Revenue Increase for Water Utilities from Improved Metering—
An Empirical Analysis of an Installation Project in Livingstone, Zambia

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Abstract

Water utilities in developing countries are progressively moving towards automatic meter reading (AMR) technology in an attempt to deal with revenue losses from both technical and non-technical issues associated with analog meters. Technically, the accuracy of AMR meters avoids meter reader mistakes; non-technically, AMR meters reduce the possibilities of shirking or corruption. AMR meters thus in turn affect customer consumption and payment decisions. As the availability of evidence on utilities' revenue increase from AMR meters is limited, this study fills the gap by testing the impact of installation of AMR meter in the context of a regional water utility in Zambia. The difference-in-difference design shows that the use of AMR meters increases households' billed water quantities. Customer payment amounts are in excess of the increases in amount billed. The estimated results are then used to calculate the justified upfront investment in water metering system.

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1. Introduction

The cost of water metering and usage-based billing are high compared to revenue, particularly in settings where consumption levels are low and not all customers pay their bills (Noll, Shirley and Cowan, 2000). In most countries, water is billed monthly based on in-person meter readings, which measure the amount consumed since the previous reading. This system is associated with two types of revenue losses. First, readings may be inaccurate because the meters themselves are incorrect (Shields, 2011). Second, the in-person nature of meter reading leaves an opportunity for households to bribe meter reader (Davis, 2004). Inaccurate metering may, in turn, affect customer consumption and also whether they pay their bills reliably. Studies have shown that cost recovery is impeded by low collection efficiency due in large extent to the non-payment of water bills (Dagdeviren, 2008)

In light of these drawbacks, this paper provides empirical evidence on how a switch to Automatic Meter Reading (AMR) in Livingstone, Zambia affects billed water quantities and customer payment behavior. AMR water meters are able to automatically capture and transmit households' monthly water usage back to the water utility, which has the potential to improve revenue recovery compared to conventional analog water meters. This paper seeks to quantify changes in the costs and benefits to the water utility and to calculate the rate of return to AMR metering in the Zambian context.

Funded by Devolution Trust Fund, the pilot project “Dambwa Automatic Meter Reading Metering Project” was initiated in Livingstone in 2014. The project installed around 2000 AMR meters in one neighborhood in Livingstone to either replace analog meters or cover previously unmetered customers. The project sought to reduce measurement inaccuracies caused by analog water meters. Ultimately, the project goal was to increase revenue and lower cost by reducing overconsumption and underreporting, and by eliminating in-person meter reading from the revenue collection process.

The primary purpose of this paper is to evaluate whether the installation of AMR meters had an impact on households’ water bills or bill payment, and to examine the value of the meters to the Southern Water and Sanitation Company (SWSCO, the regional regulated water utility). The evaluation is based on billing and payment data obtained from the SWSCO’s system. The data covers households’ bills and payments before and after the project, and lasts 40 months in total.

This paper evaluates the AMR project impact by comparing the project households that received AMR meters during September 2014 to December 2014 with a similar set of households in Livingstone that used analog water meters both before and after the installation period. The study uses a difference-in-difference design with household and month-year fixed effects to identify the impact of the AMR meters on billed water quantity and water payment behavior. An alternative comparison group is constructed using matching method to test the robustness of the results. The pre-treatment parallel trends are validated through visual inspection.

The results show that the installation of AMR meters in Dambwa, Livingstone increased the quantity of water billed by 18% and the amount owed on the bill by 21.1%. The greater increase in the amount owed is due to the increasing block tariff on which customer bills are based. Households' water payments increased on average by 9.43%, which amounts to 20.39 Zambia Kwacha.

However, the nature of the data makes it difficult to determine the source of the increase in the water quantity billed to the household each month. Specifically, an increase in the amount billed cannot separate water consumption behavior from changes in the accuracy of reported water quantity. As noted above, metering accuracy could improve because the replaced meters were faulty in some way or because meter readers were misreporting, either intentionally or not.

The increase of households water payment is aligned with the increase of water bills. The increase amount for households payment is larger than water amount owed to the utility, indicating that households may think AMR meters more reliable and are more willing to pay their bills. Because the price of the AMR meters used in the project is not available, the paper uses the estimation results to calculate the maximum meter cost that would be justified by this increase in monthly revenue.

The rest of the paper is structured as follows: Section 2 covers the study context and relevant literature review; Section 3 introduces the data used in the study; Section 4 displays empirical strategy and regression model for evaluating the effects of the installation project; Section 5 demonstrates results; Section 6 presents a number of robustness checks; Section 7 discusses the cost-effectiveness of newly installed meters.

2. Background and Literature Review

This section will discuss the general background on water utilities and water usage situations in Zambia, followed by a summary of current literature related to water supply in developing countries. Finally, it will introduce the project area, Livingstone, Dambwa in particular.

2.1. General Background

While a great portion of the world population enjoys an adequate supply of piped water and the convenience of water meters, there is still a lag in water and sanitation coverage in some African and Asian countries (Duflo, Galiani & Mobarak, 2012). Water meters, one type of water infrastructure investment, has only been installed by an estimated two billion households and buildings worldwide. Considering that the water supply is among the most capital-intensive of all utility sectors, water infrastructure in developing countries like Zambia will depend on the financial viability of water utilities, including their abilities to recover the revenue owed to them by customers.

Unlike many countries with limited water resources, Zambia is endowed with abundant water resources. Nearly 35% of the fresh water resources in the SADC (South Africa Development Community) are in Zambia (Republic of Zambia, 2006). With such water abundance, the general public has high expectations for quality water coverage and service. Therefore, the Zambian central government has set a goal of universal access for water and sanitation services in *Vision*

2030 (Republic of Zambia, 2006).

In order to achieve this goal, there is a long way for the country to go: in terms of water supply, urban Zambia suffers from a worse situation than compared to rural areas. Urban water supply and infrastructure development are not able to meet the increasing number of urban residents (Duflo, Galiani & Mobarak, 2012), some of whom are migrating from rural areas. The National Water and Sewerage Company (NWSCO) reports that water coverage in urban areas in 2009 and 2010 were 73.9% and 77.5%, respectively (NWSCO, 2010), and that water coverage declined from 83% in 2014 to 82.6% in 2015 (NWSCO, 2015). Despite efforts put toward improving water services and coverage, the pace of development, as shown by water coverage percentages, cannot accommodate the expanding urban population and water consumption needs.

The commercialization and privatization of the water sector in Zambia has transferred operation and service responsibilities from the government to the private sector. Licensed water and sanitation companies issued by The National and Water Supply Sanitation Council are responsible for providing water and sewage services nationwide. The privatization process has taken place since 1989 due to the federal government's heavy financial burden and inability to extend public water access after the economic recession (Dagdeviren, 2008). By 2016, Zambia had established 11 Water and Sanitation Companies (Commercial Utilities) and several private schemes that are in charge of water and sanitation services under the supervision and regulation of the National Water and Sanitation Council (Chitonge, 2011).

Privatization of the water sector has, to some extent, advanced the development of water services across the nation, particularly in urban areas. Up to now, around 6.27 million people live in the Commercial Utilities' service areas (NWSCO, 2015) while Zambia's total population is around 15.5 million. However, significant regional differences exist across Zambia due to different Commercial Utilities' establishment time and development situations across the country. The Fifth National Development Plan acknowledges the unevenness in the provision of services. The government is planning to rehabilitate and develop urban water supply systems in the country's most developed areas including Livingstone (GRZ, 2006).

2.2 Related Literature

Economic analysis of residential water supply improvements in developing countries generally falls into two categories: 1) studies on how water supply affects residents' health, and 2) studies of household welfare. The method used in these majority studies is based on the comparisons between the with-project and the without-project situations (Economics and Development Resource Center, 1998).

One of important objectives of water supply projects is the improvement of health after the reduction and ultimate elimination of water-related disease (Economics and Development Resource Center, 1998). For example, Galiani et al (2005) studied the average impact of the privatization of water services on child mortality in Argentina. The paper uses a difference-in-difference approach with matching to examine the impact on child mortality before and after the water sector's privatization in Argentina. Galiani et al concludes that privatization of the water sector has decreased child mortality. Their argument is that privatization has expanded the water supply and sewerage network, and improved water service quality.

The welfare studies on water programs have shown that the improved water service system has less contribution to the improvement of physical health while there is an improvement of households' welfare. For example, urban Morocco piped water adoption program (Devoto, Duflo, Dupas, Pariente and Pons, 2012) shows that after the adoption of piped water, people's physical health did not improve since the quality of water provided remains the same. However, there is an improvement of households' welfare. Conclusion on randomized experiments in Zambia (Ashraf, Berry and Shapiro 2010) and Kenya (Kremer et al., 2011) also provide evidence that willingness to pay for water quality, compared with other types of water services, is relatively low.

Therefore, results towards the studies of the effect of the piped water and the installation of water meters differ across contexts. Unlike previous literature, this study focuses on the utility not households, and the revenue recovery instead of the water program on households' health.

2.3 Study Context

Cost recovery and improved access to water are the stated aims of privatization of the water sector (McDonald, 2002). Specifically, the creation of commercialized utilities is expected to improve billing and revenue collection rates, reduce overstaffing and rationalize tariffs so that utilities are able to achieve full cost recovery. However, Dagdeviren (2008) concludes that cost recovery through corporatization of suppliers and commercialization of services is likely to be unattainable due to infrastructure limitations when reforms are based on increased tariffs and cuts in capital expenditure. Improvements and investments in infrastructure are more effective in reducing the costs. The AMR metering program studied in this paper is one of the examples.

The most common ways of accessing urban water services in Zambia are through kiosks (mostly peri-urban areas) and piped water (mostly urban areas). Households that received piped water may be metered and billed according to their consumption, or be unmetered and charged a fixed monthly rate. Metered households are typically charged according to increasing block tariffs though a variety of tariff structures are observed in different settings (GTZ, 2008).

Current approaches to water provision have their benefits and costs. Households that rely on kiosks are charged fixed monthly water rates. The kiosk is regarded as a success in providing water for peri-urban households and thus being promoted. However, it might not be an ideal approach for companies that want to recover the cost of their investment. Kiosks also sometimes not hygienic enough, which prevents some portions of consumers from getting healthy water (GTZ, 2009).

Fixed monthly water rates for households with piped water connections also present tradeoffs. On the one hand, commercial utilities can avoid metering inaccuracies and reduce costs of meter reading and recording. Also, piped water has obvious advantages from the households' perspectives because it allows households to avoid going to kiosk to fetch water. However, it will generally be more expensive for utilities to provide and therefore more expensive to households. On the other hand, metering and billing based on consumption gives households a sense of how much water is consumed every month. In addition, fixed rate billing sets the marginal cost of water consumption to zero, which may lead to wasteful water use and higher payment per unit for low consuming, who may also be poor.

There are a number of analogies between the challenges of supply and cost recovery for electric and water utilities. Ghajar and Khalige (2003) argue that technical and non-technical losses are major problems for the electricity distribution network. Technical losses include energy losses for the utilities resulting from physical properties of the network such as meter inaccuracy. Non-technical issues such as fraud (meter tampering, false reading, etc.), theft (illegal network connections), collection (failure to collect money owed) and billing (companies do not know how much electricity has been consumed), according to Ghajar and Khalige (2003) are more significant issue than technical losses.

The water distribution systems share similarities with the electricity distribution network. The mechanical nature of analog water meters makes them malfunction easily, and may lead to underreporting or over-reporting of water consumption. Moreover, since meters need to be read at the end of each billing month, meter readers might make mistakes when reading or writing the number. In addition, meter readers may collude with customers to understate the actual water usage, which both reduces revenues for the water company and drives up water consumption since the customer only pays a fractin of the true cost. Utilites' low revenue recovery refrains water infrastructure investment (Ghajar & Khalife, 2003), which consequently limits the expansion of the service work and lower the supply quality.

Several approaches have been tried in Zambia to see if there are better ways to provide water services in light of current water service conditions (including water supply, water meters, and sanitation and sewerage services). For instance, in 2013, Lusaka Water and Sewerage Corporation launched an installation program, aiming to install 69,000 Standard Transfer

Specification (STS)-compliant individual prepaid meters by 2019 to improve payment levels and streamline revenue management. Although positive responses have been received such as easier management, Heymans, Eales and Franceys (2014) argue that the project does not meet the original expectations. Disputes of the billing system and illegal connection to water have been found after completion of the project.

2.4 The Project

In the project studied here, Southern Water and Sewerage Company piloted an AMR water meter installation project in Dambwa Central neighborhood in Livingstone, Zambia. Livingstone is the capital of the Southern Province in Zambia. It borders Zimbabwe and has abundant water resources thanks to Zambezi River. The population was 169,237 in 2016 with population density 234.5 inhabitants/km^2. The population in Livingstone increased by 37.8% from 2000 to 2010. (NWSCO, 2015). Considering the relatively developed water infrastructure in Livingstone compared to unmetered rural places, piloting the project in Livingstone makes it easier to observe the effects of AMR meters by a comparison with customers on conventional analog meters.

The AMR metering pilot took place the southwest of Livingstone known as Dambwa. The population of the whole neighborhood is about 14,000. The program installed AMR meters for around 2,000 households who are living in the area plus nine commercial and three institutional customers.

Water and electric utilities around the world are progressively moving towards automatic meter (AMR) reading technology to provide value–added services to customers (Scot and Schlenger, 2000; Scot, 1998; Scott, 1999). The characteristics of AMR metering for customers are described by Ghajar and Khalige (2003):

- Faster reading of the meter, allowing for the reduction of the number of meter readers and reduction of operating costs.
- Better accuracy of reading, allowing for the reduction of bill complaints.

Apart from these two evident differences from analog meters, AMR meters are able to signal the metered data to a central database so that the meter readings are collected. The meter reading will be saved for later download to a billing or data collection computer.

2.5 Possible Impacts and Mechanisms

Several possible impacts may occur in Dambwa, Livingstone after the meter installation. One of possible impacts may be that there is no significant change resulting from the installation as households' water quantity consumption may not be affected by AMR meters, and AMR meters did not significantly improve metering accuracy.

If customers' water usage behavior in Dambwa does not change after the AMR meter installation, there are two main possible impacts. First, the accuracy AMR metering will increase the billed water quantity and customers' water amount owed if there was underreporting issue resulting from either the inaccuracy of analog water meters or collusion between meter readers and customers. Second, AMR metering also possibly decrease the billed water quantity and water amount owed due to the previous over-reporting and leakage issues.

If Dambwa customers' water usage does change after the installation of AMR meter installation, there could also be several other possibilities. First, if customers in Dambwa consume more water due to the reliability of AMR meters, and there existed underreporting of water quantities before the treatment, the billed water quantity after the installation will increase more. Second, if customers consume more water, and over-reporting issues existed before the installation, the change of billed water quantity is unknown. It depends on how much more water has been consumed after the installation. For example, if the increase of consumption is less than the water amount over reported, there will be a decrease of the billed water quantity and water amount owed after the installation. Third, if customers consume less water because of more accurate metering and underreporting of water quantities, the change of billed water quantity is also unclear. It is likely that there is no obvious change as the decrease of water consumption offsets the increase of metered water quantity. Fourth, if customers consume less water and over-reporting issue existed, the billed water quantity and water amount owed will decrease.

Payment amount would also change according to the change of billed water quantity. In general, the change of payment amount will align with the change of the billed water quantity and water amount owed. However, there may be other possibilities. First, as the increase of water amount owed to the utility, poor households may not be able to afford the increased bills and they might avoid monthly payments. Second, if households think AMR meters are more reliable on reporting water quantities, they might tend to be more willing to pay their bills, and thus the payment amount will increase.

3. Data

This section will first introduce the data used and how the panel data for the analysis was set up. It will then turn to data description, major cleaning steps, and the process of constructing a comparison group and data limitations.

3.1 Data Sources

The raw data used in the analysis is monthly billing and payment data extracted from Zambia Southern Water and Sanitation Company. The billing data covers 42 newly delineated water zones at the account level in Livingstone. It covers 12,379 industrial, commercial and residential accounts' monthly water usage information in Livingstone, including water quantity billed and the amount charged to the account. The payment data originally covered 19,483 accounts' monthly payment transactions, including each accounts' payment amount and sanitation surcharge. The original accounts covered include metered and unmetered accounts that receive flat rates. As a result, the accounts covered by the payment data exceeded those covered by the billing data.

The panel was set up by merging monthly billing and payment data based on the same meter account number in each dataset. Observations that were unmerged with billing data were dropped. A list of accounts receiving AMR meters was merged into the billing and payment data to identify the treatment group that received AMR meter installation.

The duration of the panel is from March 2013 to August 2016 (42 months). The AMR meter installation period was from September 2014 to December 2014, during which all households in Dambwa, regardless of whether they had previously installed analog meters or were unmetered, were charged with flat rates based on the average of previous three months' water consumption. As a result, months before September are considered as pre-treatment period while months after December as post-treatment period for both the treatment and comparison areas. The observations from September 2014 to December 2014 were dropped.

Several steps were done to further improve the dataset. First, water zones were made consistent over time. As every re-delineation would divide certain original zones into two new zones or add a new water zone based on geographic expansion of water service areas, readjusting zones gave every account a consistent geographic reference, which is important for constructing a comparison group.

Second, the study focused on low water consumption households, while other accounts were dropped. SWSCO has divided its customers into three categories based on the average amount of water consumed within a month. They are "Domestic Low", "Domestic Medium" and "Domestic High". The paper focused on "Domestic Low" household accounts. From the billing data, low water consumption households consume around 15.7 cubic meters per month on average. As most of households in Dambwa Central are categorized into "Domestic Low" category and these households are most vulnerable to meter switch, focusing on low water consumption households will make it easier to evaluate the impacts of switching meters from analog meters to AMR meters.

Third, because the purpose of the analysis is to examine the impact of AMR meters, compared to the previous working meters, on the change in households' water usage, accounts that did not appear more than thirteen times before and after the installation window for the treatment and control groups were dropped with the purpose of identifying a full year of data on each side of the project window. The number of 13 was chosen to identify the seasonality in consumption both before and after the program. Moreover, accounts that never had working meters before the installation were deleted, and accounts that stopped service after the installation were dropped.

Finally, since billing data may have outliers due to either faulty meters or the recording system, quantity values above the 99.5% percentile or below the 0.5% percentile were dropped to avoid the influence of outliers. Also, payment amounts that exceeded the range were also dropped.

The main outcome variables in this dataset are monthly quantity billed based on meter readings, water charge and payment amount. Quantity is measured and reported monthly from SWSC while water charge is its corresponding amount in Zambian Kwacha. Payment amount is the actual households' payments after receiving billings. As payment frequency could be more than once a month for households, each payment amount within a month was added up for a total value and a separate variable measuring the number of separate payments.

3.2 Constructing a Comparison Group

Dambwa Central accounts received AMR meters, and thus this area is the treatment group. Four water zones in Maramba were selected as the control group. These four water zones in Maramba shares similar characteristics with Dambwa Central. The density of the two neighborhoods is similar and both are residential areas. More importantly, it has the similar average billed water quantity pattern with Dambwa Central households during pre-treatment period.

Table 1 presents the descriptive statistics of the baseline sample in the pre-treatment period (prior to September, 2014). The table shows that the mean of billed water quantity in the four water zones in Maramba is 11.06 cubic meters while 12.92 cubic meters in Dambwa Central. Water amount owed and household payment amount are smaller in the four zones of Maramba accordingly due to less water quantity billed. Although Dambwa Central and the four zones of Maramba share different mean of billed water quantities, the level differences are addressed in the difference in difference analysis, which instead relies on similar trends over the pre-treatment period as can be seen from Figure 2, 3 and 4.

3.3 Data Limitations

The data presents limitations despite the abundant observations for both the billing and payment data. First, despite the availability of billing and payment data, households' actual water consumption remains unknown. Existing data is not able to separate the actual households' water consumption from reported water quantity records in billing data. Therefore, one cannot conclude from the estimation result that the AMR meter installation changed households' water consumption behavior.

Second, the dataset has missing values: some accounts may connect to working meters but do not show its status on the data, and these observations were excluded in the panel; some accounts remained in the panel show a working analog meter connection but do not have valid water quantities in certain months[1]. As a result, the estimation may be affected by either the exclusion of related observations or inclusion of irrelevant data.

Third, records of households moving in and out of Dambwa Central and the four zones of Maramba areas are unidentified. It might be the case that the landlord's account stays the same but tenants could move in and out, which will compromise the consistency of the water quantity billing over the time, due to different usage behaviors of tenants. However, the unavailability of the information would not lead to the biased estimation unless this happens differentially between the project area and other areas.

4. Empirical Strategy

This section discusses the basic specification and the identification assumption.

4.1 Hypothesis and Difference-in-difference model

The assumption of this study is that the average monthly water quantity billed and average monthly water amount owed to SWSCO would change in Dambwa Central area once AMR meters were successfully installed, with the expectation of realized benefits.

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[1] In the billing data, there are 18 water meter status categories. Working meters are denoted as 7. Other meter status include faulty meter, stuck meter, damaged meter, new or replaced meter, unclear meter and so on. While most of working meters are categorized to 7, some meters that are in fact working do not have any information on which status they are. On the contrary, some meters shown in the data as working status may actually have been faulty meter or switched to receive flat rate.

Ideally, the hypothesis may be tested by observing the same households' water consumption with and without AMR meters at the same time, and by having the water quantity measured and reported by the same meter readers. Practically, the test on changes of water consumption and water amount owed is essentially a test on the difference between the installation's effects on reported water usage from households who are connected to AMR meters and those who still use analog working meters.

The difference-in-difference model has previously been applied to studies of policies and projects that affect the water sector. The DID model identifies program effect by estimating the difference between outcomes in Dambwa Central and the four water zones in Maramba before and after the installation. Therefore, a simple DID model is：

$$\mathrm{Log}(Y_{it})=\alpha+\pi_1(\mathrm{Treat}_i * \mathrm{Post}_t)+\delta_1 x_{it} + u_i+v_t+e_{it} \qquad (1)$$

where Y_{it} is water quantity, water amount owed or payment amounts for account i in month t. Considering the substantial variation of quantity and skewed distribution of water quantities, the log form of the dependent variables were adopted.

Treat_i is an indicator variable that takes on the value one if the household in Dambwa Central was assigned an AMR meter, and Post_t is an indicator variable that equals one for months in or after January 2015. x_{it} controls for the previous month's water meter status. Specifically, if it equals 1, the meter was not working in the previous month because the property was vacant, the meter was damaged, unclear or faulty.

Two types of fixed effects were included in the model. Household-level fixed effects, u_i, controls for permament heterogeneity across households such as household size, household income, and the number of water appliance, while year-month fixed effects, v_t, controls for time related features such as seasonality that are similar across Dambwa Central and four water zones in Maramba. Standard errors are clustered at the household account level.

The parameter of interest is π_1, the impact of the installation of AMR meters on households' water usage and their corresponding payment amounts. This parameter captures differences in water quantity, water charge and payment amounts before and after the installation, between the areas that did and did not receive AMR meters. π_1 is expected to be positive if AMR meters reduce under-reporting water quantity.

4.2 Identification Assumption

Since the four water zones in Maramba share similar water characteristics with Dambwa Central, executing the difference-in-difference (DID) approach is appropriate. However, robustness checks are needed to further examine whether Maramba has a similar pre-parallel trend to satisfy the prerequisite of a DID model.

The identification assumption for the DID equation (1) is that the control group provides a valid counterfactual for changes in water quantity and payment amounts for Dambwa Central when other factors are constant. That is to say, there should be a parallel trend between Dambwa

Central and the four water zones in Maramba.

Two potential hypotheses may violate the assumption. First, pre-existing trends in water quantity, water amount owed or payment amount may be systematically different. Second, the increase or decrease in reported water quantity in the post-treatment period might not result from the installation of AMR meters.

To examine the pre-trend for the two groups, the paper plotted the evolution of the average water quantity, water amount owed and households payment amount in Figure 2, Figure 3 and Figure 4 over time between the treatment and control groups. The Figures provide support that the trends were similar in the pre-treatment period.

Other counfounding factors may influence the results. In other words, it may not be AMR meters but other factors that lead to the changes of water usage in Dambwa Central. One of factors could be the interruptions by construction or emergencies. However, available information indicates no significant interruptions occurred except for those during the installation period. From the available information, there were no regulations or measures that distinguish Dambwa Central's water usage from other areas in Livingstone. Robustness checks will further explore the validity of the empiricl strategy and comparison group.

Overall, the meter installation appears orthogonal to trends in observable determinants of water quantity consumption. The findings suggest that the study is unlikely to be biased by changes in unobservable variables.

5. Empirical Results

This section presents the main impacts of AMR water meter installation on the average reported water quantity based on billing records from SWSCO. It then presents the corresponding effects on amount owed and households' payments.

5.1 Main Results on Water Quantity

Difference-in-difference estimates of the AMR meter installation's effect on reported water quantity is in Table 2. The regressions include customer and month-year fixed effects with clustering at the household account level. The first three columns analyze effects in levels and the last three columns show outcomes in logs. Column (1) and (4) provide the results without any controls. Column (3) and (5) control for status of the previous month's meter and linear time trend. Column (3) and (6) control both the time fixed effects and households fixed effects, indicating that the AMR metering installation is associated with 2.218 more cubic meters of water billed after the treatment. The estimates in column (6) show approximately an 18% increase on average in households' reported water quantity in Dambwa Central.

Several factors may affect the increase is households' reported water quantity in Dambwa Central. First, the measurement accuracy of AMR meters can substantially increase the reported water quantity. It is possible that analog water metering in Dambwa Central underestimated household water consumption. Second, AMR metering avoids direct interaction between households and meter readers, which consequently reduces the risk of under-reporting due to collusion. Third, customers may increase their water consumption in view of the newly AMR meters. The improvements, as discussed, may all contribute to the increase in the quantity billed.

5.2 Main Results on Water Amount Owed

The same approach was applied to determine the effect of AMR metering on total water charge. Regression results in Table 3, column (6) show that for each household, there is an average of a 21.1% increase in the water amount owed to the Company after the installation of AMR meters. The result is consistent with the estimated results on the increase of billed water quantity after the treatment. The percentage is greater than 18%. The increase of water amount owed aligns the increase of the increase of water quantity after AMR meter installation.

However, in column (3), the level form indicates that AMR meters brings an increase of roughly 17.40 kwacha (or $1.93) water amount owed to SWSCO. The number, when converting it to percentage change, is smaller than the one in log form because household accounts receiving zero water charge are included as zeros in the level regressions while in log form, all household accounts who receive zero drop out of the estimation model.

5.3 Main Results on Water Payment

Table 4 presents the results of the installation on the household's payment amount to show the comparison between the reported water quantity and its corresponding water bills charged by SWSC, as well as households' actual payments. Compared to the payment amount in pre-treatment period in Dambwa Central, Column (6) shows approximately a 9.43% increase on payment amounts after the treatment in Dambwa Central, amounting to an increase of 20.39

Zambian kwacha (or $2.19). The increase amount is larger than water amount owed to SWSCO. The increase on water payment amount outpaced the increase on water amount owed, which might show households' willingness to pay under the new metering system.

The increased percentage on the payment amount, compared to the percentage change of water amount owed, is lower in the log model while the average payment amount is higher than amount owed to the Company in the billing data in the level model. Recognizing the percentage difference, one possible reason might be that zero payments observations are included in the level form while in log form, they are dropped. Another possible reason might be that households with higher water consumption paid bills more frequently in the post-treatment period while the ones with lower water usage did the opposite way or remained the same payment behaviors.

In contrast, households' monthly payment frequency seems not to be affected by the installation of AMR meters. As can be seen in Table 5, by adding time and households fixed effects, linear time trend and controlling previous meter status, Column (4) shows no statistically significant effect on household's payment frequency caused by AMR meter installations.

5.4 Missing Values

Table 6 shows the impact of AMR meter installation on the change of missing values of billed water quantity and payment amount[2]. The dependent variables are the dummy variables. If the dependent variables equal to one, they stand for missing values of billed water quantity and water amount owed respectively. The regressions include both household fixed effect and month-year

[2] There is no missing value for water amount owed as SWSCO will charge every account the sanitation fee and sewerage fee.

fixed effect. Column (1) and (2) present the effects of AMR meter installation on the missing value of billed water quantity. After adding water amount owed and payment amount as control variables, the estimation result shows that the installation program does not have a significant impact on the decrease of missing values of billed water quantity. Column (3) and (4) present the estimation results for the missing values of payment amount. Column (4) includes water amount owed and billed water quantity as control variables. The results show that the AMR meter installation decrease the missing value of payment amount. It is significant at 1-percent level.

From the results, less number of payment was missed after the installation of AMR meters. It might indicate that households are more willing to pay the bills that the water quantities are metered by AMR meters. For households, the measurement of water consumption further prove that households are more willing to pay the bills under AMR metering.

6. Robustness Checks

This section provides a number of robustness checks that support the main findings. First, an alternative control group is used to test whether the finding is robust using household accounts outside of the four water zones of Maramba. Second, a falsification test is conducted to test the validity of the four water zones of Maramba as a comparison group. Third, the analysis is repeated using different panel lengths to test sensitivity to the months used to identify the customer fixed effects. Fourth, the analysis is repeated under different restrictions of the number non-missing observations before and after the treatment to test if results are sensitive to these data restrictions.

6.1 An Alternative Comparison Group

In section 4.2, the paper tested the parallel trend assumption underlying the validity of the difference in difference design. Though the visual inspection suggests parallel trends, it is not possible to rule out that households in the four water zones of Maramba changed their water consumption and payment behavior after the AMR installation happened in Dambwa Central for reasons that are not picked up in the pre-installation period. As such, the paper performs the DID estimation using an alternative control group.

The nearest-neighbor matching was applied to find an alternative control group. The methodology matched each household account i in Dambwa Central to household account j in the control pool whose billed water quantity in the pre-treatment window is closest to household account i. Variable "quantity" was used in this matching, that is each month of pre-project quantity was used in the matching. The control pool included all household accounts in areas other than Dambwa Central, the four zones in Maramba (the comparison group used in the estimation) and Livingstone Town.

Repeating the main analysis using the alternative control group shows that installation of AMR meters brings positive impacts: 6.28%, 7.87% and 5.56% increase respectively on water quantity billed, water amount owed and water payment, as shown in Table 7. However, the increase percentages on water quantity billed, water amount owed and water payment are only significant at 10-percent level. The results share the same direction as the positive effects obtained when using the four water zones in Maramba as a control group. However, the estimates are much smaller under the nearest-neighborhood matching, and the estimation results are not significant under 1-percent level. This suggests that results are sensitive to the choice of comparison group, though the direction of the effect appears robust. This also implies that the effect of AMR meters might not be that large to households.

6.2 Falsification Test

Another concern about the validity of the main results is that consumption in Maramba may have been affected directly by the installation of the AMR meters due to, for example, water outage resulting from road construction or changes to the water supply infrastructure. Some other factors may have also affected consumption in the four water zones in Maramba around the same time as the project. Therefore, the paper also attempts to provide evidence that the four water zones in Maramba shows no impact under the installation of AMR meters in Dambwa Central area by conducting a falsification test.

In this falsification test, the four water zones in Maramba was assumed to receive AMR meters with the same installation time as Dambwa Central area. A “fake comparison group” was constructed using the nearest-neighbor matching method as stated above. Households in the comparison group were chosen from areas other than Dambwa Central, the four water zones in Maramba and Livingstone Town area. Billed water quantities in pre-treatment window was again used as the matching variables.

The hypothesis is that, if the falsification test works, the false treatment effect will be close to zero and not statistically significant as the four water zones in Maramba did not, in fact, receive meters. The test will use the same model and approach discussed in the empirical section. The paper further restricts accounts in the treatment and comparison groups to at least 17 months' working status in pre and post treatments.

The dependent variables in Table 8 are the log of quantity, water amount owned and payment amount. Columns (1) to (3) include time fixed effects while Columns (4) to (6) include household fixed effects. The DID coefficient is shown in the third row. As shown in Table 7, none of the coefficients are statistically significant at the 10% interval. Also, they are in negative signs, and are all relatively small compared to the point estimates for the true treatment group—Dambwa Central.

The conclusion from the falsification test is that the actual comparison group is unaffected by treatment to the Dambwa Central area. In other words, water consumption behavior and payment behavior for households in the four water zones in Maramba remain roughly the same before and after the installation of AMR meters in Dambwa Central. This improves confidence in the use of the four water zones in Maramba as a comparison group, and suggests that other factors did not affect the comparison group around the time of the AMR installation that would have affected water use.

6.3 Time Windows

There are other concerns for the DID model's robustness. First, it is possible that other programs or interruptions happened after the installation in Dambwa Central, which may affect households' water consumption. Second, seasonality in the control group may influence the ultimate DID estimate. Third, water tariff adjustment on February 2014 may change households water usage behavior to some extents. While the latter two of these are not a direct threat to the DID estimate, they may affect the estimated magnitude. But it is possible that the latter two will affect the ultimate estimation if they interact with the treatment group.

To test this possibility, different time windows were introduced to the DID analysis. To address the first concern, the paper restricted the panel to 13 months before and after the installation to allow the household fixed effects to consider similar seasonal variation before and after installation and to reduce the likelihood of other program's influence relative to a longer panel. To address the second concern, the paper restricted the pre-treatment period from February 2014 to August 2014, during which water tariff are not adjusted.

The results are shown in Table 9. Column (1) to (3) display DID estimates by limiting the panel data to 13 months before and after the installation. The percentage changes share the same sign with what have estimated in Table 2, Table 3 and Table 4. The magnitudes are slightly larger, suggesting that seasonality and possible interruptions would underestimate the impact of AMR meters on billed water quantity and payment amount.

Column (4) to (6) exhibit DID estimates restricting the panel to a time range that was without tariff adjustment. They show lower percentage increase on billed water quantity and higher percentage increase in households payment amount compared to results in Table 2, Table 3 and Table 4. Particularly, the percentage increase on the water amount owed is close to the percentage increase on payment amount—15% and 14.4% respectively, indicating that the absence of water tariff adjustment may make households more willing to pay the bills.

6.4 Other Checks

The dataset used for analysis restricts the number of occurrences for non-missing meter accounts to both 13 months before and after AMR meters installation in order to control seasonality and balance the number of accounts before and after the installation. However, the restriction reduces the number of observations. Insufficient observations might lead to biased estimation. Therefore, the paper tested the DID coefficients under different restrictions for the minimum number of appearances before and after the installation (from 7 to 17). Figure 5 shows that there are subtle differences between different conditions except for the most aggressive restriction. As pre-treatment period only lasts 18 months, the estimation is limited to small samples when the minimum number of times a household appears in the data prior to the project is set to 17, i.e. a household can only have one missing observation over that full period, something few households manage to do.

7. Cost-Effectiveness of AMR Meters Installation

Previous sections have shown the impact of AMR meters on measured monthly water quantity billed as well as households' payments. In this section, the paper discusses whether or not it is cost-effective to promote AMR meters for SWSCO (or other water companies).

While cost-effectiveness evaluates the "effect" a program achieves for a given level of cost incurred or conversely the amount of cost required to achieve a given impact (Dhaliwal, 2012), the results might depend on whose perspective is considered. For example, customers and the water utilities have different purposes towards AMR meters. For water utilities, profit and cost recovery are the first concern. The relevant impact for SWSCO is the increased revenue and lower cost because of the AMR metering accuracy. For Dambwa Central residents, daily water consumption and costs are important, as well as billing accuracy. For others, such as international donors, the overall social effects and how much water is saved might be the main concern.

For the purpose of this cost effectiveness analysis, the paper will focus on the perspective of water utilities. It will take the point estimates from the previous regression results as given in Table 3 and Table 4. The calculation will be for an average household account with a focus on recurring costs. Therefore, changes after the program should be included while costs to the water company that remain the same should be excluded since they are not part of program cost and are the same between the treatment and control groups. For example, this analysis will exclude fixed costs of water supply and regular costs such as administration and operating cost.

One limitation of this analysis is that it is hard to separate changes in meter reading accuracy from actual changes in water quantity used. The cost-effectiveness analysis takes a conservative assumption: all changes in the quantity billed come from changes in consumption, so the only benefit to the Company is through higher amount of payments from households. There might be another contribution to revenue from more accurate metering, which may underlie some of the quantity outcomes. The analysis further assumes that the water price is roughly equal to the marginal cost of providing piped water, so that the change in consumption is not associated with any additional gain. If either of these assumptions are wrong – either non-revenue water decreases because billing becomes more accurate or the water price is set above marginal cost – the estimated cost recovery will be a lower bound and the Company will benefit more.

Southern Water and Sanitation Company would expect the average customer owes them 17.40 Kwacha (or $1.93) more on water quantity per month following the AMR installation, while the average customer pays them 20.39 Zambia Kwacha more each month. The detailed costs and the differences between AMR meters and analog working meters are shown in Table 10. The monthly recurring cost per meter is 1.96 Kwacha under an AMR meter compared to 3.74 Kwacha under an analog meter. If the monthly recurring cost of installing an AMR meter is the only factor to consider and if it is assumed that fuel has to refill every month for AMR meters, each AMR meter will make SWSCO's cost a 0.02 Kwacha more per month without calculating the gain from increased billed water quantity.

The price of an AMR meter is usually higher than an analog meter. Since the price of the AMR meter installed is unknown, the paper looks at what the maximum justifiable AMR meter price is at different payback periods, given that the cost of the analog meter is 600 Kwacha. If the price for installing an AMR meter exceeds the maximum justifiable AMR meter price, installing an AMR meter is thus not cost-effective.

The paper intends to answer the question that if there is a choice to install either an AMR meter or an analog meter for households who are unmetered, which one is a better choice for revenue recovery for SWSCO. It is assumed that after the installation, there are no other costs except for the costs listed in Table 10. Also, all of the revenue collected will be used to recover the investment on AMR meters. Moreover, the estimated maximum AMR meter price is adjusted by annual interest rate in Year 2017 in Zambia, which is 14% annually.

As such, the paper intends to solve:

$$F_{AMR} - F_{ANA} \leq \sum_{t}^{T} \frac{(B_{AMR} - C_{AMR}) - (B_{ANA} - C_{ANA})}{(1+r)^{t}}$$

$$F_{AMR} - F_{ANA} \leq \sum_{t}^{T} \frac{(B_{AMR} - B_{ANA}) - (C_{AMR} - C_{ANA})}{(1+r)^{t}} \qquad (2)$$

where F_{AMR} and F_{ANA} are fixed cost of installing an AMR meter and fixed cost of installing an analog meter respectively; B_{AMR} is monthly recurring revenues from AMR meters and B_{ANA} is monthly recurring revenues from analog meter while C_{AMR} and C_{ANA} are the recurring cost. t is the number of months after the installation of AMR meters.

The detailed costs are listed in Table 10, (F_{AMR} -F_{ANA}) equals to (m-676.25) Kwacha, where m denotes the price of AMR meter. Specifically, the cost of installing a meter includes the cost of meter itself, fitting fees, and the cost of spare parts. The cost information obtained from SWSCO is in total amount. The paper then calculates the cost for each meter each month. $(B_{AMR} - B_{ANA})$ is calculated from taking estimated points, which is 2.99 Kwacha, $(C_{AMR} - C_{ANA})$ is 0.02 Kwacha. The recurring costs include the cost of capturing data, the cost of maintaining the operation of meters and the cost for staff. They are also per meter per month's cost.

The result is shown in Figure 6. The Figure plots the maximum meter price at different payback periods after the installation of an AMR meter that would make the firm indifferent between installing an AMR meter and an analog meter. It suggests that in month i, compared with analog meters, the price of an AMR meter cannot exceed the maximum justifiable AMR price, or SWSCO is not able to recover the revenue within the month i. If the payback window is only for one month, the required maximum price of AMR meters for recovering the cost is below 680 Kwacha, otherwise it is not worth investing. As payback window gets longer, when considering the interest rate, the increase of required maximum price is not proportional to the increase time of payback window. If the payback window gets to 20 months after the installation, the required maximum price is around 695 Kwacha. As a result, whether or not investing in AMR meters depends on how long the payback windows the utility expects. If the utility's expectation of payback period is shorter, the maximum justifiable price will be lower, which is to say that if the utility wants to invest in AMR meters and wants to recover the cost, the price of AMR meters should be lower if payback period is shorter.

8. Conclusion

Results in this paper provide supportive evidence that the improvement of water meters increase the bills collected and payment amounts from customers. The increase of bills may result from the accurate measuring of the newly installed meters that solve the previous under-measurement problem. Meanwhile, it might also result from less collusion between the Company's staff and customers as AMR meters avoid in-person meter reading.

However, the results do not provide evidence on payment patterns after Dambwa received AMR meters. Households' payments are influenced more by the previous reported water quantity and current water amount owed to SWSCO. Also, there is no evidence supporting that the households' real water consumption changed when using AMR meters. Separating the increase from technical side and actual consumption based on billing data is not possible when meter readings are the only measure of water consumption.

In summary, the AMR meters help the billing collection and increased households' payment amounts, which improved the company's revenue recovery. From a water utility stand point, the benefits of installing AMR meters helps the revenue increase as the benefits exceed the cost if we do not consider the fixed costs the meters. However, the utility might encounter trade-off between installing an AMR meter or an analog meter if the price of the AMR meter goes too expensive that exceeds the revenue collected.

Table 1 Descriptive Statistics

	Livingstone					
	Mean	*Standard Deviation*	*Min*	*Max*	*# of Observations*	*# of Missing Observations*
Quantity	22.7	60.57	1	7377	138,206	127,407
Water Charge	83.38	325.26	0	41957.7	147,297	118,316
Sewerage Charge	12.23	64.09	0	8391.54	147,297	118,316
Payment Amount	175.03	926.79	0.4	145,733	164,163	0
	Four Water Zones in Maramba					
	Mean	*Standard Deviation*	*Min*	*Max*	*# of Observations*	*# of Missing Observations*
Quantity	11.06	6.63	1	56	9,482	276
Sewerage Charge	4.87	5.38	0	45.32	9,758	0
Water Charge	34.72	25.8	0	228	9,758	0
Payment Amount	55.98	44.26	1.5	747	7,872	1,886
#Payment per Month	1.24	0.52	1	6	7,872	1,886
	Dambwa Central					
	Mean	*Standard Deviation*	*Min*	*Max*	*# of Observations*	# of Missing Observations
Quantity	12.92	8.08	1	64	6,137	334
Sewerage Charge	7.96	6.49	0	51.3	6,471	0
Water Charge	40.96	32.63	0	273.6	6,471	0
Payment Amount	76.58	57.36	3.5	580	4,555	1,916
#Payment per Month	1.28	0.58	1	8	4,555	1,916

Note: Table 1 is to compare statistics of four water zones in Maramba and Dambwa accounts before the treatment. Each column presents the variable name, standard deviation, the minimum value, the number of observations and the number of missing observations. The sample is at household account level for the period prior to September, 2014.

Table 2 Estimation Results for Water Quantity Billed

	(1) quantity	(2) quantity	(3) quantity	(4) log(quantity)	(5) log(quantity)	(6) log(quantity)
Post	0.713***	0.171	0.124	0.0366**	-0.00443	0.00242
	(0.179)	(0.318)	(0.313)	(0.017)	(0.0299)	(0.0296)
Treat	1.892***	1.834***		0.126***	0.121***	
	(0.367)	(0.368)		(0.0335)	(0.0336)	
Treat × Post	2.032***	2.083***	2.218***	0.164***	0.168***	0.180***
	(0.336)	(0.337)	(0.335)	(0.0289)	(0.029)	(0.0292)
Last Month Missing	-0.265*	-0.255*	-0.192	-0.0346**	-0.0340**	-0.01315
	-0.154	-0.151	-0.120	-0.0135	-0.0133	-0.0109
Time Fixed Effects	No	Yes	Yes	No	Yes	Yes
Household Fixed Effects	No	No	Yes	No	No	Yes
Observations	35,008	35,008	35,008	35,008	35,008	35,008
Adjusted R-squared	0.045	0.07	0.067	0.03	0.055	0.059

Note: Dependent variables are water quantity consumed for Column (1), (2) and (3) and log of water quantity for Column (4), (5) and (6) measured in cubic meter. Column (1) and (3) do not include any fixed effects. Column (2) and (4) include year-month fixed effects. Column (3) and (6) additionally include households fixed effects.

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3 Estimation Results for Amount Owed to the Company

	(1) amount_owed	(2) amount_owed	(3) amount_owed	(4) log(amount_owed)	(5) log(amount_owed)	(6) log(amount_owed)
Post	16.59***	28.06***	27.90***	0.289***	0.496***	0.493***
	(1.033)	(1.898)	(1.862)	(0.0197)	(0.0347)	(0.0342)
Treat	9.168***	9.335***		0.195***	0.199***	
	(1.710)	(1.709)		(0.0399)	(0.0400)	
Treat × Post	17.52***	17.18***	17.40***	0.206***	0.198***	0.211***
	(1.960)	(1.965)	(1.967)	(0.0337)	(0.0339)	(0.0340)
Last Month Missing	-0.619	-0.564	0.378	-0.0239	-0.0225	0.0102
	(0.900)	(0.880)	(0.707)	(0.0166)	(0.0163)	(0.0127)
Time Fixed Effects	No	Yes	Yes	No	Yes	Yes
Household Fixed Effects	No	No	Yes	No	No	Yes
Observations	35,796	35,796	35,796	35,008	35,008	35,008
Adjusted R-squared	0.108	0.136	0.156	0.082	0.109	0.137

Note: Dependent variables are water amount owed for Column (1), (2) and (3) and log of water amount owed for Column (4), (5) and (6) measured in cubic meter. The amount owed to the utility also includes sanitation and sewerage fees. Column (1) and (3) do not include any fixed effects. Column (2) and (4) include year-month fixed effects. Column (3) and (6) additionally include households fixed effects. The number of observations in log forms are smaller than ones in level form, accounting for months where the charges were zero.

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 4 Estimation Results for Household Payment Amount

	(1) amount	(2) amount	(3) amount	(4) log(amount)	(5) log(amount)	(6) log(amount)
Post	25.49***	214.8***	212.9***	0.334***	1.671***	1.648***
	(1.383)	(7.747)	(7.304)	(0.0169)	(0.0651)	(0.0589)
Treat	20.93***	20.68***		0.321***	0.318***	
	(2.204)	(2.210)		(0.0335)	(0.0336)	
Treat × Post	20.06***	19.80***	20.39***	0.0919***	0.0914***	0.0943***
	(2.601)	(2.596)	(2.567)	(0.0279)	(0.0282)	(0.0271)
Last Month Missing	-1.153	-1.587	-1.328	-0.0372**	-0.0407***	-0.0253**
	(1.599)	(1.464)	(1.309)	(0.0159)	(0.0154)	(0.0124)
Time Fixed Effects	No	Yes	Yes	No	Yes	Yes
Household Fixed Effects	No	No	Yes	No	No	Yes
Observations	28,635	28,635	28,635	28,635	28,635	28,635
Adjusted R-squared	0.091	0.256	0.281	0.111	0.200	0.225

Note: Dependent variable is water amounts households paid for Column (1), (2) and (3) and log of water amounts households paid for Column (4), (5) and (6) measured in cubic meter. Column (1) and (3) do not include any fixed effects. Column (2) and (4)i include year-month fixed effects. Column (3) and (6) additionally include households fixed effects.

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5 Estimation Results for Monthly Count of Payments

	(1) count	(2) count	(3) count	(4) count
Post	-0.0258***	1.747***	1.685***	1.351***
	(0.00910)	(0.0434)	(0.0457)	(0.0589)
Treat	-0.0817***	-0.0476***		
	(0.0155)	(0.0149)		
Treat × Post	0.00562	0.00710	0.00402	0.0145
	(0.0170)	(0.0165)	(0.0162)	(0.0178)
Log of Household Water Payment	0.526***	0.360***	0.410***	0.645***
	(0.0101)	(0.00948)	(0.00974)	(0.0139)
Log of Water Charge	-0.233***	-0.150***	-0.107***	-0.0747***
	(0.00843)	(0.00789)	(0.00686)	(0.00788)
Last Month Missing	0.00112	-0.000735	-0.00284	
	(0.0119)	(0.0105)	(0.0102)	
L.Log of Household Water Payment				-0.0584***
				(0.00679)
L.log of Water Charge				-0.271***
				(0.0124)
Time Fixed Effects	No	Yes	Yes	Yes
Household Fixed Effects	No	No	Yes	Yes
Observations	28,154	28,154	28,154	21,840
Adjusted R-squared	0.256	0.450	0.494	0.543

Note: Dependent variable is households number of payment within a month. Column (1) excludes fixed effects, column (2) adds time fixed effects, Column (3) adds households fixed effects. Column (4) adds household fixed effects. Lags of log of household water payment and log of water charge are also included. The number of observations for Column (4) is smaller than others, accounting for months where the charges were zero.

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 6 Estimation Results for Missing Values

	(1) missing_quantity	(2) missing_quantity	(3) missing_amount	(4) missing_amount
Post	0.00198	0.0138*	-0.576***	-0.622***
	(0.00547)	(0.00825)	(0.0202)	(0.0217)
Treat*Post	-0.0231***	-0.00419	-0.0574***	-0.0455***
	(0.00628)	(0.00507)	(0.0115)	(0.0109)
Last Month Missing	0.00549	0.00209	-0.00345	-0.00344
	(0.00345)	(0.00323)	(0.00719)	(0.00726)
Water Amount Owed		-0.000776***		0.00193***
		(5.43e-05)		(0.000354)
Payment Amount		5.54e-05***		
		(1.57e-05)		
Water Quantity				-0.0124***
				(0.00174)
Time Fixed Effects	Yes	Yes	Yes	Yes
Household Fixed Effects	Yes	Yes	Yes	Yes
Observations	35,796	28,635	35,796	35,008
Number of id	949	949	949	949
Adjusted R-squared	0.017	0.042	0.078	0.083

Note: All the dependent variables are dummy variables. If the values of dependent variables equal to one, they mean that there are missing values on quantity and payment amount. Column (1) and Column (3) execute simple difference in difference model while column (2) includes control variables of water amount owed and payment amount; column (4) includes control variables of water amount owed and billed water quantity.

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 7 Robustness Test — An Alternative Comparison Group

	(1) log(quantity)	(2) log(charge)	(3) log(amount)	(4) log(quantity)	(5) log(charge)	(6) log(amount)
Post	0.0273	0.498***	1.629***	0.0293	0.501***	1.659***
	(0.0221)	(0.0261)	(0.0486)	(0.0221)	(0.0260)	(0.0431)
Treat	0.0809**	0.0967**	0.144***			
	(0.0376)	(0.0448)	(0.0372)			
Treat × Post	0.0686**	0.0857**	0.0594*	0.0628*	0.0787**	0.0556*
	(0.0336)	(0.0394)	(0.0312)	(0.0338)	(0.0397)	(0.0299)
Last Month Missing	0.00513	0.00660	0.0152	0.00552	0.00679	0.0132
	(0.0148)	(0.0174)	(0.0196)	(0.0144)	(0.0168)	(0.0184)
Time Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Household Fixed Effect	No	No	No	Yes	Yes	Yes
Observations	47,221	47,221	38,616	47,221	47,221	38,616
Adjusted R-squared	0.047	0.079	0.158	0.079	0.135	0.227

Note: The table shows the robustness check by constructing an alternative comparison group. The nearest-neighbor matching method was used to construct the alternative comparison group from water zones other than Dambwa and Livingstone town. All dependent variables are in log forms. The dependent variables for Column (1) and Column (4) are the log form of billed water quantity, the dependent variables for Column (2) and (5) are water amount owed to the utility while the dependent variables for Column (3) and (6) are the monthly customer payments.

Column (1) to (3) include time fixed effects while Column (4) to (6) add household fixed effect
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8 Falsification Test — Maramba as "A Fake Treatment Group"

	(1) log(quantity)	(2) log(charge)	(3) log(amount)	(4) log(quantity)	(5) log(charge)	(6) log(amount)
Post	0.0370*	0.509***	1.686***	0.0375*	0.510***	1.689***
	(0.0218)	(0.0257)	(0.0514)	(0.0218)	(0.0257)	(0.0454)
Treat	-0.191***	-0.228***	-0.265***			
	(0.0308)	(0.0365)	(0.0310)			
Treat × Post	-0.0318	-0.0382	-0.0217	-0.0330	-0.0395	-0.0165
	(0.0241)	(0.0284)	(0.0238)	(0.0243)	(0.0285)	(0.0234)
Last Month Missing	-0.0170	-0.0188	0.00285	-0.0146	-0.0172	-0.00359
	(0.0151)	(0.0176)	(0.0174)	(0.0124)	(0.0144)	(0.0152)
Time Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Household Fixed Effect	No	No	No	Yes	Yes	Yes
Observations	50,725	50,725	42,441	50,725	50,725	42,441
Adjusted R-squared	0.059	0.087	0.168	0.080	0.131	0.227

Note: The table shows the placebo test results taking four water zones in MARAMBA as a fake treatment group. Nearest matching method is used to find a corresponding control group from zones other than Dambwa and Livingstone town. All dependent variables are in log forms. Column (1) to (3) include time fixed effects while Column (4) to (6) add household fixed effect.

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 9 Robustness Tests on Different Pre-treatment Periods

	(1)	(2)	(3)	(4)	(5)	(6)
	log(quantity)	log(charge)	log(amount)	log(quantity)	log(charge)	log(amount)
Time Windows	2013m9 -- 2015m12			2014m3 -- 2015m12		
Post × Treat	0.210***	0.246***	0.128***	0.128***	0.150***	0.144***
	(0.0313)	(0.0361)	(0.0285)	(0.0317)	(0.0364)	(0.0297)
Last Month Missing	0.0194	0.0228	-0.00499	0.0157	0.0185	0.0150
	(0.0147)	(0.0169)	(0.0162)	(0.0163)	(0.0188)	(0.0182)
Time and Household Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	27,155	27,155	22,631	24,539	25,407	21,164
Adjusted R-squared	0.070	0.136	0.241	0.070	0.123	0.255

Note: The table replicates the difference-in-difference approach by limiting the panel data to two time windows. The dependent variables are in log forms and all the regressions include time and households fixed effects. Column (1) to (3) show the results from Sep. 2013 to Dec. 2015. Column (4) to (6) show the results with the panel limited to Mar. 2014 to Dec. 2015. All dependent variables are in log forms. Column (1) to (3) include time fixed effects while Column (4) to (6) add household fixed effect.

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 10 Expected Costs at Account Level

	AMR Meter	Analog Meter	Difference
Cost of Installing a Meter			
Meter	m	600	m-600
Fittings	50	141	(91)
Spare Parts	19.75	5	14.75
Total Fixed Costs	m+69.75	746	m-676.25
Wage and Service Cost per Meter per Month			
Data Capture	0.47	0.38	0.09
Fuel	1.8	0	1.8
Maintenance	1.46	1.62	(0.16)
Wage Cost	0.04	1.75	(1.71)
Total Recurring Cost	3.77	3.75	0.02

Note: The cost is calculated on household account level. All the costs are measured in Zambia Kwacha. As the price for AMR meters is unknown, the table uses "m" to denote the cost of AMR meter. The numbers in brackets are negative numbers.

Figure 1 The Number of Studied Households Water Accounts

Figure 1-1 The Number of Working Meter Accounts

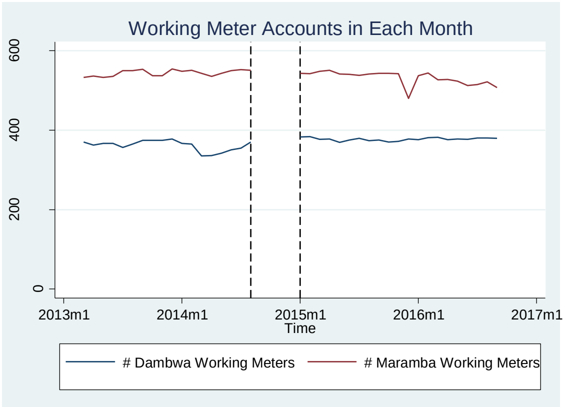


Figure 1-2 The Number of Working Meter Accounts That Receive Water

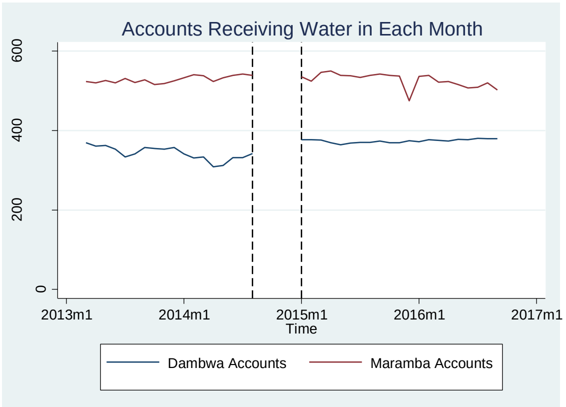
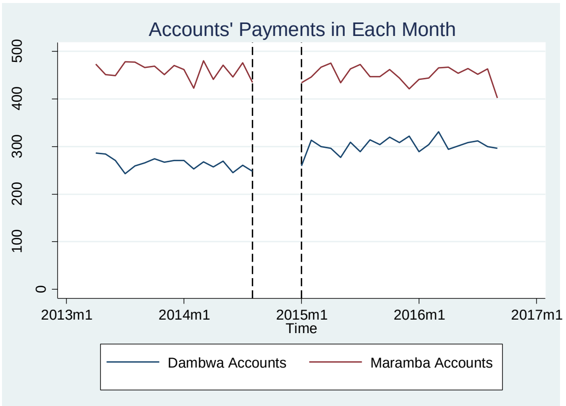


Figure 1-3 The Number of Payments



Note: Figure 1-1 shows the number of working meter accounts in Dambwa and the four water zones in Maramba before and after the installation. Figure 1-2 shows the number of working meter accounts that consume water in each month. Figure 1-3 shows the number of accounts that pay bills. The number of payments in Maramba goes up compared to the payment counts in Dambwa after the installation.

Figure 2 Trends for Billed Water Quantity

Figure 2-1 Water Quantity Trend Before AMR Meter Installation

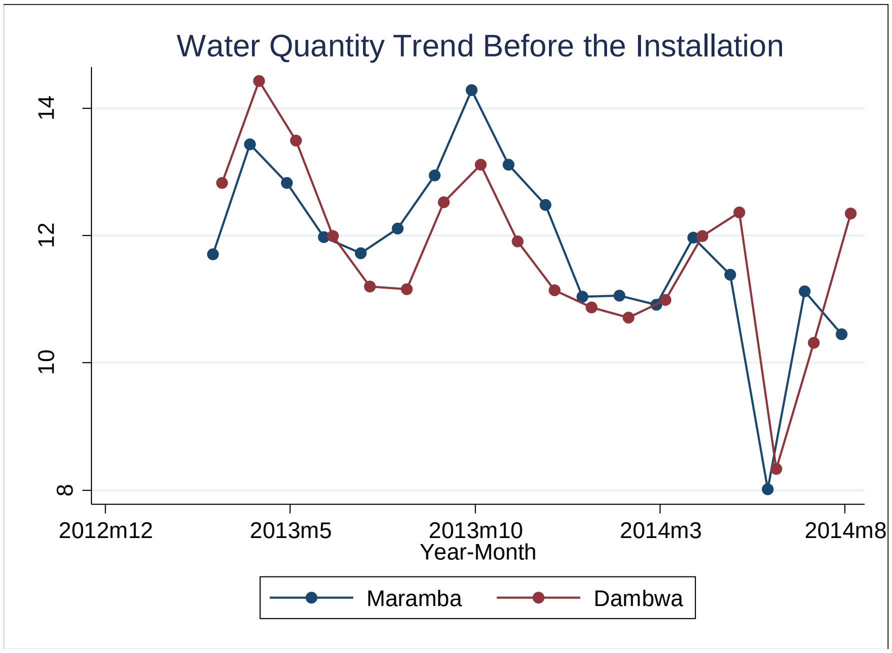
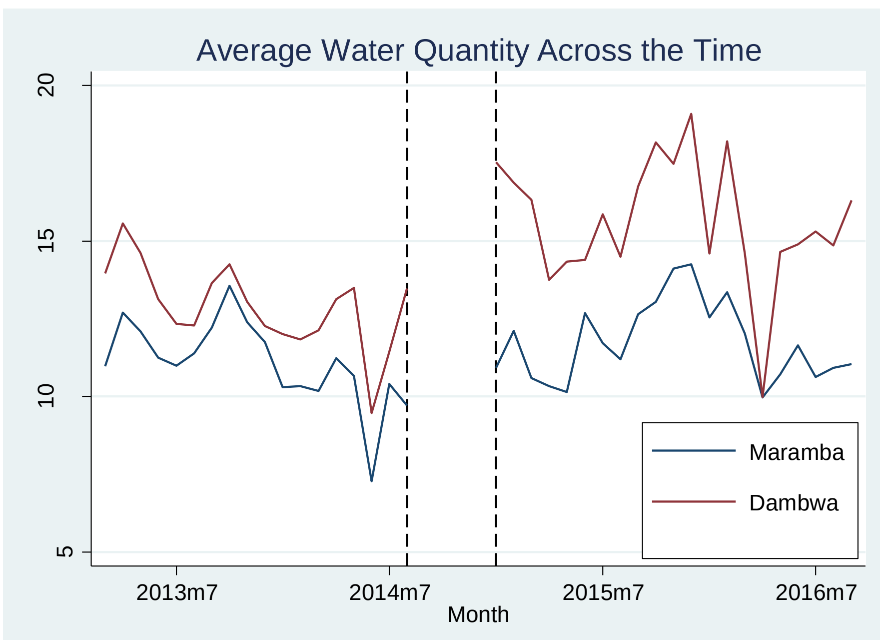


Figure 2-2 Water Quantity Trend Before AMR Meter over the Time



Note: Figure 2-1 shows the linear fit line of the mean water quantities each month before the installation period for the comparison and treatment groups. Figure 2-2 shows monthly average water quantity before and after the installation for both the comparison and treatment groups.

Figure 3 Trends for Water Amount Owed

Figure 3-1 Trends for Water Amount Owed Before AMR Meter Installation

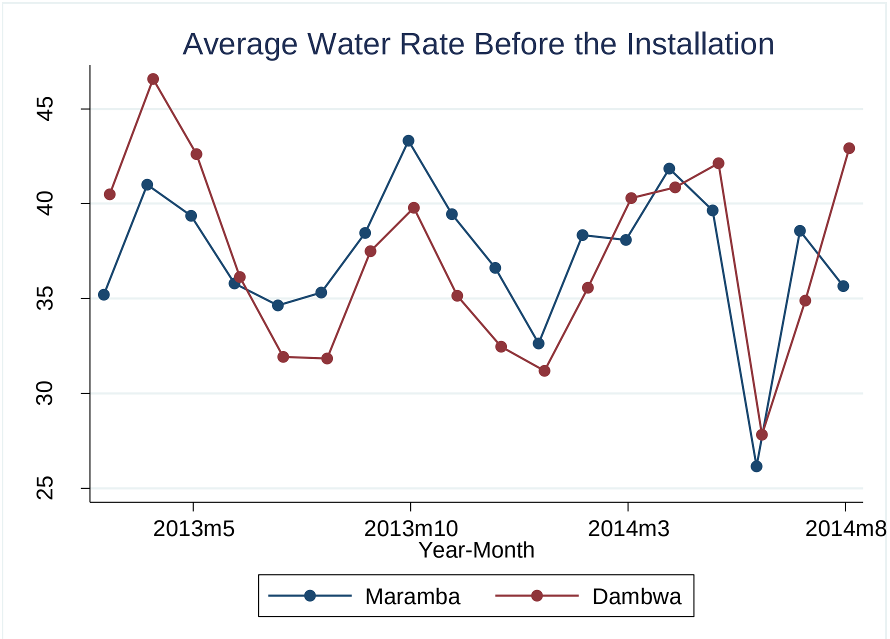
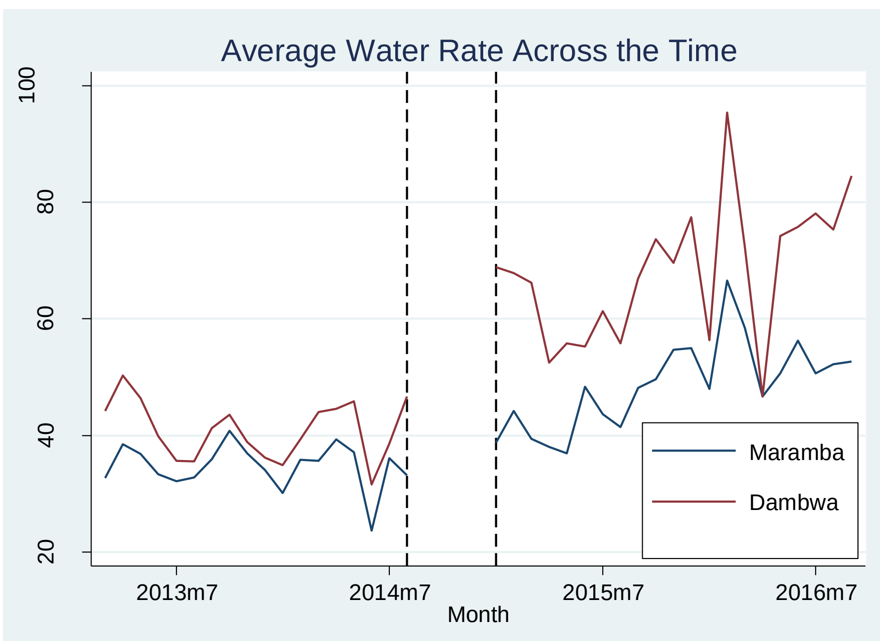


Figure 3-2 Trends for Water Amount Owed over the Time



Note: Figure 3-1 shows the linear fit line of the mean water amount customers owed to the Company each month before the installation period for the comparison and treatment groups. Figure 3-2 shows monthly average water amount owed before and after the installation for both the comparison and treatment groups.

Figure 4 Trends for Households Water Payment

Figure 4-1 Trends for Water Payment Before AMR Meter Installation

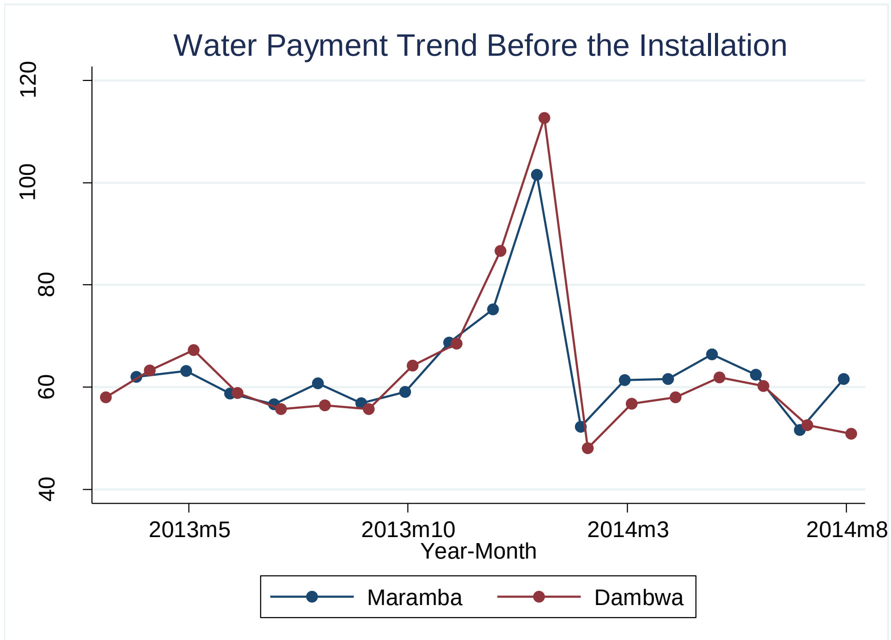
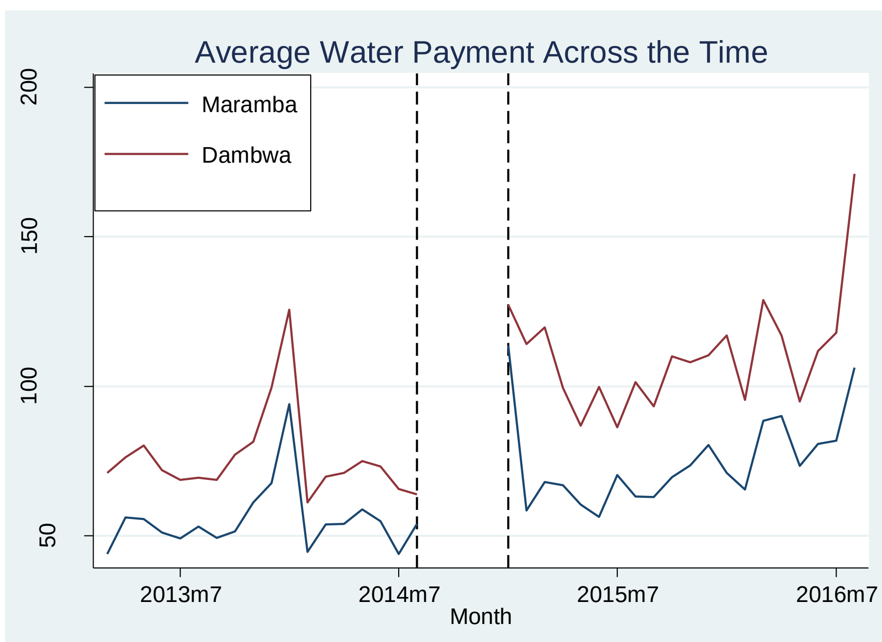
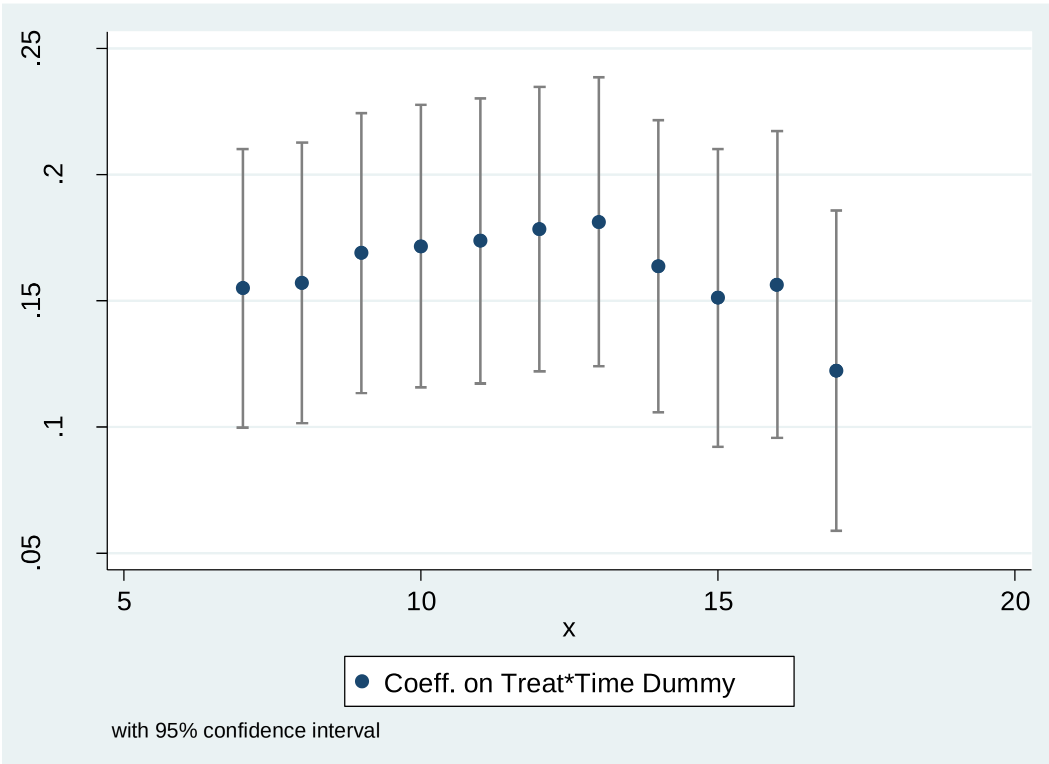


Figure 4-2 Trends for Water Payment over the Time



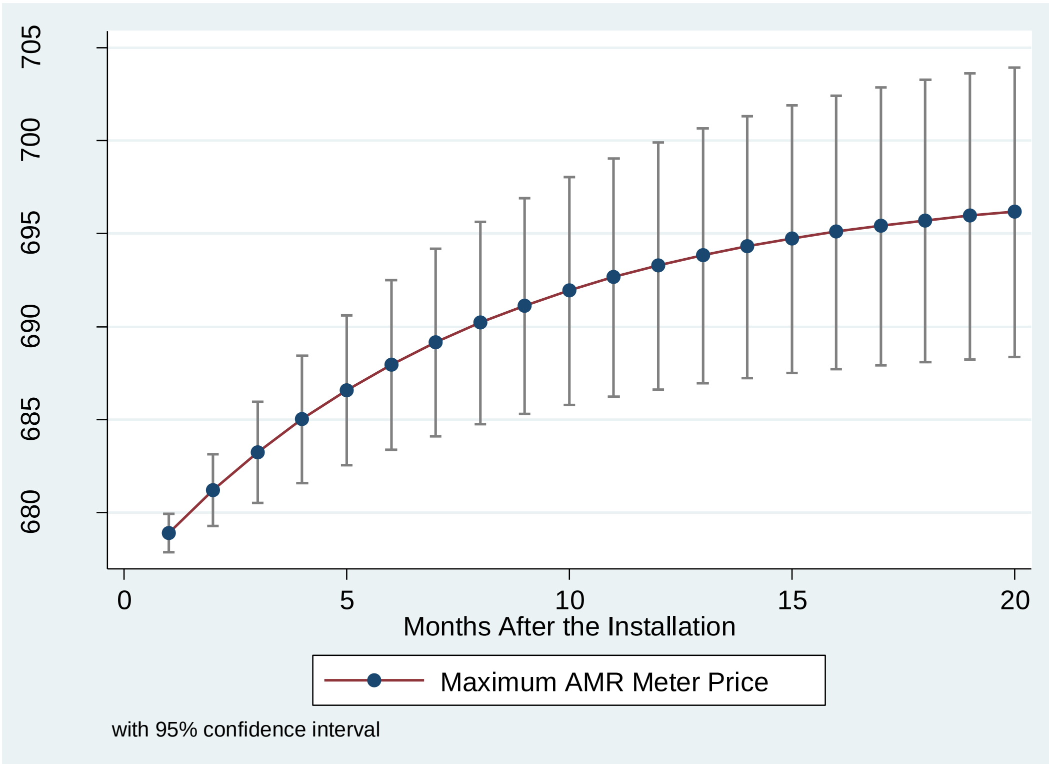
Note: Figure 4-1 shows the linear fit line of the mean of water payment amount each month before the installation period for the comparison and treatment groups. Figure 4-2 shows monthly average water payment amount before and after the installation for both the comparison and treatment groups.

Figure 5 Robustness Check on the DID Regression Results with Different Number of Accounts Dropped in Pre and Post Treatment Period



Note: The Figure shows coefficients on treat*time dummy by conditioning on the number (7 to 17) of account appearances before and after treatment. It shows that the coefficients lie stably except for the last one. As the total months in pre-treatment period is 18 months, the likelihood of the accounts that appear more than 17 times is small.

Figure 6 Maximum Meter Price at Different Payback Periods



Note: The Figure plots the maximum meter price at different payback periods after the installation of an AMR meter that would make the firm indifferent between installing an AMR meter and an analog meter. At zero month, this is just the cost of installing an analog meter. The price is estimated in Zambia kwacha. The estimates are adjusted to the present value referring current interest rate in Zambia, 14%.

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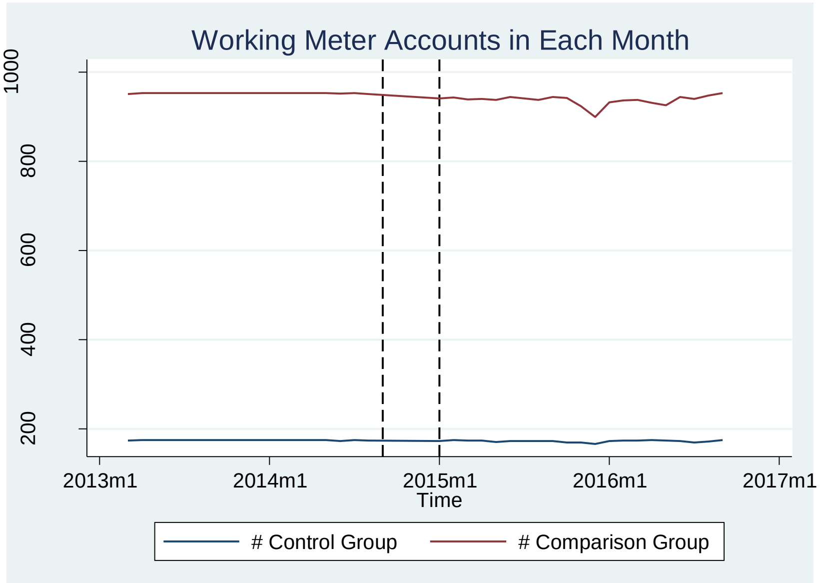
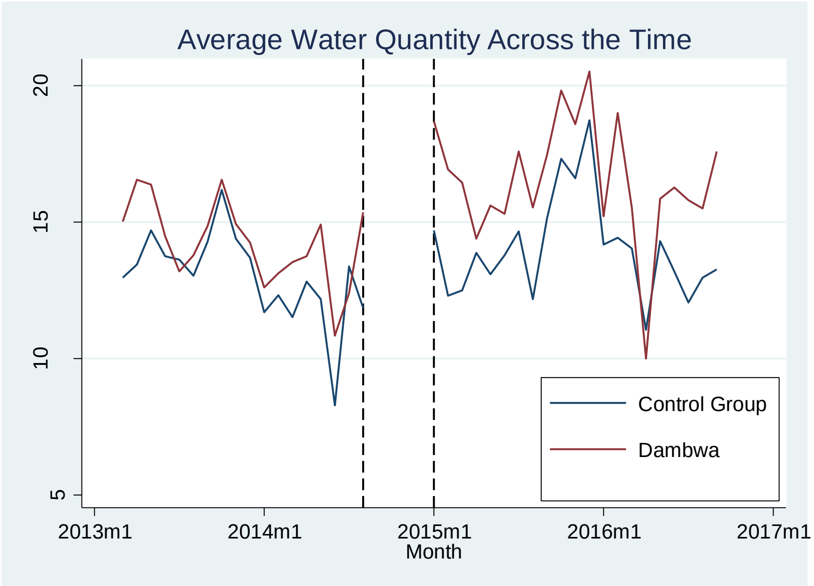
Appendices

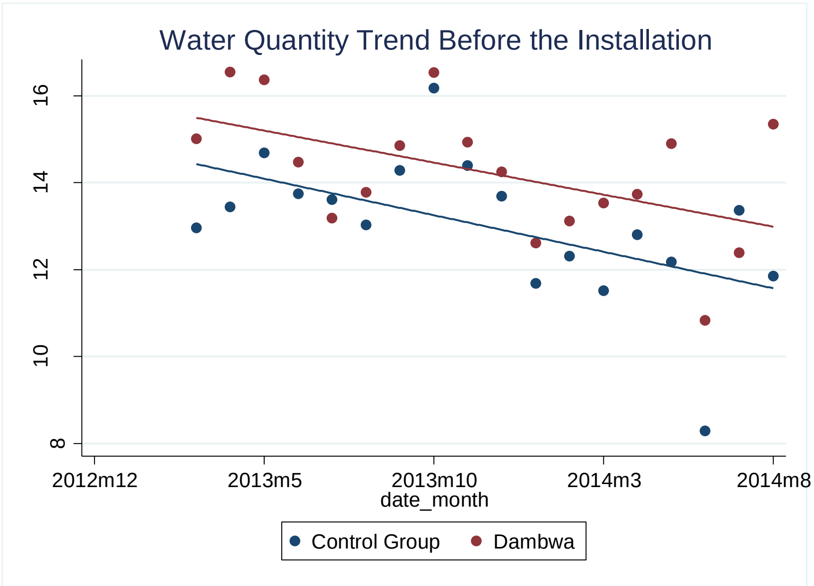
A.1. Constructing an alternative comparison group:

A.1.1 The Number of Working Meter Accounts Over the Time for the Two Groups



A.1.2 Trends for Billed Water Quantity





Note: The figures are graphed base on the monthly mean water quantity from billing data. The comparison group here is constructed by using the nearest matching method

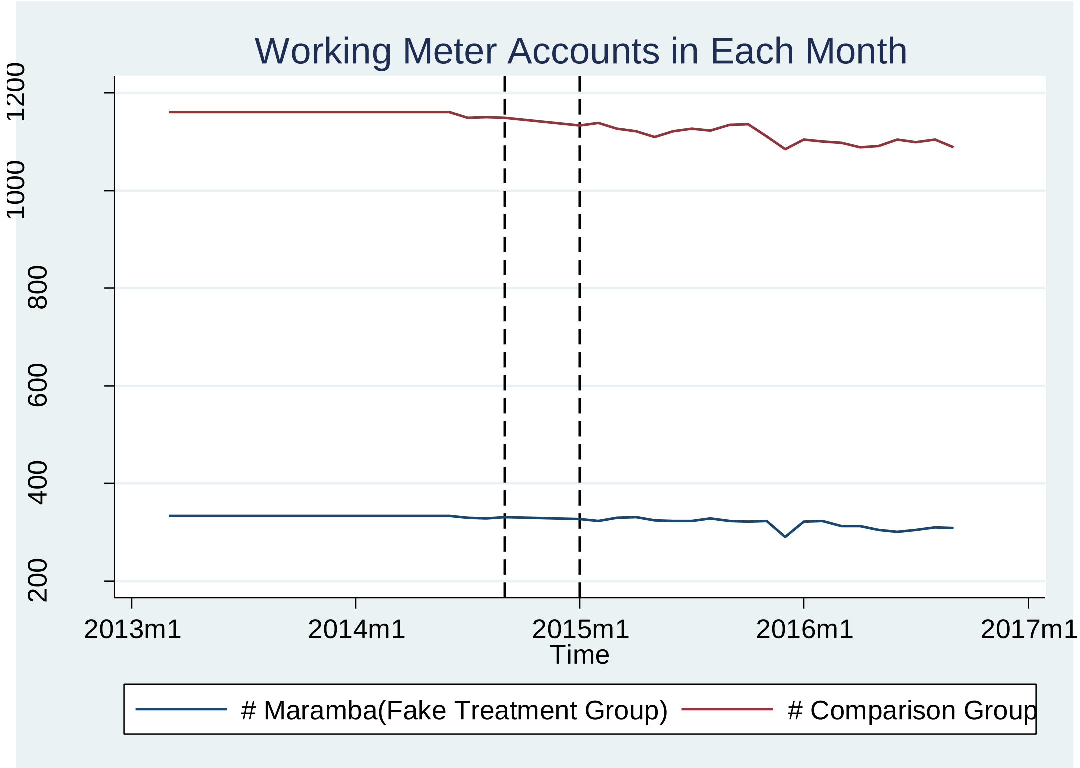
A.1.3 Descriptive Statistics

	Alternative Comparison Group					Dambwa Central				
	Mean	*Standard Deviation*	*Min*	*Max*	*# of Observations*	*Mean*	*Standard Deviation*	*Min*	*Max*	*# of Observations*
Quantity	13.00	7.17	1	57	19028	14.25	7.99	1	55	3191
Water Charge	43.07	28.33	0	233.70	19037	48.17	32.35	0	222.30	3198
Payment Amount	71.21	53.03	1.5	1026.96	15077	81.98	58.69	5	580	2469
#Payment per Month	1.27	0.56	1	7	15077	1.30	0.58	1	8	2469

Note: The descriptive statistics is for the matching methods when using an alternative comparison group to estimate DID coefficient.

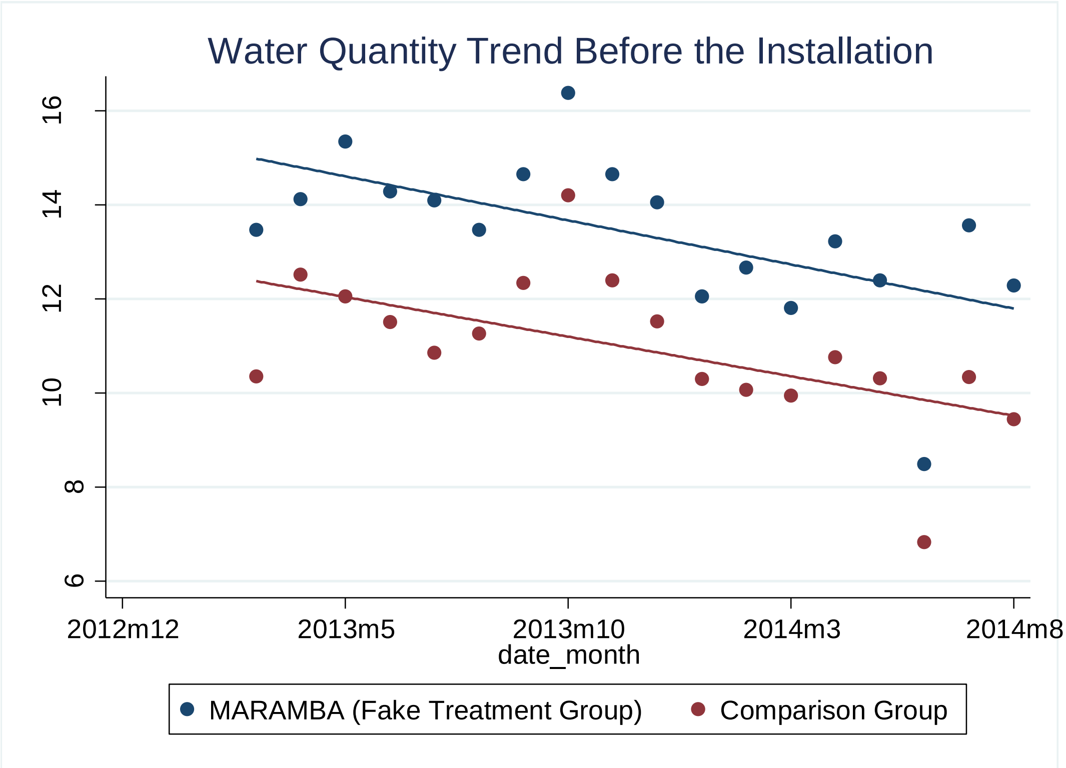
A.2 A Fake Comparison Group

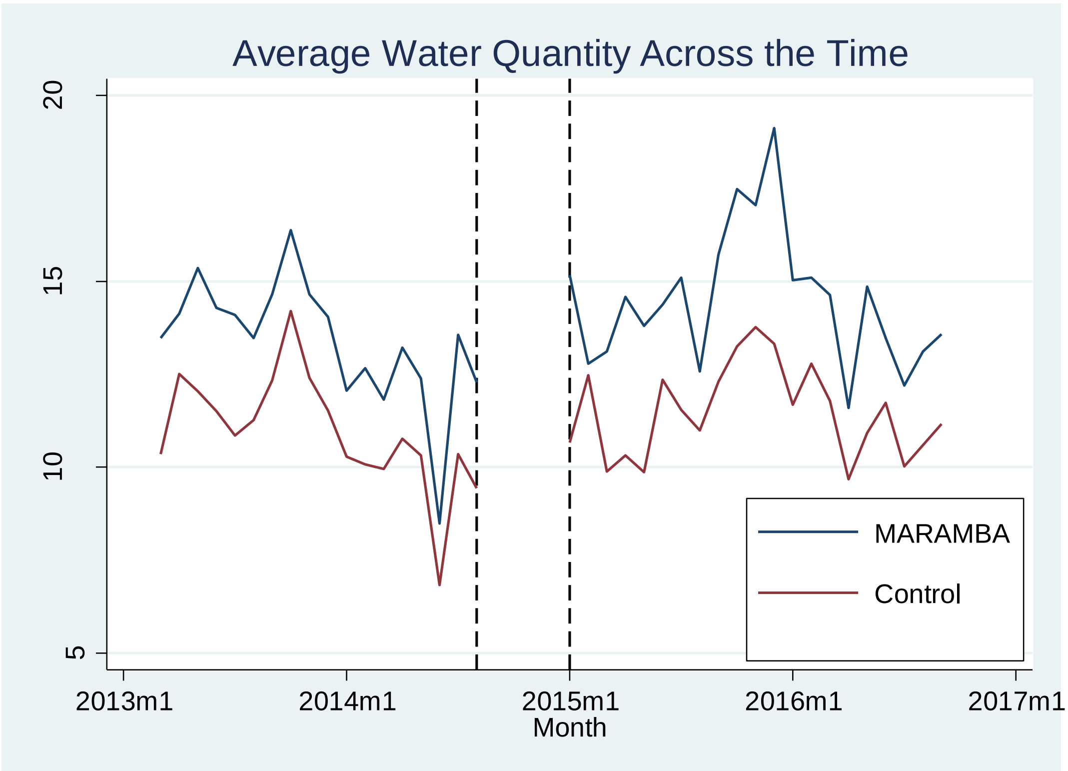
A.2.1 The Number of Working Meter Accounts Over the Time (Restricting the number of account appearances to 13)



Note: the number of working meter accounts shown in this figure restricts the number of account appearances to 13. It is obvious that the number of accounts remain stable before and after the installation time for the fake treatment group. However, the number of accounts dropped a lot after the treatment period. It might affect the average water quantity, resulting the decrease of average water quantity. The estimation results thus will be biased.

A.2.2 Trends for Billed Water Quantity





A.2.3 Estimation Result for Water Quantity Amount Owed Excluding Sanitation and Sewerage Fees

	(1)	(2)	(3)	(4)	(5)	(6)
	charge	charge	charge	log(charge)	log(charge)	log(charge)
Post	13.56***	23.01***	22.96**	0.268***	0.473***	0.471***
	(0.875)	(1.601)	(1.574)	(0.0197)	(0.0346)	(0.0342)
Treat	6.167***	6.330***		0.143***	0.147***	
	(1.439)	(1.439)		(0.0394)	(0.0395)	
Treat × Post	13.60***	13.28***	13.48***	0.207***	0.199***	0.212***
	(1.634)	(1.639)	(1.640)	(0.0337)	(0.0339)	(0.0340)
Last Month Missing	-1.562**	-1.458**	-1.017*	-0.0410***	-0.0391**	-0.0163
	(0.731)	(0.719)	(0.591)	(0.0156)	(0.0155)	(0.0125)
Time Fixed Effects	No	Yes	Yes	No	Yes	Yes
Household Fixed Effects	No	No	Yes	No	No	Yes
Observations	35,796	35,796	35,796	35,008	35,008	35,008
Adjusted R-squared	0.093	0.120	0.146	0.069	0.096	0.129

Note: Dependent variables are water amount owed for Column (1), (2) and (3) and log of water amount owed for Column (4), (5) and (6) measured in cubic meter. Column (1) and (3) do not include any fixed effects. Column (2) and (4) include year-month fixed effects. Column (3) and (6) additionally include households fixed effects. The number of observations in log forms are smaller than ones in level form, accounting for months where the charges were zero. It charges only water consumption, excluding sanitation and sewerage charges.

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1