IDB WORKING PAPER SERIES Nº IDB-WP-1152

# Turn Off the Faucet:

## Solving Excess Water Consumption with Individual Meters

Paul E. Carrillo
Ivette Contreras
Carlos Scartascini

Editors:
Marcello Basani
Francesco De Simone

Inter-American Development Bank
Water and Sanitation Division /
Department of Research and Chief Economist

October 2021

# Turn Off the Faucet:

## Solving Excess Water Consumption with Individual Meters

Paul E. Carrillo*
Ivette Contreras*
Carlos Scartascini**

Editors:
Marcello Basani
Francesco De Simone

* George Washington University
** Inter-American Development Bank

October 2021

**Cataloging-in-Publication data provided by the**
**Inter-American Development Bank**
**Felipe Herrera Library**

Carrillo, Paul E.
Turn off the faucet: solving excess water consumption with individual meters / Paul E. Carrillo, Ivette Contreras, Carlos Scartascini; editors, Marcello Basani, Francesco De Simone.
p. cm. — (IDB Working Paper Series ; 1152)
Includes bibliographic references.
1. Water consumption-Ecuador-Econometric models. 2. Water-meters-Ecuador-Econometric models. I. Contreras, Ivette. II. Scartascini, Carlos G., 1971- III. Basani, Marcello, editor. IV. De Simone, Francesco, editor. V. Inter-American Development Bank. Water and Sanitation Division. VI. Inter-American Development Bank. Department of Research and Chief Economist. VII. Title. VIII. Series
IDB-WP-1152

http://www.iadb.org

Copyright © 2021 Inter-American Development Bank. This work is licensed under a Creative Commons IGO 3.0 Attribution-NonCommercial-NoDerivatives (CC-IGO BY-NC-ND 3.0 IGO) license (http://creativecommons.org/licenses/by-nc-nd/3.0/igo/legalcode) and may be reproduced with attribution to the IDB and for any non-commercial purpose, as provided below. No derivative work is allowed.

Any dispute related to the use of the works of the IDB that cannot be settled amicably shall be submitted to arbitration pursuant to the UNCITRAL rules. The use of the IDB's name for any purpose other than for attribution, and the use of IDB's logo shall be subject to a separate written license agreement between the IDB and the user and is not authorized as part of this CC-IGO license.

Following a peer review process, and with previous written consent by the Inter-American Development Bank (IDB), a revised version of this work may also be reproduced in any academic journal, including those indexed by the American Economic Association's EconLit, provided that the IDB is credited and that the author(s) receive no income from the publication. Therefore, the restriction to receive income from such publication shall only extend to the publication's author(s). With regard to such restriction, in case of any inconsistency between the Creative Commons IGO 3.0 Attribution-NonCommercial-NoDerivatives license and these statements, the latter shall prevail.

Note that link provided above includes additional terms and conditions of the license.

The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the Inter-American Development Bank, its Board of Directors, or the countries they represent.

BY NC ND

## Abstract

When consumption of water and other utilities is measured collectively and payment for such services is equally shared among members of the group, individuals may use more than what is socially optimal. In this paper, we evaluate how installation of individual meters affects water consumption. Using rich administrative data from the public water utility company in Quito, Ecuador, it is estimated that water consumption decreases by about 8% as a result of the introduction of individual metering. The effect is large and economically significant: in order to obtain the same effect prices would have to double. Individual water metering could be a useful tool to curve down consumption in both developing and developed countries.

**JEL classifications:** D12, D62, Q21, Q25, Q58

**Keywords:** Water consumption, Commons problem, Institutions, Individual meters, Price elasticity, Regression discontinuity, Difference-in-difference

---

The authors gratefully acknowledge EPMAPS for its collaboration in this research project and the Inter-American Development Bank for its financial support. In particular, this work would had not been possible without the comments and suggestions made by Marcello Basani and the INE/WSA team. We also thank an anonymous reviewer for additional comments. The information and opinions presented herein are entirely those of the authors, and no endorsement by the Inter-American Development Bank, its Board of Executive Directors, or the countries they represent is expressed or implied.

# 1 Introduction

Access to water remains limited for many people around the world, and increased demand from population growth, urbanization and agricultural and industrial use is putting stress on many water systems (WRI, 2019). In many places, groundwater is being depleted, and a warming planet is shifting rainfall away from the equator toward the poles, putting the lives of millions at risk (Figure 1).[1] Moreover, water shortages affect both developing and developed countries.[2]

Policymakers have made water conservation a key priority. For example, the United Kingdom's environmental agency aims to reduce individual water consumption by 40% in the next 20 years (Agency, 2018). Some states in the United States, like California, are using extensive campaigns to curve down water use, and cities around the world, including the city of Quito, Ecuador, are concerned about the long-term sustainability of their water supply.[3]

What policies can effectively decrease domestic water consumption? Regulations and pricing mechanisms are generally the preferred choice and have been implemented in many settings. Increasing prices has always been one of the preferred tools for reducing water, electricity, and natural gas consumption, and, in many cases, it works (Bastos et al., 2015). However, the consumption of utilities is in many cases measured *collectively* for all members of a building or a community. For example, the 2018 American Community Survey shows that 55% of US households living in multifamily units report that their water and sewer expenditures are included in their rent or condominium fee.[4] Payment for such services is then equally shared among households. This sharing system leads to the well-known "tragedy of the commons": individuals may use more than what is socially optimal when the cost of *collective* consumption is evenly shared among the group (Hardin, 1968). The use of a common good far beyond its socially optimal level is unfortunately all too common. Deforestation, animal extinction, the depletion of natural resources, and climate change are all examples of the consequences of inadequate resource management (Hardin, 1998; Stavins, 2011).

---

[1] Unicef predicts that by 2040, almost 600 million children will be living in areas of extremely high water stress (Unicef, 2017).

[2] For example, California has faced severe water shortages in the near past, and many western states in the United States are vulnerable to droughts (Kearney et al., 2014).

[3] The sixth United Nations development goal consists of ensuring availability and *sustainable management* of water and sanitation for all.

[4] In the United Kingdom, only about a half of all household possess individual meters (`https://www.bbc.com/news/business-45788802`).

Empirical evidence describing the role of the commons problem in water consumption, however, is limited. The literature has mostly focused on analyzing survey data about perception of externalities related to residential water consumption (Corral-Verdugo et al., 2002; Ohler and Billger, 2014). An important exception is Jack et al. (2018), which shows that there could be overconsumption even within a household if family members are imperfectly altruistic. Institutions tend to alleviate the commons problem, at least in part (Copeland and Taylor, 2009; Ostrom, 1990; Stavins, 2011), and could improve service provision (Galiani et al., 2005).

Given the commons problem, can policies that promote individual measurement of water consumption reduce its use? Our paper evaluates, for the first time, how the installation of private water meters in residential neighborhoods and/or buildings that initially had collective meters affects water consumption. Administrative data from Quito's Public Water Company allow us to identify residential neighborhoods and buildings that switched from collective to individual metering during the years 2014-2016. Using a regression discontinuity approach, comparing water consumption in a period right after the installation with a period right before, it is estimated that water consumption decreases by approximately 8% as a result of individual metering–a very large effect. According to our estimates, the price-elasticity of water consumption in Quito, ranges between -0.07 and -0.10, which suggests that installing individual meters has the same effect on water consumption as an increase in prices of over 100%.[5]

The findings in this paper have important implications. First, they provide a clear estimation of the size of the commons problem in the context of water consumption. While there is an ample literature exploring instances of commons problems, there are very few works that can precisely estimate the impact; in most instances, the nature of the problem precludes adequate record-keeping (see Ostrom (1990) for a discussion). Second, they provide a measure of the price elasticity of water consumption in a developing country. Demand is quite inelastic, which may preclude addressing any potential shortage through the price mechanism. This is even more relevant because, in contexts of scarcity, elasticity may be particularly low (Garrone et al., 2019). Third, they show the relevance of institutional solutions to the commons problem and provide a clear additional policy response to simply

---

[5] Our estimates of the effect of water meters are similar to internal estimates made by the Thames Water Company, the public utility provider in London, United Kingdom. In the case of London, the company indicates that the provision of "smart" meters plus the advice of experts and the identification of leaks made possible by the smart meters reduces average consumption by about 12% (`https://www.thameswater.co.uk/help/water-meters/getting-a-water-meter`). It is not clear, however, how the company computed those changes.

increasing prices. While price hikes could in theory be an effective mechanism to curve water consumption down, prices are very difficult to change in practice.[6] Fourth, we provide a simple model to illustrate water consumption choices in the context of multi-units bill sharing, building on Jack et al. (2018).

The rest of the document is organized as follows. Section 2 presents a conceptual framework that guides specification and interpretation of empirical models. Section 3 discusses the institutional framework and the data. In Section 4, we estimate the effect of individual meters' installation on water consumption. Section 5 estimates the price-demand elasticity of water consumption in the city of Quito. The last section concludes.

## 2 Conceptual Framework

In this section, we build a simple model to illustrate water consumption choices when the water bill is shared with other households in a building or a residential community. Our analysis is similar in spirit to Jack et al. (2018), who analyzed intra-household water consumption heterogeneity allowing the individual's water conservation behavior to diverge from the household optimal choice. In our application, however, we ignore intra-household behavior and treat the household as a unit that chooses how much water to consume when the water bill is shared with their neighbors under a communal meter. Due to well-known moral hazard issues, we expect buildings with communal meters to display higher water consumption than their counterparts with individual meters. In addition, we expect that apartments in buildings with communal meters will show a lower price elasticity of demand.

As in Jack et al. (2018), we model water use as a function of conservation effort conducted by each household $i$. Then, water use is given by $w_i = \bar{w}(1 - e_i)$, where $e_i$ is a measure of conservation effort that can take values between 0 and 1. $\bar{w}$ represents the maximum quantity of water that can be consumed in the case that $e_i = 0$.

There are $n$ housing units in a building, and the total cost of water is equally shared among households. Each household $i = 1, ..., n$ has an income $y_i$, and the total income of the building is given by $Y = \sum_{i=1}^{n} y_i$. The household's conservation effort $e_i$ features a convex cost $(c + h_i)e_i^2$ where $c$ is a constant for all households and $h_i$ is a realization of a random variable $h$ that takes values between $[0, 1]$. The household heterogeneity $h_i$ takes into account that

---

[6] Water tariffs are typically subsidized (and are even lower than their marginal costs) due to equity concerns and evidence that access to clean water brings large positive externalities (Galiani et al., 2005). Increasing water prices is widely unpopular and is usually resisted by the population across the world (Ungku, 2017; Robinson, 2019; Angst, 2021).

some households will find it more difficult to save water than others. The building's total water consumption is defined as $W = \sum_{i=1}^{n} w_i$, and $P$ is the price per unit of water charged by the utility company.

How is water demand determined when costs are shared among all households? When costs are shared, each household pays $\frac{PW}{n}$ and takes other households' water conservation effort as given. The maximization problem for household $i$ becomes

$$\max_{e_i} \quad y_i - \frac{PW}{n} - (c + h_i)e_i^2 \tag{1}$$

where $W = \bar{w}(1 - e_i) + \sum_{j \neq i} \bar{w}(1 - e_j)$. The first order condition that household $i$ solves is $e_i = \frac{P\bar{w}}{2n(c+h_i)}$, and optimal water consumption is equal to

$$w_i^* = \bar{w} - \frac{P\bar{w}^2}{2n(c + h_i)} \tag{2}$$

The corresponding price elasticity of demand is $\varepsilon_i^* = -\frac{P\bar{w}}{2n(c+h_i) - P\bar{w}}$.[7]

We are now interested in understanding how a household will behave when an individual water meter is installed. In this case, household $i$ solves the following optimization problem:

$$\max_{e} \quad y_i - Pw_i - (c + h_i)e_i^2 \tag{3}$$

The first order condition that it $i$ solves is $e_i^{**} = \frac{P\bar{w}}{2(c+h_i)}$, and optimal water consumption is given by

$$w_i^{**} = \bar{w} - \frac{P\bar{w}^2}{2(c + h_i)} \tag{4}$$

In this setting, the price elasticity of demand is defined by $\varepsilon_i^{**} = -\frac{P\bar{w}}{2(c+h_i) - P\bar{w}}$.

The above analysis lets us draw several observations. First, a simple comparison of equations 3 and 4 demonstrates that $w^* > w^{**}$. That is, as long as the water bill is shared among several units, households have incentives to overconsume water. Secondly, water consumption increases with $n$, the size of the apartment complex. Finally, our conceptual framework shows that the price elasticity of demand for households that share their water bill is smaller than their counterparts who have individual meters (the absolute value of $\varepsilon_i^{**}$ is greater than the one of $\varepsilon_i^*$ as long as $n \geq 2$). Apartments with individual meters will have

---

[7] To ensure that the price elasticity of demand is negative we assume that $2n(c + h_i) > P\bar{w}$.

a more elastic response towards changes in prices. In the following sections, we test some of the results coming from the analytical framework.

# 3 Institutional Context and Data

To study the sensitivity of water consumption to the installation of individual water meters, we partnered with Quito's (Ecuador) Water and Sanitation Public Company EPMAPS. EPMAPS provided the administrative data for this study. In this section, we review institutional details including EPMAPS' geographic coverage, its price schedule, and the operation of individual and communal water meters. We also discuss data sources and descriptive statistics.

## 3.1 Water Company

### Overview

EPMAPS is a public company that exclusively supplies drinking water and sewage services to the Metropolitan District of Quito (including urban core areas as well as suburbs and surrounding rural communities). Figure 2 shows EPMAPS' coverage. Shaded areas in the figure correspond to urban areas, while non-shaded areas show the surrounding rural communities. Water consumption in Quito is measured each month, and right after measurement, EPMAPS' workers leave an invoice at the customer's residence.[8] The invoice further includes information on clients' water consumption in the current month, as well as in the last six months.

### Price Schedule

EPMAPS uses a non-linear and differentiated price schedule for its residential clients. The price scheme used in December 2016 includes a fixed connection fee of \$2.10 and a variable fee that depends on water consumption. If water consumption per month is up to 11 $m^3$, each cubic meter has a price of \$0.31. For consumption levels between $12m^3$ and $18m^3$, EPMAPS charges \$3.41 (11 X \$0.31 = \$3.41) for the first 11 $m^3$ and \$0.43 for each additional cubic meter. When monthly consumption exceeds $18m^3$, EPMAPS charges \$6.42 (11 X \$0.31 + 7 X \$0.43 = \$6.42) for the first 18 $m^3$ and \$0.72 for each additional cubic meter. All clients that have a sewage connection also pay a 38.6% sewage fee. Figure 3 shows the price schedule.

---

[8] In addition, EPMAPS sends the bill by email, and clients can check their account and pay online.

As can be observed, there are kinks in the pricing schedule that make each $m^3$ consumed after each cutoff more expensive.

The price schedule also depends on clients' income. Using information from the Municipal Land Registry, EPMAPS has categorized its clients into 9 economic tiers. The highest economic tiers, 1-4 (upper and upper-middle tiers), do not receive any subsidy. Conversely, clients who belong to lower tiers (5-9) may receive a subsidy of up to 22%. The subsidy reduces the final tariff of water and sewage by 5% to the clients that belong to economic tier 5, 10% reduction to economic tiers 6 and 7, and 22% to tiers 8 and 9. This subsidy is applied only if water consumption is less than or equal to 20 $m^3$. In other words, clients that belong to economic tiers 5-9 that consume more than 20 $m^3$ do not receive any subsidy (the normal price scheme is applied). EPMAPS additionally provides a subsidy to all households in rural areas (see Figure 2). Rural residents of all economic tiers pay \$0.155 for each cubic meter for the first 30 $m^3$ and \$0.43 for each additional cubic meter.

EPMAPS' price scheme was gradually modified between June 2015 and June 2016. Table 6 shows details of these changes. It is important to highlight that: a) there have been no changes in the subsidy schedule (for low-income clients and/or clients in rural areas) or the fixed connection fee; b) all prices experienced no changes between May 2008 and June 2015; and c) tariff changes were not announced to customers. Clients did not know about the price changes until they were implemented and received the invoice.

Lastly, people over the age of 65 also receive a discount. This discount corresponds to 50% of the final bill if water consumption is less than 20 $m^3$. However, the discount is not automatically applied when they turn 65. Clients are required to visit EPMAPS' offices and submit an application and documentation to receive this subsidy.

### Individual and Communal Meters

Many gated communities, buildings and condominium associations in Quito feature *communal* water meters which measure total water consumption of a group of households. EPMAPS refers to those communal accounts as "principal" accounts. The members of a principal account may request EPMAPS to install individual meters called "supplementary" accounts.

The account holder of the principal account can visit EPMAPS offices to request the installation of individual meters. A formal application must be submitted. Individual meters can be provided to units that hold individual property titles. After the request is completed, EPMAPS conducts a preliminary inspection and prepares a feasibility report. Sometimes, there are engineering constraints that prevent the installation of individual meters and the application is denied. Once the installation request is approved, each supplementary account's holder should pay the meter's cost (approximately \$60). The average waiting time is 30 days, but it does not exceed 60 days.

Homeowners with a communal water meter have a clear incentive to install independent meters. As previously discussed, supplemental meters may help clients to keep track and measure their own water consumption. Moreover, a supplemental meter may also reduce marginal prices given that an individual unit level consumption might belong to a lower price tier than the communal account given EPMAPS' non-linear price schedule (See Figure 3).

## 3.2 Data

The empirical analysis uses administrative data from EPMAPS. For the universe of its clients, the data contain information about i) monthly water consumption, ii) geographic location of all clients, iii) basic demographic characteristics of customers, and iv) a list of all "principal" accounts before and after the installation of the "supplementary" individual water meters. Descriptive statistics are provided in Table 6 below.

For our main analysis, we focus on all the monthly invoices sent to EPMAPS' clients between January 2014 and December 2016.[9] After removing a few observations with inconsistencies and observations with water consumption levels above the 99.9th percentile, our data set includes almost 7 million observations per year.[10]

Table 6 shows descriptive statistics during 2016. In December 2016, the data set included 587,138 observations (individual water accounts). The clients in this data set consume 25.2 cubic meters per month on average, with an average bill of \$20. Note that more than 5 percent of the sample features no water consumption. These are not measurement errors, but cases where EPMAPS has found out that there is no water consumption after an inspection. Most of the sample (92%) are residential clients who use much less water than corporate clients (public and private firms). Consumption patterns in 2016 are representative of those in previous years.[11] Hereafter, we focus on the sample of residential customers.

With the help of EPMAPS, we have identified 80 "principal" accounts that (a) have installed supplementary accounts between January 2014 to December 2016, and (b) have reported positive water consumption at the beginning of this period. Condition (b) allows

---

[9] In June 2017, EPMAPS had almost 590 thousand active clients.

[10] Less than 0.1% of the observations had negative values and were removed from the sample.

[11] To avoid cluttering, these descriptive statistics are not reported in this document and are available upon request.

us to exclude principal accounts of *new* buildings, where the installation of supplementary accounts is requested after the construction process ended.[12]

# 4 Effect of Installation of Individual Meters Installation on Water Consumption

In this section, we evaluate the effect of the installation of individual water meters in residential complex and/or buildings. The identification strategy is straightforward. We compare water consumption of *all* households within the residential complex/buildings immediately before and after the installation of supplementary meters. This identification strategy allows us to attribute any discontinuity in water consumption at the time the supplementary meters were installed as the causal effect of this intervention. As a robustness test, we also employ an alternative identification strategy based on a difference-in-differences (DD) specification.

## 4.1 Regression Discontinuity

Formally, we use a regression discontinuity design to estimate the change in water consumption right after the installation of the individual meters (for more information about regression discontinuity model, see Lee and Lemieux (2009)). The dependent variable is total water consumption $q_{it}$ from *principal* account $i$ in month $t$. The explanatory variables include month fixed effects $\lambda_t$ to capture seasonal factors and common trends in water consumption, building fixed effects $\rho_i$ to account for idiosyncratic conditions of each residential complex/building, and a binary variable $T$ that takes the value of one during all the post-treatment period (after the supplementary meters' installation). The model takes the following form:

$$q_{it} = \beta T_{it} + g(t_i) + \rho_i + \lambda_t + \epsilon_{it}, \tag{5}$$

where $t_i$ is the number of periods (months) since the supplementary meters' installation in principal account $i$, $g(.)$ is a function that will be estimated with a high degree of flexibility, and $\epsilon_{it}$ is a random unobservable component that is independent from the other variables. The coefficient of interest is $\beta$, which measures the discontinuity in water consumption at the time of installation of supplementary meters. This coefficient could be interpreted as the causal effect of the intervention.

---

[12] In these cases, water consumption always (and mechanically) increases from the moment that the dwellings are occupied.

The results of a simplified version of equation 5 (a version that omits the fixed effects) can be presented graphically to display the results of the regression discontinuity in a simple and intuitive way. Figure 4 includes the average consumption as a function of the number of months since the installation to the supplemental meters. The thick line is a polynomial that has been flexibly and independently specified at each side of the threshold (the installation date). We would like to evaluate if there is a discontinuity in this relationship precisely at the time of the installation (vertical line). The empirical evidence is clear and suggests that, right after treatment, average consumption of water significantly declines.

To refine the graphical analysis, $\beta$ has been estimated using different versions of equation 5. Table 3 presents the results for the simplest specification when $g(.)$ is excluded. In this case, the parameter $\beta$ measures the change in average water consumption just after the intervention. The coefficient estimated in the first column uses observations from 12 months before the supplemental meters' installation and twelve months after. The value of the coefficient is statistically significant and suggests that water consumption has decreased on average by 19.4 $m^3$ (approximately 8%) as a result of the intervention. This value does not significantly change when temporal fixed effects are included (second column), nor when the number of observations is reduced to take into account the period six months before or six months after the intervention (third and fourth column).

Furthermore, Table 4 shows the results of the estimation of $\beta$ and its standard deviation using seven different possible specifications for the function $g$ and six different samples.[13] The specifications (in each column) vary from a linear model to a cubic model with independent parameters in each side of the threshold. Moreover, each model has been estimated with different samples, with observations for 24, 18, 12, 9, 6 and 3 months before and after the intervention. All models include fixed effects for each combination of month and year, and fixed effects for each client. The results in Table 4 confirm the patterns shown in Table 3 and in the graphical analysis. Even though the estimated value of $\beta$ varies for each specification, the values are most of the time negative and statistically significant. If we focus on the coefficient in the first row (which measures the difference between the average water consumption before and after the intervention), this coefficient is extremely robust and statistically significant even when the sample is reduced to only three months before and after treatment.[14]

To sum up, there is robust empirical evidence that water consumption *declines* sharply

---

[13] The sensitivity analysis presented in Table 4 follows the recommendations in Lee and Lemieux (2009).

[14] It is important to note that, given the small number of observations, non-linear models are not necessary informative when the bandwidth is small.

as a consequence of the installation of supplementary meters. The simplest (and intuitive) model presented in Table 4 suggests that installation of individual meters reduces water consumption by approximately 8%. Note that our identification strategy (regression discontinuity) estimates the effect of the intervention in the short run. In other words, it measures the immediate effect of the program on water consumption.

## 4.2 Difference-in-Differences

We also explore the effect of the installation of individual meters on water consumption using a difference-in-differences approach. To create a valid control group, we follow Montalvo (2011) and Smith (2015), who use synthetic controls to compute the comparison group. This approach is a straightforward extension of Abadie (2010).[15]

As in Montalvo (2011), we create a synthetic control for each of the 80 units that received a new water meter. The pool of accounts in the control (363,603 untreated EPMAPS' accounts) is used to compute optimal weights and the synthetic control for each treated unit. The evolution of water consumption of the 80 synthetic controls is then compared to water consumption of the treated units before and after the meter installation. Figure 5 shows the *average* water consumption for the treatment group (80 synthetic accounts) and control group (80 treated accounts) before and after the installation. Given the large number of the donor pool, it is not surprising that the synthetic control and the treatment group display almost identical trends during the pre-treatment period. Trends sharply diverge after the installation of the meter, significantly decreasing for the treatment group.

After creating the synthetic control for each of the 80 units in our treated sample, we use a conventional difference-in-differences setup to measure how the difference in average water consumption between the treated and the control group changes after the water meter installation. The first and second column of Table 5 present the results. The coefficients on the interaction term (-21.6) are remarkably close to the estimate from the regression discontinuity model in the previous subsection. They suggest that monthly water reduction decreased by about 21.6 cubic meters per month (about 8%) relative to the control group after the installation of the water meters.[16]

---

[15] Abadie (2010) creates synthetic control groups by selecting a vector of weights to minimize the distance between the pre-intervention characteristics of the treated unit and the characteristics of a "donor pool" of observations that were not treated. The weights are applied to non-treated units to create a "synthetic control."

[16] Note that the "synthetic observations" have been estimated in a first stage and that our conventional standard errors do not account for this additional source of randomness. Statistical inference is subject to this caveat.

For 37 of the 80 treated accounts we have detailed information about the account holders' demographic characteristics such as gender, age, and educational attainment. For robustness, we repeated the process of creating synthetic controls for each of these 37 accounts using a "donor pool" of 351,108 accounts (this donor pool is smaller than the one used for the first process that included 80 accounts, since we only kept the accounts with the characteristics listed above). The last two columns of Table 5 reproduced model 1 and 2, but only for this subset of 37 accounts. The effect is somewhat larger, suggesting again that the installation of water meters leads to a reduction in water consumption.

### 4.3 Discussion

Our preferred estimates suggest that the installation of water meters led to a decrease in water consumption of about 8%. What is the external validity of these findings? Note again that account holders self-selected into treatment as they had to apply for the installation of a water meter. Hence, our results apply to similar settings where households that have common water meters *voluntarily* choose to get (and pay for the installation of) individual water meter units. The results are relevant because they show that, even if we assume that those individuals who obtained individual metering were self-motivated to reduce consumption, they still needed the appropriate institutional framework to make it possible. Assessing the potential effects of a *mandatory* individual water meter installation program is an important topic for future research.

## 5 Economic Significance: Water Price Elasticity

Results in Section 4 suggest that the provision of individual water meters can decrease water consumption by about 8% in the short run. To evaluate the magnitude and economic significance of this finding, in this section we estimate the price elasticity of demand for water.

As was previously discussed, EPMAPS' price schedule gradually changed in Quito's urban areas between June 2015 and June 2016.[17] We exploit these changes to identify the sensitivity of water demand to prices.

Following the literature (Ito, 2014), we separately estimate the effect of changes in *marginal* and *average* prices on water consumption. Define $T_t(q_t)$ as the total bill that

---

[17] For details, see Section 3 and Table 1.

a client has to pay in period $t$ (month) and note that, due to the non-linear pricing schedule, $T_t(q_t)$ depends on the level of water consumption $q_t$. The total tariff includes the fixed connection fee (\$2.10) and the sewage fee (38.6%)[18]. In a similar way, we define $MP_t(q_t)$ as the marginal price and $AP_t(q_t) = T_t(q_t)/q_t$ as the average price. Because we observe the level of consumption $q_t$, the variables $MP_t(q_t)$ and $AP_t(q_t)$ can be easily calculated using the price schedule described in Table 1.[19] For each period $t$, we can estimate the annual increase (in percentage terms) of: i) water demand $\Delta q_t = \log(q_t+1) - \log(q_{t-12}+1)$, ii) average price $\Delta AP_t(q_t) = \log(AP_t(q_t)) - \log(AP_{t-12}(q_{t-12}))$ and iii) marginal price $\Delta MP_t(q_t) = \log(MP_t(q_t)) - \log(MP_{t-12}(q_{t-12}))$.[20] In order to estimate how individuals adjust their water consumption when prices changes, we estimate the following econometric models:

$$\Delta q_{it} = \alpha \Delta AP_{it} + \lambda_t + \mu_{it}, \tag{6}$$

and

$$\Delta q_{it} = \beta \Delta MP_{it} + \lambda_t + \epsilon_{it}, \tag{7}$$

where $\lambda_t$ represents fixed effects for each period. The coefficients $\alpha$ and $\beta$ measure water price elasticity. It is important to note that water consumption in period $t$ is billed the following month $(t + 1)$. For this reason, some empirical models will feature lagged independent variables.

Estimation of equations 6 and 7 is not straightforward due to endogeneity problems. In particular, since EPMAPS' price scheme is non-linear, both the marginal price and average price also depend on the level of consumption $q$. Consequently, variables $AP$ and $MP$ are correlated with the error term, and the basic OLS estimation will produce biased and inconsistent estimators. To solve this problem, the literature suggests using instrumental variable techniques (Ito, 2014; Saez et al., 2012). In our application, we use the following instruments for marginal price:

$$\Delta MP^I_{it} = \log(MP_{it}(\widehat{q}_{it}) - \log(MP_{it-12}(\widehat{q}_{it})),$$

and for average price:

$$\Delta AP^I_{it} = \log(AP_{it}(\widehat{q}_{it}) - \log(AP_{it-12}(\widehat{q}_{it})),$$

---

[18] The sewage fee is included only if the client uses this service

[19] Both marginal and average prices have been deflated by Quito's consumer price index.

[20] Since 5% of the observations report zero consumption, we add one unit to the variable $q$ before applying the logarithm in order to keep these observations in the estimation.

where $\widehat{q}$ is a predetermined consumption level. These types of instruments isolate the variation of prices created by the changes in the price scheme, and they have been used in public finance applications (Blomquist and Selin, 2009; Saez et al., 2012) and for estimation of the price elasticity of demand for electricity (Ito, 2014).

To compute these instruments, we first need to identify a predetermined consumption value $\widehat{q}_{it}$. Water consumption at the beginning of the period $\widehat{q}_{it-12}$ appears as an obvious alternative for a predetermined water consumption level $\widehat{q}_{it}$. However, this option is not ideal, because it may create a negative correlation with the error term, as water consumption is seasonal and generally fluctuates around its yearly average (mean reversion). To address this concern, Blomquist and Selin (2009) and Saez et al. (2012) suggest to use the consumption at the midpoint between $t$ and $t-12$ instead. [21] Given our monthly data, the midpoint $t_m = t-6$ and $\widehat{q}_{it} = \widehat{q}_{it_m}$.

Armed with valid instruments, we proceed to estimate equations 6 and 7 using instrumental variables and two-stage least squares (2SLS). The sample includes a balanced panel with a little over 400,000 residential customers in years 2014 to 2016.[22] Both marginal and average prices were deflated with Quito's consumer price index. In all models, standard errors are calculated using clusters for each customer.

Table 6 presents estimation results. The first and second column present estimates of equation 7. The coefficient in the first column ($\widehat{\beta}$ = -0.03) shows that water consumption hardly reacts with changes in marginal prices. In the second column, we control for temporal effects by adding a set of 23 month-year fixed effects. Once temporal trends are accounted for, the sign of $\widehat{\beta}$ changes, but its value is still small in magnitude and close to zero. This result is not surprising, and it is consistent with previous research that has found that consumers do not react to changes in *marginal* prices (Ito, 2014). In the third and fourth columns, we estimate the link between water consumption and *average* prices (equation 6) and find substantial larger elasticities. The estimated coefficient in the fourth column where temporal fixed effects are accounted for suggests that the price elasticity is -0.07.[23]

As mentioned before, water consumption in period $t$ is measured and billed as period $t+1$ starts. Therefore, it is possible that current water consumption depends on prices in past months (see Bastos et al. (2015) for a discussion of how individuals react to pricing and

---

[21] Ito (2014)and Blomquist and Selin (2009) discuss the validity of this instrument.

[22] As pointed out before, EPMAPS' price scheme was gradually modified in the years 2015 and 2016. Since we need to calculate annual changes in water consumption, we use a sample that includes observations for the years 2014 to 2016.

[23] Both $\widehat{\alpha}$ and $\widehat{\beta}$ are statistically significant at any conventional level.

billing). In the last four columns of Table 6 we estimate models where water consumption in a current month depends on prices in the previous period. Results in columns 5 and 6 confirm that water consumption in Quito does not react to changes in marginal prices. On the other hand, coefficients in the last column suggest that water price elasticity may be close to -0.1 ($\widehat{\alpha}$ = -0.107). In sum, a general increase in prices of 10% reduces water consumption by about 1%.

# 6 Conclusions

This paper empirically demonstrates that installing individual meters can significantly reduce water consumption in neighborhoods and buildings that have communal meters. Using a regression discontinuity approach, we estimate that the installation of individual meters reduces water consumption by approximately 8%. This is probably a lower limit of the true effect, since marginal prices of water increase with consumption. When individual meters are installed, households also face lower marginal prices fueling consumption up. Despite this offsetting effect, we find that individual metering curbs down water consumption in Quito, Ecuador. This result is robust, statistically significant, and consistent with predictions from economic theory: when the cost of a good is shared within a group, there are incentives to consume more than the optimal level.

To evaluate the economic relevance and scale of this effect, we have estimated water price elasticity. Results allow us to conclude that drinking water in Quito is a highly inelastic good (elasticity ranges between -0.07 and -0.10.) Therefore, installing individual meters has a similar effect on consumption as increasing water prices by about 100%.

Our results align with the long standing literature on the “tragedy of the commons” and have clear policy implications. In order to encourage water conservation, water utility companies should promote individual meter installation in both new and existing developments. Moreover, the existence of individual metering would make consumption more responsive to changes in prices and any other type of regulations that could be enacted to curb consumption.

# References

Abadie, Diamond, H. (2010). Synthetic control methods for comparative case studies: Estimating the effect of california's tobacco control program. *Journal of the American Statistical Association*, 105(490):493–505.

Agency, U. E. (2018). The state of the environment: water resources. Technical report, UK.

Angst, M. (2021). 'This is outrageous': Residents protest big rate increases from San Jose Water. *The Mercury News*. Accessed on 1 October 2021. Available at https://www.mercurynews.com/2021/02/13/this-is-outrageous-residents-protest-big-rate-increases-from-san-jose-water-company/.

Bastos, P., Castro, L., Cristia, J., and Scartascini, C. (2015). Does energy consumption respond to price shocks? evidence from a regression-discontinuity design. *The Journal of Industrial Economics*, 63(2):249–278.

Blomquist, S. and Selin, H. (2009). Hourly Wage Rate and Taxable Labor Income Responsiveness to Changes in Marginal Tax Rates. CESifo Working Paper Series 2644, CESifo Group Munich.

Copeland, B. and Taylor, S. (2009). Trade, tragedy, and the commons. *American Economic Review*, 99(3):725–749.

Corral-Verdugo, V., Armenta, M., Pérez-Urias, F., Orduña-Cabrera, V., and Espinoza Gallego, N. (2002). Residential water consumption, motivation for conserving water and the continuing tragedy of the commons. 30:527–35.

Galiani, S., Gertler, P., and Schargrodsky, E. (2005). Water for life: The impact of the privatization of water services on child mortality. *Journal of Political Economy*, 113(1):83–120.

Garrone, P., Grilli, L., and Marzano, R. (2019). Price elasticity of water demand considering scarcity and attitudes. *Utilities Policy*, 59.

Hardin, G. (1968). The tragedy of the commons. *American Association for the Advancement of Science.*

Hardin, G. (1998). Extensions of the "tragedy of the commons". *Science*, 280(5364):682–683.

Ito, K. (2014). Do consumers respond to marginal or average price? evidence from nonlinear electricity pricing. *American Economic Review*, 104(2):537–63.

Jack, K., Jayachandran, S., and Rao, S. (2018). Environmental externalities and free-riding in the household. Working Paper 24192, National Bureau of Economic Research.

Kearney, M. S., Harris, B. H., Hershbein, B., Jácome, E., and Nantz, G. (2014). In times of drought: Nine economic facts about water in the united states. Technical report.

Lee, D. S. and Lemieux, T. (2009). Regression Discontinuity Designs in Economics. NBER Working Papers 14723, National Bureau of Economic Research, Inc.

Montalvo (2011). Voting after the bombings: a natural experiment on the effect of terrorist attacks on democratic elections. *The Review of Economics and Statistics*, pages 1146–1154.

Ohler, A. M. and Billger, S. M. (2014). Does environmental concern change the tragedy of the commons? Factors affecting energy saving behaviors and electricity usage. *Ecological Economics*, 107(C):1–12.

Ostrom, E. (1990). *Governing the Commons.* Cambridge University Press, Cambridge, UK.

Robinson, L. (2019). Residents gather to protest water rate hike in Baltimore. *WBALtv.* Accessed on 1 October 2021. Available at https://www.wbaltv.com/article/protest-water-rate-hike-in-baltimore/28250248.

Saez, E., Slemrod, J., and Giertz, S. (2012). The elasticity of taxable income with respect to marginal tax rates: A critical review. *Journal of Economic Literature*, 50(1):3–50.

Smith (2015). The resource curse exorcised: Evidence from a panel of countries. *Journal of Development Economics*, 116:57–73.

Stavins, R. N. (2011). The problem of the commons: Still unsettled after 100 years. *American Economic Review*, 101(1):81–108.

Ungku, F. (2017). Water price hike sparks rare public protest in singapore. *Reuters.com.* Accessed on 1 October 2021. Available at https://www.reuters.com/article/us-singapore-protest/water-price-hike-sparks-rare-public-protest-in-singapore-idUSKBN16I0H8.

Unicef (2017). *Thirsting for a Future. Water and children in a changing climate.* United Nations Children's Fund, New York, NY.

WRI (2019). Aqueduct 3.0: Updated decision-relevant global water risk indicators. Technical report, Washington, DC.

Table 1:
EPMAPS' Pricing Schedule (UDS per cubic meter): Urban Areas 2008 - 2016

| Period | Fixed Connection Fee ($) | 0 - 20 $m^3$ ($/$m^3$) | 21 - 25 $m^3$ ($/$m^3$) | >25 $m^3$ ($/$m^3$) |
|---|---|---|---|---|
| May/2008 - Jun/2015 | 2.10 | 0.31 | 0.43 | 0.72 |

| Period | Fixed Connection Fee ($) | 0 - 11 $m^3$ ($/$m^3$) | 12 - 18 $m^3$ ($ /$m^3$) | 19 - 20 $m^3$ ($/$m^3$) | 20 - 25 $m^3$ ($/$m^3$) | >25 $m^3$ ($/$m^3$) |
|---|---|---|---|---|---|---|
| Jul/2015 | 2.10 | 0.31 | 0.32 | 0.344 | 0.454 | 0.72 |
| Aug/2015 | 2.10 | 0.31 | 0.33 | 0.378 | 0.478 | 0.72 |
| Sep/2015 | 2.10 | 0.31 | 0.34 | 0.413 | 0.503 | 0.72 |
| Oct/2015 | 2.10 | 0.31 | 0.35 | 0.447 | 0.527 | 0.72 |
| Nov/2015 | 2.10 | 0.31 | 0.36 | 0.481 | 0.551 | 0.72 |
| Dec/2015 | 2.10 | 0.31 | 0.37 | 0.515 | 0.575 | 0.72 |
| Jan/2016 | 2.10 | 0.31 | 0.38 | 0.549 | 0.599 | 0.72 |
| Feb/2016 | 2.10 | 0.31 | 0.39 | 0.583 | 0.623 | 0.72 |
| Mar/2016 | 2.10 | 0.31 | 0.4 | 0.618 | 0.648 | 0.72 |
| Apr/2016 | 2.10 | 0.31 | 0.41 | 0.652 | 0.672 | 0.72 |
| May/2016 | 2.10 | 0.31 | 0.42 | 0.686 | 0.696 | 0.72 |
| Jun/2016 | 2.10 | 0.31 | 0.43 | 0.72 | 0.72 | 0.72 |

| Period | Fixed Connection Fee ($) | 0 - 11 $m^3$ ($/$m^3$) | 12 - 18 $m^3$ ($ /$m^3$) | >18 $m^3$ ($/$m^3$) |
|---|---|---|---|---|
| As of Jul/2016 | 2.10 | 0.31 | 0.43 | 0.72 |

*Note:* This table shows EPMAPS' price schedule. Clients with sewage service are charged an additional 38.6%. Prices correspond to marginal water prices (USD by cubic meter.)

Table 2:
Monthly Water Consumption in Quito: January - December 2016

| | All Clients | | Residential Clients | | Commerce / Industry | | Public | |
|---|---|---|---|---|---|---|---|---|
| | Consumption ($m^3$) | Bill ($) | Consumption ($m^3$) | Bill ($) | Consumption ($m^3$) | Bill ($) | Consumption ($m^3$) | Bill ($) |
| Percentile ($m^3$) | | | | | | | | |
| 5th | 0.0 | 2.5 | 0.0 | 2.5 | 0.0 | 2.2 | 0.0 | 2.2 |
| 10th | 2.0 | 3.3 | 2.0 | 3.3 | 1.0 | 3.2 | 1.0 | 3.0 |
| 25th | 8.0 | 5.5 | 8.0 | 5.5 | 4.0 | 7.7 | 9.0 | 8.5 |
| 50th | 16.0 | 9.6 | 16.0 | 9.2 | 16.0 | 20.1 | 38.0 | 34.0 |
| 75th | 27.0 | 20.6 | 27.0 | 19.1 | 42.0 | 45.2 | 173.0 | 172.1 |
| 90th | 46.0 | 39.1 | 43.0 | 35.1 | 96.0 | 99.9 | 449.0 | 458.7 |
| 95th | 67.0 | 59.2 | 59.0 | 50.5 | 171.0 | 173.5 | 649.0 | 680.0 |
| Average ($m^3$) | 25.2 | 20.0 | 22.9 | 16.9 | 43.1 | 46.6 | 139.0 | 144.2 |
| Standard Deviation ($m^3$) | 50.0 | 44.8 | 39.9 | 29.8 | 90.9 | 94.1 | 213.9 | 236.5 |
| # Clients in December | 587,138 | 587,138 | 536,281 | 536,281 | 46,862 | 46,862 | 3,686 | 3,686 |
| # Bills in 2016 | 6,959,538 | 6,959,538 | 6,393,969 | 6,393,969 | 516,830 | 516,830 | 45,213 | 45,213 |

*Note:* This table shows water consumption descriptive statistics. Observations above the 99.9th percentile have been excluded.

Table 3:
Effect of the Installation of Individual Meters on Water Consumption

Dependent Variable: Monthly Water Consumption ($q_t$)

| | Bandwidth: 12 months | | Bandwidth: 6 months | |
|---|---|---|---|---|
| Explanatory variables | [1] | [2] | [3] | [4] |
| Treatment: 1 month after installation | -19.466*** | -19.369*** | -21.094** | -17.443* |
| | (6.923) | (6.871) | (8.578) | (9.392) |
| Clients Fixed Effects | Yes | Yes | Yes | Yes |
| Months Fixed Effects | No | Yes | No | Yes |
| # Observations | 1,870 | 1,870 | 955 | 955 |
| Average dependent variable value before treatment | 240.1 | 240.1 | 245.0 | 245.0 |

*Note:* This table estimates the change in total water consumption in buildings and residential neighborhoods after the installation of individual meters in Quito, Ecuador. This sample includes residential clients with "principal" accounts in urban areas. The model has been estimated using Ordinary Least Squares (OLS). Statistically significant coefficients at 1%, 5% and 10% levels have been marked with ***, ** and *, respectively.

Table 4:
Effect of Installation of Individual Meters on Water Consumption, Robustness Checks

Sensitivity Analysis

| | Bandwidth: Number of months before and after treatment | | | | | |
|---|---|---|---|---|---|---|
| Model | 24 | 18 | 12 | 9 | 6 | 3 |
| None | -5.11 | -14.99*** | -19.37*** | -20.49*** | -17.44* | -25.35** |
| | (5.03) | (5.68) | (6.87) | (7.92) | (9.39) | (12.48) |
| Linear | -33.98*** | -25.54** | -19.41 | -12.87 | -11.75 | -35.28 |
| | (9.80) | (10.74) | (13.21) | (15.94) | (17.08) | (22.70) |
| Quadratic | -34.38*** | -25.16** | -18.55 | -12.61 | -11.73 | -35.32 |
| | (9.84) | (10.80) | (13.25) | (15.94) | (17.10) | (22.73) |
| Cubic | -20.48 | -19.14 | -13.52 | -16.41 | -42.74* | 5.73 |
| | (12.60) | (14.31) | (17.86) | (19.73) | (22.40) | (35.13) |
| Linear x Treatment | -34.01*** | -25.59** | -20.76 | -14.04 | -12.96 | -30.15 |
| | (9.81) | (10.73) | (13.11) | (15.94) | (16.86) | (21.70) |
| Quadratic x Treatment | -18.15 | -20.69 | -13.36 | -20.45 | -42.58* | 37.30 |
| | (14.06) | (16.19) | (19.92) | (22.36) | (25.44) | (55.74) |
| Cubic x Treatment | -25.39 | -18.86 | -24.84 | -31.48 | 32.36 | 13.76 |
| | (19.46) | (22.28) | (26.60) | (32.80) | (45.93) | (45.23) |
| Number of observations | -3,502 | 2,709 | 1,870 | 1,420 | 955 | 478 |

*Note:* Each cell shows the effect of the installation of individual meters on water consumption, for each combination of model (rows) and sample (columns). The dependent variable is water consumption. All models include customers' fixed effects as well as months' fixed effects. Statistically significant coefficients at 1%, 5% and 10% levels have been marked with ***, ** and *, respectively.

Table 5:
Effect of Installation of Individual Meters on Water Consumption: Difference-in-Differences

Dependent Variable: Monthly Water Consumption ($q_t$)

| | 80 accounts | | 37 accounts | |
|---|---|---|---|---|
| Explanatory variables | [1] | [2] | [3] | [4] |
| Treated x Post | -21.624*** | -21.624*** | -33.593*** | -33.593*** |
| | (7.756) | (7.767) | (10.795) | (10.832) |
| Treated group (1=treated, 0=control) | -11.933** | -11.933** | 1.128 | 1.128 |
| | (4.703) | (4.705) | (6.724) | (6.752) |
| Post (1=After installation, 0=before installation) | 1.644 | 8.783 | -11.689** | -20.138 |
| | (3.180) | (13.752) | (5.559) | (20.553) |
| Clients Fixed Effects | Yes | Yes | Yes | Yes |
| Months Fixed Effects | No | Yes | No | Yes |
| # Observations | 3,740 | 3,740 | 1,766 | 1,766 |

*Note:* This table estimates the change in total water consumption in buildings and residential complexes after the installation of individual meters in Quito, Ecuador. The sample includes residential clients with "principal" accounts in urban areas. The model has been estimated using a Difference-in-Differences Approach. The statistically significant coefficients at 1%, 5% and 10% have been marked with ***, **,* respectively.

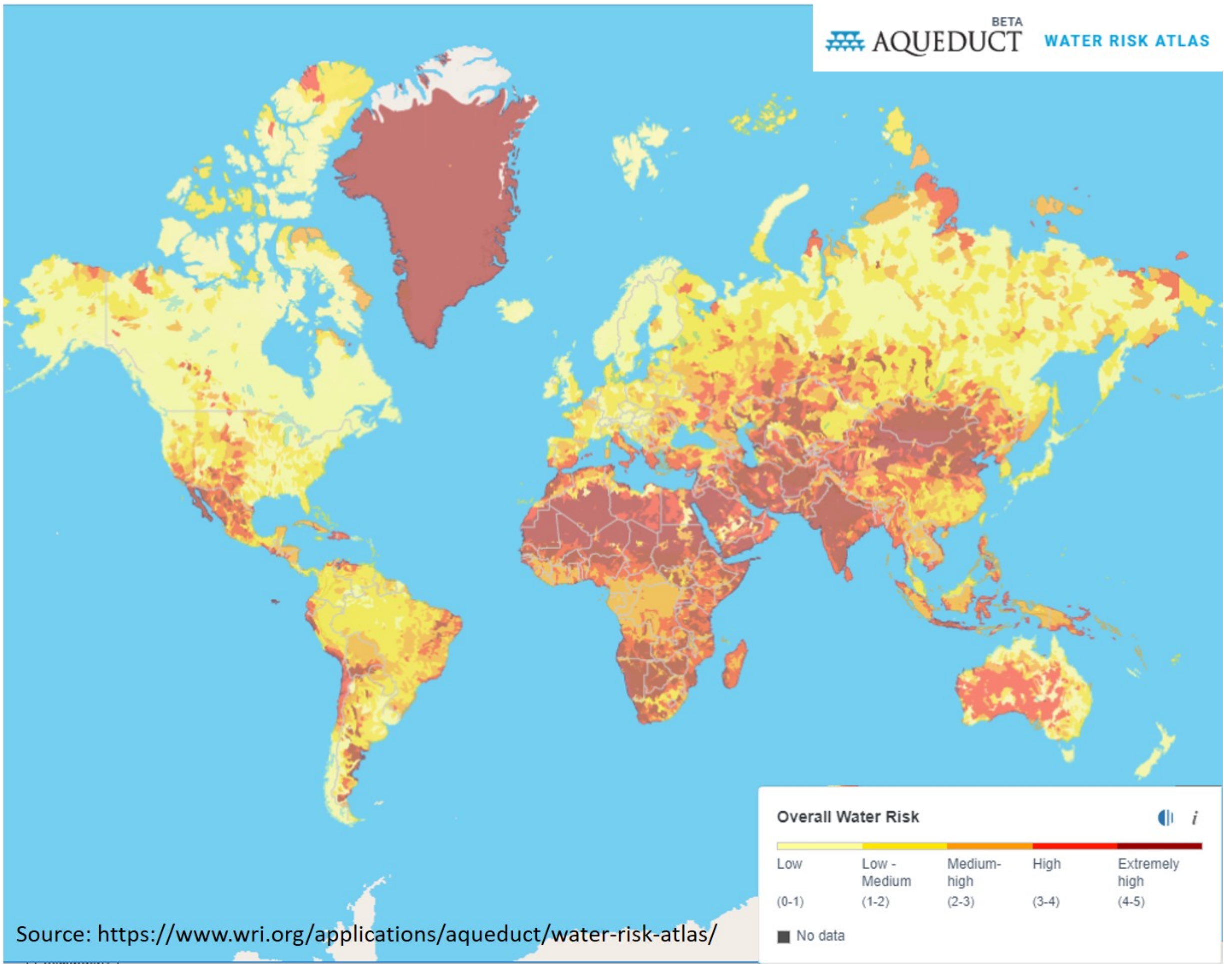
## Table 6:
## Water Price Elasticity of Demand (Quito 2015-2016)

Dependent Variable: $\Delta\ q_t = \log(q_t)$ - $\log(q_{t-12})$

| Explanatory variables | [1] | [2] | [3] | [4] | [5] | [6] | [7] | [8] |
|---|---|---|---|---|---|---|---|---|
| $\Delta\ MP_t = \log(MP_t)$ - $\log(MP_{t-12})$ | -0.033*** | 0.033*** | | | | | | |
| | (0.004) | (0.005) | | | | | | |
| $\Delta\ AP_t = \log(AP_t)$ - $\log(AP_{t-12})$ | | | -0.152*** | -0.073*** | | | | |
| | | | (0.005) | (0.009) | | | | |
| $\Delta\ MP_{t-1}$ | | | | | -0.029*** | 0.033*** | | |
| | | | | | (0.004) | (0.005) | | |
| $\Delta\ AP_{t-1}$ | | | | | | | -0.182*** | -0.107*** |
| | | | | | | | (0.007) | (0.012) |
| Year-Month Fixed Effects | No | Yes | No | Yes | No | Yes | No | Yes |
| # of Observations | 9,770,184 | 9,770,184 | 9,770,184 | 9,770,184 | 9,363,093 | 9,363,093 | 9,363,093 | 9,363,093 |

*Note:* This table estimates the price elasticity of demand for water in Quito, Ecuador. The sample includes a balanced panel with 407,091 residential clients in urban areas. The model has been estimated using the Two-Stage Least Squares method. The instruments used have been discussed in the text. The standard errors (in parenthesis) have been estimated using clusters at the client level. Statistically significant coefficients at 1%, 5% and 10% levels have been marked with ***, ** and *, respectively.

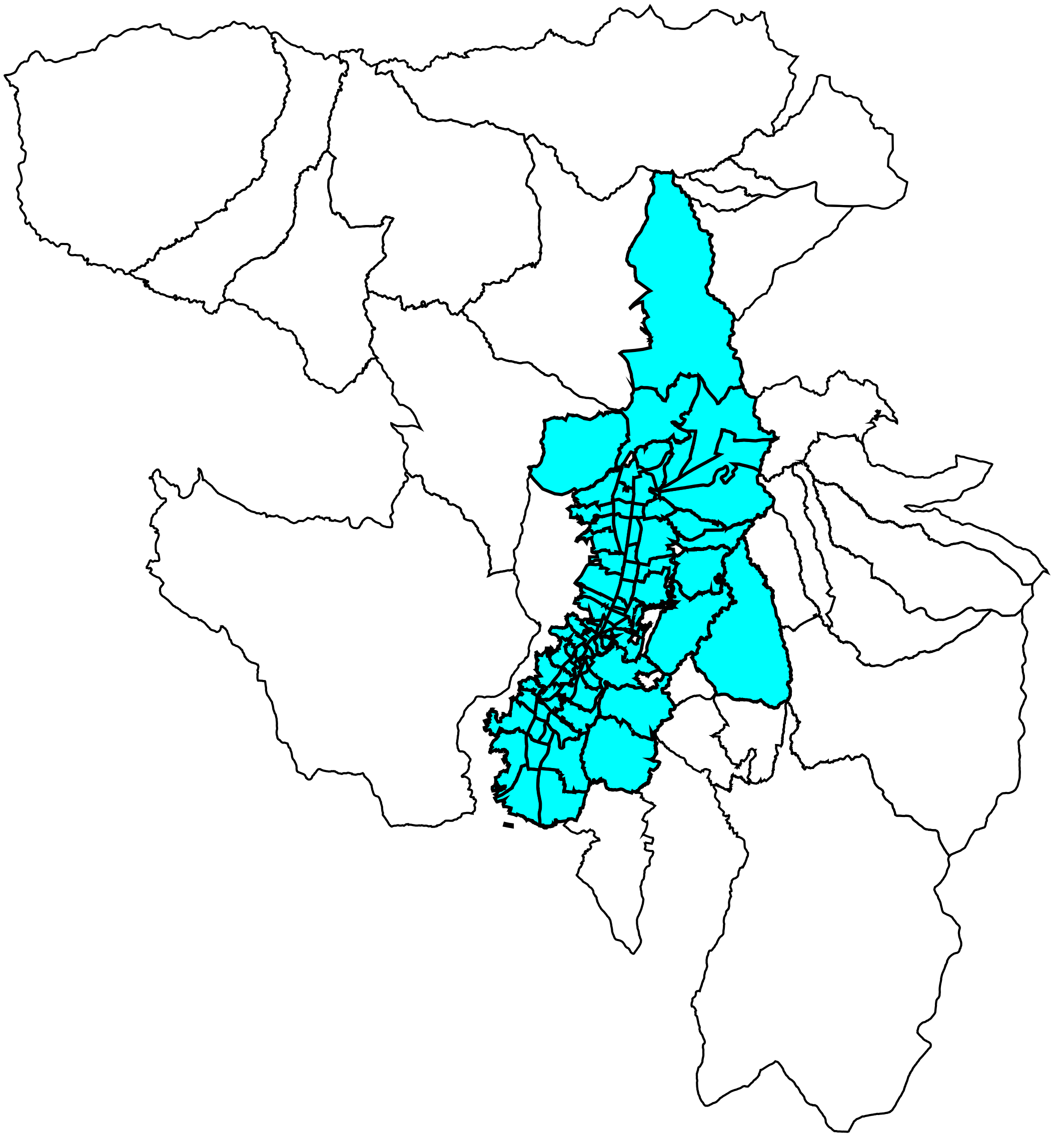
Figure 1:
WRI Water Risk Atlas



Source: https://www.wri.org/applications/aqueduct/water-risk-atlas/

*Notes:* Overall water risk measures all water-related risks by aggregating all selected indicators from the Physical Quantity, Quality and Regulatory & Reputation Risk categories. Higher values indicate higher water risk (WRI, 2019).

Figure 2:
EPMAPS' Geographic Coverage: Urban Area (Shaded) and Rural



*Notes:* This map shows EPMAPS' geographic coverage.

Figure 3:
Water Price Schedule in the City of Quito

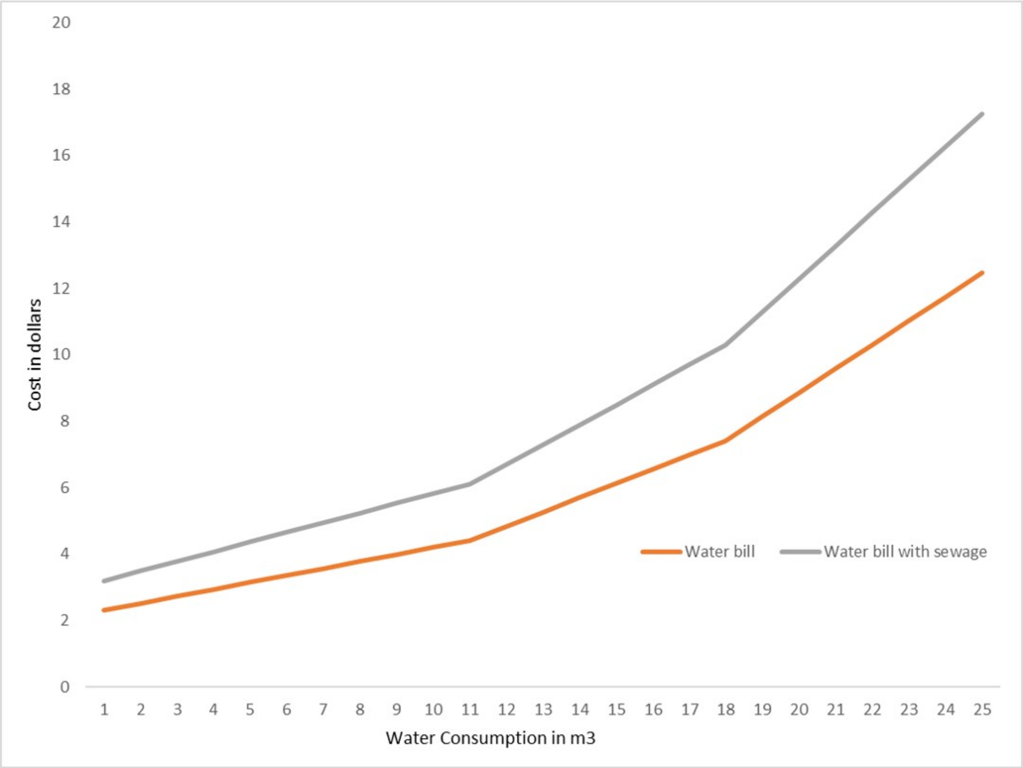
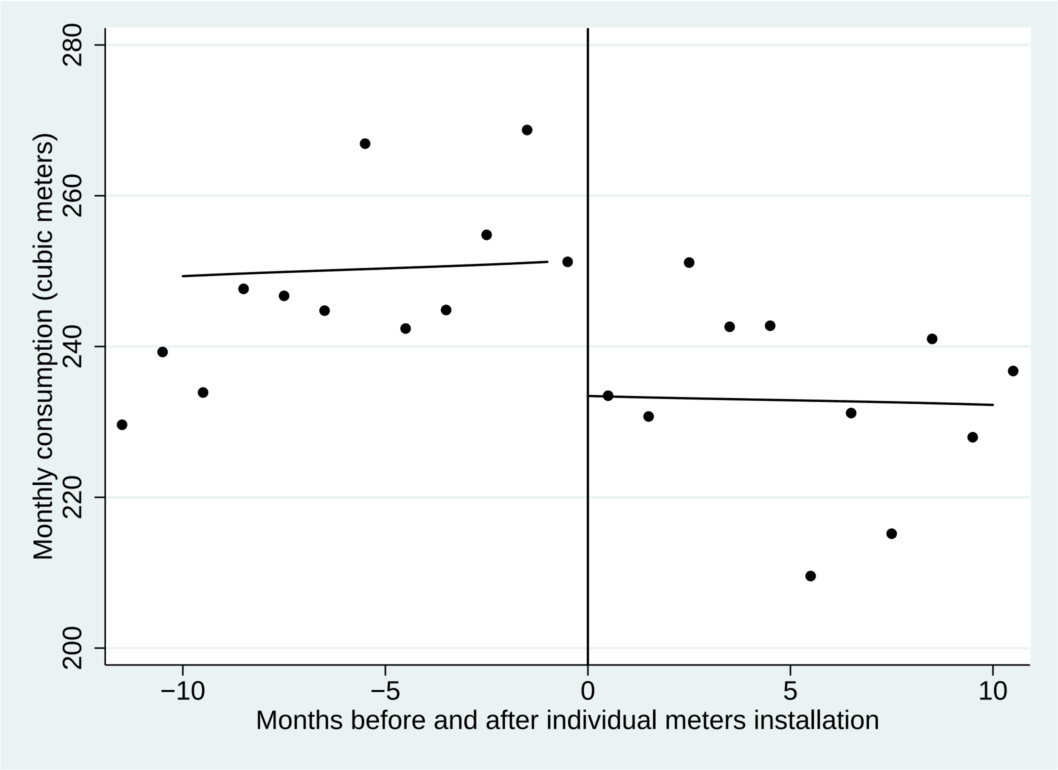


Figure 4:
Average Water Consumption as a Function of the Number of Months before and after Installation of Individual Meters



*Notes:* Each point shows the monthly average water consumption of clients with a "principal" account in the period from 2014 to 2016. The vertical line corresponds to the date when the supplementary meters were installed. We include a non-parametric estimation of this relationship independently calculated in the periods before and after treatment.

Figure 5:
**Average Water Consumption by Group (treatment vs control)**