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 investments. In 1997, Manila awarded private concession contracts to two private companies to take over for the existing public utility. Each company is assigned to provide water to their assigned halves of Metro Manila. Both companies have gradually replaced the decaying pipe infrastructure inherited from the public utility.

To measure the effect of pipe replacements, one of the companies has 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. To measure each water connection's exposure to pipe replacement projects, connections are first located within "small areas" — the smallest geographic designations used by the company 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 the greatest total length of tertiary pipes were installed within that small area.[1] 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

[1] Tertiary pipes installed in the replacement year account for 85% of the total tertiary pipe length in small areas.

water connections conducted by an independent evaluator to monitor compliance with the water utility's service obligations. 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. Household-level water usage is calculated by dividing total connection usage by the number of households sharing 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 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. Since billing records form a monthly-panel, survey responses must be interpolated

Since billing records are

To examine household demographics, billing data are merged at the connection-level to a water connection survey conducted independently to monitor the quality of the utility's service.

[2]

The water connection survey also includes measures

Additional survey data also includes information on demographics and water quality as well as investments!

Water pipes are linked to areas... The utility locates water connections within small areas each containing around 270 connections.

Each small-area is assigned a pipe replacement year as the year when the greatest total length of tertiary pipes are installed within the small area. This pattern is consistent with

This calculation includes only tertiary pipes (excluding)

which allows for linking

The pipe map documents the installation year for each length of pipe, which forms the basis for the pipe replacement measure. The

Section: Data

[2] Households using connections alone tend to be larger and wealthier than households that share connections with other households according to previous research (**?**).

- only households connected earlier (explain) (what share are those?!) - consumption per HH - reweight data for household level?! YES! - survey panel and other panel; date representation, how its imputed, etc. - Put in a table describing pipe-replacement; describe staggered approach; predict pipe-replacement? - industrial/commercial footnote later!!

Consumption is measured according to average consumption for not-shared households! What extra assumption is that!!! NEED ROBUSTNESS!!!

MEASURING AVERAGE PRICES

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. [summarize the findings]

Consumers also 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. 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 large expense given average monthly household incomes of 26,023 PhP.[3] The average booster pump uses a 0.9 horsepower engine, which generates monthly costs of around 486 PhP at prevailing energy prices.[4] 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 not derive large benefits from improvements in piped water quality. Only 12% of households use

[3]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.

[4]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.

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.[5] Figure 1 plots average monthly water usage per household in the 4 years before and 6 after pipe replacement. 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 level in the following 6 years. This sustained increase in consumption suggests that pipe replacement may provide sustained 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 engineering 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

[5] By contrast, water quality improvements may have an ambiguous effect on water consumption. On one hand, cleaner water may induce households to use more tap water for cooking and cleaning. On the other hand, cleaner water may increase the productivity of cleaning and bathing, which may lead households to use less piped water.

Table 1. Average Survey Responses Before and After Pipe Replacement

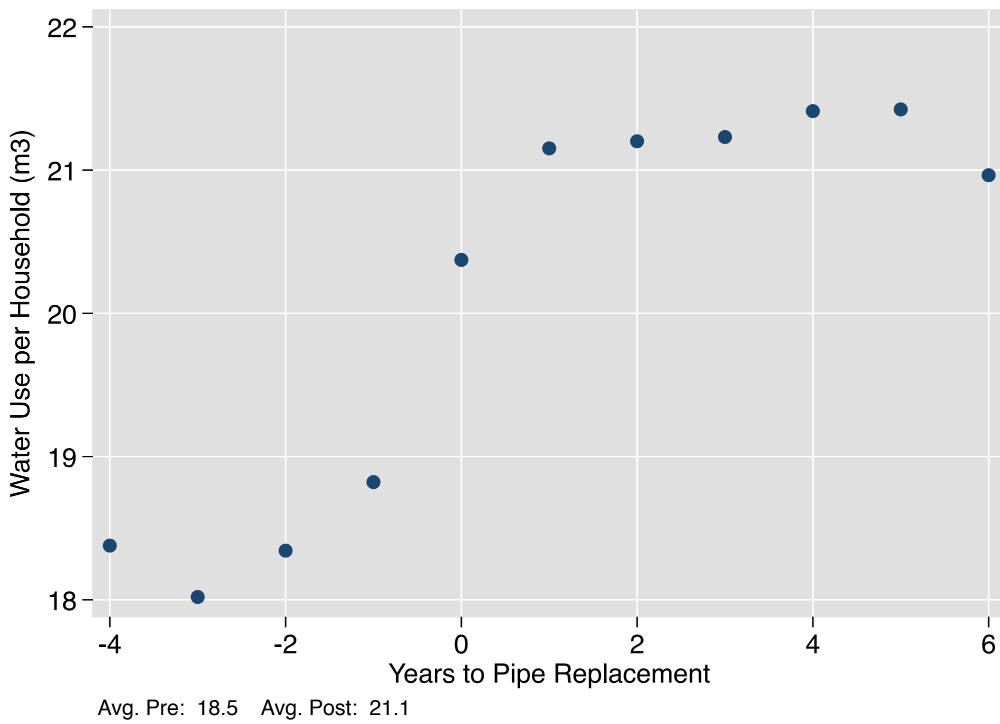
	Before	After	All
Piped Water Service Quality			
Water has strong pressure (6pm-12am)†	0.26	0.56	0.48
Water has no pressure (6pm-12am)†	0.27	0.04	0.09
Water interruptions in last 3 months	2.27	1.94	2.13
Water has foreign bodies	0.23	0.04	0.12
Water is discolored	0.07	0.03	0.04
Water has unusual taste/smell	0.12	0.03	0.05
Household Service Quality Investments			
Has booster pump	0.37	0.11	0.16
Hours booster pump is used per day	2.86	2.47	2.51
Has water storage tank	0.42	0.36	0.39
Has water filter	0.10	0.10	0.10
Purchases filtered water	0.68	0.74	0.69
Purchases from a deepwell	0.05	0.02	0.03
Spending on non-piped water (PhP)	91.02	88.60	87.18
Drinks from the tap	0.50	0.46	0.52
Demographics			
Household size	4.92	4.94	4.96
Employed members	1.57	1.37	1.48
High-skilled employment	0.11	0.08	0.09
Lives in duplex	0.24	0.29	0.26
Lives in single house	0.49	0.46	0.51
Number of other households sharing tap	0.86	0.88	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

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

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



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 (cite appendix). 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 (cite appendix).

[RE-WRITE WITH NEW DEFINITION!] The government regulator also 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 (cite appendix for tariff). The water company periodically visits consumers and updates prices according to the activities observed at each consumer's residence. In some cases, consumers request price changes, which prompts the company to investigate the household and determine the appropriate price. Table 2 provides average characteristics of households that are always observed with the regular price (in column (1)), that are always observed with the high price (in column (2)), and that are observed changing prices during the sample (in column (3)). While the 2,442 households that experience price changes 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 4 years before and after households are switched from the regular price to the high price (in red) as well as before and after households are switched from the high price to the regular price (in blue). Before the price change, average usage for both groups follows relatively constant trends. The price change is associated with a usage jump for households switched to the regular price and a corresponding usage slide for households switched to the high price. The changes in consumption appear relatively persistent up to 4 four years after the price changes. These patterns indicate that household water usage is sensitive to large, discrete price changes.

Figure 2. Usage and Price Changes

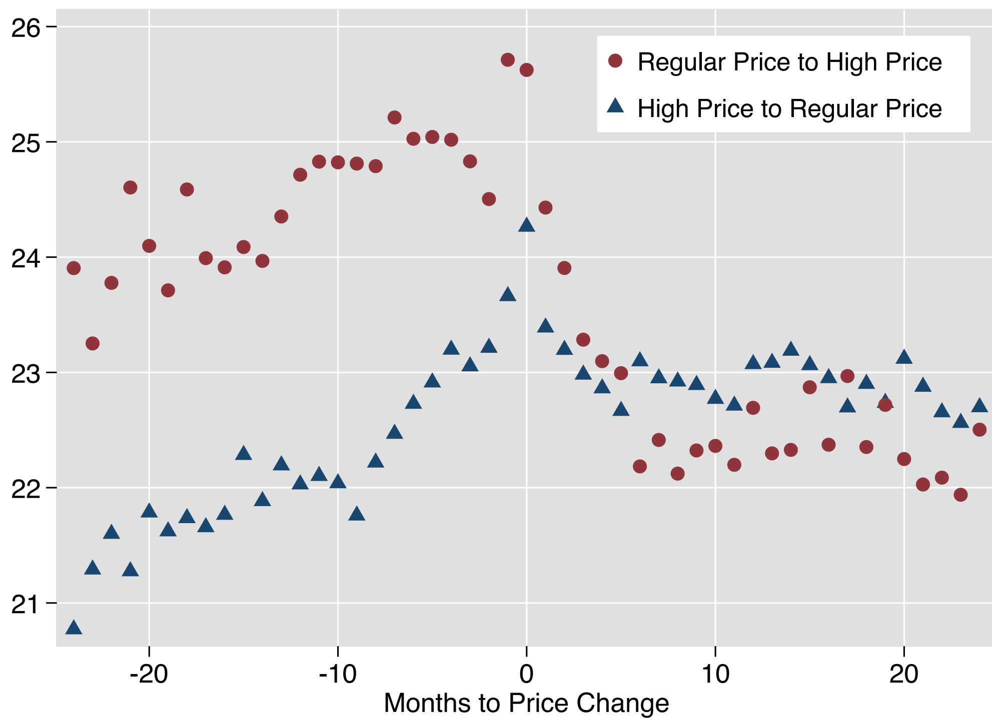


Table 2. Average Household Characteristics by Prices Charged

	Always Reg. Price	Always High Price	Change Reg. to High Price
Usage per Household (m3)	19.91	19.81	23.40
Household size	4.98	4.68	4.99
Employed members	1.49	1.40	1.40
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	0.92	0.95
Households	43,494	3,818	729

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 consumption 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 consumption, which nests the assumption that each unit of water consumption 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 consumption 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 consumption 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 consumption. This assumption is consistent with descriptive evidence that households appear unresponsive to marginal prices (cite appendix). F is total cost of renting and using a booster pump each month. This approach assumes that Manila has a competitive market for renting/selling booster pumps that is unaffected by improvements in piped water service quality.[6] 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

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

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

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

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

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

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

form after substituting terms for w^*

$$\frac{dV}{dR} = \frac{w^*}{\alpha}\frac{dQ}{dR} - F\frac{dB^*}{dR} \tag{5}$$

This expression summarizes the consumer welfare effects of pipe replacements in terms of (1) the marginal effect on service quality weighted by water consumption 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 consumption, w^*, implying that service quality improvements affect all units of water consumption. 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 consumption.

5. Empirical Strategy

The estimation strategy recovers household price sensitivity as well as the changes in service quality and booster pump use in response to pipe replacement projects. These estimated quantities along with observed water use and booster pump costs summarize the change in consumer welfare from pipe replacement projects as given by equation (5). The estimating equation takes the following form

$$y_{itl} = \beta_1 \text{ After Pipe Replacement}_{tl} + \beta_2 \, p_{it} + \theta_t + \lambda_i + \epsilon_{itl} \tag{6}$$

where the outcome, y_{itl}, is either monthly water consumption or booster pump use. Outcomes are measured for household, i, in small area, l, at calendar month, t. After Pipe Replacement$_{tl}$ takes a value of one for months after pipe replacement and zero otherwise. Since the data identify only the year that pipes were replaced, all months from the replacement year onwards are considered after pipe replacement. p_{it} measures the average price faced by each household in each month. θ_t includes calendar month fixed effects while λ_i includes household fixed effects.

When the outcome is monthly water consumption, the estimating equation maps directly onto the equation for optimal household consumption 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 consumption for the same household before and after pipes are fixed while accounting for any temporal consumption 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.

Identifying β_1 and β_2 requires assuming that pipe replacements and household-specific price changes are not correlated with any other factors that may also affect water demand at the same time. One concern may be that pipe improvements are paired with other infrastructure investments that drive increases in local income, population, and water demand. Alternatively, the water company may strategically target pipe improvements to either boost areas with declining demand or accelerate areas with growing demand. 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. These patterns are consistent with company reports that pipe replacements were not explicitly linked to other infrastructure projects and were instead planned primarily to minimize engineering costs.

Another concern is that households may increase their water demand as they are switched to the high price because they often open roadside food-stands. Conversely, households that close their roadside food-stands may decrease their consumption at the same time as they are switched to the low price. Both cases suggest that the empirical approach would underestimate household price sensitivities. Figure 2 provides little evidence of strong pre-trends leading up to price changes. While this evidence is suggestive that these events are uncorrelated with long-term trends in water demand, this approach is unable to exclude the possibility that other factors may influence water demand at the same time as these events.

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.[7] 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 consumption. 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.[8]

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 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 con-

[7] Online markets span the entire city.

[8] 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	1.88[a]	-0.20[a]
	(0.13)	(0.03)
Avg. Price (PhP)	-0.59[a]	0.01
	(0.10)	(0.02)
Mean	19.83	0.16
R^2	0.002	0.043
N	4,004,445	10,560
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	63.3	97.4	160.7
	(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.

nections 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	1.14	-14.81[a]	-0.20[a]
	(1.33)	(4.55)	(0.03)
Mean	18.48	27.53	0.28
R^2	0.892	0.798	0.595
N	67,827	67,827	67,824

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 *full-information* counterfactual provides an optimal benchmark where the regulator chooses when to replace pipes to maximize total welfare given full information on demand and costs. In the *regular-replacement* counterfactual, the regulator simply replaces all pipes at a fixed interval. In the *quality-standards* counterfactual, the regulator establishes a minimum water pressure threshold and replaces pipes when pressure falls below the threshold. In the *cost-recovery* counterfactual, the regulator schedules replacements to balance savings from lower pumping costs against upfront costs of the pipe replacements. In the *firm-level* counterfactual, the regulator lets the firm decide when to replace pipes under the assumption that the firm has full demand and cost information.

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 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 consumer surplus and $V(k_t)$ is net revenue, which depends on revenue from water sales, $W(k_t)$, costs of water leakage, $E(k_t)$, and payments on any loans to fund pipe replacements, $L(k_t)$. 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. $L(k_t)$ is the payment on the loan needed to fund a pipe replacement. 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.

The regulat wher net revenues for a section of the service area are positive or negative. In practice, the regulator is likely to stagger pipe replacements across sections of the service area so that total net revenues across all service areas remain close to zero. However, in periods where total net revenues are positive or negative, the regulator may need to rebate or extract more revenue from consumers. The model implicitly assumes that the regulator is able to maintain revenue neutrality by adjusting fixed monthly service charges paid by consumers.

This framework also holds the water tariff fixed.

In the *regular-replacement* counterfactual, the regulator is uninformed about consumer surplus and revenues. Instead, the regulator only knows 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 observes not only the age of the pipes, but also 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 the part of producer surplus attributable to leakage costs, $E(k_t)$. The regulator then replaces pipes to minimize leakage costs and pipe replacement costs.

The marginal price is enough to cover the other fixed costs, and the firm gets to keep the leftovers!

In the *firm-level* counterfactual, the regulated firm is assumed to be fully aware of producer surplus, $PS(k)$, and the regulator allows the firm to maximize producer surplus, $PS(k) - L(k_t)$.

Total welfare versus producer/consumer divide?

In the empirical set-up, ...

Discuss the empirical set up! Discuss the limitations in the empirical set-up. Roughly correspond to natural divisions of the service area.

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.[9]

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

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

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

own surplus from replacing pipes.[10]

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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[10]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

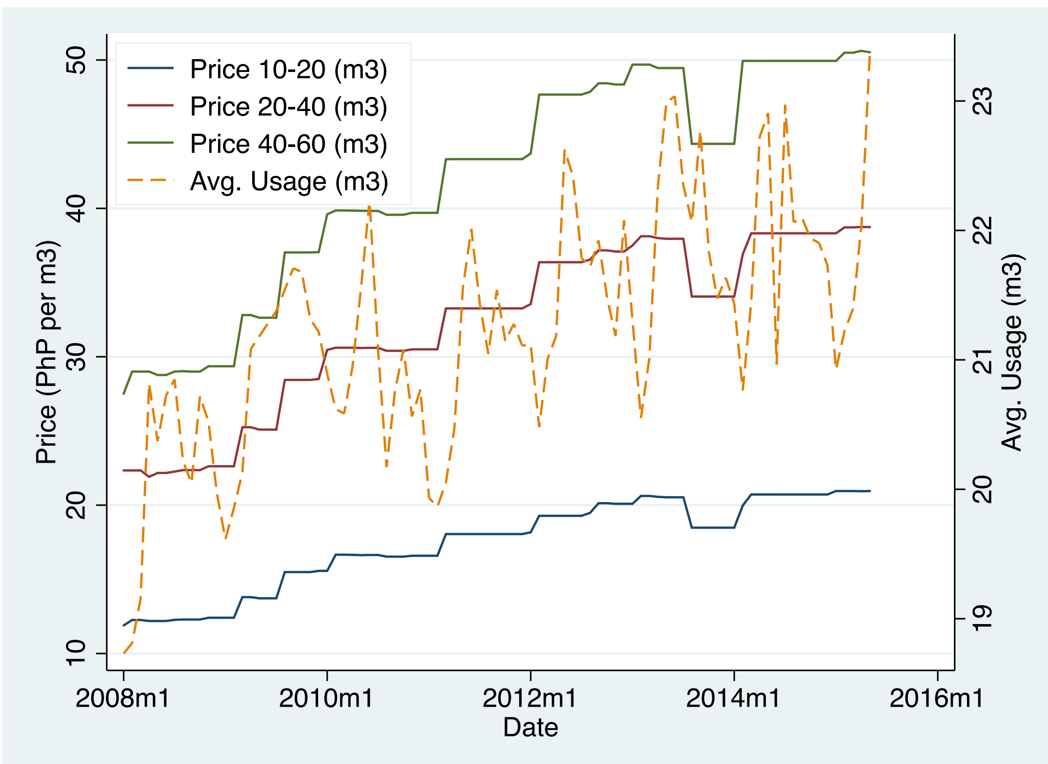

Figure 4. Tariff Schedule

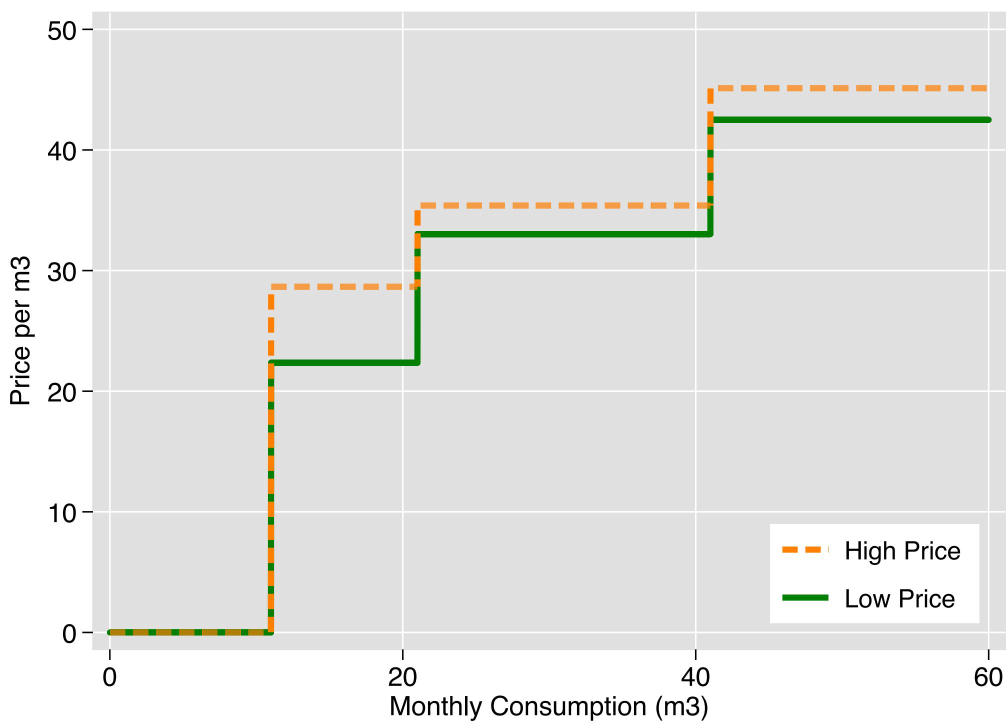

Figure 5. Consumption Histogram

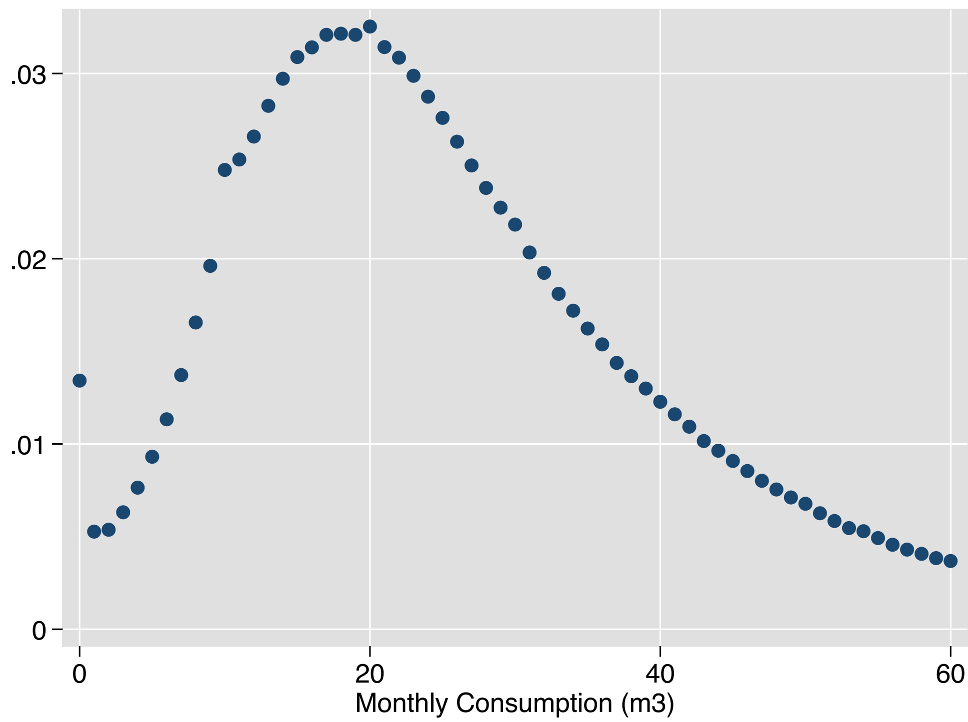

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Table 7. Water and Booster Pump Use per Household Estimates

	(1) Water Use	(2) Water Use	(3) Booster Pump Use	(4) Booster Pump Use
Post	1.57[a]	1.69[b]	-0.21[a]	-0.21[b]
	(0.28)	(0.80)	(0.02)	(0.09)
Avg. Price (PhP)	-0.15[a]	-0.11	0.00	0.00
	(0.05)	(0.16)	(0.00)	(0.00)
Post × Household Size	-0.00		-0.00	
	(0.05)		(0.00)	
Post × Employed Household Members	-0.15[c]		0.01	
	(0.08)		(0.00)	
Post × High Skilled Employment	-1.10[a]		-0.01	
	(0.28)		(0.02)	
Post × Subdivided House/Duplex	0.59[b]		0.01	
	(0.25)		(0.01)	
Post × Freestanding House	1.04[a]		0.01	
	(0.22)		(0.01)	
Post × Monthly Income (10,000 PhPs)		-0.38		0.05
		(0.43)		(0.05)
Household Size	1.68[a]		0.00	
	(0.09)		(0.00)	
Employed Household Members	0.20		0.00[b]	
	(0.13)		(0.00)	
High Skilled Employment	0.00		0.07[a]	
	(0.48)		(0.01)	
Subdivided House/Duplex	-1.31[a]		-0.05[a]	
	(0.40)		(0.01)	
Freestanding House	0.39		-0.02[a]	
	(0.33)		(0.01)	
Monthly Income (10,000 PhPs)		0.12		0.00
		(0.32)		(0.03)
Mean	19.83	19.83	0.16	0.16
Household FE	✓	✓		
Small Area FE			✓	✓
R^2	0.556	0.582	0.344	0.320
N	4,004,448	501,075	49,319	6,041
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]