The Welfare Effects of Infrastructure Quality: Evidence from Water Pipe Replacements in Manila

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November 2020

Replacing Water Pipes

- 12 out of 15 developing cities have intermittent water supply
  - Most people boil tap water before drinking [WRI, 2019]
- Fixing water pipes has high fixed costs, but produces marginal cost savings and health benefits

$300 Billion War Beneath the Street: Fighting to Replace America's Water Pipes

New York Times, Nov. 10th, 2017

- Consumer surplus is often absent from the policy dialogue

This paper

- **Research Question**: how do pipe replacement projects affect welfare?
  - Households consume more water
  - Households spend less on substitutes for water quality (filters, storage containers, booster pumps)
  - Pumping costs decrease and billing increases for the utility
- **Method**: analyze the staggered roll-out of 600 km of new pipe in Manila with billing records and survey data on water quality
- **Preview of Findings**: pipe replacements lead to 10% more water consumption and 54% less booster pump use
  - Cost savings alone $<$ Fixed costs
  - Cost savings $+$ Consumer surplus $>$ Fixed costs

Data on Piped Water in Manila

- A large, regulated monopoly in Manila provided billing records for 1.5 mil. connections from 2008-2015
- Billing records merge with survey data on 50,000 total residential connections spread across 2008, 2010, and 2011
  - Outcomes measured per household and weighted by household
- The pipe replacement year is identified for each small-area ($\sim$2,900) according to the year that accounts for the greatest amount of pipe replacement in each area
  - Only consider replacements for areas with pre/post data
  - Robust to using nearest pipe to each connection

Water Quality Before/After Pipe Replacement

	Before	After	All
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
Households	10,235	9,136	49,319

† when not using booster pump.

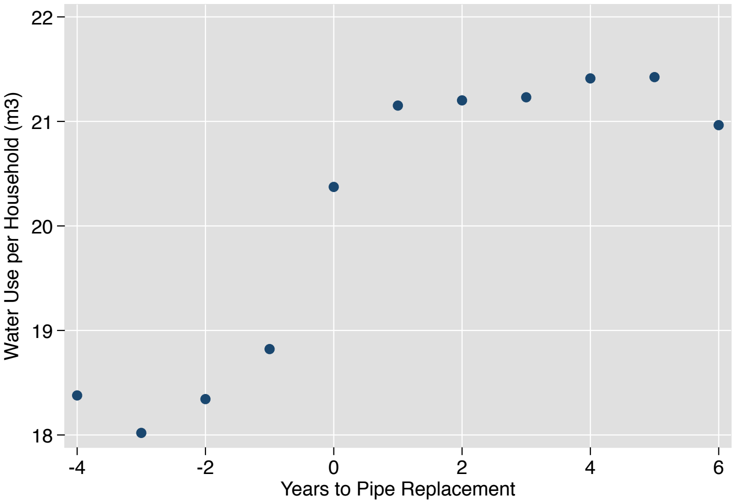
- Large quality improvements

Quality Substitutes Before/After Pipe Replacement

	Before	After	All
Uses booster pump	0.39	0.11	0.16
Hours booster pump is used per day	2.79	2.57	2.51
Uses water storage tank	0.41	0.34	0.39
Uses 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
Boils tap water before drinking	0.23	0.19	0.21
Households	10,235	9,136	49,319

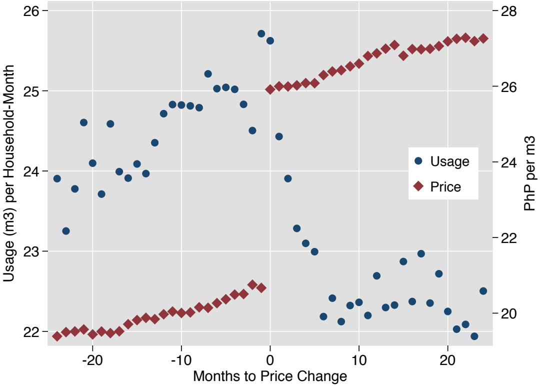
- Much less booster pump use
- Small changes in other substitutes

Average Usage per Household with Years to Pipe Replacement



Avg. Pre: 18.5 Avg. Post: 21.1

Average Usage per Household with Months to Price Change



- 729 households are switched to a high-price tariff when they are detected with businesses (ie. roadside stands)
- Switched households use more water but have similar demographics to other households

Household Demand for Water

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

$$s.t.$$

$$p\,w + x + B\,F = Y$$

- α is the price-sensitivity
- $Q(B,R)$ is water quality depending on booster pump use (B) and pipe replacements (R)
- w is water usage
- x is all other goods
- γ is the fixed preference for water
- p is the water price (assumed to be constant)
- F is the monthly cost of the booster pump
- Y is income

Solve for the Welfare Effect of Pipe Replacements

- Water demand as a function of booster pump choice

$$w = \gamma - \alpha p + Q(B, R)$$

- Effect of pipe replacements on consumer welfare

$$\frac{dV}{dR} = \frac{w}{\alpha}\frac{dQ}{dR} - F\frac{dB}{dR}$$

Estimating Demand

First Stage

$$p_{it} = \phi_1 \text{Post Pipe}_{tl} + \phi_3 \text{Post p ch}_{it} + \phi_1 \text{Pre t}_{it} + \phi_2 \text{Post t}_{it} + \phi_t + \phi_i + \epsilon_{itl}$$

Second Stage

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

$$b_{itl} = \beta_1 \text{Post Pipe}_{tl} + \beta_2 \hat{p}_{it} + \beta_3 \text{Pre t}_{it} + \beta_4 \text{Post t}_{it} + \beta_t + \beta_i + \varepsilon_{itl}$$

- w_{itl} is water consumption and b_{itl} is booster pump use
- i is household, t is month, and l is location
- Post Pipe$_{tl}$ indicates months after pipe replacements
- Pre t$_{it}$ and Post t$_{it}$ are pre and post trends relative to the first price change
- Post p ch$_{it}$ indicates months after the first price change

Estimating Water Demand

Second stage

$$w_{itl} = \gamma_1 \text{Post Pipe}_{tl} + \gamma_2 \hat{p}_{it} + \gamma_3 \text{Pre t}_{it} + \gamma_4 \text{Post t}_{it} + \gamma_t + \gamma_i + \varepsilon_{itl}$$
$$b_{itl} = \beta_1 \text{Post Pipe}_{tl} + \beta_2 \hat{p}_{it} + \beta_3 \text{Pre t}_{it} + \beta_4 \text{Post t}_{it} + \beta_t + \beta_i + \varepsilon_{itl}$$

Effect of pipe replacements on consumer welfare

$$\frac{dV}{dR} = \frac{w}{\alpha}\frac{dQ}{dR} - F\frac{dB}{dR}$$

- $\gamma_1 = \frac{dQ}{dR}$
- $\beta_1 = \frac{dB}{dR}$
- $\gamma_2 = \alpha + \frac{dQ}{dB}\frac{dB}{dp}$
- $\beta_2 = \frac{dB}{dp}$

Results

	Water Use	Booster Pump Use
After Pipe Replacement	2.01***	-0.22***
	(0.15)	(0.02)
Avg. Price (PhP)	-0.59***	-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

Includes connection and calendar month fixed effects. Standard errors are clustered at the small-area level.

Heterogeneous Effects

	Water Use	Booster Pump Use
Post	1.17***	-0.22***
	(0.33)	(0.03)
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***	-0.01
	(0.36)	(0.02)
Post × Subdivided House/Duplex	0.76*	-0.00
	(0.31)	(0.01)
Post × Freestanding House	1.11***	-0.01
	(0.28)	(0.01)
Mean	19.83	0.16
Household FE	✓	
Small Area FE		✓
R^2	0.006	0.026
N	4,004,445	48,982
Dataset	Billing Panel	Household Survey

Effects on Consumer Welfare

	Better Water Quality	Less Spending on Booster Pumps	Total
Expression	$\frac{w}{\alpha}\frac{dQ}{dR}$	$-F\frac{dB}{dR}$	$\frac{dV}{dR}$
Estimates (in PhP)	67.7	108.9	176.6
	(12.9)	(16.8)	(24.4)

- Average water bill per household is 532 PhP
- Average monthly household income is 26,023 PhP
- The monthly operating cost of booster pumps, F, is 486 PhP
  - Electricity is expensive and pumps are used for 2.6 hrs per day
  - Does not include upfront price ranging from 1,200 to 15,000 PhP

Do pipe replacements pay for themselves?

	Billing	Supply Costs
After Pipe Replacement	57.07***	-74.04**
	(4.30)	(22.77)
Mean	531.94	27.53
R^2	0.511	0.798
N	4,002,952	67,827

- Fixed costs equal 17,021 PhP per household
- 10 year loan at 5% interest implies monthly payments of 181 PhP
- Consumer surplus of 161 PhP + Cost savings of 131 PhP > Loan payments of 181 PhP
- Does not include health benefits, commercial users (6%), other infrastructure benefits

Takeaways

- Consumer surplus matters for pipe replacement policies
- Important to measure both direct effects (ie. consumption) and indirect effects (ie. quality substitutes) of quality investments
- Thanks for coming and for your feedback!