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AMI water meters deliver end-use water and financial savings in leaky households: experimental evidence from California

Amanda M Rupiper[1], Robert T Good[2], Jonathan Ackerman[2], Jack Gregory[3], Katrina K Jessoe[3,*] and Frank J Loge[2,*]

[1] Department of Chemical and Environmental Engineering, University of California, Riverside, CA 92521, United States of America
[2] Department of Civil and Environmental Engineering, University of California, Davis, CA 95616, United States of America
[3] Department of Agricultural and Resource Economics, University of California, Davis, CA 95616, United States of America
[*] Authors to whom any correspondence should be addressed.

E-mail: kkjessoe@ucdavis.edu and fjloge@ucdavis.edu

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Abstract

Advanced metering infrastructure (AMI) for residential water consumption is exploding globally giving water utilities the ability to improve their water tracking, billing, and distribution systems' leak detection. With AMI, utilities have also gained the opportunity to provide real-time high-resolution water consumption information to their customers to induce conservation. Using a randomized controlled trial we find that on average homes that install AMI and receive conservation based messaging significantly reduce water consumption by 5.24 gallons per household per day beyond savings already obtained from home water reports. Of the estimated water savings we attribute 92.8% to leak reduction. While the payback period from the deployment of AMI meters and treatment in all homes is over 41 years, homes that experience leaks realize financial savings of \$60/year and a treatment payback period of four years. This is because treatment did not induce water or financial savings in homes without leaks. These findings indicate that even on top of existing conservation programs, AMI messaging that targets end-user leaks could result in significant water savings, economic benefits to end-users, and advance conservation goals.

1. Introduction

Recently, the Western United States experienced a historic and unprecedented multi-year drought, and droughts are expected to become more frequent and severe with climate change. With approximately 12% of water in U.S. urban systems lost to end-user indoor leaks, leak loss prevention and repair presents one option to manage increasingly scarce water supplies (DeOreo *et al* 2016, El-Zahab and Zayed 2019, Rupiper *et al* 2022). While strategies exist to detect leaks occurring in the distribution system, until recently end-use leak detection has proven difficult (Seyoum *et al* 2017). Typically, end-users become aware of their leaks either by the visible appearance of a leak or sizable increases to their water bills. Both scenarios only identify sizable leaks and likely only after the leak has endured for some time. One primary advantage of advanced metering infrastructure (AMI) which enables consumers and utilities to track water use in real time is the ability to identify water leaks earlier, faster, and more accurately than is possible with more traditional monthly or bimonthly billing approaches (Monks *et al* 2019).

In the electricity setting, AMI has improved load management and induced energy conservation. AMI in the electricity sector is widespread, allowing for time variant pricing and targeted conservation messaging and appeals. When deployed in conjunction with real time feedback, dynamic pricing has proven an effective lever to manage demand (Jessoe and Rapson 2014, Ito *et al* 2018). Real time feedback and social messaging enabled by AMI metering have also induced overall energy conservation (Erhardt-Martinez *et al* 2010, Asensio and Delmas 2016). Empirical evidence on the use of AMI metering to induce end use water savings is less well understood (West *et al* 2021).

AMI metering infrastructure is rapidly being rolled out across water utilities globally. As of 2022, 38 million AMI meters have been installed in North America and 17.8 million in Europe, comprising 33% and 12% market penetration, respectively (Jones 2023) Worldwide, it is estimated that over 400 million smart water meters will be installed by 2026 (ABI Research 2019). Water suppliers install these meters to track and bill water more accurately, identify leaks in the distribution system and reduce non-revenue water, which includes treated water lost to leaks or unbilled due to metering inaccuracy or theft (Brueck *et al* 2018, Mix *et al* 2020). Less focus has been placed on the effects of AMI meters downstream of the distribution system (i.e. in the home), though the water savings could be significant.

AMI data could be used to provide tailored and targeted messaging and feedback to consumers and has the potential to shape when and how conservation occurs. With water AMI technologies, water agencies gain the ability to identify and alert customers about water leaks in near real-time; communicate transitions across volumetric based rate tiers; and advise consumers about their water use relative to similar households (Moore and Hughes 2008, Brent *et al* 2015, Mix *et al* 2020).

Work in the residential water setting has demonstrated that behavioral nudges communicated through monthly or bi-monthly home water reports (HWR) deliver water savings. HWRs employ social norms comparisons, by comparing a household's water use to that of a peer group and offer water savings tips and recommendations. Across a range of locations and weather conditions, these nudges have induced water conservation of 3%–5% (Ferraro and Price 2013, Brent *et al* 2015, 2020, Bhanot 2017, Goette *et al* 2019, Jessoe *et al* 2021). A summary of the savings obtained from HWR related nudges is available in the Supplemental Information appendix (SI appendix). What remains uncertain is if and the extent to which AMI metering can enhance water savings beyond that achieved from HWRs alone.

In this article, we assess if and the channels through which AMI metering infrastructure can induce end-use water conservation. We designed and deployed a randomized controlled trial to evaluate the impact of AMI based water user communication on water consumption in a utility already deploying HWRs to all customers. We then isolate the water conservation effects attributable to hard capital changes, defined in our setting as leak reduction and repair, monetize private water savings, and determine the pay off period for smart meters based on leak reduction.

On average, AMI enhanced messaging reduces end-use water consumption by 5.24 gallons per household per day or 2.7%, and is additive to the 3%–5% savings obtained from HWRs. However, the financial savings from treatment is not sufficient to justify AMI installation costs in the average home. Approximately 92.8% of the estimated water conservation is attributable to leak detection and repair. In households observed to have a leak prior to treatment, the intervention reduced daily water use by 30.0 gallons per household per day and led to annual savings of $60. Water conservation in leaky homes does not require households to incur lifestyles costs such as modified yards or shorter showers. Leak related water savings can be additive to previous or on-going conservation measures.

2. Experimental design

This study took place within the potable water service territory of the East Bay Municipal Utilities District (EBMUD). The EBMUD serves approximately 328 000 single-family residential customers throughout its 332-square-mile service area including the cities of Oakland and Berkeley, California, USA. Beginning in July 2019, we tracked hourly water use in 7862 households with newly installed AMI meters. We tracked pre-intervention water use in all households from July 2019 to October 2019, and define this time span as the baseline period. Our treatment period spans 1 October 2019 to 1 October 2020. All households in our sample received bi-monthly HWR that used bi-monthly billing data to inform customers about their water consumption relative to similar households.

Approximately half of the households were randomly assigned treatment, referred to as 'AMI+'. Treatment households were provided AMI-enhanced content in their bi-monthly HWR, email, text or phone notifications from EBMUD, and access to an online portal that leveraged AMI data to inform customers about their use relative to peers and ways to conserve water. AMI+ households also received real-time notifications if a leak was identified downstream of the AMI meter. Further details about the frequency and content of notifications sent to AMI+ households can be found in the SI appendix.

As detailed in the SI appendix, we demonstrate that daily and hourly water use are balanced across control and treatment households. An implication of the randomized assignment to control and treatment and the resulting balance is that we attribute the difference in water use across the AMI+ and AMI only groups, where the latter refers to control households, to the treatment itself. Since all homes in our study received bi-monthly HWRs, a comparison across control and treatment households will reveal the water conservation achieved on top of HWRs.

To quantify the causal effect of treatment on hourly water use, we estimate a two-way fixed effects model,

Equation (1). Average Treatment Effect, Hourly Regression

$$y_{ih\tau} = \alpha + \beta_1 WS_{i\tau} + \gamma_i + \gamma_\tau + \gamma_h + \alpha T_{h\tau} + \mu P_{h\tau} + \varepsilon_{ih\tau}.$$

Our outcome of interest, $y_{ih\tau}$, captures hourly water use for household i in hour h of day τ. The regressor of interest $WS_{i\tau}$ is an indicator variable set equal to 1 if a household is assigned to the AMI+ treatment during the treatment period. To increase the precision with which treatment effects are estimated, we also control for household fixed effects γ_i, hour of day fixed effects γ_h, calendar date fixed effects γ_τ, temperature $T_{h\tau}$ and precipitation $P_{h\tau}$. To account for spatial correlation over time, standard errors are clustered at the household. Additional details about group assignment and randomization, balance across control and treatment, and data analysis are provided in the SI appendix.

To gain insight into the mechanisms underpinning treatment induced water conservation, we implemented a two-step procedure to bound the water savings attributable to leak messaging and non-leak messaging. First, we developed and used a machine learning algorithm to classify households as having a leak in the baseline period, having a leak in the treatment period, or never having a leak. Using pre-treatment hourly interval data, we denoted a household as having a continuous leak if (i) hourly water use in every hour spanning a 72 hour interval was positive and (ii) burst leaks greater than 74.8 gallons occurred consecutively over an 8 hour span. A household was assigned a no-leak status if our algorithm failed to detect a leak in the pre-treatment and treatment periods. Second, we estimated equation (1) separately for all households identified as having a leak in the pre-treatment period, and households classified as never having a leak. Treatment effects in the no-leak group provide an estimate of water conservation from behavioral messaging, and treatment effects from the leak group inform us about the gross conservation effect from leak and non-leak messaging.

One limitation of the leak analysis is that the randomized controlled trial was not designed to detect differences in water use from assignment to treatment for leak and non-leak households. This may confound the interpretation of our analysis for two reasons. First, if we restrict our analysis to either leaky or non-leaky households, baseline water use may differ across control and treatment households. These differences may influence the response to the 'AMI+' treatment. Second, leaky households may differ from non-leaky households in attributes (e.g. home age) aside from leaks. These attributes may explain differences in response to treatment between leaky and non-leaky households. As such, we view the leak results as cross-tabulations of the treatment effects with respect to leaks. Balance tables comparing baseline water use across control and treatment households in each sub-group are provided in the SI appendix.

3. Results

On average, AMI metering enabled messaging and communication led to water conservation. AMI+ households consume 5.24 (P = *0.036*; 95% CI, (−10.14, −0.33)) fewer gallons per day than control households, which equates to a 2.7% reduction in overall water consumption. Water consumption reductions appear almost immediately after the start of the treatment period and endure until the end of treatment.

Time-series leak data provide a descriptive preview that leak reduction is strongly correlated with treatment induced water conservation. Figure 1, which plots active leaks over the baseline and treatment periods across control and treatment households, indicates that leaks in AMI+ households reduced dramatically relative to control households during the treatment period. In our sample, 14.9% of households were classified as having a leak in the baseline period, where the number of leaks was equally distributed across control ($n = 581$) and treatment households ($n = 593$). In the treatment period, the number of households experiencing leaks did not differ across control and treatment households, with leaks detected in approximately 21.3% of households. What does significantly differ in the treatment period is the frequency and duration of leaks across these two groups. Treatment households developed 1.08 ± 0.426 (P = *0.011*) fewer leaks per year and leaks had on average a 115.8 ± 66.1 (P = *0.080*) hour shorter run time. The impact of the shorter leak run times and reduced leak occurrence drives the lower number of active leaks in the AMI+ group plotted in figure 1.

The reduction in leak frequency and leak duration explains a substantial portion of the 5.24 gallon per day treatment effect. For the households classified as having a leak in the pre-treatment period, an assignment to treatment is correlated with a 30.0 (P = *0.007; 95% CI, (−51.7, −8.27)*) gallon per day reduction in use. By contrast for the 78.7% of control and treatment households with no leak detected in either the baseline or treatment period, AMI enabled messaging leads to neither economically nor statistically meaningful reductions in water use of 0.44 (P = *0.827*; 95% CI, (−4.37, −3.50)) gallons per household per day.

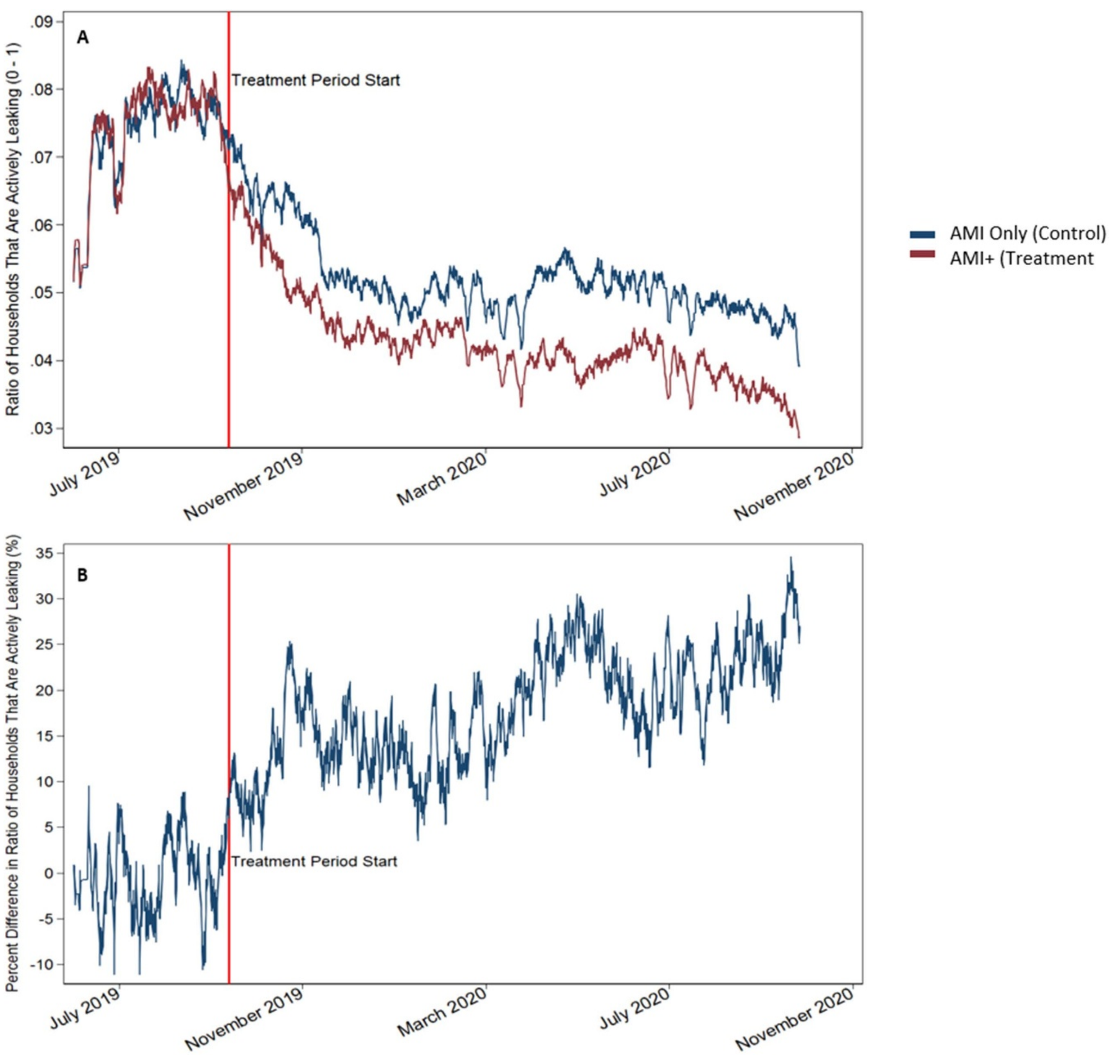

Figure 1. (A) Time series fraction of households actively leaking in the AMI only and AMI+ groups, (B) time series percent difference in the fraction of actively leaking households between the AMI only and AMI+ groups. *Source*: Authors.

To bound water conservation from leaks, we assume that the 30.0 gallon per day conservation effect captures water savings from AMI based leak and non-leak messaging, and the 0.44 reduction is from AMI based non-leak messaging alone and take the difference of the two effects. This calculation indicates that leak related changes account for approximately 92.8% of the overall conservation effect and 98.5% of the savings estimated in a 'leaky' household.

4. Discussion

AMI installation and leak notification and messaging may not save as much water as other conservation options, but importantly this conservation instrument may impose fewer lifestyle costs. Social comparisons that nudge you to reduce shower times may cut your water bill, but at the cost of less satisfying showers. Watering restrictions certainly reduce irrigation but at the expense of your plants and yard. In contrast, notifications informing that your toilet has a leak requires an inexpensive fix and subsequent water savings with no change to lifestyle.

Water and cost savings obtained from leak reduction and repair can be additive, and an additional tool to induce conservation during times of scarcity. All of the homes in our sample were receiving bi-monthly social norms comparisons from HWR. Still we find that leak notification and messaging enabled through AMI led to an average 2.7% conservation effect. Our findings indicate that even in areas with a robust set of conservation practices, AMI based leak messaging and notifications can provide additive water savings at a net benefit to customers.

However, water and financial savings do not accrue to all households. We calculate a lower-bound estimate of the financial savings from end-use water conservation attributable to AMI meter installation and the AMI+ treatment. The costs to purchase and install an AMI meter are roughly $200, and the cost of operating the 'AMI +' treatment (i.e. maintaining the AMI enhanced web portal and messaging) is $1.52 per household-year (Blaize 2018). On average, the variable production costs to procure, treat and distribute 1 million gallons of water in EBMUD is $5,680. We use variable production costs in place of retail rates to value water savings, since fixed costs are often bundled into retail rates. Importantly, this calculation excludes additional benefits of AMI meter installation such as more accurate billing, and do not assume that the cost of water increases over time.

From a cost-benefit perspective, where an AMI meter is installed matters. The placement of AMI meters in all homes would result in an upfront $200 installation cost and average annual net savings of $9.34 per household. Assuming a 3.5% discount rate, the payback period is 41 years. However, financial and water conservation savings occur almost exclusively in leaky households. In households without a leak, AMI enabled messages did not lead to end-use water conservation. For these households, the net-savings from the AMI+ treatment are negative. In contrast, the targeted placement of meters in homes with leaks would yield annual net savings of $60.68 per household. Applying a 3.5% discount rate and the $200 upfront meter installation cost, the payback period is approximately four years.

Our finding that AMI meter installation and AMI enabled messages can deliver water and financial savings in leaky homes hinges on the assumption these homes can be identified. One pragmatic challenge to the targeted installation of AMI meters is how to detect leak prone homes. In the absence of AMI meters, utility-led leak detection primarily occurs from comparisons of water bills month to month and year over year, or to similar homes. Future work should focus on improving the speed and accuracy with which utilities can identify and target candidates for AMI metering. Even if targeting of leaky households occurs without AMI data, the installation of AMI meters is still likely to deliver water and financial savings. This is because while the number of households with leaks did not differ across control and treatment households, the frequency and duration of leaks was significantly lower in treatment households. Less frequent and shorter leaks may not occur without AMI meter installation.

5. Conclusions

In the face of population growth and climate change, water utilities must carefully consider how to manage their water supplies and reduce consumption. AMI may be one avenue toward improved management and understanding of a water supply by allowing for faster identification of leaks and more accurate and detailed messaging to consumers. Installation of an AMI meter in residential households by itself does not induce customer change, but targeted messaging that utilizes AMI data to provide feedback to consumers, results in significant water savings of 5.24 gal/household/day on average. The water savings from AMI enabled messaging were obtained on top of HWR indicating that the savings estimated in our study is in addition to existing conservation activities and programs. However, with a payback period of 41 years, the financial savings attributable to treatment is not sufficient to justify AMI installation costs in all homes.

Of the estimated water savings, as much as 92.7% can be attributed to leak reduction as a result of shorter leak durations or a reduced frequency of leaks in households that received enhanced AMI messaging. The targeted placement of meters in leaky homes results in sizable net economic benefits of $60 per year and a payback period from meter installation of 4 years. Resource savings associated with AMI enabled customer feedback are achieved quickly after treatment, and could help water utilities meet conservation goals and reduce costs.

Data availability statement

The data cannot be made publicly available upon publication because they are owned by a third party and the terms of use prevent public distribution. The data that support the findings of this study are available upon reasonable request from the authors.

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Ethical Statement

This project was reviewed and given IRB clearance: 975 373-1.

ORCID iDs

Amanda M Rupiper https://orcid.org/0000-0002-1177-156X
Katrina K Jessoe https://orcid.org/0000-0002-9476-8664

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