Microcredit from Delaying Bill Payments

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Abstract

Delaying bill payments to public utilities may provide an important strategy for households with volatile incomes to smooth their consumption. At the same time, tolerating late payments may reduce net revenues for utilities, which often leads to higher prices to cover costs. Using billing records from a large water utility in Manila, this paper estimates a household consumption and savings model to evaluate counterfactual payment policies. A popular proposal to ensure upfront payments — prepaid metering — recoups less revenue than is needed to compensate households for their loss of consumption smoothing. Alternatively, a revenue-neutral policy allowing more late payments increases welfare by encouraging greater consumption smoothing.

Keywords: credit constraints; consumption smoothing; water utilities.
JEL Codes: O13; E21; L95.

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1. Introduction

Key notes to fill in later: - Ignore externalities of booster pumps - No quantity margin because of splitting of taps and because census data indicates really high coverage - Reweight by household number - Also measure by closest pipe for robustness - Measure cost savings from less NRW! – flag potential spillovers in NRW that we're missing... - could do non-linear pricing robustness check

2. Data and Setting

As a pioneer in water infrastructure investments among developing cities, Manila provides a useful context to study the welfare effects of these types of pipe replacements. Before 1997, a single government utility provided water to Manila resulting in low levels of service quality (Dumol [2000]). In 1997, Manila awarded private concession contracts to two private companies to take over for the public utility. Each company was assigned to provide water to their assigned halves of Metro Manila. The two companies are regulated by a government agency who sets the water tariff in order to ensure that the companies are able to cover their costs while earning a fair rate of return on their assets. The regulator also reserves the right to disallow costs that it views as inessential to water provision. Privatization led to large improvements in water access such that by 2015, piped water usage was almost universal.[1] This paper analyzes data provided by one of the companies.

In 2008 in agreement with the government regulator, the water company started aggressively replacing the decaying pipe infrastructure that it inherited from the public utility. Guided by hydrological concerns, the company separated the service area into smaller sections and replaced most pipes in each section on a sequential basis. The existing pipes were mostly installed between 1980 and 1990 with an average year of 1986.[2] Between 2008 and 2015, the water company replaced over 57% of its nearly 6,000 km of pipes.

To measure the effect of pipe replacements, the company provided a map of their water pipes including the installation year for each pipe as well as water billing records for their 1.5 million water connections from January, 2008 to June, 2015.[3] To mea-

[1] Less than 2% of households report using well water, water peddlers, or other alternative water sources for cooking according to the 2015 Census of Population and Housing.

[2] DISCUSS APPENDIX ABOUT PIPE AGE.

[3] Data is missing for the month of June, 2014.

sure each water connection's exposure to pipe replacement projects, connections are first located within "small areas" — the smallest geographic designations used by the company with 2,976 total areas each containing around 270 connections. Next, since projects often replace many pipes in the same place at the same time, each small area is assigned a "pipe replacement year" according to the year when at least 80% of the total length of tertiary pipes were installed within that small area. 576 small areas are observed before and after their "pipe replacement year." Tertiary pipes act as local feeders transporting water from large primary and secondary pipes directly to households. Therefore, tertiary pipe replacements likely affect service quality within local areas while primary and secondary pipe replacements may have diffuse impacts throughout the pipe network. By excluding primary and secondary pipe replacements, this approach limits the potential for spillover effects of pipe replacements onto neighboring areas at the cost of potentially underestimating the total welfare gains from these projects.

Billing records measure monthly water prices and usage for each water connection, which may serve multiple households. In order to link connection-level consumption to household welfare, billing records for each connection are merged to a survey of residential water connections conducted by an independent evaluator to monitor compliance with the water utility's service obligations.[4] This connection survey records demographics for the household that owns the connection as well as the number of other households and people that also use the connection. The survey also includes household demographics for the connection owner, different measures of water service quality, as well as household investments in booster pumps, water filters, and water storage tanks.

The main outcome of interest is household-level water usage, which is calculated by dividing total connection usage by the number of households sharing the connection. Outlier months with over 200 m3 of consumption are excluded from the analysis. All empirical results are weighted at the household-level to ensure that results are representative of the population of households.

The survey randomly interviewed water connection owners covering 15,000 connections in 2008, 24,000 connections in 2010, and 23,000 connections in 2012. Because a similar sampling design was followed across survey rounds, 13% of connections were interviewed in two years, and 1.4% of connections were interviewed in three years while remaining connections were interviewed in only one year. The connection sur-

[4]The billing records also cover commercial and industrial accounts.

vey is merged to the billing records by the connection id number and the interview month. For billing-record months without corresponding interviews, survey responses are interpolated with responses from the most recent interview.

Since households face an increasing block water tariff, the average water price faced by households is calculated as the average amount paid per cubic meter of water usage for each calendar month and tariff category after dropping outlier values below 5 PhP/m3 and above 100 PhP/m3.[5] Outliers are often due to billing credits/errors. To measure savings from pipe replacements, the water company also provided records of project costs as well as the quantity of water supplied, which often exceeds the quantity of water billed. These attributes are measured according to "district metering areas," which are around three times larger than small areas and are delineated based on hydrological considerations in order to monitor water loss.

3. Descriptives

Descriptive evidence indicates that fixing pipes improves water pressure, quality, and reliability, which may each affect consumer welfare. Table 1 tracks water service improvements by comparing average household survey responses before and after pipe replacement for areas that are observed both before and after.[6] The share of households reporting strong water pressure during peak evening usage from 6pm to 12am increases from 25% to 58% after pipe replacements. Likewise, the share reporting no pressure over the same interval decreases from 29% to 4%. Water interruptions decline slightly from 2.28 to 1.93 in the last three months, which is consistent with the water company facing periodic droughts. Water quality shows large improvements with the share of respondents reporting discolored, unusual tasting, or contaminated water dropping by at least 5 percentage points for each measure.

Households often invest in products and behaviors to compensate for low piped water service quality. These investments help reveal which aspects of piped water service are most valuable to consumers as well as most affected by pipe replacement.

Large investments in booster pumps suggest that households strongly value water pressure and reliability. Booster pumps are both expensive to purchase and operate. In Manila, booster pumps range in price from 1,200 to 15,000 PhP, which represents a

[5] Households either face a standard tariff or a high-price tariff depending on whether they are observed with business activities at their residence. See Section 3 for more discussion.

[6] Areas that may have experienced pipe replacements before the start of the sample are included in the "All" category.

large expense given average monthly household incomes of 26,023 PhP.[7] The average booster pump uses a 0.9 horsepower engine, which generates monthly costs of around 486 PhP at prevailing energy prices.[8] Before pipe replacement, 40% of households invest in booster pumps that increase water pressure. After pipe replacement, the share of households using booster pumps drops to 15%. This finding is consistent with booster pumps providing an important substitute to pressure from new water pipes.

Small investments in water filters combined with frequent purchases of filtered water both before and as well as after pipe replacement indicate that households may derive fewer benefits from improvements in piped water quality. Only 12% of households use water filters both before and after pipe replacements. Low filter usage may stem from the fact that less than half of households report drinking from the tap while over 70% of households report purchasing filtered water from local water-refilling stations. These behaviors remain constant after pipe replacements. Taken together, these findings indicate that water quality improvements from pipe replacements may not be primary drivers of changes in household welfare.

Households cope with unreliable water supply by investing in water storage tanks. Before pipe replacement, 43% of households report using water storage tanks. This percentage only drops to 36% following pipe replacement, which is consistent with households continuing to report frequent water outages even after pipe replacement. While households seems to value reliable service, small changes in storage tank use suggest that reliability improvements are unlikely to account for a large share of the welfare gains from pipe replacements.

Increases in water pressure from pipe replacements may lead households to increase their monthly water consumption. Rapid water flow allows households to complete a greater number of water-using activities like cleaning and bathing in the same amount of time. Greater water pressure may also allow households to engage in new activities that require minimum pressure levels such as showering. Cleaner water may induce households to use more tap water for cooking and cleaning. Figure 1 plots average monthly water usage per household in the 4 years before and 6 after pipe re-

[7]Figures come from scraping results from the first page of searching "booster pumps" on the popular online marketplace in Manila, `https://www.lazada.com.ph/`, yielding 24 entries with horsepower listed. Average monthly household income is computed for Metro Manila using the 2015 Family Income and Expenditure Survey.

[8]A 1 horsepower engine uses around 0.786 Kw per hour. Table 1 indicates that households use their booster pumps for 2.6 hrs per day, which implies around 78 hours per month. In 2012, tariffs for the electricity utility in Manila averaged around 8.8 PhP per KwH.

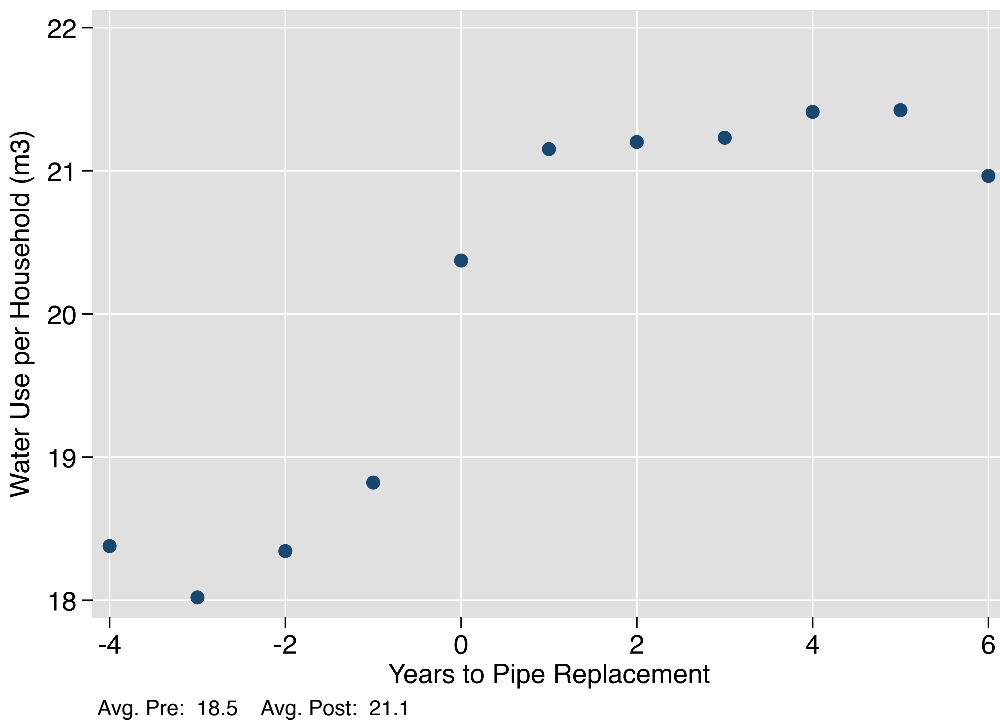
Table 1. Average Survey Responses Before and After Pipe Replacement

	Before	After	All
Piped Water Service Quality			
Water has strong pressure (6pm-12am)†	0.25	0.58	0.48
Water has no pressure (6pm-12am)†	0.29	0.04	0.09
Water interruptions in last 3 months	2.28	1.93	2.13
Water has foreign bodies	0.24	0.04	0.12
Water is discolored	0.08	0.03	0.04
Water has unusual taste/smell	0.12	0.03	0.05
Household Service Quality Investments			
Has booster pump	0.39	0.11	0.16
Hours booster pump is used per day	2.79	2.57	2.51
Has water storage tank	0.41	0.34	0.39
Has water filter	0.11	0.10	0.10
Purchases filtered water	0.69	0.74	0.69
Purchases from a deepwell	0.05	0.02	0.03
Spending on non-piped water (PhP)	90.94	89.25	87.18
Drinks from the tap	0.49	0.45	0.52
Demographics			
Household size	4.91	4.94	4.96
Employed members	1.56	1.38	1.48
High-skilled employment	0.11	0.08	0.09
Lives in duplex	0.25	0.29	0.26
Lives in single house	0.48	0.45	0.51
Number of other households sharing tap	0.84	0.86	0.90
Households	10,235	9,136	49,319

† when not using booster pump. Bill, Unpaid Balance, Payment, and Income are in PhP. Measures exclude months where households remain disconnected through the end of the sample period. Billing data include households for household-month observations. Income data include households for household-month observations. 45 PhP = 1 USD

placement. Usage increases from an average of 18.5 m3 before pipe replacement to 21.1 m3 after pipe replacement, which represents an 14% increase. The increase in usage occurs abruptly at the year of pipe replacement and remains at roughly the same

Figure 1. Average Consumption per Household with Years to Pipe Replacement



level in the following 6 years. This sustained increase in consumption suggests that pipe replacements may provide long-term impacts on household welfare.

The absence of strong pre-trends in usage suggests that replacement projects are not targeted to areas with particular trends in local water demand. Instead, this pattern is consistent with the company's stated goal of sequentially replacing old pipes according to hydrological specifications. Table 1 further supports this theory by indicating few demographic differences between households that receive pipe replacement projects (columns (1) and (2)) and all households (column (3)). Also, demographic characteristics appear relatively similar before and after pipe replacement, which suggests that pipe replacements were not coupled with other policies that may have also affected demand for water.

Mapping these increases in consumption into household welfare requires measuring how households trade off water usage and price. Prices are determined by the government regulator who imposes an increasing tariff schedule according to monthly usage, which is standard among public utilities (Hoque and Wichelns [2013]). Despite steep increases in marginal price at specific levels of usage, households do not appear to be sensitive to these price changes because households are not observed adjusting their consumption strategically to avoid higher prices.[9] The regulator also increases prices gradually over time to ensure that the company continues to cover operating costs. Since households also gradually increase their average usage over this interval, it is unclear whether households are responsive to these price increases.[10]

The empirical exercise analyzes an event-study where the same households are exposed to very different price levels over time. The government regulator gives the water company discretion to assign households to a high-price tariff schedule if they have any business activity at their residence, which provides a novel source of price variation in the context of public utilities. In the vast majority of cases, the high price tariff is applied to households that operate small food stands (or "Sari-Sari" stores). For a household with average monthly usage, the high-price tariff results in an average price of 26.4 PhP/m3 while the regular tariff results in an average price of 21.5 PhP/m3.[11] The water company occasionally visits consumers and assigns consumers to the high-price tariff if business activity is observed at the residence.[12] Table 2 provides average characteristics of households that are observed with the regular price (in column (1)), that are observed with the high price (in column (2)), and that are observed increasing prices during the sample (in column (3)). While the 724 households that experience price increases use more water than other households, they share similar demographic characteristics, which suggests that they may also share similar price-sensitivities.

Figure 2 plots average usage and marginal prices 4 years before and after households are first switched from the regular price to the high price.[13] Before the price change, average usage increases likely due to some households using additional water for their small-businesses. The price change at month 0 is associated with a sharp drop in usage and increase in average prices that persist for at least 24 months. These patterns indicate that household water usage is sensitive to large, discrete price changes over time.

[9] Appendix Figure 4 includes the average tariff schedule for users facing low and high prices. Appendix Figure 5 includes a histogram of usage per connection and finds little evidence of significant bunching at the tariff kink points at 10, 20, and 40 m3.

[10] Appendix Figure 3 plots average prices and usage per household over time.

[11] Appendix 4 plots the tariff.

[12] In some cases, consumers request price decreases when they close their businesses. These price-decrease events are not the focus of the analysis because consumers directly anticipate these events and may otherwise have adjusted their water usage accordingly.

[13] In very few cases, households are later switched back to the regular price, and then switched again to the high price.

Figure 2. Usage and Price Changes

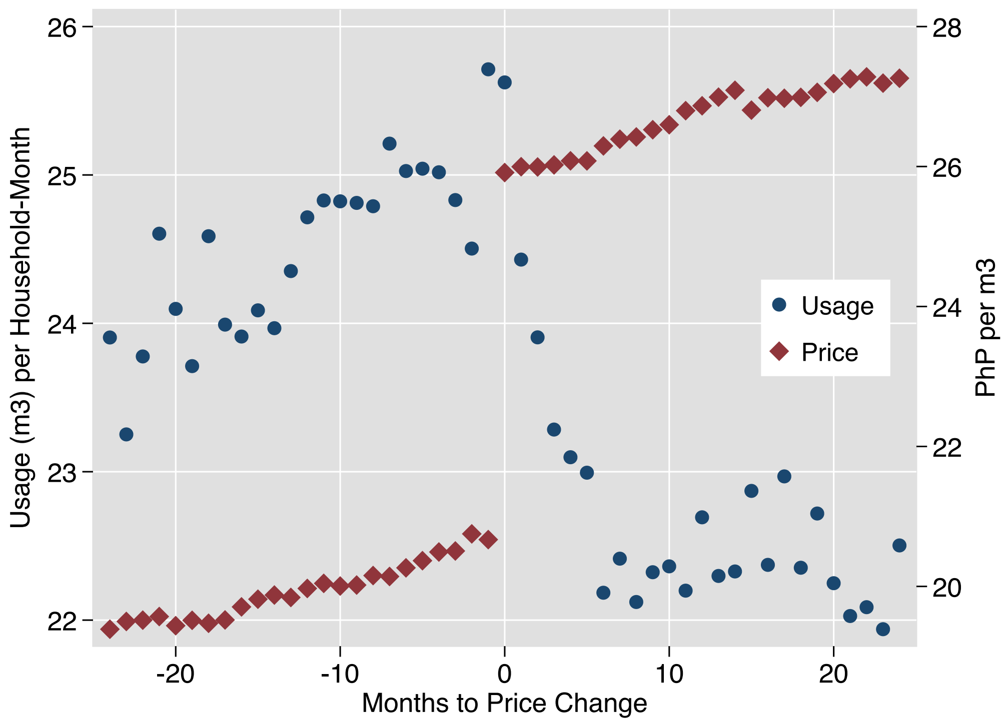


Table 2. Average Household Characteristics by Prices Charged

	Always Reg. Price	Always High Price	Change Reg. to High Price
Usage per Household (m3)	19.95	20.17	23.42
Household size	4.98	4.74	4.99
Employed members	1.49	1.42	1.39
High-skilled employment	0.09	0.06	0.05
Lives in duplex	0.26	0.26	0.27
Lives in single house	0.50	0.59	0.54
Other households sharing tap	0.90	0.93	0.96
Households	43,901	4,694	724

Reg. refers to regular price.
Pressure is 6 to midnight! Bill, Unpaid Balance, Payment, and Income are in PhP. Measures exclude months where households remain disconnected through the end of the sample period. Billing data include households for household-month observations. Income data include households for household-month observations. 45 PhP = 1 USD

4. Model

A simple model of household water demand connects changes in water usage and investments in water booster pumps to changes in household welfare as a result of pipe replacements. In this model, households choose their monthly water usage as well as whether to use a booster pump to boost their water pressure.

Each month, household utility takes the following form

$$U = \frac{1}{\alpha}\left[Q(B,R)\,w - \frac{1}{2}(w-\gamma)^2 \right] + x \tag{1}$$

where w is water usage and x represents a bundle of all other goods consumed by the household. Water service quality given by the function, $Q(B,R)$, depends on booster pump use where B equals 1 if the household chooses to use a booster pump (and zero otherwise) and as well as pipe replacements where R equals 1 after pipe replacement (and zero otherwise). $Q(B,R)$ is assumed to be differentiable in R. Water service quality enters multiplicatively with water usage, which nests the assumption that each unit of water usage is affected equally and positively by water service quality. This assumption also excludes the possibility that improved water service quality affects household utility in ways that are not directly proportional to household water usage such as by increasing housing values. In this case, the approach would underestimate the welfare benefits of improved service quality. α reflects price sensitivity, and γ reflects the satiation amount of water usage. This approach assumes that preferences for water are quasi-linear, which implies that water usage does not depend on household income [Footnote to heterogeneity table].

Households maximize utility subject to the following budget constraint

$$p w + x + B F = Y \tag{2}$$

where p is the average price of water while the price of all other goods, x, is normalized to 1. This approach includes the simplifying assumption that households respond to a single, average water price p despite facing marginal prices that increase with monthly usage. This assumption is consistent with descriptive evidence that households appear unresponsive to marginal prices.[14] F is total cost of renting and using a booster pump each month. This approach assumes that Manila has a competitive market for renting and selling booster pumps that is unaffected by improvements in piped water service quality.[15] Y is monthly household income.

Maximizing household utility in equation (1) subject to the budget constraint in equation (2) for a given choice of booster pump usage, B, yields the following expression for monthly water demand

$$w(B) = \gamma - \alpha p + Q(B, R) \tag{3}$$

Water demand depends linearly on the satiation preference, γ, price, and service quality.

Given optimal water demand, the indirect utility function at a given booster pump choice, B, is given by

$$V(B) = \frac{\alpha p^2}{2} - \gamma p + \frac{Q(B, R)^2}{2\alpha} - pQ(B, R) + \frac{\gamma Q(B, R)}{\alpha} + y - BF \tag{4}$$

The derivative of V with respect to pipe replacements, R, reflects the change in consumer welfare associated with pipe replacements. This derivative takes the following

[14] Appendix Figure 5 includes a histogram of usage per connection and finds little evidence of significant bunching at the tariff kink points at 10, 20, and 40 m3.

[15] This assumption is consistent with local service quality improvements and a city-wide market for booster pumps.

form after substituting terms for $w(B)$

$$\frac{dV(B)}{dR} = \frac{w(B)}{\alpha}\frac{dQ}{dR} - F\frac{dB}{dR} \tag{5}$$

This expression summarizes the consumer welfare effects of pipe replacements in terms of (1) the marginal effect on service quality weighted by water usage and price sensitivity as well as (2) the marginal effect on booster pump usage weighted by the cost of booster pumps. This approach assumes that welfare effects are proportional to usage, w^*, implying that service quality improvements affect all units of water usage. Welfare effects are decreasing in price sensitivity, α, which captures the intuition that households with many substitute water sources (ie. high α) may benefit less from improvements in service quality. According to this approach, welfare changes do not require measuring fixed preferences, γ, separately from levels of service quality, $Q(B, R)$. Therefore, this approach is robust to different patterns of selection into booster pump use based on different levels of service quality or fixed preferences for water usage.

5. Empirical Strategy

The empirical strategy estimates household price sensitivity as well as changes in water usage and booster pump use in response to pipe replacement projects. These estimated quantities inform the effect on consumer welfare of pipe replacement projects given by equation (5). Using an instrumental variables approach, the empirical strategy isolates price variation from connections being switched into high price tariffs. The first stage equation takes the following form

$$p_{it} = \phi_1 \text{Post Pipe}_{tl} + \phi_2 \text{Post Price}_{it} + \phi_3 \text{Pre Trend}_{it} + \phi_4 \text{ Post Trend}_{it} + \phi_t + \phi_{il} + \epsilon_{itl} \tag{6}$$

where i indexes the water connection, t indexes calendar month, and l indexes small area. p_{it} is the average price per cubic meter of monthly water use. Post Pipe$_{tl}$ is an indicator for months during and after January of the pipe replacement year. Post Price$_{it}$ is an indicator for months after a connection is first switched into a high-price tariff.[16] Post Price$_{it}$ is the instrumental variable that is excluded in the second stage. To account for trends in water usage around the time of the price change, Pre Trend$_{it}$ counts the months leading up to the first price increase and takes a value of zero otherwise. Like-

[16] In rare instances, connections may be switched into high-price tariffs more than once during the study period. The instrumental variables design ensures that the estimation uses price variation only from the first price increase, which is more likely to be unexpected by households than later price increases.

wise, Post Trend$_{it}$ counts months after the first price increase and takes a value of zero otherwise. ϕ_t are calendar month fixed effects. ϕ_{il} are connection fixed effects when the second stage has water usage as an outcome. ϕ_{il} are small-area fixed effects when the second stage has booster pump use as an outcome because booster pump use is only observed in months where the connection survey was fielded.

Given predicted prices from the first stage equation, the second stage equations take the following form

$$w_{itl} = \gamma_1 \text{Post Pipe}_{tl} + \gamma_2 \hat{p}_{it} + \gamma_3 \text{Pre Trend}_{it} + \gamma_4 \text{Post Trend}_{it} + \gamma_t + \gamma_i + \varepsilon_{itl} \tag{7}$$

$$b_{itl} = \beta_1 \text{Post Pipe}_{tl} + \beta_2 \hat{p}_{it} + \beta_3 \text{Pre Trend}_{it} + \beta_4 \text{Post Trend}_{it} + \beta_t + \beta_l + \varepsilon_{itl} \tag{8}$$

where w_{itl} is water usage per household in cubic meters per month and b_{itl} is an indicator for connection booster pump usage.

The coefficients of interest for the impacts of pipe replacement are given by γ_1 and β_1 for water and booster pump use respectively. After controlling for calendar month and connection fixed effects, these coefficients are identified from differential changes in outcomes for areas that experienced pipe replacements compared to areas that did not over the same interval. These coefficients reflect the causal effect of pipe replacements under the assumption that no other factors changed at the same time that would otherwise affect the outcomes. This assumption is supported by qualitative evidence that pipe replacements are often driven by hydrological, engineering concerns rather than strategic responses to changes in local water demand or other consumer characteristics. Supporting this assumption, Figure 1 traces a sharp break in average usage at the year of pipe replacement with little evidence of strong trends before or after replacement projects.

The effects of prices on outcomes are given by γ_2 and β_2 for water and booster pump use respectively where $\hat{p}_{it}$ is the predicted price from the equation (6). The effects are identified from changes just before and after connections are switched to a high-price tariff after controlling for trends leading up to and after the tariff change. The validity of this instrumental variables approach requires both that the tariff change produces a large impact on prices and that no other factors affect demand for water or booster pumps at the same time as the price change. This approach assumes that while households may increase their water usage as they start small home businesses, households are unable to anticipate the exact timing of the price change so that any changes in water usage in the months just following the price change can be attributed to the higher prices. Figure 2 traces a smooth, increasing trend leading up to the price change. Usage then drops abruptly at the same time as the price change, consistent with a surprise increase in prices.

The estimated coefficients directly inform the expression for welfare in equation (5). According to equation (3), water quality linearly affects water demand. Therefore, by capturing the effect of pipe replacements on water demand, γ_1 measures the total change in water quality from pipe replacements, $\frac{dQ}{dR}$. β_1 measures the reduced form impact of pipe replacements on booster pump usage, $\frac{dB}{dR}$.

The remaining term to be estimated in equation (5) is the price sensitivity, α. γ_2 captures the reduced form effect of prices on water usage. By taking the derivative of equation (6) with respect to price, this effect can be expressed as a function of the price sensitivity as well as the effect of price on water quality through endogenous changes in booster pump use, according to the following equation

$$\gamma_2 = \alpha + \frac{dQ}{dB}\frac{dB}{dp}$$

where $\frac{dQ}{dB}$ is the effect of booster pump use on water quality, which is unobserved. $\frac{dB}{dp}$ is the effect of prices on booster pump use, which is estimated by β_2. If β_2 is zero, then the expression reduces to $\gamma_2 = \alpha$. Although the booster pump decision is not explicitly modeled, β_2 may be zero or close to zero when booster pump use is primarily driven by other factors besides the price of water. For example, booster pumps may be a perfect substitute for water quality such that all households below a certain water quality level choose to use booster pumps while all households above this level do not use booster pumps. In this example, the booster pump decision is orthogonal to water prices.

Given fixed effects the are identified from

When the outcome is monthly water usage, the estimating equation maps directly onto the equation for optimal household usage given by equation (3). β_1 captures the effect of pipe replacement on service quality, $\frac{dQ}{dR}$. Likewise, β_2 captures the negative of household price sensitivity, α. Remaining fixed preferences for water and levels of service quality are absorbed in household and month fixed effects, λ_i and θ_t. These fixed effects ensure that the effect of pipe replacements is identified from variation in water usage for the same household before and after pipes are fixed while accounting for any temporal usage patterns common to all households. Likewise, price sensitivity is estimated from variation in price for the same household switching between regular and high prices. Calendar month fixed effects absorb price variation affecting all households equally over time as the company updates water tariffs.

When the outcome is booster pump use, the estimating equation captures the effect of pipe replacements on booster pump use. This approach assumes that demand for booster pumps can be linearly approximated by the estimating equation such that β_1 reflects $\frac{dB}{dR}$. Since booster pump use is a binary outcome, this approach represents a linear probability model. Time fixed effects account for variation in booster pump usage over time common to all households while household fixed effects account for differences in booster pump use across households. β_1 reflects the effect of pipe replacements on booster pump use under the assumption that no other factors independently affect booster pump use at the same time. One concern may be that the prices for booster pumps change in response to pipe replacement projects. Pipe replacements occur in small geographic areas while markets for booster pumps are likely to cover much wider areas.[17] Therefore, individual pipe replacement projects are unlikely to influence prices for booster pumps.

6. Results

Table 4 includes results of the effect of price and pipe replacements. Column (1) provides results on household water use finding an increase of 1.79 m3 per household per month after pipe replacement. The estimate is statistically significant at the 1% and economically large representing an 8% increase in average usage. The estimated increase is smaller than the descriptive increase in Figure 1 likely because the regression approach controls for increasing trends in water use over the sample period.

Column (1) also provides an estimated price sensitivity of 0.17, which is statistically significant at the 1% level. Given an average price of 21.5 PhP/m3, this estimate also implies a price elasticity of 0.17. This elasticity estimate is on the lower end of similar studies in the developing world, which find elasticities ranging from 0.01 to 0.98.[18]

Column (2) finds that pipe replacement projects are associated with a 20% decrease in booster pump use, which is statistically significant at the 5% level. This decline is smaller than the descriptive decline in Table 1 likely since the regression approach accounts for decreasing booster pump use over the sample period.

Fixed costs:

On average, pipe replacement projects replace 25.3 km of pipes at a cost of 166 million PhP. The average cost per pipe length is 9 million PhP per kilometer. Since

[17] Online markets span the entire city.

[18] See Szabó [2015], Diakité et al. [2009], and Strand and Walker [2005].

Table 3. Household Water and Booster Pump Use Estimates

	(1) Water Use	(2) Booster Pump Use
After Pipe Replacement	2.01[a]	-0.22[a]
	(0.15)	(0.02)
Avg. Price (PhP)	-0.59[a]	-0.00
	(0.10)	(0.01)
Mean	19.83	0.16
R^2	0.001	0.018
N	4,004,445	48,982
Dataset	Billing Panel	Household Survey

Weighting, discussion of different samples, clustering, controls (especially rate classes). This table predicts usage per household with pipe replacement and price with different fixed effects.

Table 4. Change in Consumer Surplus

	Service Quality	Booster Pump Use	Total
Expression	$\frac{w^*}{\alpha}\frac{dQ}{dR}$	$-F\frac{dB^*}{dR}$	$\frac{dV}{dR}$
Estimates	67.7	108.9	176.6
	(12.9)	(16.8)	(24.4)

Weighting, discussion of different samples, clustering, controls (especially rate classes). This table predicts usage per household with pipe replacement and price with different fixed effects.

around 0.73 km of pipes are replaced per small area, total project costs per small area are around 6.6 million PhP. With 275 connections per small area, project costs average 24,000 PhP per connection.

6.6 million PhP/(275*1.41)

New Revenues:

Residential connections are billed 68 PhP more per month while commercial connections are billed 145 PhP more per month. Given that 94% of connections are residential and 6% of commercial, the total billing increase is around 73 PhP per month per connection.

Decrease in Marginal Costs:

After pipe-replacement, usage per connection decreases by 21 m3 per month. Given marginal costs of 5 PhP per m3, then this decrease implies a cost reduction of 105 PhP per month.

((73)*12)/24000 ((400)*12)/24000 ((73 + 105 + 80)*12)/24000

Table 5. Total Water Supplied and Billed Estimates

	(1) Volume Billed	(2) Volume Supplied	(3) % Non-Revenue Water	
After Pipe Replacement	-116.32[a]	-23.26[a]	-5.25	-0.31[a]
	(34.42)	(6.88)	(6.88)	(0.05)
Mean	192.98	38.60	26.91	0.28
R^2	0.740	0.740	0.756	0.563
N	44,965	44,965	45,882	44,965

Say it includes both fixed effects (Describe fixed effects...) . Weighting, discussion of different samples, clustering, controls (especially rate classes). This table predicts usage per household with pipe replacement and price with different fixed effects. Standard errors are clustered at the small-area level (in parentheses). The water service area is divided into 2,974 small-areas. [c] $p<0.10$,[b] $p<0.05$,[a] $p<0.01$ 45 PhP = 1 USD

Table 6. Usage per Connection Regression Estimates

	(1) Usage (m3)	(2) Bill (PhP)	(3) Usage (m3)	(4) Bill (PhP)
After Pipe Replacement	2.56[a]	72.90[a]	3.21[a]	144.76[a]
	(0.17)	(6.04)	(0.33)	(26.43)
Mean	27.96	699.18	49.98	3,253.21
Connection Type	Residential	Residential	Commercial	Commercial
R^2	0.568	0.567	0.683	0.718
N	4,012,392	4,010,876	4,557,094	4,550,439

Weighting, discussion of different samples, clustering, controls (especially rate classes). This table predicts usage per household with pipe replacement and price with different fixed effects. Standard errors are clustered at the small-area level (in parentheses). The water service area is divided into 2,974 small-areas. [c] $p<0.10$,[b] $p<0.05$,[a] $p<0.01$ 45 PhP = 1 USD

7. Counterfactuals

The following counterfactuals identify the welfare effects of optimal pipe replacements under five different information environments. The counterfactuals focus on the role of pipe replacements by holding fixed other aspects of water utility regulation. The full population of Manila is assumed to remain connected to service indefinitely. The water tariff is assumed to be determined independently of pipe replacements and to exactly cover all costs of water production (except pipe replacements). Unless otherwise specified, any cost savings or cost overruns as a result of the pipe replacements are assumed to be passed on to consumers in the form of fixed rebates or charges, which do not affect consumers' marginal incentives to consume water. Pipe replacements are assumed to be independent of operating costs such as labor or maintenance expenditures.

The *full-information* counterfactual simulates how often a regulator would optimally replace pipes in order to maximize welfare under full information. For each section of the service area, the regulator maximizes present-discounted consumer welfare indefinitely given by the following expression

$$
\begin{aligned}
max_{R_t \in \{0,1\}} & \sum_{\tau=t}^{\infty} (1+\delta)^{t-\tau} [CS(k_t) + V(k_t)] \\
V(k_t) &= W(k_t) - E(k_t) - L(k_t) \\
k_{t+1} &= (1 + k_t)\,(1 - R_t \mathbb{1}\{k_t > l\}) \\
L(k_t) &= \frac{r(1+r)^l}{(1+r)^l - 1} \overline{L}\, \mathbb{1}\{k_t \leq l\}
\end{aligned}
$$

where t indexes month, $\delta(> 0)$ is the discount factor, and k_t is the age of the pipes. $CS(k_t)$ is the consumer surplus from pipe replacements as defined in equation (ref!), which is assumed to be decreasing in pipe age. $V(k_t)$ is the net revenue from pipe replacements, which depends on revenue from (increased) water sales, $W(k_t)$, costs of water leakage, $E(k_t)$, and payments on any loans to fund pipe replacements, $L(k_t)$. $V(k_t)$ is passed on to consumers as a fixed rebate or charge (ie. by adjusting the monthly service charge). Due to pipe deterioration, consumer surplus and water revenue are both assumed to be decreasing in pipe age while water leakage is assumed to increase with pipe page.

Each month, the regulator chooses whether to replace pipes ($R_t = 1$) or not ($R_t = 0$). Replacing pipes sets the pipe age, k_t, back to zero and is only possible if the regulator has paid off any debt from a previous pipe replacement where l indexes the duration of the debt. The regulator is assumed to fund a pipe replacement with a loan of total size, $\overline{L}$, at monthly interest rate, r, over duration, l. The expression for $L(k_t)$ calculates the size of the monthly loan payments. In this framework, the optimal schedule of pipe replacements balances net revenue against consumer surplus from new pipes.

In the *regular-replacement* counterfactual, the regulator only observes the age of the pipes and chooses to replace pipes as soon as they reach a certain age, $\overline{K}$. In the *quality-standards* counterfactual, the regulator also observes the water pressure reaching consumers, $P(k_t)$. The regulator then chooses to replace pipes once the water pressure falls below a certain threshold, $\overline{P}$. In the *cost-recovery* counterfactual, the regulator does not observe water pressure, but instead observes leakage costs. The regulator then replaces pipes to minimize leakage costs, $E(k_t)$ and pipe replacement costs, $L(k_t)$.

In the *firm-level* counterfactual, the regulated firm is assumed to be fully aware of not only leakage costs, $E(k_t)$, but also revenue from water sales as result of pipe replacements, $W(k_t)$. To incentivize the firm to act on this information, the regulator allows the firm to enjoy the net revenues from pipe replacements, $V(k_t)$. The firm then chooses replacement rates to maximize, $V(k_t)$. In this case, consumer surplus, $CS(k_t)$ is equal to consumer welfare because consumers no longer receive transfers equal to net revenues. This arrangement is equivalent to "price-cap" regulation where the regulator sets a maximum price and firm is able to enjoy profits at prices up to the maximum while incurring investment costs.[19]

Specify, exactly what is allowed to vary across places and what isn't!

The simulations assume an annual discount factor of δ=4% and an annual interest rate of r = 5%, which is consistent with loans covering recent water investments.

Costs, $L_()$, are measured...

Consumer surplus and producer surplus are assumed to linearly decline in pipe age, k_t. This assumption is consistent with civil engineering research documenting a roughly linear relationship between pipe failure and age.[20]

Since the majority of pipes are replaced

Appendix on decom.

Results are discussed below in Table [x].

then the regulator maximization problem has an interior solution where the regulator choses whether to . In practice, simulations solve the maximization problem recursively using

[19]See Joskow [2007].

[20]See Ward et al. [2017], Kleiner and Rajani [2001], and Aydogdu and Firat [2015].

The fourth counterfactual imagines an uninformed regulator and a fully informed firm where the firm decides when to replace pipes. The regulator does not adjust prices to compensate the firm for pipe replacements, which leaves the firm to maximize its own surplus from replacing pipes.[21]

according to advice from water engineers who measure costs of replacements as well as pumping cost savings. The regulator then replaces pipes to optimize upfront replacement costs against marginal savings in pumping costs.

without knowing the replacement costs or how replacements would affect water demand. However, the regulator is able to measure water pressure either through consumer surveys, consumer complaints, or pressure gauges. The regulator then establishes a minimum pressure threshold and replaces pipes when the pressure drops below the threshold.

Section Welfare: - Welfare benefits with 10 yr 5% loans (assume discount rates) or 50 yr 5% loan? - Welfare benefits with cash - Are households willing to pay for pipe improvements?

- How do welfare estimates compare to traditional estimates from health measures?

Robustness: - Use nearest pipe replacement definition (selection into meter identification)

8. Appendix

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[21]Strong incentive to reduce costs: This may occur when the regulator can't credibly commit to price increases or when the firm has a strong incentive to inflate costs which the regulator cannot verify.

Figure 3. Price Time-Series

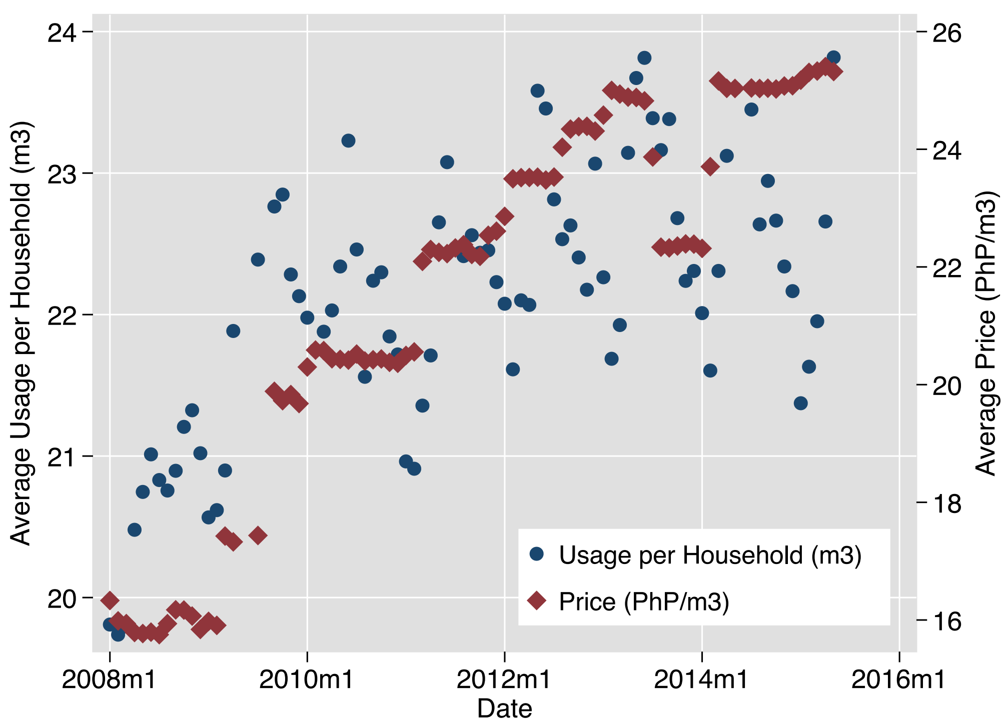

Figure 4. Tariff Schedule

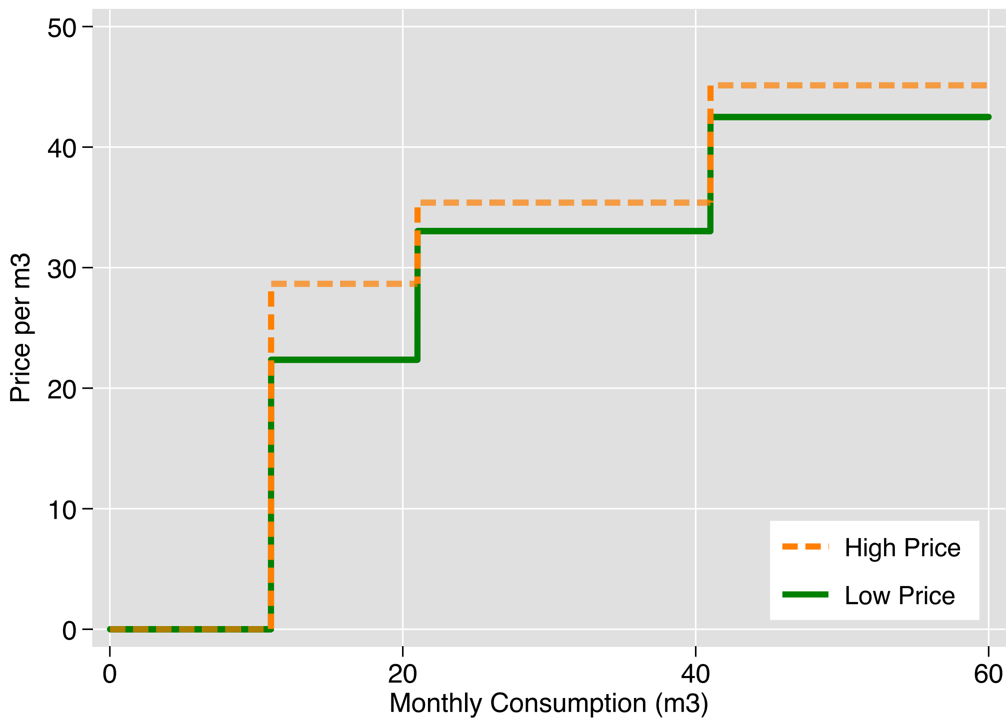

Figure 5. Usage Histogram

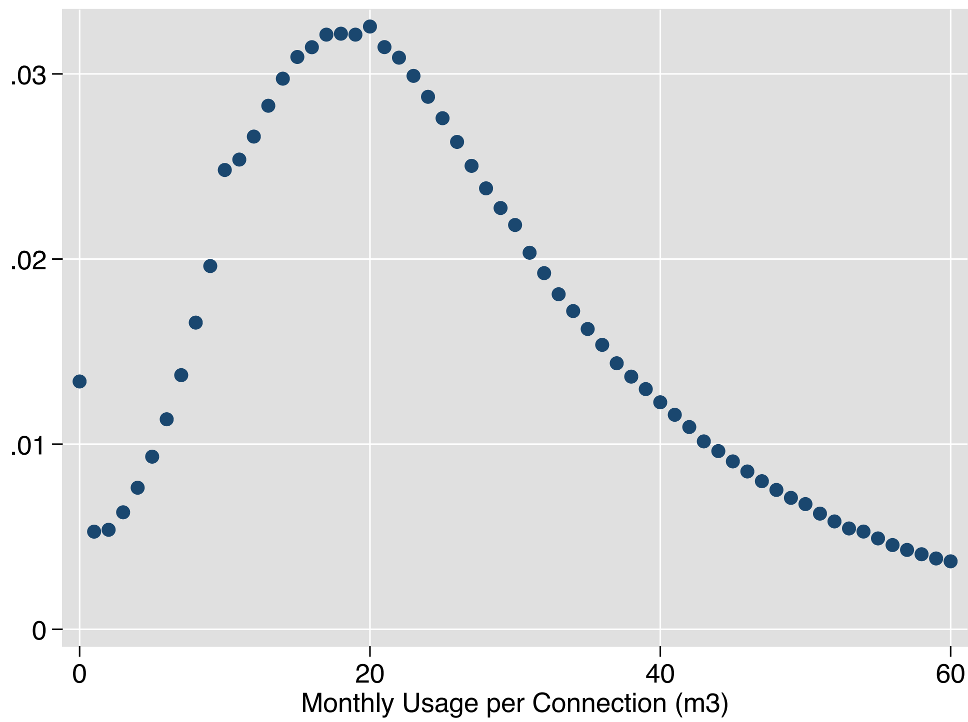

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Table 7. Water and Booster Pump Use per Household Estimates

	(1) Water Use	(2) Water Use	(3) Booster Pump Use	(4) Booster Pump Use
Post	1.17[a]	1.28	-0.22[a]	-0.25[b]
	(0.33)	(0.87)	(0.03)	(0.11)
Avg. Price (PhP)	-0.60[a]	-0.33	-0.00	0.03
	(0.10)	(0.30)	(0.01)	(0.05)
Post × Household Size	0.08		-0.00	
	(0.06)		(0.00)	
Post × Employed Household Members	-0.12		0.01	
	(0.10)		(0.00)	
Post × High Skilled Employment	-1.32[a]		-0.01	
	(0.36)		(0.02)	
Post × Subdivided House/Duplex	0.76[b]		-0.00	
	(0.31)		(0.01)	
Post × Freestanding House	1.11[a]		-0.01	
	(0.28)		(0.01)	
Post × Monthly Income (10,000 PhPs)		-0.21		0.04
		(0.45)		(0.05)
Household Size	1.67[a]		0.00	
	(0.09)		(0.00)	
Employed Household Members	0.18		0.00[b]	
	(0.13)		(0.00)	
High Skilled Employment	-0.02		0.07[a]	
	(0.47)		(0.01)	
Subdivided House/Duplex	-1.34[a]		-0.04[a]	
	(0.40)		(0.01)	
Freestanding House	0.42		-0.02[b]	
	(0.33)		(0.01)	
Monthly Income (10,000 PhPs)		0.07		0.01
		(0.37)		(0.03)
Mean	19.83	19.83	0.16	0.16
Household FE	✓	✓		
Small Area FE			✓	✓
R^2	0.006	0.000	0.026	-0.003
N	4,004,445	501,075	48,982	6,034
Dataset	Billing Panel	Billing Panel	Household Survey	Household Survey

Weighting, discussion of different samples, clustering, controls (especially rate classes). This table predicts usage per household with pipe replacement and price with different fixed effects. Standard errors are clustered at the small-area level (in parentheses). The water service area is divided into 2,974 small-areas. [c] $p<0.10$, [b]