LETTER

Mining the gap in long-term residential water and electricity conservation

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Abstract

Climate change and economic development provide a strong rationale for urban water and electricity conservation. Although behavioral and technological factors link short-term conservation of both resources, their long-term residential consumption trends have diverged across industrialized nations: from 1990 to 2010, per capita water use decreased, while per capita electricity use increased. This long-term ‘conservation gap’ has not generally been examined but it presents an opportunity to better understand what drives persistent residential conservation. Here, we analyze 2002–2012 water and electricity consumption from 38 000 California residences to characterize the conservation gap and its socio-economic determinants. Aggregate per-residence consumption figures show a 19% decline in water use—concentrated in the 2007–2009 drought—and an 8% increase in electricity use—coinciding with early 2000s economic growth. We find no meaningful socio-economic variation in micro-scale consumption trends across the study area but the ‘gap’ tendency is greater in residences with low customer-turnover, suggesting that widespread factors—including the proliferation of consumer electronics and small appliances—drove electricity use increases. Long-term water conservation was also widespread, suggesting that droughts provide immediate, locally-driven conservation imperatives that have been successfully leveraged for long-term water savings. Similar episodes were not generally available to electricity policy makers during the study period, but extreme climate events could drive energy efficiency campaigns in the future.

1. Introduction and background

1.1. Introduction

Climate change and economic development provide a strong rationale for the world’s residential communities to conserve water and electricity in the long-term. The residential sector accounts for 23% of global energy demand, 17% of CO\textsubscript{2} emissions [1], and up to 12% of freshwater withdrawals [2]. By mid-century, demographic change and economic growth are expected to increase residential water and energy use by 55% [3] and 52% [4], respectively. Long-term conservation and efficiency are thus essential to mitigating climate change [5, 6] and adapting to a future with scarce and uncertain freshwater supplies [7, 8]. The close co-dependence of household water and energy consumption presents a key opportunity for coordinated residential conservation efforts [9–12]. Energy used to heat water for cooking, washing, and bathing means that each liter of residential water savings has direct energy-related side-benefits of 25–26 Wh [13, 14]. Recent work suggests water and energy use are also linked by human behavior [15, 16]. Water demand responds to changes in electricity prices and vice-versa, making both complementary goods in the household economy [17]. In the short-term, several studies also find that interventions targeting water use spill over into electricity use [18, 19], suggesting that conservation of each associates with an overarching ‘pro-environmental’ identity [20].
Despite short-term links between residential water and electricity use and conservation, recent data show that their long-term consumption trends have diverged considerably across the world's industrialized nations: per capita domestic water consumption in OECD countries declined by 20% between 2000 and 2012 [3], part of an ongoing decline since the 1980s [3]; per capita electricity consumption increased by 20% between 1990–2011 [21].

There are many possible reasons for this trend-gap, including differential supply-side efficiency improvements and impacts from the spread of consumer electronics [22] and small appliances [21] that counteract electricity efficiency gains, among others. In the long-term, sustained reductions in residential resource use result both from shifts in household conservation habits and housing-stock efficiency investments [23]. Although several studies have examined the mechanisms by which such long-term conservation of water [24] or electricity [23, 25] are induced by well-designed customer feedback interventions, prior work has not generally considered how water and electricity use evolve together or why this co-evolution has recently tended to result in a long-term ‘conservation gap’, that is, divergent trends in long-term, per capita consumption over time. The conservation gap thus remains poorly understood, even if it presents an opportunity for policy-makers to better understand what drives persistent conservation in the residential sector.

In this study, we analyze 11 years of water and electricity billing data from 38 000 single-family residences in two adjacent Southern California cities to shed new light on the recent, long-term co-evolution of water and electricity consumption and the conservation gap, which we define as the difference between long-term, per capita electricity and water consumption growth. We examine the relationship between water and electricity consumption trends and California’s evolving socio-hydrologic and policy context. We then assess how micro-level, long-term conservation profiles are defined by the study area’s diverse demography and customer characteristics. For the purpose of this study, we define ‘long-term conservation’ as the combination of conservation behavior and investments in resource-efficient technologies that produce long-term reductions in consumption, as measured over a period of 10 years or more.

1.2. Study setting
The water and electricity data for this analysis consist of 2002–2012 customer bills from Huntington Beach and Costa Mesa in Orange County, California. The two cities have a combined population of over 300 000 with census block-group median incomes of $26 000–$250 000. Electricity is supplied by Southern California Edison who serves much of Southern California. Municipal water is provided by two utilities: Huntington Beach and the Mesa Water District (Mesa Water).

Our data cover a tumultuous 11-year period that includes California’s landmark 2006 Global Warming Solutions Act, the 2007–2009 global economic crisis that included ‘Great Recession’, and the start of the 2012–2016 drought, the most severe in the state’s recorded history [26]. Similar state and local water and electricity efficiency efforts during the period permit a particularly apt comparison of long-term usage trends. As part of regulatory efforts made to reduce California’s CO₂ emissions, its utilities provided more than $1b for customer-funded energy efficiency improvements in 2003–2013 [27]. Various incentives for residential water efficiency have also been promoted since the 1990s by Southern California’s Metropolitan Water District [28, 29] a water supply and planning agency serving both Huntington Beach and Mesa Water.

Despite these similarities, California’s 2006–2010 drought produced short-term local policy responses primarily relevant to the water sector, which differed markedly for Mesa Water and Huntington Beach. From November 2009 to June 2011, Huntington Beach imposed Level 1 mandatory watering restrictions limiting outdoor watering to 3 d a week. Mesa Water’s response was limited to a September 2009 ordinance preventing wasteful outdoor watering.

2. Results

2.1. Political, economic and hydrologic context
Panels A and C of figure 1 display the study population’s 2002–2012 average water and electricity use after removing seasonality with season and trend decomposition using loess [30]. The other panels in figure 1 display climate and economy measures that provide useful context to long-term water and electricity consumption trajectories: Panel B overlays U.S.-wide, scaled, seasonally-adjusted sales revenue from consumer electronics and appliance stores and gross-domestic product per capita (GDP); Panel D displays California’s South Coast regional Palmer drought severity index (PDSI), a common measure of drought severity.

The figure clearly shows a long-term conservation gap: on average, electricity consumption increased by 0.7% per year while water consumption decreased by 2% per year. Across 2002–2012, this correspond to an 8% increase and 19% decrease in electricity and water use, respectively.

The consumption time-trend breakpoints shown by the dashed lines and dots in Panel A show that overall 2002–2012 electricity growth results from two distinct trends, roughly coinciding with the economic cycle. Mean electricity use grew rapidly from 2002 to 2006—by 2.3% per year—before peaking in late 2006, shortly before the onset of the 2007–2009 Great Recession. From 2007 onwards, however, electricity consumption growth is actually negative, averaging −0.35% per year (likely due to the short-term effects of the recession).
Figure 1. (A). Seasonally-adjusted bi-monthly mean electricity use for study population; (B). U.S. scaled, seasonally adjusted retail sales from consumer electronics and appliances stores and GDP per capita; (C). Seasonally-adjusted mean water use for study population; (D). Palmer drought severity index (PDSI) for the California (CA) South Coast hydrologic region (PDSI < 0 indicates dry conditions). Note: events are: 1. California AB32 climate bill; 2. September 2008 stock-market crash; 3. California Governor drought state of emergency.

Table 1. Study block group and customer characteristics.

| Variable Type     | Variable                                      | Av.  | Std. Dev | % Chg. (2000–2010) |
|-------------------|-----------------------------------------------|------|----------|---------------------|
| Residences (#/block-group) | 310                                           | 210  | -        | -                   |
| Costa Mesa (# block-groups) | 35                                            | -    | -        | -                   |
| Huntington Beach (# block groups) | 94                                            | -    | -        | -                   |
| Pop. Dens. (ppl mile$^{-2}$) | 7800                                          | 3900 | 15       |                      |
| Median HH Inc. ($)   | 92 000                                        | 26 000 | 33        |                      |
| Owner Occupied (%)  | 75                                            | 21   | -1.4     |                      |
| Median age (yrs)    | 41                                            | 5.0  | 11       |                      |
| Family Pop. (%)     | 85                                            | 9.4  | -3.6     |                      |
| Median HH Size (ppl) | 2.5                                           | 0.5  | 4.4      |                      |
| Av water consumption (L/d) | 1100                                         | 520 |          |                      |
| Av elect consumption (kWh/d) | 19                                           | 10  |          |                      |
| Household turnover (h.h./yr$^{-1}$) | 0.17                                          | 0.14 | -        |                      |
| Subsidized (%)      | 19%                                           | 15%  | -        |                      |

Also evident in Panel B is the similarity of deseasonalized monthly retail sales trends from U.S. consumer electronics and appliance stores and per capita GDP, which offers a plausible reason for coupled residential electricity use and economic growth during this period.

The study area’s water consumption appears to be driven more by local hydrology than economic conditions. Panel C shows water consumption declining in the early 2000s, leveling-off in 2005–2008 and then declining more rapidly in 2008–2010. Panel D shows these declines in water consumption coincided with abnormally dry conditions in 2008–2010 (i.e. a negative PDSI), which led to governor Schwarzenegger drought state of emergency in February 2009 (the first since 1991).

2.2. Demographic and customer determinants

We continue by analyzing variation in neighborhood-scale, long-term water and electricity consumption profiles, relating them to the observable features of residential customers and U.S. Census block groups.

Table 1 summarizes these features, which are available at the scale of U.S. Census block-groups. As
the table shows, many demographic measures vary widely across Costa Mesa and Huntington Beach's 129 block-groups, especially population density, median household income, and a block-group's number of residences. The right-most column of table 1 indicates that population density, median household income, and median age increased noticeably from 2000 to 2010. The share of family households and owner-occupied units declined slightly during this period, but were still around 75%–85% in 2010.

The customer features summarized table 1 are computed for each of the study's 38 000 single-family residences individually. Water and electricity consumption averaged 1100 l/d and 19 kWh d$^{-1}$ in 2002–2012, respectively. Household turnover averaged 0.17/year, which translates to an average occupancy duration of 6 years. Almost 20% of residences received an electricity rate subsidy through California's Alternative Rates for Energy and Family Electric Rate Assistance programs.

2.3. Neighborhood demographics

Since demographic information is available at the spatial-scale of U.S. Census block-groups, we analyzed demographic differences in long-term consumption profiles (i.e. means and time-trends) at the block-group level. Figure 2 plots water and electricity consumption means (panel A) and time-trends (panel B), estimated separately for each of the study area's 129 block-groups and stratified by city. As figure 2(A) shows, mean water and electricity consumption correlated strongly at the block-group level: every 1000 l/d of water consumption is associated with 5.6 kWh d$^{-1}$ of additional electricity consumption. Costa Mesa’s block-groups generally have higher average water consumption than similar blockgroups in Huntington Beach. The consumption time-trends in figure 2(B) indicate that all block-groups reduced water use between 2002 and 2012; most block-groups increased average electricity use (although a sizable fraction decreased it). As shown in figure 2(B), block-group level water and electricity consumption time-trends do not correlate significantly.

We related consumption means and time-trends to the study area's demography using regression on principal components. Figure 3(A) displays variable loadings of the first two principal components of demographic characteristics, which account for 80% of variation in block-group demographic characteristics across the two cities. The first principal component (PC1)—plotted along the x-axis—mostly reflects socio-economic measures associated with affluence: high income and educational attainment, low population density, and high-median age. The second principal component (PC2) is plotted along the y-axis and captures family- and, to a lesser extent, race-related measures. A low Principal Component 2 value is associated with high median household size, more married and family households, and a less racially-white population.

Figure 3(B) summarizes the results of regressing 2002–2012 consumption means and time-trends on these first two principal components and a city indicator variable. A key result from figure 3(B) is that Costa Mesa and Huntington Beach have significant differences in their long-term consumption profiles: average 2002–2012 water consumption is significantly higher and exhibits higher growth (i.e. more positive time-trend estimates) in Costa Mesa than in Huntington Beach, even after accounting for demographic variability captured by the first two principal components. This finding likely reflects mandatory Level 1 outdoor watering restrictions in place in Huntington Beach from 2009–2011. Costa Mesa's block-groups exhibit more electricity consumption growth but the effect size is smaller. Despite these differences, the conservation gap in the two cities is quite similar.

Figure 3 also shows that the first two principal components significantly associate with mean consumption levels. Principal Component 1 correlates positively, and Principal Component 2 negatively, with mean water and electricity consumption, respectively. Both of these relationships are
unsurprising. High values of Principal Component 1 indicate features associated with neighborhood affluence and we would expect it to associate with greater water and electricity use. Low values of Principal Component 2 reflect a greater share of family occupied residences and larger household sizes, also implying more water and electricity consumption per residence.

Although the above findings indicate that mean water and electricity consumption levels correlate significantly with neighborhood demographics, figure 3(B) shows they do not generally correlate with long-term consumption time-trends or the conservation gap (defined as the arithmetic difference between water and electricity consumption time-trends). More affluent and family-oriented block-groups exhibit higher water consumption time-trends but the relationship is not significant. Neighborhood demographics have a miniscule and insignificant effect electricity usage growth and the conservation gap, suggesting that, at least in the study area, the gap was a widespread phenomenon with no distinct socio-economic signature.

2.4. Residence-level analysis

We continue with a fine-grained analysis of long-term, residence-level consumption profiles—fitting similar 2002–2012 consumption time-trends on each residence. Figure 4 displays joint and marginal distributions for resulting residence-level consumption time-trends. As is clear from the figure, there is substantial heterogeneity in residence-level consumption growth. For the median residence, 2002–2012 water consumption declines by 2.1% per year and electricity consumption increases by 0.6% per year, roughly representative of the aggregate conservation gap tendency; however, 43% of residences actually experienced an electricity use decrease and 31% a water use increase during the period, so the conservation gap only weakly characterizes consumption trajectories.

More surprising from figure 4 is the positive and significant relationship between a residence’s water and electricity consumption growth: a 1-unit increase in water consumption growth associates with a 0.40-unit increase in electricity consumption growth. The simple relationship accounts for 18% of residence-level variability in electricity time-trends; its magnitude is virtually unchanged by the addition of block-group-fixed effects, meaning that the same co-dependence exists among socioeconomically similar households.

The long-term conservation gap manifests itself in this relationship as a positive intercept: independent of its water use growth, a residence’s electricity growth in our population is expected to be 1.5% per year.

Figure 5(A) summarizes the results of multivariate regressions of residence-level water and electricity consumption time-trends on observable customer characteristics; we also ran the same regression with each residence’s conservation gap, computed as before by subtracting water consumption time-trends from electricity consumption time-trends.

The figure shows that the strong co-dependence of water and electricity time trends is not affected by inclusion of other customer characteristics: electricity use remains the main determinant of a residence’s water consumption growth and vice-versa. Receipt of an electricity subsidy by a residence’s occupants does not correlate significantly with water consumption growth, electricity consumption growth, or the conservation gap—reinforcing our earlier conclusion about the minimal role of socioeconomic factors in explaining neighborhood-level consumption time-trends. The trend-gap model in particular has an adjusted-R² of just 0.02, showing its limited...
ability to account for residence-level variation in our conservation-gap measure.

Still, we find a small but highly significant relationship between a residence’s customer turnover (i.e. the number of observed electricity customers per year) and its long-term water-electricity conservation gap. Higher household turnover is positively associated with water consumption growth (i.e. lower long-term water savings) but negatively associated with electricity consumption time-trends (i.e. less long-term electricity consumption growth). As expected, this means that turnover associates negatively with the conservation gap.

The plots in figure 5(B) investigate this relationship further. These plots show average changes in trended resource consumption after an electricity billing account change (roughly corresponding to a move-in date). Each line plots this change for accounts with a given observed occupancy duration, which varies in 2-month increments. The figure strikingly illustrates the opposing effects prolonged occupancy had on long-term water and electricity consumption in the study area: households occupying a residence for longer periods of time exhibit greater declines in water consumption but greater increases in electricity consumption. For all households, trended electricity consumption rises rapidly in the initial months of occupancy and levels off thereafter. In the SI, we show that a change-of-household generally produces significant reductions in a residence’s electricity consumption, such that these early electricity use increases may partly reflect the transient recovery of consumption levels from a move-out and subsequent move-in. However, the finding is also consistent with the idea that widespread lifestyle factors (e.g. accumulation of electricity-consuming appliances and equipment in a dwelling over time) contributed to the long-term water-electricity conservation gap during this period.

3. Conclusion

This study presents an initial view into the long-term conservation gap in residential water and electricity use. For the study area in 2002–2012, the gap consisted of a 19% decrease in average water use—concentrated in unusually dry periods—and an 8% increase in average electricity use—coinciding with economic growth in the early 2000s. Our analysis of micro-level, conservation patterns finds no meaningful differences in ‘gap’ tendencies across the study area’s diverse demography, suggesting it was a
widespread phenomenon impacting a heterogeneous set of households. Still, we find the conservation gap was slightly but significantly magnified in residences with low customer turnover, so it was at least partly been by factors intrinsic to prolonged occupancy and/or home-ownership. This last finding is especially notable given previous evidence that renter-occupied housing with high customer-turnover generally has a lower likelihood of energy-efficient appliance upgrades [5, 31]. It suggests that other countervailing factors exerted a greater influence on overall residential electricity use in the long-term.

More broadly, our results are consistent with the pervasive influence of consumer-electronics and small appliances as drivers of residential electricity consumption growth in an era that saw, among other things, the birth of the smart phone and tablet. The proliferation of consumer electronics and small appliances has been cited as a driver of electricity use increases across OECD countries in the early 2000s [21]—by 2013, consumer appliances alone accounted for roughly 12% of total residential electricity use in the U.S [32]. This transformation is likely to have affected everyone, regardless of a household’s socioeconomic status.

Nonetheless, we note that the long-term conservation gap we observe was far from inevitable. Residence-level patterns reveal broad heterogeneity in water and electricity consumption growth, such that a sizable share of residences conserved both water and electricity in 2002–2012. The strong correlation between residence-level water and electricity consumption time-trends also suggests a broadly similar tendency to conserve both resources in the long-term. As the bivariate relationship’s positive intercept suggests, factors affecting all residences meant that—independent of the change in its water consumption—a residence’s electricity use was expected to increase by 1.5% per year between 2002 and 2012.

Of course, this study only provides an initial analysis of divergent water and electricity consumption trends and many other factors may have contributed to the conservation gap. New data on urban form, for example, allow for more granular, city-scale assessments of how building age and other features affect long-term consumption trends. Both occupant and

### Table 1: Covariate Estimates (2002-2012)

| Covariate                  | Water Cons. Trend ($\beta_w$) | Elect. Cons. Trend ($\beta_e$) | Trend Gap ($\beta_e - \beta_w$) |
|----------------------------|-------------------------------|-------------------------------|---------------------------------|
| Intercept                  | 0.14***                       | 0.03***                       | -0.07***                        |
| Customer turnover (acct/year) | 0.06***                       | -0.02***                      | -0.05***                        |
| Electricity Subsidy        | 0.01                          | 0                             | 0                               |
| Water cons. trend (%/year) | 0.42***                       | 0.43***                       |                                 |
| Elect cons. trend (%/year) | 0.04***                       | 0.01**                        | -0.02**                         |
| Water cons. mean (L/d)     | -0.01*                        | 0.01**                        | 0.02**                          |
| Elect cons. mean (kWh/d)   | 0.19                          | 0.19                          | 0.02                            |

*p-values: * < 0.10, ** < 0.05, *** < 0.01*
building characteristics are important determinants of residential water and electricity use [33–35], meaning that more useful insights might still be mined from long-term water and electricity consumption trends. For example, customer-level data on building characteristics would permit us to evaluate the extent to which higher electricity consumption growth in low-turnover residences is driven by larger owner-occupied dwelling size, which may enable accumulation of electricity-consuming appliances and other equipment.

Two additional factors that this study does not explicitly consider are the long-term effects of price and income changes on water and electricity consumption. Residential electricity consumption is generally more elastic to income changes than water consumption [36, 37], such that income growth could account for some of the gap tendency. However, we do not find that income growth was significantly associated either with water or electricity growth at the block-group level, suggesting its role was limited (additional details are given in the SI). Similarly, increases in inflation-adjusted water and electricity prices were roughly equal in our population, averaging 1.6% yr\(^{-1}\) and 1.8% yr\(^{-1}\), respectively. Given typical estimates of long-term price elasticities [37, 38], these values imply similar demand changes (\(\sim 0.6\)\% yr\(^{-1}\) for water and \(-0.8\)\% yr\(^{-1}\) for electricity), meaning pricing is unlikely to explain much of the study population’s conservation gap tendency either.

A more actionable implication from this study is that—in arid or semi-arid regions of the world—drought episodes provide a more immediate impetus for long-term conservation than exists for electricity. The fastest water use reductions in the study area coincided with California’s 2007–2009 drought, when extraordinary water savings measures were taken by both Mesa Water and Huntington Beach. The different approaches of the two cities are reflected in their long-term usage trajectories: conditional on their demographic composition, neighborhoods in Huntington Beach saved significantly more water—likely because of their distinct local water management regime, which included 2009–2011 mandatory watering restrictions. Even with these local differences, every census block-group in the study sample reduced water use from 2002–2012, meaning water savings were more widespread than electricity consumption growth.

The immediacy of the water conservation imperative has useful implications for the energy sector at a time when continued increases in per capita energy use have led to calls for new approaches to energy conservation [39]. Climate change mitigation is a key rationale for long-term energy conservation. Its widespread but heterogeneous impacts vary regionally, presenting an opportunity for electricity policy makers. In California, as in the U.S. Southwest and other semi-arid regions of the world, for example, climate change is expected to increase the frequency and severity of droughts and extreme heat events [40]. These in turn could be leveraged by policy makers to promote energy conservation and efficiency programs, for example by timing campaigns with droughts or incorporating drought-related concerns into messaging. Severe droughts are known to be associated with heightened public concern and voluntary water conservation behavior [41–43]. Previous evidence of pro-environmental behavioral spillovers [18] makes it entirely plausible that droughts and other extreme climatic events could trigger behaviors relevant to long-term electricity conservation. Although lack of matched water and electricity billing data for 2012–2016 prevents us from evaluating this hypothesis here, it is entirely consistent with this study’s finding that residence-level water and electricity consumption time-trends were strongly co-dependent. The extent to which this co-dependence arises from the same behavioral spillovers found to characterize short-term water and electricity conservation [18] is thus an important question for future research.

4. Methods:

4.1. Study data
This analysis uses matched water and electricity data for 37,666 residences in Costa Mesa and Huntington Beach, California. We also used 2000 and 2010 census data from the U.S. Census Bureau, which provides demographic data on 159 ‘block-groups’ (i.e. statistical sub-divisions of 600–3000 people used by the Census Bureau to manage census data collection and representation [44]). Additional details on matching of water and electricity accounts and exclusions of from the final sample—including 261 residences with rooftop solar photovoltaic panels and 52 block-groups without data for both 2000 and 2010—are provided in the supplemental information (SI) (available online at stacks.iop.org/ERL/16/024007/mmedi).

4.2. Trend-filtering
To identify breaks in consumption time-trends, we use the trend-filtering algorithm proposed in Tibshirani 2014 for adaptive estimation of piecewise polynomial functions [45], assuming a polynomial of order 1. The linear trend-filtering algorithm identifies optimal sets of nonzero coefficients \(\hat{\beta}\) over a discrete difference operator \(D\) using penalized least squares (with penalty \(\lambda\)):

\[
\hat{\beta} = \underset{\beta \in \mathbb{R}^n}{\text{argmin}} \frac{1}{2} ||y - \beta||^2_2 + \lambda ||D^2 \beta||_1 \]

\[
D = \begin{pmatrix} 0 & 1 & 0 & 0 & \ldots & 0 \\ 0 & 0 & 1 & 0 & \ldots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \ldots & 0 & 1 \end{pmatrix}
\]

We performed trend filtering with the ‘genlasso’ R package [46], using 5-fold cross-validation and the
The 1-sigma rule was used to choose the regularization parameter \( \lambda \).

### 4.3. Long-term usage trends

Long-term usage trends were computed for each block-group individually by regressing the logarithm of its mean water and electricity use at time \( t \) on a vector of weather controls and linear time \( (t) \), as in (1):

\[
\log(c_{it}) = \alpha_i + \sum \theta_{jk} x_{i,t} + \beta_i t + \varepsilon_{it} \tag{1}
\]

Where \( c_{it} \) is mean water or electricity consumption in block-group \( i \) and time-period \( t \), \( \alpha_i \) is a block-group fixed-effect, \( x_{i,t} \) are time-varying weather variables with effects \( \theta_{jk} \), \( \beta_i \) is a secular time trend and \( \varepsilon_{it} \) is a random error term. The weather variables included in (1) are: mean precipitation, heating-degree days and cooling-degree days, computed across each bi-month. For the residence-level analysis, the same regression as in (1) was run except that each residence's water and electricity consumption used as opposed instead of the block-group average. From each type of time trend estimate, we then obtain a quantitative estimate of the long-term conservation gap for each block-group \( (g_i) \) as the difference between the electricity consumption time-trend \( (\beta_{ei}) \) and the water consumption time-trend \( (\beta_{wi}) \):

\[
g_i = \beta_{ei} - \beta_{wi} \tag{2}
\]

### 4.4. Regression on principal components

We analyzed demographic variation in 2002–2012 consumption means and time-trends using weighted least squares regression on principal components, which is a concise way of summarizing the dependence of a variable on sets of potentially correlated explanatory variables. This procedure was performed in two steps. In the first step, we performed principal components analysis on the study area’s demographic characteristics. In the second step, 2002–2012 water and electricity means and consumption time-trends were regressed on the top two principal components obtained from the first step—which accounted for roughly 80% of variability in demographic characteristics—and a binary city indicator variable. The regression in this second step was performed using weighted least squares with inverse-variance weights to account for varying levels of uncertainty in block-group level mean and time-trend estimates. Additional details on each of the two steps in the regression on principal components are given in the SI.

### 4.5. Regressions on residence characteristics

We analyzed residence-level variation in long-term water-electricity conservation patterns by regressing residence-level consumption time-trends on other observable customer characteristics. The models described in (3)-(5) below were fit to each type of consumption time-trend estimate (water, \( \beta_{iw} \) and electricity, \( \beta_{ie} \), fit as in (1) above) and the trend gap \( (g_i, \text{computed as in (2) above}) \). The dependent variables in (3)-(5) are block-group fixed effects \( (\alpha_j) \), customer turnover \( (\text{turnover}) \), an indicator coding for receipt of an electricity rate subsidy through California’s Alternative Rates for Energy and Family Electric Rate Assistance programs at any point during 2002–2012 \( (\text{subsidy}_e) \), mean water and electricity consumption in 2002–2012 \( (w_i \text{and } e_i \text{respectively}) \), and a random error term \( (\varepsilon_{it}) \).

\[
\beta_{ei} = \alpha_j + \zeta_1 \text{turnover}_i + \zeta_2 \text{subsidy}_i + \zeta_3 \beta_{iw} + \zeta_4 w_i + \zeta_5 e_i + \varepsilon_{it} \tag{3}
\]

\[
\beta_{wi} = \alpha_j + \zeta_1 \text{turnover}_i + \zeta_2 \text{subsidy}_i + \zeta_3 \beta_{iw} + \zeta_4 w_i + \zeta_5 e_i + \varepsilon_{it} \tag{4}
\]

\[
g_i = \alpha_j + \zeta_1 \text{turnover}_i + \zeta_2 \text{subsidy}_i + \zeta_4 w_i + \zeta_5 e_i + \varepsilon_{it} \tag{5}
\]

A Breusch–Pagan test [47] was performed to check for dependence of error variances with independent variables. Since all models failed this test, all standard errors were computed with the White robust error covariance matrix estimator [48].

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