which may not be the case if poor households are larger or sharing with neighboring households. Household sharing of taps is common in developing cities and has been documented as an important source of water supply for low-income households (Devoto *et al.* (2012); Violette (2017)).

2.2 Water Sharing

Water source options for households in Livingstone include piped water, boreholes, public taps, and shallow wells. However, public taps and shallow wells are uncommon, and 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. Furthermore, only two percent of SWSC customers have a private borehole because the water table is lower than in other regions of Zambia. When households are disconnected from their individual water connections, the survey data shows that most choose to share with a neighboring households within 100 meters of their home.[2]

When a disconnected household shares with an unmetered account, the household can likely do so at zero marginal price for use and pay only the "hassle cost" of transporting the water. However, if a disconnected household shares with a metered account, the marginal

[2]Households that were disconnected at the time of the survey were asked how far they travel to fetch water, and 100 meters is the 90th percentile of the responses.

price for water can increase substantially as a result of the IBT structure. Figure 5 shows hypothetical water bills for households in Livingstone, Zambia when household share one water connection or using individual connections. The IBT tariff structure disincentives sharing by increasing the average monthly price of water when more households use the same connection. Unconnected households that are unable to pay the fixed cost of a (re)connection would therefore prefer to share with an unmetered household unless the hassle cost of sharing with an unmetered account is prohibitively high. The water utility assumes that there is some degree of overuse occurring in unmetered households and charges these households between the 80th and 85th percentile of metered monthly fees (see Figure 6).[3]. Household survey responses suggest that some disconnected households did not reconnect because they were waiting for SWSC to provide them with a meter.

Panel (D) of Table 1 shows summary statistics of the cost of alternative sources of water that the household would use if disconnected. I estimate the opportunity cost of time using a stated preference approach. The household survey included the following question to estimate time costs.

> "Suppose you are walking to work or to the market every day and you could save 30 minutes total of traveling time, but it would cost you an amount of money to do so. Would you be willing to pay X Kwacha to save 30 minutes of travel time?"

Household were asked about each increasing value from 5 to 50 Kwacha. Households were asked to state the value directly if they were willing to pay more than 50 Kwacha. The household survey gathered information on the distance to the alternative source, the number of trips made per week, the travel time to the alternative source, and the payments made to the owner of the water source. I find that the average cost of alternatives is 223 Kwacha, but the median cost is only 67 Kwacha. Travel time costs represents the bulk of the cost of alternative water sources, and payments made to the water source owner is often low. The median household reports making no payments to access sources of water on another

[3] The water utility estimates unmetered consumption by using the metered quantity that would result in an equivalent unmetered bill. Non-revenue water (or unbilled water losses) are estimated using this estimate of unmetered consumption (see Figure 7)

property. Figure 8 shows the share of customers whose alternative source of water costs less than the median metered bill, between the median metered and the unmetered tariff, and households whose alternative source costs more than the unmetered monthly tariff. Nearly 60 percent of households reported an alternative water source cost of less than the median metered monthly bill for their taxcode designation.

Table 3 shows regression results of the probability of a household sharing its connection with other households. Columns (1) and (2) present logit regressions of an indicator for whether the survey respondent was supplying water to other households through its water connection. Columns (3) and (4) present regression results of the number of households that are using the respondent's connection. The number of neighboring unmetered connections in a household's 100-meter radius decreases the probability of sharing and the number of sharing households, and the number of disconnected households increases the probability of sharing and the number of sharing households. The number of sharing households increases when the respondent has an unmetered connection, but this is only significant when controlling for the number of neighbors with unmetered and disconnected accounts.

2.3 Metering

Water accounts in Livingstone contain a combination of metered (volumetric charges) and unmetered (fixed charges) connections. SWSC aims to reach full coverage of metered accounts and will meter entire regions when meters are provided either from NWASCO or external donors. If no meters are available when a new connection is added, the account will be established as unmetered. Additionally, if a metered household's meter breaks, the connection will be converted to unmetered. Figure 9 show the geographical distribution of metered accounts and unmetered accounts in Livingstone from 2013 to 2019. The fixed cost of the meter is incorporated into the household's monthly bill as a 10 ZMW meter rental fee. Figure 10 shows the distribution of the difference in estimated water quantity and total monthly bills between the month prior to meter installation and the first full month after the meter was installed. Approximately 46 percent of Domestic Low households and 39 percent of Domestic Medium and High households experience an increase in their total water bill after metering.

Figure 11 shows trends in metering over time. Meter rates are higher among Domestic Medium and High households. In the absence of metering events, the share of households that are metered trends downward over time as new unmetered connections are added and as meters break. Mutikanga *et al.* (2011) estimate a meter failure rate of 6.6 percent per year in Kampala, Uganda. Increases in metering occur during large metering campaigns when the water utility acquires new meters from the water utility or external donors, typically in large quantities. Metering campaigns largely occur within the boundaries of administrative zones that are defined by the water utility. Customer service agents (CSAs) are responsible for issuing payment reminders, reading meters, and conducting disconnections in one of 43 administrative zones. Administrative zones typically span several geographically separate regions, and I term these subsets of administrative zones subzones. Figure 12 shows administrative zone boundaries for May, 2019. Metering campaigns generally follow administrative billing zone boundaries, however, usually a subzone of the administrative zone will be metered at one time. Metering campaigns occurring in a household's administrative zone may simultaneously affect enforcement in that zone, the substitution possibilities for disconnected households, and reductions in monthly bills.

3 Conceptual Model

I model household utility as quasilinear in water consumption. The household's monthly utility maximization problem is as follows.

$$\max_{\{w,x\}} \quad x + 2w - \frac{w^2}{\alpha} \tag{1}$$

$$s.t. \quad x + P \leq y \tag{2}$$

Water consumption is given by w, and x is numeraire consumption. The parameter α represents the household's satiation quantity of water. Households maximize utility subject to their budget constraint, $x + P \leq y$, where y is monthly household income. Monthly payments on water are given by P and will depend on whether the household is metered, whether it is sharing with other households, and whether the household is drawing from the household with a connection. I summarize monthly payments as follows as a function of the number of households sharing one tap, n.

$$P = \begin{cases} T & \text{if unmetered, own connection, not sharing} \\ \frac{T}{n} & \text{if unmetered, own connection, sharing} \\ \frac{T}{n} + hw & \text{if unmetered, drawing from other connection} \\ p(w)w & \text{if metered, own connection, not sharing} \\ p(W)w & \text{if metered, own connection, sharing} \\ (p(W) + h)w & \text{if metered, drawing from other connection} \end{cases} \tag{3}$$

For unmetered households, total monthly payments are equal to the unmetered monthly tariff, T, and are independent of consumption. I assume that when multiple households are sharing the same unmetered connection that each household splits the cost equally. When a household draws from a connection that is not their own property, it must pay a hassle cost, h, per unit of water that it consumes. The hassle cost includes travel time, carrying costs, and inconvenience of transporting water. When a household is metered, the price paid is equal to the average price, $p(w)$, multiplied by the total water consumed, w. Because metered households are charged according to an IBT, the average price is a function of water consumption. When multiple households are sharing one metered tap, the average price is a function of total water consumption, $W = w_1 + w_2 + ... + w_n$. I assume that sharing households pay the average price multiplied by their individual consumption.

When the household owns the connection and is unmetered, consumption will occur at the household's satiation consumption level, $w_u^* = \alpha$, regardless of whether it is sharing with other households. The household with the unmetered connection maximizes utility by sharing with as many households as possible in order to reduce monthly water costs. The household drawing water from an unmetered connection will consume less than their satiation quantity due to the hassle cost of transporting water, $\hat{w}_u^* = \alpha - \frac{\alpha h}{2} < w_u^*$. In the following sections, I discuss the potential responses of households to metering events under this conceptual framework.

3.1 Extensive Margin: Connections

A household will choose to reconnect if the utility from use of their own connection is greater than the utility of sharing with others. When metering events occur, the household may experience a change in their monthly water bill if treated with a meter and a simultaneous change in their substitution possibilities. As the density of unmetered connections decreases, the cost of sharing increases because there are fewer unmetered connections that allow use at a zero marginal price. Disconnected households may either travel farther for access to an unmetered connection, which raises the hassle cost of use, or share with a metered connection, which may raise the marginal price of use if aggregate consumption moves to a higher price tier.

3.2 Intensive Margin: Consumption

When a household becomes metered and is not sharing with others, consumption falls to less than the satiation quantity because the household now faces a positive marginal price for water. When a metered household is sharing with others, the consumption responses become less clear. Consumption declines as households face a higher average price. However, a household's effect on the average price is not internalized by the household and is instead shared among all n sharing households. This interhousehold externality may reduce responsiveness to price. Jack *et al.* (2018) show evidence of this type of externality within households in Livingstone, and Carrillo *et al.* (2021) show significant water reductions when residential complexes transition from collective to individual metering. Furthermore, because most Domestic Low households have a backyard tap, it may be difficult for households to monitor the consumption of neighbors (see Figure 3).

4 Quasi-Experimental Evidence

4.1 Payments and Disconnections

The primary empirical analysis conducted in this paper models payment and disconnection indicators in an event study framework. Because metering events happen for different subzones in different periods, I use a two-way fixed effect estimator. Equation 4 shows the estimating equation.

$$\text{Indicator}_{it} = \sum_y \beta_y D_{it}^y + \alpha_i + \gamma_t + \varepsilon_{it} \tag{4}$$

I define a metering event as the month in which the largest change in metering in the subzone occurs if at least 20% of households in the administrative subzone become newly metered. Figure 13 shows the timing of metering events. In this specification, D_{it}^y are event-time dummies indicating when the largest event is y periods away. Specifically, $D_{it}^y = I[t - e_m = y]$, where t is the year and month of the observation and e_m is the year and month of the metering event. The estimating equation includes dummies for the five months before and the 10 months after the metering event as well as customer level fixed effect, α_i, and month and year fixed effects, γ_t. Indicator_{it} includes an indicator for making a payment, an indicator for being disconnected, and revenue per customer. To avoid perfect multicollinearity of the event-time dummies, β_{-2}, the month two periods before the metering event, is omitted and therefore normalized to 0. The β_y coefficients represent the evolution of payments and disconnections relative to the month before the metering event. I apply the following endpoint restrictions, which imply that the effect of metering should diminish more than 7 months before the event and more than 10 months after the event.

$$\beta_y = \begin{cases} \bar{\beta} \text{ if } y > 10, \\ \underline{\beta} \text{ if } y < -7 \end{cases} \tag{5}$$

A primary concern with the above analysis is that assignment of metering events is not random. Because metering event follow administrative boundaries, I assume that metering decisions are made primarily by the water utility. However, household demand for meters may influence metering decisions through customer complaints and meter applications. Households can apply for a meter, but meters are only available when delivered (typically in large quantities) from the water utility regulator or external donors. Table 4 presents logit regressions of the probability that a subzone will experience a metering event in one of the eight metering events observed over the sample period. Because metering decisions are likely made months in advance, I include subzone characteristics from 5 months before the metering event. The share of unmetered customers in a subzone is the largest predictor of the probability of a subzone experiencing a metering event. Conditional on the share of unmetered customers, subzones with more connected and Domestic Medium and High households and subzones that pay a higher average share of their water bill are more likely to experience a metering event. This suggests that the water utility prioritizes metering events to areas of higher baseline revenue. In the primary analysis, I therefore examine the effect of metering events separately for Domestic Low and Domestic Medium and High households.

Another concern is that enforcement may simultaneously change with metering events. Meter reading requires additional tasks from customer service agents who are responsible for bill distribution, payment reminders, and disconnections. It is not clear ex ante whether metering would result in higher or lower levels of enforcement. Customer service agents face additional tasks through meter reading, but this may also increase engagement with households. Spink (2022) shows that increases in enforcement results in higher disconnections for Domestic Low households. McRae (2015) shows suggestive evidence of increases in enforcement occurring during electricity metering events in Columbia. Households that become metered additionally face a more transparent billing process and may have higher trust in the water utility when metered. Szabó and Ujhelyi (2015) show evidence of short-run payment increases of information and engagement interventions but argue that the observed effect is primarily resulting from reciprocating the utility provider's efforts.

Figure 15 presents the estimation results of equation 4. Because metering events may take several months to complete, I normalize the β_{-2} dummy, which indicates two months prior to the metering event, to equal zero. The probability that a household is metered increases sharply at the time of the metering event. Domestic Low households experience a higher increase in the probability of becoming metered at the time of metering events, likely because Domestic Low areas have a lower baseline level of metering.

Disconnections begin to decline in the month prior to the metering event suggesting some anticipatory behavior of metering. Either the household or the water utility may be reconnecting when meters are installed. However, not all disconnected customers are reconnected during metering events, which suggests that this is behavior primarily from the household. Disconnections decrease by 7 percentage points for Domestic Low households after the metering event. This represents a 30 percent decrease from prior to metering. Disconnections rebound slightly after more than 10 months after the metering event, but Domestic Low households remain more than 4 percentage points less likely to be disconnected after metering events. For Domestic Medium and High households, disconnections decrease by 2 percentage points in the two months following metering and rebound to the levels observed prior to metering thereafter.

The probability that a household makes a payment to the water utility increases steadily after the metering event for all customers to about 11 percentage points higher than prior to metering. This represents a higher percent increase for Domestic Low households whose probability of making a payment was 0.5 prior to metering compared to 0.6 percent for Domestic Medium and High households. Revenue increases peak between 3 and 8 months after metering. Domestic Low households increase total monthly payments by approximately 30 percent and Domestic Medium and High households increase total monthly payments by 40 percent.

Figure 16 shows the results of equation 4 separately for households that are treated with meters, households that were metered prior to the metering event, and households that remain unmetered after the metering event. The observed pattern in payments and disconnections is driven primarily by households that are treated with meters. Treated households experience a 17 percentage point increase in the probability of making a payment, a 45 percent increase in total monthly payments, and a 50 percent decrease in the probability of being disconnected in the month immediately following a metering event. Disconnections rebound in the months following a metering event for treated households, but they remain 30 percent less likely to be disconnected after more than 10 months following metering.

For households that were already metered before the metering event, an increase in payments and a decrease in disconnections are expected because these households face a higher cost of alternative sources of water when the share of unmetered connections decreases. Additionally, households that were sharing with unmetered connections may now choose to share with metered connections. There is some evidence of a decline in disconnections for metered households, and a modest increase in revenue of approximately 15 percent per month is observed after 6 months. Households that remain unmetered following the metering event may have fewer households sharing with them if previous sharing partners reconnect to their individual connection or may have more households sharing with them if households that remain disconnected must find a new unmetered connection to draw from. Figure 16 shows that households that remain unmetered after the metering event increase monthly payments by only 10 percent per month. There is also some evidence of an increase in disconnections for households that remain unmeterd.

4.2 Water Reductions Under Metering

In this section, I examine changes in consumption for households that have become newly metered. A primary empirical challenge is that unmetered consumption is not observable, and water use is observed only in the months following the meter installation. Following an approach similar to McRae (2015), I exploit the lag between consumption and billing to estimate consumption responses to metering. McRae (2015) measures the welfare effect of electricity metering in Columbia by estimating the extent to which customers adjust consumption once metered. Since households do not receive a bill for consumption in month x until a month and a half after the billing period has ended (see Figure 14), it is possible that households may take several months adjust consumption downward if they were consuming more than the efficient metered quantity during the unmetered months. This may be especially true if the household was sharing with others when unmetered and decides to cease sharing once metered. To determine the the effect of metering on an individual customer's billing and consumption behavior in the months following the meter installation, I estimate the following equation.

$$\text{Quantity}_{it} = \sum_{y} \beta_y M_{it}^{y} + \alpha_i + \gamma_t + \varepsilon_{it} \tag{6}$$

In this equation, M_{it}^{y} is a dummy for y months after the meter installation, $M_{it}^{y} = I[t - m = y]$. Similar to equation 4, I include customer fixed effects, α_i, and month-by-year fixed effects, γ_t. Meters are generally not installed at the beginning of the billing cycle, and meters installed in the middle of the month may reflect only a fraction of monthly consumption. I therefore examine consumption changes relative to the first full month of metered consumption.

Figure 17 shows the results of estimating equation 6. Consumption for newly metered Domestic Low households remains relatively constant in the months following meter installation. For Domestic Medium and High households, consumption begins to decline immediately following the installation of the meter. After 10 months, households reduce consumption by an average of 23 percent. In a similar analysis of electricity consumers in Columbia, McRae (2015) finds that consumption decreases by approximately 30 percent in the four months following meter installation and remains relatively constant thereafter. The observed decline in consumption among electricity customers in McRae (2015) and Domestic Medium and High households in this study may be due to the lack of sharing. Sharing is less common among Domestic Medium and High households, and electricity is also more difficult to share with neighbors. The conceptual model described in Section 3 indicates that quantity reductions resulting from a higher average price might be counterbalanced by the household not internalizing the effect of their own consumption on the average price paid by all sharing households. Another possibility is that Domestic Low households may face higher water rationing and thus have limited ability to adjust consumption.

5 Conclusion

This paper provides suggestive evidence of the effect of water connection metering. From the water utility's perspective, metering is advantageous. Metering produces significant revenue gains and increases the number of households with an active connection, both of which are performance indicators used by the water utility regulator. Higher revenue may also allow the water utility to invest in quality improvements which may increase demand among customers. While meters are expensive to acquire, the cost of the meter is paid by the household through monthly meter rental fees.

The welfare effects to customers, however, are unclear. Areas for further research include estimating the welfare effects of metering particularly for households whose primary source of water is through sharing. High-water use households are made worse off by metering. For low-consumption customers, metering events both lower the cost of an individual connection and make sharing with other households more expensive. Both effects would lead to an increase in payments and a reduction in disconnections after metering events as observed in this study. An ideal experiment to tease apart these two mechanisms is a cluster randomized control trial of meter installations.

This paper analyzes the effect of metering in a setting where households primarily use piped water either from their own connection or their neighbor's. Metering events therefore raise the cost of alternative sources of water, and the results show a large decrease in disconnections after metering events. In many developing country settings, households often have a wider set of alternatives including shallow wells and surface water. Metering events in these settings may raise the cost of sharing a piped-water connection but not the cost of other substitute sources of water that are often less clean. Metering in areas of high shallow well use may therefore produce significant health externalities if households substitute toward shared wells instead of establishing an individual connection.

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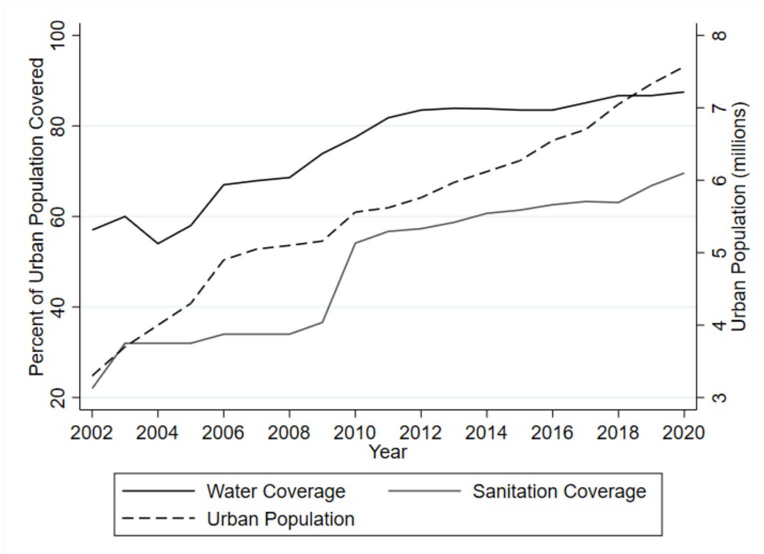
Appendices

A Figures and Tables

Figure 1: Trends in Water and Sanitation Coverage in Zambia



Notes: This figure presents trends in water and sanitation coverage for urban and peri-urban areas in Zambia. Solid lines represent the percent of the urban population with access. Source: NWASCO Urban and Peri-Urban Water Supply and Sanitation Sector Reports, 2001-2020 (NWASCO, 2020).

Figure 2: Locations of Domestic Low, Medium, and High Households in Livingstone

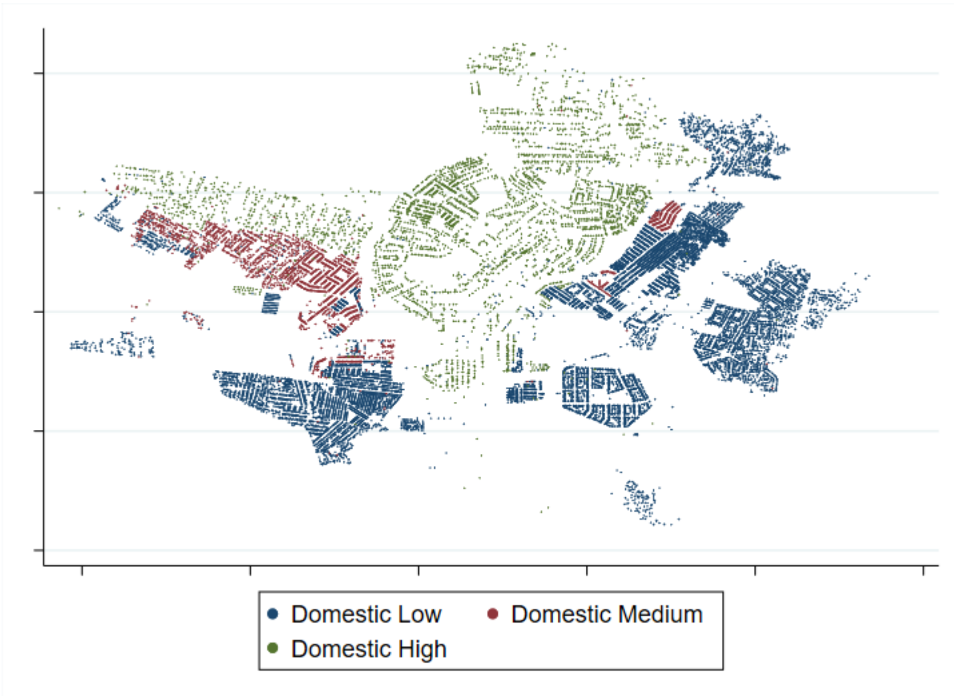


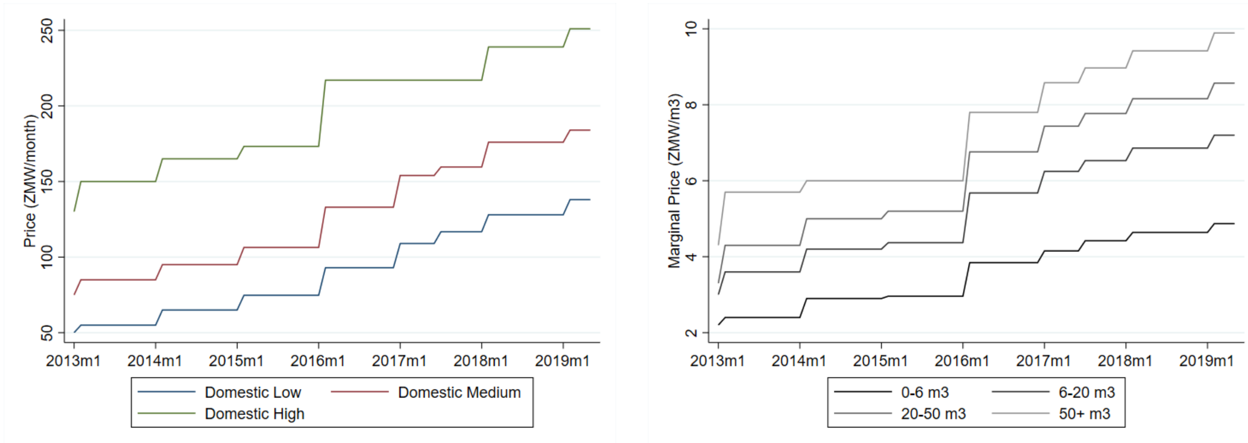
Figure 3: Domestic Low Household and Water Connection

(a) Domestic Low Property

(b) Domestic Low Water Connection

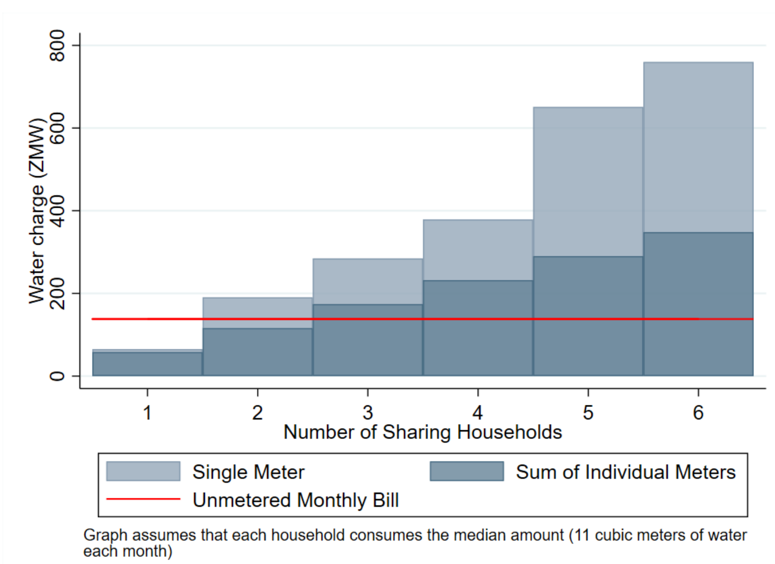
Figure 4: Water Tariffs for Metered and Unmetered Households

(a) Unmetered Monthly Tariffs (b) Metered Price Schedule



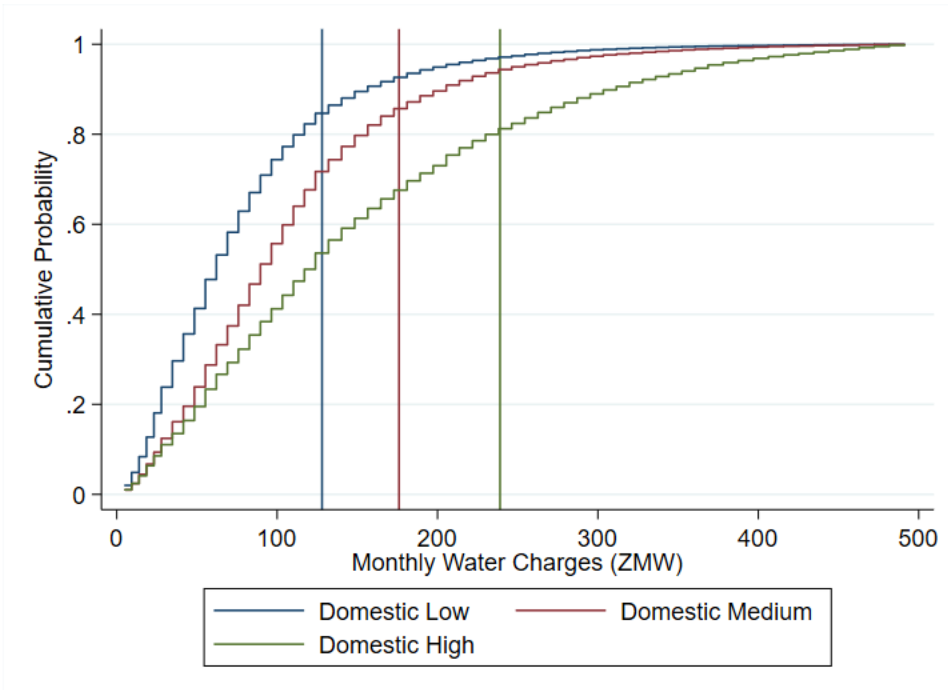
Notes: This figure presents the unmetered monthly tariff over the same period in sub-figure (a) and the the increasing block tariff price structure for metered households from 2013 to mid-2019 in sub-figure (b). Metered households are charged by the cubic meter at different marginal rates for each consumption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

Figure 5: Hypothetical Water Bills Under Sharing Metered Connections



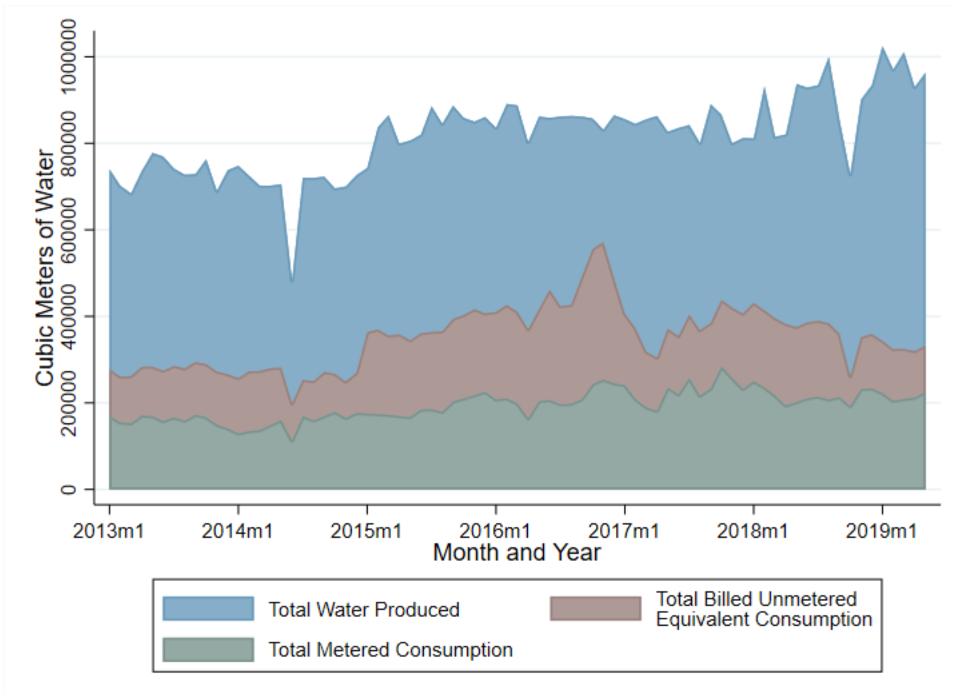
Notes: This figure presents water charges for households when using individual meters and when sharing the same meter. The horizontal line denotes the unmetered tariff for Domestic Low households.

Figure 6: CDF of Water Charges for Metered Customers and Unmetered Monthly Tariffs



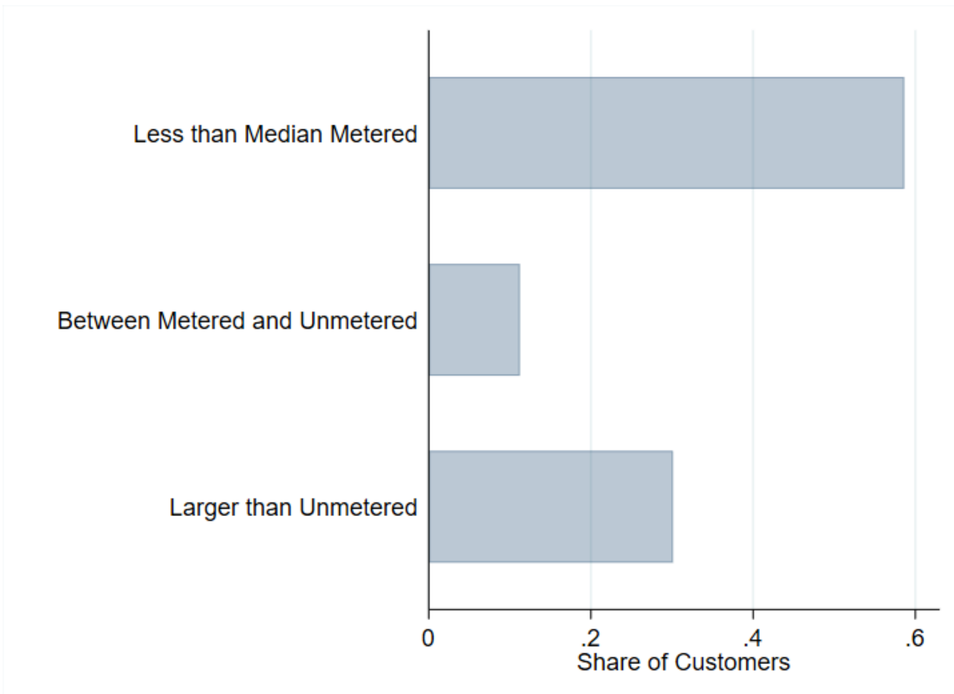
Notes: The sample is restricted to metered households consuming a positive quantity of water between February, 2018 and January, 2019 (a time period when tariffs were not changed). The vertical lines denote the unmetered monthly bill for Domestic Low customers (in blue), Domestic Medium customer (in red), and Domestic High customers (in green) for January, 2019. Unmetered households are charged between the 80th and 85th percentiles of metered monthly charges.

Figure 7: 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 8: Cost of Alternate Sources of Water



Notes: This figure presents a bar graph of the reported cost of alternative sources of water for the household. The cost of alternative sources of water includes payments made to the water source and time costs for fetching aggregated to a monthly level. The unmetered tariff used is the June, 2019 tariff for the respective group: Domestic Low, Medium or High. The median metered monthly bill is calculated in June of 2019 for each group.

Figure 9: Trends in Metering from 2013 to 2019

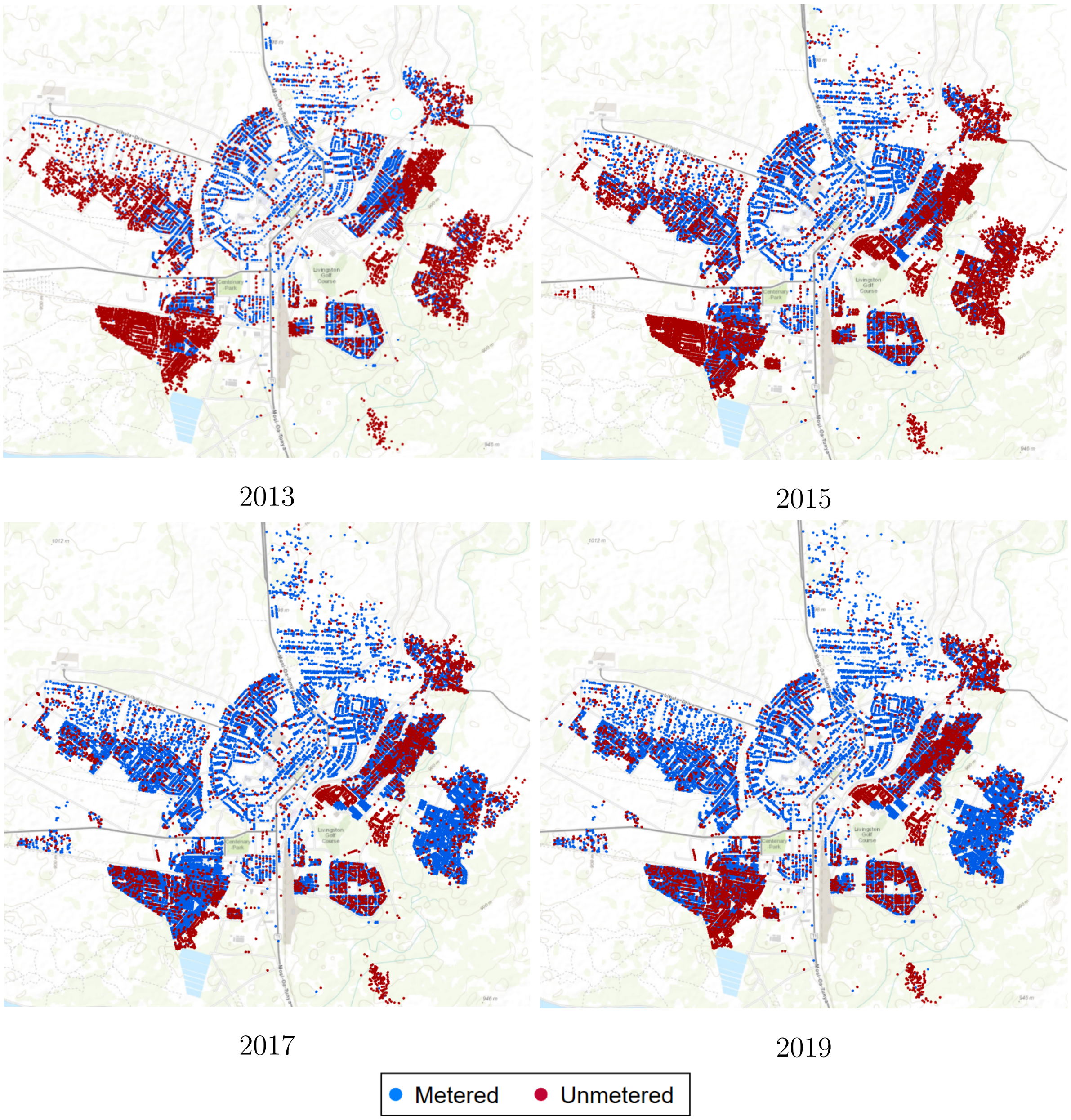
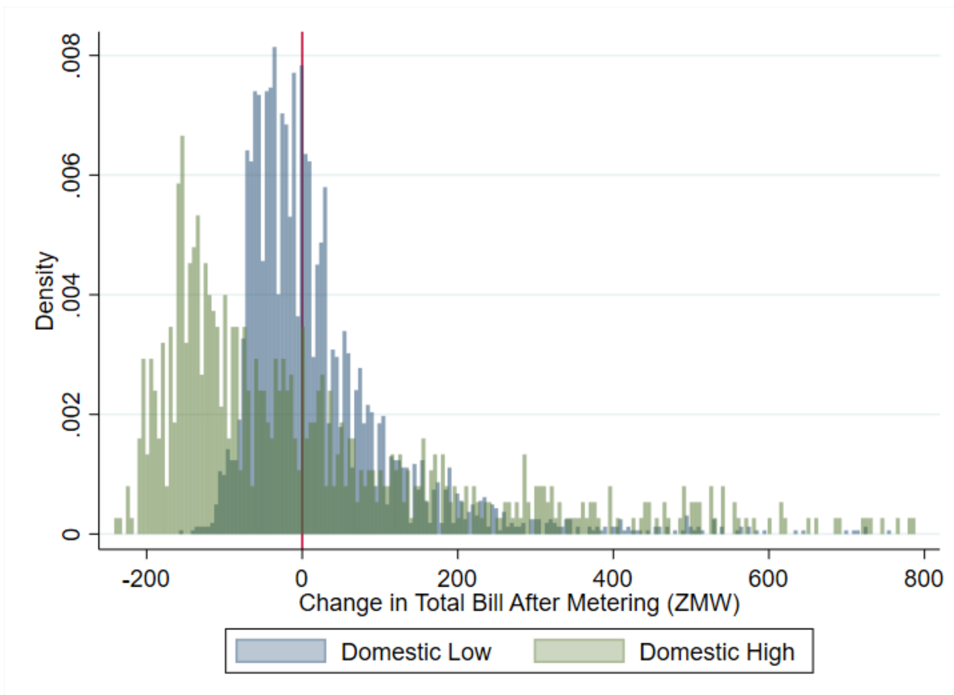
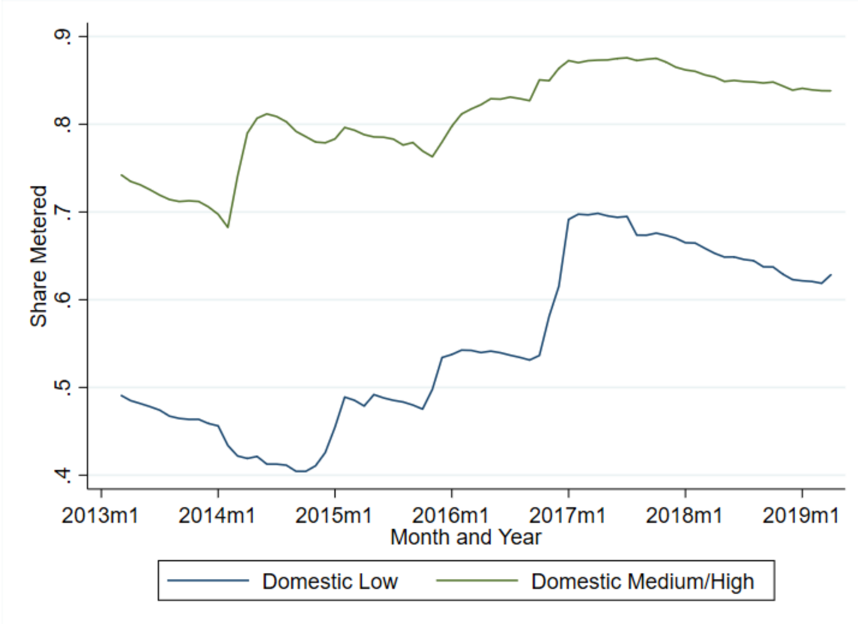


Figure 10: Change in Total Bill After Metering



Notes: This figure presents a histogram of the change in total bill for households after metering. The sample is restricted to households that are connected in the period before and the period after metering. Negative values indicate that the household's bill decreased after being metered.

Figure 11: Trends in Metering



Notes: This figure presents trends in the share of customers metered separately for Domestic Low and Domestic Medium and High households. The share of households that are metered in the absence of metering events trends downward because new unmetered customers are added to the water network and previously installed meters break.

Figure 12: Water Utility Administrative Zones Boundaries in May 2019

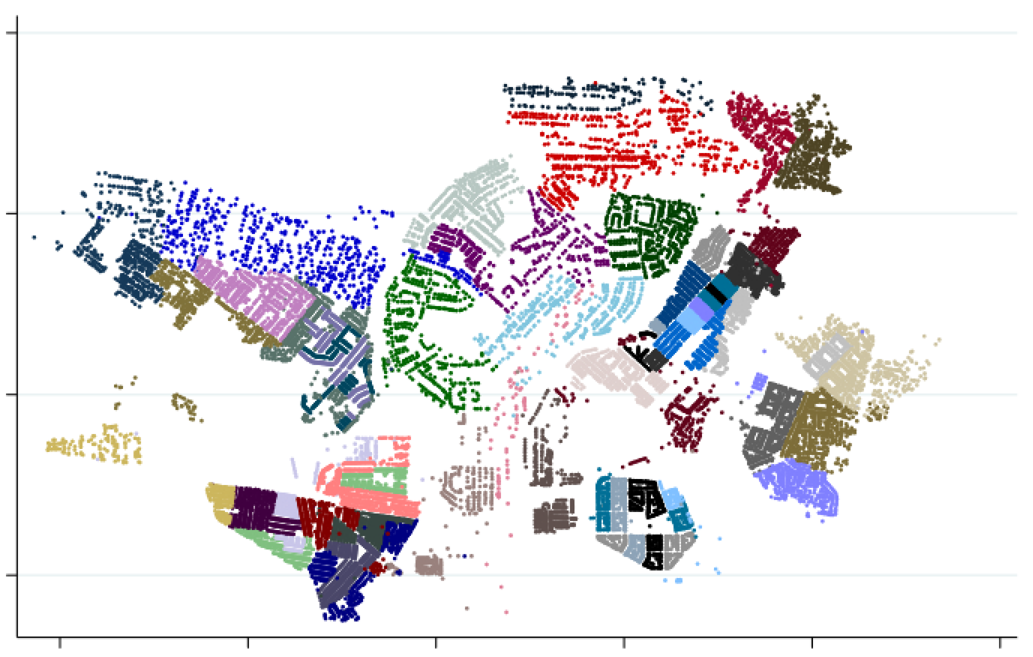
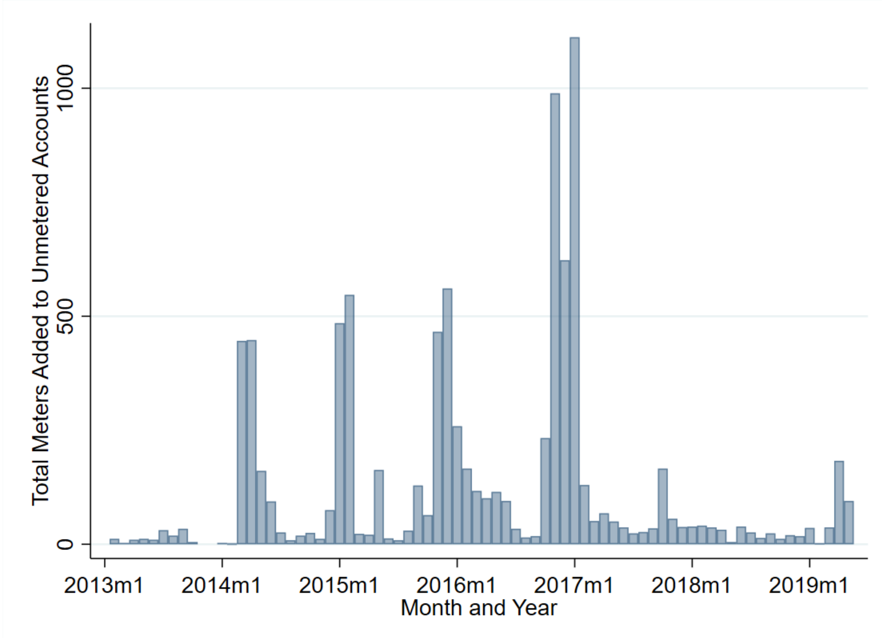


Figure 13: Timing of New Meters Added



Notes: This figure presents a histogram of the timing of when new meters were added to unmetered accounts. This includes both large metering events studied in this paper and replacement of broken meters to accounts previously metered.

Figure 14: Timeline of Billing, Payments, and Disconnections

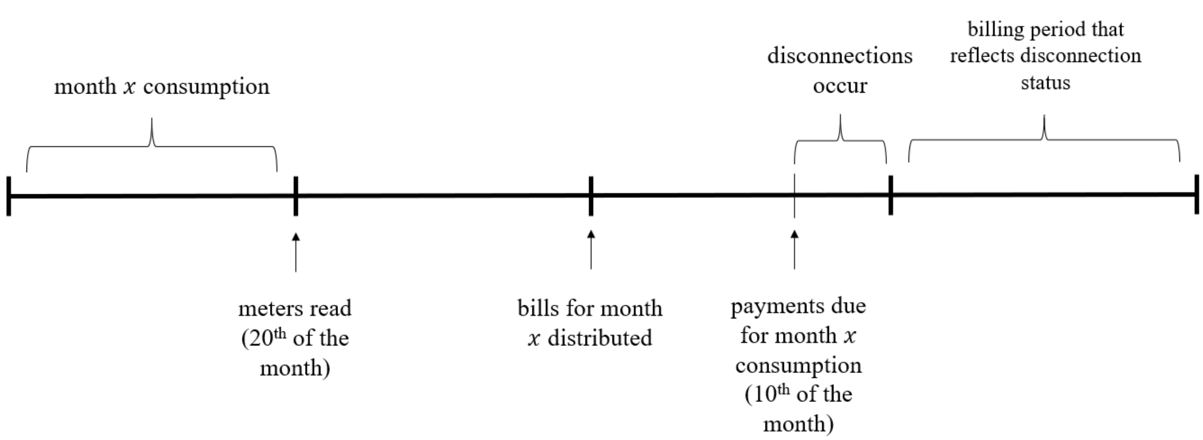
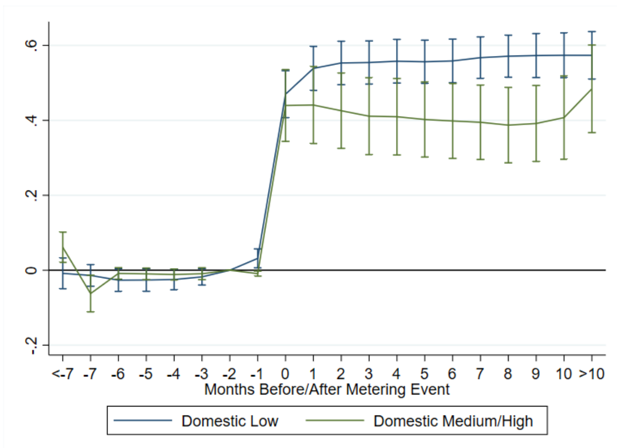
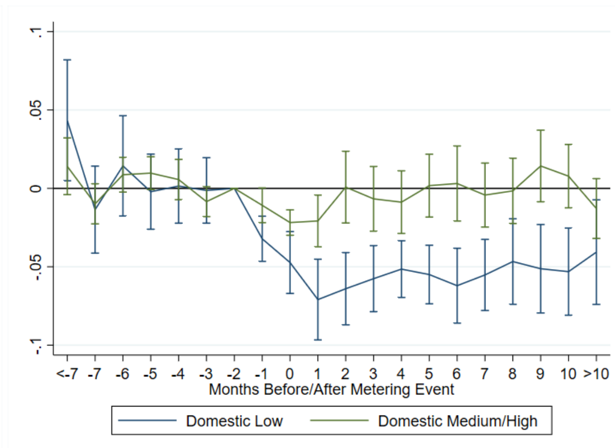


Figure 15: Event Study Results of Metering Events

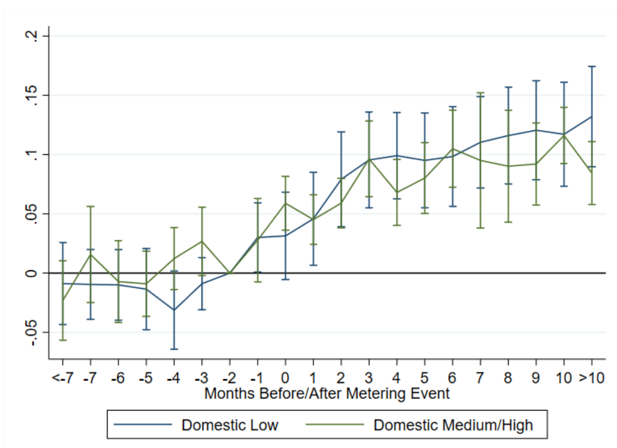
(a) Metered



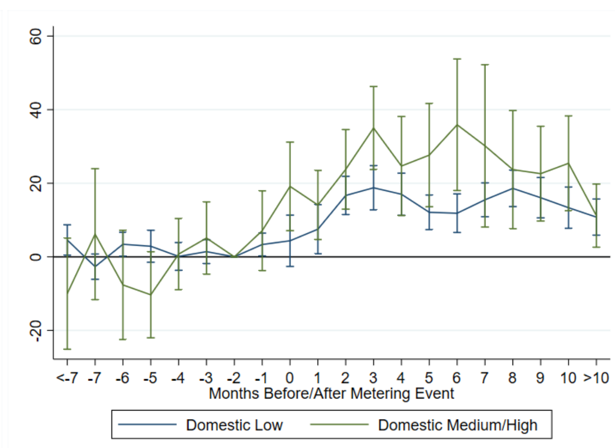
(b) Disconnected



(c) Made Payment

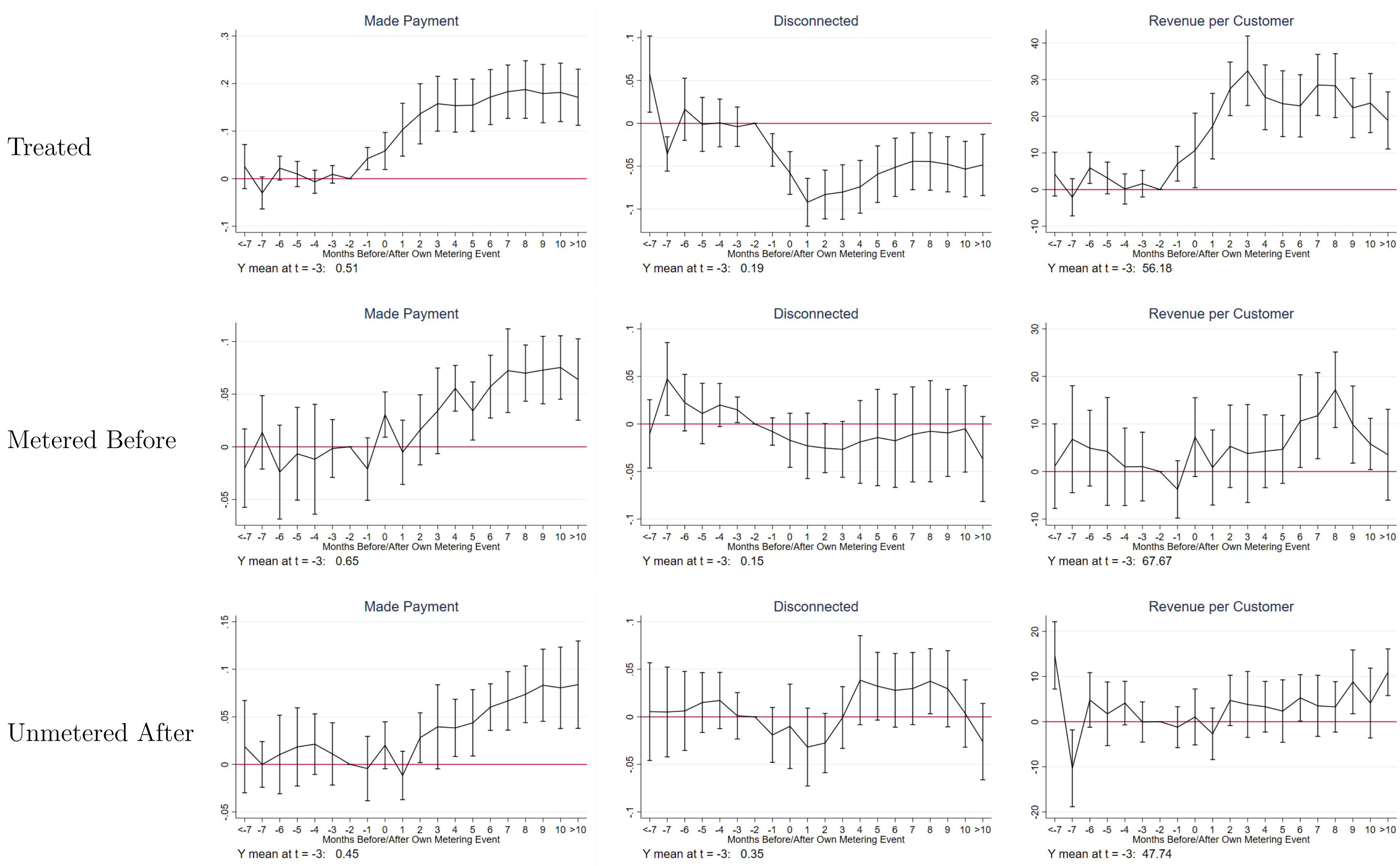


(d) Total Revenue



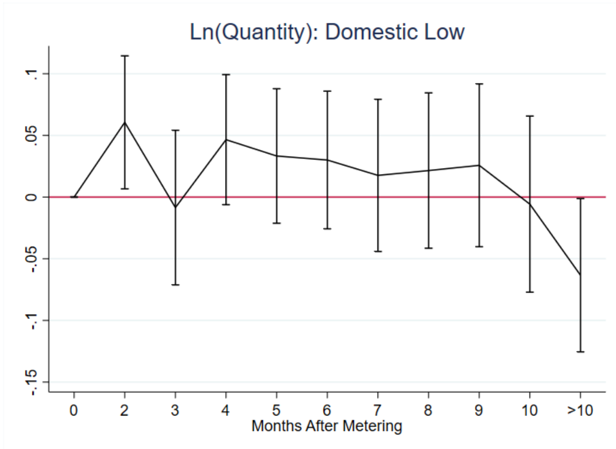
Notes: This figure plots point estimates and 90 percent confidence intervals for event-time dummies in estimating equation 4 separately for Domestic Low and Domestic Medium and High households. All regressions include customer fixed effects and year-by-month fixed effects. The omitted event-time dummy is $t = -3$. Standard errors are clustered at the subzone level.

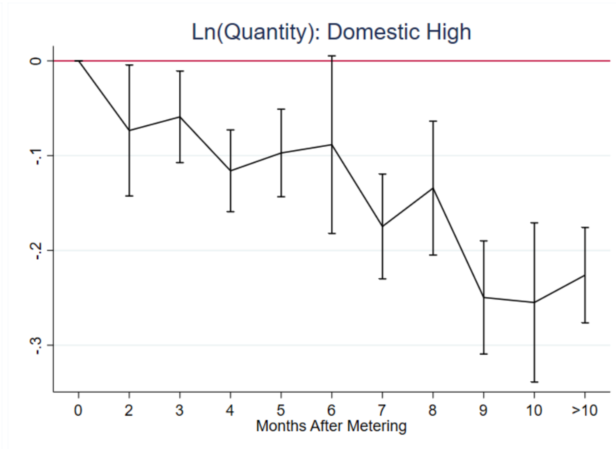
Figure 16: Event Study Results of Metering Events by Metering Status



Notes: All regressions include customer fixed effects and month and year fixed effects. Treated households are those that were unmetered two months prior to the metering event and are metered two months after the metering event. Households are defined as being metered before the event if they were metered 5 months prior to the month of the metering event and remained metered at least 3 months after the metering event. Households are defined as being unmetered after the event if they were unmetered 3 months before the event and remain unmetered 5 months after the event. Standard errors are clustered at the subzone level.

Figure 17: Event Study Results of Consumption After Metering





Notes: This figure presents results of estimating equation 6 for Domestic Low households in panel (a) and Domestic Medium and High households in panel (B). Because meters may be installed mid way through the month and understate monthly consumption, the period immediately after meter installation, $t + 1$, is normalized to zero.

Table 1: Summary Statistics

Variable	Mean	Std. Dev.	P10	P50	P90
Panel A: Administrative Data (Billing level)					
Comsumption (cubic meters)	19.8	22.88	0	17	37
Total Current Charges (ZMW)	99.96	127.62	0	76.62	210.8
Comsumption|Connected (cubic meters)	23.69	23.11	6	17.33	39.81
Total Current Charges|Connected (ZMW)	119.88	131.66	31.27	90.48	226.8
Outstanding Balance (ZMW)	494.39	896.59	43.89	225.67	1260.79
Total Payments (ZMW)	88.31	184.1	0	50	211
Unmetered	.35	.48	0	0	1
Disconnected	.18	.38	0	0	1
Panel B: Administrative Data (Customer level)					
Domestic Low	.65	.48	-	-	-
Domestic High	.21	.4	-	-	-
Connected to Sewer	.4	.49	-	-	-
Distance to a Pay Station (km)	1.11	.73	.34	.99	1.95
Age of Account (months)	65.09	21.2	29	78	78
Has a Private Borehole	.02	.13	-	-	-
Panel C: Household Survey Data					
Monthly Income (ZMW)	2654.35	3059.83	500	2000	6000
Water Bill Share of Income	.11	.09	.02	.07	.3
Indoor Plumbing	.47	.5	-	-	-
Septic Tank	.41	.49	-	-	-
Electricity Connection	.9	.31	-	-	-
Piped Water Primary Source	.98	.14	-	-	-
Panel D: Cost of Alternatives					
Opportunity Cost of Time (one hour)	23.1	25.01	5	15	45
Distance to Alternative Source (m)	227.07	650.14	3	30	500
Time Costs to Alternative Source	203.08	625.41	4.67	46.67	490
Payments to Alternative Source	19.97	43.28	0	0	50
Total Costs for Alternative Source (ZMW)	223.13	632.18	11.67	67	490

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. Panel C presents summary statistics of the 2019 randomized survey of 808 households. All income, charges, outstanding balance, and payment variables are expressed in Zambian Kwacha (ZMW). Distance to a Pay Station represents the minimum distance from the household to one of nine pay stations in Livingstone. Years of Schooling is the total number of years of schooling of the household member with the highest education level. Household Size represents the total number of adults and children living in the household at the time of the survey. Number of Sharing Households is the number of additional households that are drawing water from the respondent household's water source.

Table 2: 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 3: Water Sharing Regressions

	Sharing		Number of Sharing Households	
	(1)	(2)	(3)	(4)
Unmetered	0.312	0.429	0.174	0.251**
	(0.262)	(0.285)	(0.111)	(0.122)
Domestic Low	0.304	0.045	0.086	-0.029
	(0.269)	(0.323)	(0.103)	(0.125)
Number of Unmetered Neighbors		-0.029*		-0.017**
		(0.017)		(0.007)
Number of Disconnected Neighbors		0.057**		0.031***
		(0.023)		(0.010)
Observations	652	635	652	635
R Squared	0.007	0.022	0.006	0.022

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

Notes: The dependent variable in columns (1) and (2) is an indicator for whether other households are drawing water from the respondent's connection. The dependent variable in columns (3) and (4) is the number of households that are drawing water from the respondent's connection. Columns (1) and (2) are logit regressions and report pseudo R-squared values. The sample is restricted to households that were connected at the time of the survey. The number of unmetered and disconnected neighbors is within a 100-meter radius of the respondent household.

Table 4: Probability of Metering Event

	(1)	(2)
Share Unmetered ($t-5$)	3.679***	5.056***
	(0.710)	(0.904)
Share Domestic Low	-1.212**	-1.144**
	(0.476)	(0.513)
Share Connected to Sewer	0.378	0.754
	(0.507)	(0.552)
Share Disconnected ($t-5$)		-1.856*
		(1.043)
Share of Total Bills Paid ($t-5$)		3.996**
		(1.801)
Share New Accounts ($t-5$)		-3.933
		(2.967)
Observations	384	384

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

Notes: This table presents logit regressions in which the dependent variable is an indicator for the subzone experiencing a metering event. Coefficients represent the log odds ratio. The sample is restricted to the months in which metering events that occur. Column (1) includes only the share of unmetered households and fixed characteristics of the subzone. Column (2) includes variables from the billing data. Data are aggregated by subzone at each metering event. Variables are lagged 5 periods because the water utility is likely to make the decision of where to meter several months in advance.