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Water Affordability in the United States

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Key Points:

- One in ten households have essential water and sewer expenditures exceeding 4.5% of their income
- Those in the lowest decile of income spend on average 6.8% of their income on essential water and sewer service
- Affordability policies that provide lump-sum rebates to low-income households are less distortionary than lowering marginal water prices

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract

In the US, the cost of water and wastewater services is rising three-times faster than inflation. Over the next 20–25 years, required investments in water infrastructure are estimated to exceed $1 trillion, further increasing service costs. Combined with stagnating income levels, especially for poor households, increased costs will likely aggravate water affordability issues. Here, we document the extent of water affordability concerns in the US across income, geography, and race. We find that 10% of households face water affordability concerns, defined as expenditures on essential water and sewer services greater than 4.5% of annual household income. Households in the lowest income decile pay on average 6.8% of their annual income on water and sewer service. Our estimates are based on a large-scale data set on water and sewer rates matched with Census block-group-level socioeconomic characteristics and covering approximately 45% of the US population. We demonstrate that using median household income at the county level drastically understates the extent of the water affordability problem. Additionally, we find that the number of households facing affordability concerns is positively associated with the proportion of black residents and negatively associated with Hispanic residents even after conditioning on prices and poverty levels. Lastly, we show that self-sufficient water affordability policies that provide a lump-sum rebate to low-income households and are paid for by income taxes redistribute the burden borne by low-income customers with fewer unintended consequences for non-essential consumption than policies that change marginal incentives for water and sewer consumption.

Plain Language Summary

Provision of affordable water and sewer service is a growing concern in the United States, although the extent of the problem is not known and the effectiveness of different policy options are underexplored. We compile a database of water and sewer prices for approximately 45% of the United States population to estimate annual expenditures on water and sewer service. We find that nearly one in ten households spend more than 4.5% of their annual household income on water and sewer service, and that affordability concerns are correlated with race after conditioning on poverty levels. Our results have implications for how to characterize water affordability and for how corrective distributional policies can be designed most effectively.

1. Introduction

Water is necessary for human survival. The United Nations identified "equitable access to safe and clean drinking water and sanitation as an integral component of the realization of all human rights" (UN General Assembly, 2010). Water is also an economic good, whose price should reflect its value to society and the long-run costs associated with its treatment and distribution to customers (Olmstead, 2010). Utilities typically price water to recover costs of provision and recent evidence suggests that utilities do not price water to reflect scarcity (Luby et al., 2018). To maintain current levels of service in the United States, however, water and wastewater infrastructure will require substantial investment over the next several decades, with some estimates totaling more than 1-trillion USD (American Water Works Association, 2012). Compliance with the US Environmental Protection Agency's (EPA) Clean Water Act and Safe Drinking Water Act further adds to water supply costs (Jerch, 2019; National Academy of Public Administration, 2017). The vast majority of those costs will end up on household water and wastewater bills, potentially tripling the current cost of water and sewer service for US households (American Water Works Association, 2012). Water providers are thus faced with balancing multiple, competing objectives: efficient pricing, covering costs, and also keeping water bills affordable (Martins et al., 2016; Whittington et al., 2015).

In this paper, we demonstrate how widespread water affordability issues are in the US, how policies can be designed to reduce burdens on low-income populations, and how underlying economic incentives drive policy effectiveness. We estimate that approximately 10% of households in the US face water affordability concerns

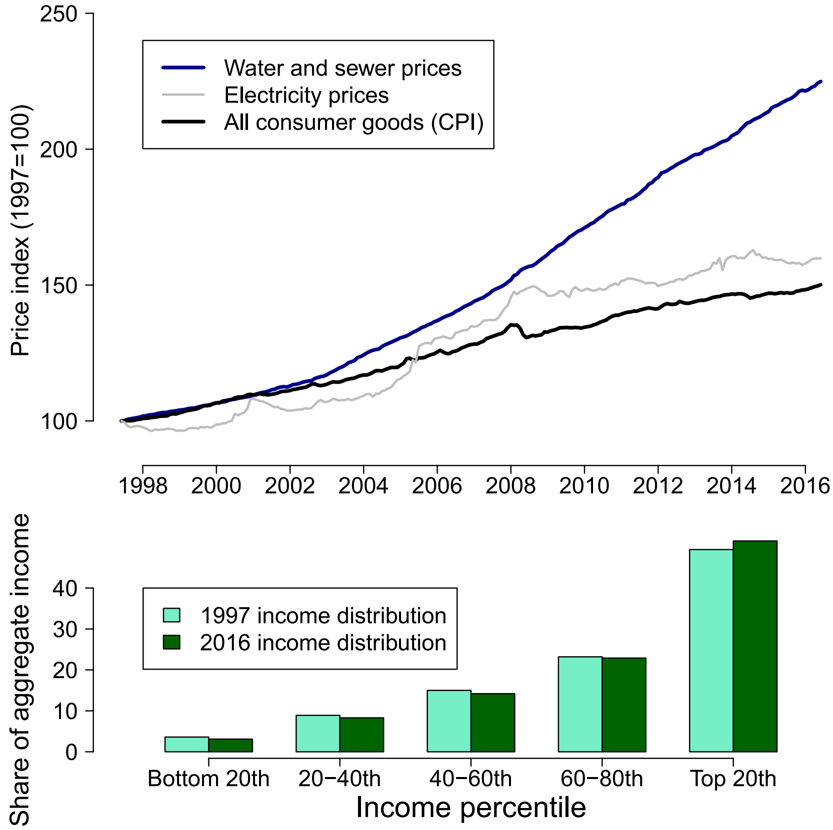

Figure 1. U.S. price indexes and income distribution over time. Top panel: monthly price (U.S. city average, all urban consumers, seasonally adjusted) for all consumer goods, electricity, and water and sewer. Series begins in December 1997 (=100). Water and sewer price index includes trash collection. *Source*: U.S. Bureau of Labor Statistics. Bottom panel: Share of aggregate income received by each fifth of households in 1997 and 2016. *Source*: U.S. Census Bureau, Current Population Survey, Annual Social and Economic Supplements.

by assembling a large-scale data set of water and sewer rates, using rate structures from 1,545 utilities and covering approximately 45% of the US population. Our data set is compiled from rates surveys conducted by the Environmental Finance Center at the University of North Carolina at Chapel Hill (UNC EFC) and the American Water Works Association (AWWA) and includes water and sewer prices matched with community-level socioeconomic characteristics and typical water use. With these data, we show the importance of using the full income distribution at a local level, rather than median household income (MHI), for accurately capturing the water affordability burden for low-income households. We estimate that households in the lowest income decile spend on average 6.8% of their annual income on essential water and sewer services. Additionally, we find that water affordability concerns are positively associated with the proportion of black residents and negatively associated with Hispanic residents within a Census block-group even after conditioning on prices and poverty rates. Finally, we investigate the effectiveness of different policies designed to alleviate affordability concerns. To do so, we simulate the effects of self-funded assistance programs that combine different benefits—lower water rates versus rebates—and funding sources—higher water rates versus local income taxes for non-assisted households. We show that, relative to policies that change marginal incentives for water and sewer consumption, policies that provide a lump-sum rebate to low-income households and are paid for by income taxes achieve affordability targets with fewer additional distortions to total household expenditures and water conservation.

In the US, recent trends suggest that the cost of water and wastewater is rising three times faster than other goods and services at a time when economic inequality is increasing (Figure 1). States and municipal authorities are beginning to develop policies to reduce the burden of water and sewer bills for low-income households. In 2015, California passed a law to develop a statewide low-income water rate assistance program (California State Assembly, 2015) an, the City of Philadelphia implemented in July 2017 the nation's first income-based water rates (City of Philadelphia, 2015), and many utilities are adopting low-income water rate assistance programs. In 2021, in response to the increased stringency of water affordability issues during the COVID-19 pandemic, the federal government started the Low Income Household Water Assistance Program (LIHWAP). The LIHWAP provides grants to states in order to fund programs that assist low-income households with water and wastewater bills. In this paper, we provide wide-scale estimates of the extent of the water affordability problem and our results contribute to the design of effective water affordability policies.

An emerging strand of the literature has paid increasing attention to water affordability and the geographic distribution of the most vulnerable communities, though few nationwide estimates are available. In perhaps the first paper to perform such a calculation, Mack and Wrase (2017) provide a large-scale geographic assessment of communities that are at-risk of water poverty, although their analysis relies on several limiting assumptions. The authors evaluate water bills at a constant level much larger than typical household consumption levels and overlook geographic differences in water prices and consumption patterns, resulting in an assumption that every household in the country spends $120 per month in water bills. Moreover, that study evaluates affordability using the median income at the Census-tract level, which limits the validity and usefulness of those estimates because it ignores the lower part of the income distribution where affordability concerns are likely more prevalent. In practice, these assumptions are equivalent to a fixed-income threshold that assigns unaffordable water services to all households in any Census tract with median annual income below $32,000. In the present manuscript, we approach a similar question with much more tenable assumptions. By examining the full household income distribution at a finer resolution, our framework not only addresses the shortcomings of previous analyses but also provides a richer set of policy-relevant results that allow for policy simulations and assessment of distributional impacts.

In another related study, Teodoro (2018) offers a critique of EPA's affordability metric. The author proposes two metrics that assess water and sewer bills relative to alternative income measurements: hourly minimum wage or the 20th percentile of household disposable income. Bases on these two metrics, the study then estimates the extent of affordability concerns for the 25 largest cities in the United States. In a subsequent paper, the author expands the analysis and estimates affordability metrics to a stratified sample of 360 utilities covering a served population of 38 million (Teodoro, 2019). In an update to that analysis, Teodoro and Saywitz (2020) replicate the framework using an expanded set of utilities and data that is 2-years more recent, which shows that affordability concerns have increased. Additionally, in a parallel effort, Patterson and Doyle (2021) develop a geographically detailed data set of water rates and demographic characteristics for nearly 2,000 utilities in four states. Patterson and Doyle (2021) compare and contrast five different metrics of affordability. They adopt a metric similar to ours in which water expenditures are compared to household income across the distribution of income, which allows policymakers to evaluate the consequences of alternative income thresholds.

Though similar in spirit, the descriptive component of our paper emphasizes the need to evaluate water affordability while accounting for full income distribution rather than specific quantiles. In doing so, our method delivers a flexible metric that not only informs policymakers about the consequences of their choices but also—and most importantly—allows for a detailed evaluation of potential policies to alleviate concerns about water affordability. In the Supporting Information S1, we provide a detailed comparison to the methods proposed in Mack and Wrase (2017), Teodoro (2018), Raucher et al. (2019), and Patterson and Doyle (2021) and discuss their differences and complementarities.

1.1. Measuring Affordability

EPA's oft-used threshold for determining a "high burden" of water and sewer bills—whether combined water and sewer bills (CWSBs) exceed 4.5% of a community's median household income—has received increasing scrutiny as an adequate measure of a household's ability to pay for water and sewer services (Mumm & Ciaccia, 2017; National Academy of Public Administration, 2017; Teodoro, 2018). The origins of this median household income threshold can be traced back to EPA guidance for determining economic impacts of water quality regulations, but no formal justification for the level of the threshold was provided (U.S. EPA, 1995, 1997). Common concerns are that using median household income at a community level poorly captures the burdens on the most vulnerable low-income residents and the 4.5% threshold (for CWSBs) is arbitrary; some of these concerns have been included in more recent guidance for the evaluation of financial capabilities of local governments in providing clean water (U.S. EPA, 2020). In this analysis, we follow the panel recommendations from the National Academy

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of Public Administration (NAPA) for defining community affordability criteria for clean water services (National Academy of Public Administration, 2017). These recommendations include development of an improved affordability metric that is: (a) readily available from public data sources; (b) clearly defined and understood; (c) simple, direct, and consistent, (d) valid and reliable according to conventional research standards, and (e) applicable for comparative analyses.

In line with current EPA guidance and forward-looking NAPA recommendations, we put forward transparent and readily calculable metrics for ease of communication and decision-making by policymakers. Furthermore, we contrast the burden of water and sewer expenditures under varying definitions of water affordability. Our preferred affordability measure is defined as the proportion of households that pays more than 4.5% of annual household income on water and sewer service at the essential level of consumption (50 gallons per person-day, or gppd). We adopt 50 gppd as our level of essential water use following Raucher et al. (2019), Teodoro (2019), and Patterson and Doyle (2021). We apply that standard at different income and geographic resolutions, and consider alternative levels of consumption. Moreover, the 4.5% threshold is readily scalable to different income thresholds—a higher threshold leads to a lower population not meeting the affordability criteria and vice-versa. Patterson and Doyle (2021) interpret their results relative to the amount of days of labor required to pay for water services, which is consistent with the rule-of-thumb suggested by Teodoro (2018) that households should not have to work more than eight hours at the minimum wage to afford water service. Incidentally, as Patterson and Doyle (2021) report, one day of labor translates to 4.6% of monthly income. So, by adopting 4.5% of income as an affordability threshold in our paper, we can present results that are consistent with EPA's threshold (which was never intended to be applied at the household level) as well as more recent frameworks to assess household-level affordability. That said, because all such thresholds are subjective policy choices, we reiterate that we do not take a stand on the definition of affordability, but we use a 4.5%-of-income threshold for convenience, to compare with other estimates, and to contrast with EPA's commonly used threshold. For context, the average US household spends 4.6% of their annual income on health insurance and 4.6% percent of their income on food away from home, according to the 2017 Bureau of Labor Statistics Consumer Expenditure Survey.

2. Materials and Methods

2.1. Data and Calculations

Our primary data set contains water and sewer rates from 1,545 utilities that cover 92,445 Census block groups from 521 counties across 42 states. This sample corresponds to approximately 52 million households and 145 million people, which comprises 45% of the total U.S. population as of 2016. This data set combines local water and sewer rates, number of service accounts, average consumption, climate characteristics, and a variety of socioeconomic indicators.

We consider three levels of geographic resolution (or aggregation). The unit of observation in the lowest resolution (the highest aggregation) is a county, which considers a representative household that has its characteristics matching county averages. Similarly, in the second resolution level, each block group is represented by a single household with the block-group median/average characteristics; for reference, Census block groups are small geographic areas with typical population between 600 and 3,000 individuals. In the third and highest resolution level, block groups are represented by 16 households that share the same socio-demographic characteristics but with different incomes corresponding to the center of US Census income brackets. Each of the 16 households has a different weight that matches the block-group income distribution.

Water and sewer rates are obtained from two sources: rate surveys cataloged by the Environmental Finance Center at the University of North Carolina at Chapel Hill (EFC), current as of 1 July 2017, and the 2016 AWWA Water and Wastewater Rate Survey. Geo-referenced data on the service area of each water district are rare, thus hindering the matching between block groups and utility companies. To overcome this limitation, we aggregate water and sewer rates to the county level, weighted by the number of accounts in each utility. Hence, the coverage of our data set reflects the households within the limits of the counties included. Aggregating CWSBs to the county level may introduce error for counties that contain multiple utilities. Many counties comprise one primary city that provides water service and some of our utilities are operated by counties themselves; for these utilities, the county aggregation introduces very little error. For counties containing multiple utilities, this process introduces measurement error into our CWSB estimate. Drivers of utility costs (e.g., water supplies, climatic conditions, regulations, system age, and so forth) tend to be spatially correlated, although our approach does introduce potential bias in an unknown direction. At a minimum, this aggregation tends to equalize the price signal across geography, which can overstate household expenses for utilities with lower-than-average prices and understate expenses for utilities with higher-than-average prices. To account for block rates, we approximate rate structures as a piecewise linear function of consumption with up to three rate blocks.

Our main water affordability metrics are based on the CWSB for a fixed level of water consumption deemed essential. We report metrics for an essential consumption at 50 gppd. To gauge the sensitivity of these metrics to the chosen consumption level we also consider alternative scenarios for levels at 40, 60, and 75 gppd. The focus on expenditures at a minimum level aligns with concerns of affordable water and sewer services for basic household needs and dignity. In doing so, these metrics intend to be robust to non-essential water use that could lead to a large CWSB.

Formally, affordability metrics are calculated as follows. Let b and c denote the block group and county, and i denote a node of the 16-node income distribution given by Census. Monthly household consumption in a block group is given by

$$W_{bc} = 30 \times h_{bc} \times \omega, \quad (1)$$

where h_{bc} is the average household size in a block group and ω is the essential daily per capita consumption level. Let Φ_c be the function mapping monthly water consumption to CWSBs for households in a county. Then, the annual share of income corresponding to the CWSB for a household in income node i is

$$\hat{s}_{ibc} = \frac{12 \times \Phi\left(W_{bc}\right)}{y_i}. \quad (2)$$

2.2. Estimation of Socioeconomic and Demographic Conditional Correlations

We investigate whether local water affordability is correlated with a set of local socioeconomic and demographic factors including:

1. Population density, measured in persons per square mile.
2. The percentage of a block group population that identifies their race as Black or African American alone.
3. The percentage of a block group population that identifies being of Hispanic or Latino origin.
4. The percentages of households with income below the Census Bureau poverty threshold, and with income between one and two times that threshold.
5. The median age of housing units.
6. The median gross rent as a percentage of the household income.
7. The average household size.
8. The percentage of rented units relative to all occupied units.

Local affordability is calculated using the distribution of income and CWSBs within each block group. In particular, the affordability metric of interest is the percentage of households with CWSBs above 4.5% of their income calculated with the essential consumption level, which we represent by $\hat{U}_{bc}$.

We estimate conditional correlations by estimating the parameter vector $\mathbf{\Gamma}$ in

$$\hat{U}_{bc} = \mathbf{X}_{bc}'\mathbf{\Gamma} + \sum_{z \in Z} \gamma_z 1\left(CZ_c = z\right) + \sum_{s \in S} \delta_s 1\left(State_c = s\right) + u_{bc}, \quad (3)$$

where $\mathbf{X}_{bc}$ is the vector of local socioeconomic and demographic factors defined above. The remaining terms in the equation represent, respectively, climate zone (CZ_c) fixed effects, state fixed effects, and an idiosyncratic error term, u_{bc}.

2.3. Policy Simulations

Local affordability metrics provide useful tools to identify affordability concerns at the community level. However, these metrics do not offer guidance on how to remediate concerns. Affordability policies can reduce the burden of water and sewer bills for low-income customers, although there is virtually no comparative research highlighting the relative effectiveness of different types of programs despite policies being adopted at scale. Assistance programs can change the incentives to consume and pay for water, with further impacts to total CWSBs and aggregate water consumption. A holistic assessment of the relative advantages of each policy needs to look beyond essential consumption and examine how households' responses to the different incentives affect expenditures and water conservation. To do so, we simulate the effects of different assistance programs on the total income share households allocate to water services and changes in volumetric water use above the essential level.

Our policy simulations are simplistic by design, although they possess the key elements inherent in many water affordability policies (California State Assembly, 2015; City of Philadelphia, 2015). In our framework, households above the 4.5% affordability threshold for essential use (50 gppd) are eligible for aid and those below the threshold are not. We consider four illustrative policy options that differ in how programs reduce water and sewer expenditures for low-income customers and in how the programs are funded. In our scenarios, low-income assistance takes the form of a uniform lump-sum transfer or a 50% rate discount for eligible households. These programs are funded either by a uniform water rate increase or a local income tax on non-eligible households. All affordability programs are assumed to be administered at the county level. These options are illustrative and abstract from local regulations that prohibit using water prices for redistributive purposes and any prevailing water affordability programs or rate structures (e.g., "lifeline" rates) that are currently in use. Additionally, we abstract from costs associated with policy implementation.

For each policy option, we adjust households' water consumption given changes in prices and income. These adjustments are based on a constant price elasticity $\epsilon_p = -0.3$ (Dalhuisen et al., 2003), a constant income elasticity $\epsilon_y = 0.1$ (Havranek et al., 2018), and initial household consumption at the estimated level (see the Supporting Information S1 for details of the estimation model and sensitivity analyses on these parameter choices). We note that estimated levels can offer only an imprecise approximation of current household consumption. However, this approximation suffices as our focus is on the relative—rather than the absolute—performance of different policy options. These illustrations demonstrate key mechanisms of assistance programs but their results should not be interpreted as predictive of absolute levels of affordability concerns.

To make a fair comparison of outcomes, all four programs have the same size, set equal to the dollar amount needed to cover the 50% rate discount option. To determine the size of the programs in each county, we first adjust water consumption for assisted households based on a 50% rate discount in all rate blocks. Then, we calculate the amount necessary to fund these discounts. We set uniform lump-sum transfers that match the size of the rate discount program. Similarly, we calculate the uniform income tax rate and the price increase needed to fund the assistance programs in each county. We assume general equilibrium changes (e.g., changes in labor supply) in response to small income changes are negligible. The average-income tax rate increase is 0.1 percentage points and the average lump-sum transfer is $34.6 per month.

3. Results

3.1. High-Resolution Income Data and Local Prices Are Critical for Measuring Household-Level Water Affordability

We calculate the number of households whose annual CWSBs exceed 4.5% of their annual household income for different definitions of income and consumption in Table 1. Comparing average water and sewer consumption at the county level with 4.5% of county-level median household income identifies virtually no households with unaffordable water and sewer service in our sample. But this is clearly misleading as it tells us only about a household with median income. Narrowing the geographic area at which we apply our median-income threshold provides a better approximation of local income distributions. Using median household income at the Census block-group level induces a modest increase in the proportion of households that exceed the water and sewer affordability threshold—0.8% for 50 gallons per person per day (gppd) and 2.2% for 75 gppd. In these results, 50 gppd is intended to capture essential water consumption; 75 gppd approximates the sample mean of reported county-average consumption of 78.1 gppd.

By using income-group midpoints of a 16-node income distribution at the block-group level to calculate affordability (see Supporting Information S1), we determine that 10.0% of households have CWSB greater than 4.5% of income for essential consumption levels. These quantities are 4–12 times greater than quantities calculated with

Table 1
Percentage of Households Who Pay More Than 4.5% of Annual Household Income on Combined Water and Sewer Bills by Income and Consumption Data Resolution

		Consumption level			
Unit of analysis	Income metric[a]	40 gppd (%)	50 gppd (%)	60 gppd (%)	75 gppd (%)
County	Median household income	0.00	0.00	0.00	0.00
Block group	Median household income	0.50	0.79	1.21	2.15
Block group	Income bracket midpoint	8.44	10.03	11.67	14.21

[a]"Median household income" represents median incomes at the county or block-group level. "Income bracket midpoint" measures incomes at the midpoint of income brackets evaluated at the block-group level.

coarser income information based on median household income. This result is driven by the fact that we are able to identify more households with unaffordable water by using more granular data on income. Income aggregation reduces our ability to identify households in the very low portion of the income distribution. When calculating the distributional burden of water and sewer expenditures, it is critical to capture the local income distribution in its entirety.

3.2. One Out of Every Ten Households Spends More Than 4.5% of Annual Income on Essential Water and Sewer Services

As shown in Table 1 and Figure 2, around 10% of households in our sample face water and sewer service rates for essential consumption (50 gppd) that exceed the 4.5% of income affordability threshold. This estimate corresponds to more than 5-million households in our sample; a nationally representative estimate of the number of households with unaffordable water and sewer services would be much larger. We obtain this estimate by applying the 4.5% affordability threshold to representative households within a 16-node income distribution for each Census block groups. Although the choice of 4.5% is arbitrary, this threshold provides a useful benchmark to compare the burden of water and sewer expenditures across geographies. Furthermore, our method is flexible in this sense and can be applied at any income threshold.

We also calculate the proportion of households above the affordability threshold based on alternative levels of consumption per person-day. As shown in Figure 3, evaluating affordability at 75 gppd (approximately the average estimated consumption level) indicates that about 14%—one out of every seven—households pay more than 4.5% of their annual income on water and sewer bills. At 40 gppd—about half of the average consumption level—unaffordability still affects one out of every 12 households in our sample. Moreover, from the focal value of 50 gppd, we note that an increase (decrease) of 10 gppd in the target essential consumption leads to an increase (decrease) of about 1.6% points in the households above the affordability threshold.

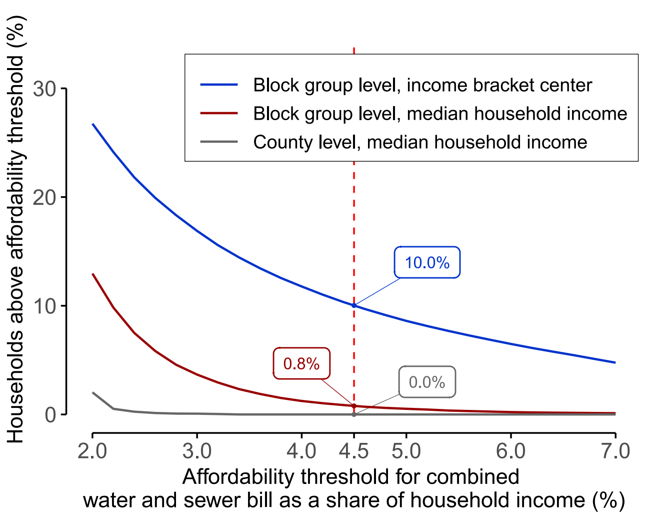

Figure 2. Proportion of households above affordability threshold for essential water and sewer expenditure as a share of income, based on varying degrees of income data resolution.

3.3. Households in the Lowest Income Bracket Pay 6.8% of Annual Income on Essential Water and Sewer Services

We calculate the burden of water and sewer bills for each income bracket and aggregate the results into 10 brackets that approximately reflect income deciles. As shown in Table 2, households with annual income less than $15,000 have, on average, essential water and sewer services that cost 6.8% of household income. This statistic represents 11.4% of households in our sample. For contrast, households in the $45,000–$59,999 income group, near the US median household income, spend on average 1.2% of their annual household income on water and sewer bills. For the top income group—households earning $200,000 or more—this statistic is only 0.3%. This analysis reveals that the vast majority of households facing unaffordable water service are concentrated in the lowest income deciles.

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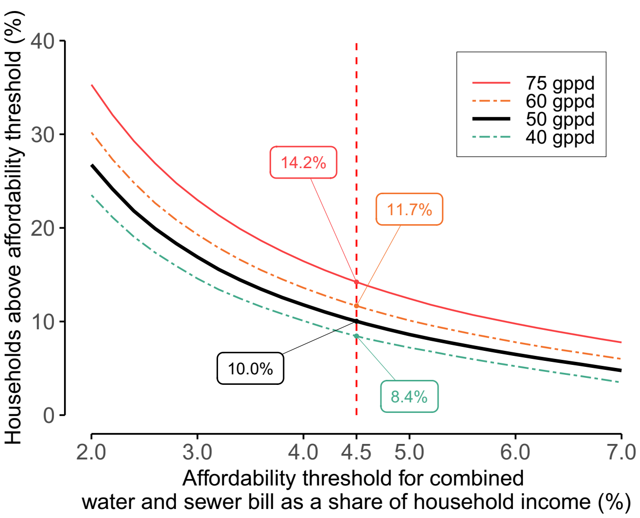

Figure 3. Proportion of households above affordability threshold for water and sewer expenditure as a share of income, based on varying levels of daily per capita consumption (in gallons per capita-day).

These results highlight the regressivity of water and sewer bills relative to contemporaneous income. Nevertheless, the literature on the expenditure burden of energy taxes has indicated that, due to limitations of contemporaneous income measurements, metrics that incorporate life-cycles might provide a more appropriate assessment (Hassett et al., 2009; West & Williams III, 2004). In the Supporting Information S1, we compare water and sewer expenditures to total household expenditure—a proxy for lifetime income. We find that water bills are still regressive even under alternative metrics of income.

3.4. Water Affordability Concerns Are Pervasive Across the US, Driven by the Local Income Distribution

Geographically, we find some differences in water affordability across the US. In panel (a) of Figure 4, we plot the proportion of households with unaffordable water within each county. We calculate affordability based on the essential consumption level (see Section 2). Some counties in the desert Southwest display high levels of unaffordable service, with rates of unaffordable water exceeding 25% of households. Several states in the Southeast also possess counties with high rates of unaffordable water and sewer bills.

County-level comparisons, however, mask important heterogeneity at a finer geographic scale. In panels (b–d) of Figure 4, we plot the same metric evaluated at the Census block-group level. This analysis reveals pockets of water affordability concerns at a more local level. In the Southeast (panel (e)), we observe a patchwork of block groups with high rates of households with unaffordable water bills. Even in the relatively wealthy Northeast (panel (d)), we identify many Census block groups with more than 25% of households facing unaffordable water and sewer services.

Local maps also illustrate the importance of analyzing water affordability issues at a high resolution. Figure 5 shows the percentage of households facing unaffordable water services in block groups of counties corresponding to two large urban areas: Atlanta, GA, and Chicago, IL. In these cities, we observe clusters of block groups with households facing unaffordable water, which in many cases geographically correlates with low-income areas. The high resolution of the data also allows us to identify several isolated pockets of water affordability concerns.

Table 2
Expenditure on Water and Sewer Relative to Income by Income Bracket[a]

Annual income[a]	Frequency (thousands)	Percentage (%)	Percentile	Average CWSB/ income (%)[b]
Under $15,000	5,923	11.4	11.4	6.8
$15,000–$24,999	4,988	9.6	21.0	3.1
$25,000–$34,999	4,899	9.4	30.5	2.1
$35,000–$44,999	4,620	8.9	39.4	1.6
$45,000–$59,999	6,036	11.6	51.0	1.2
$60,000–$74,999	5,092	9.8	60.8	1.0
$75,000–$99,999	6,361	12.3	73.0	0.8
$100,000–$124,999	4,517	8.7	81.7	0.6
$125,000–$199,999	6,013	11.6	93.3	0.4
$200,000 and over	3,468	6.7	100.0	0.3

[a]Income distribution data are obtained from the U.S. Census 2016 5-Year American Community Survey. Frequencies, percentages, and percentiles are relative to the aggregate income distribution in our sample. [b]Combined water and sewer bills (CWSB) are evaluated at 50 gppd.

Overall, we find evidence that water affordability concerns are pervasive in the Southwest and Southeast. However, we also uncover serious concerns within states and within urban areas across the United States. Because of these findings, we conclude that affordability concerns are inherently a local issue dictated by the distribution of income within a community.

3.5. Water Affordability Concerns Are Significantly Correlated With Select Community Characteristics

We conduct a statistical analysis to test whether the proportion of households with unaffordable water and sewer service is significantly correlated with socio-economic-demographic community characteristics. To develop statistical tests of conditional correlation, we regress the proportion of households above the affordability threshold on community characteristics and state and climate-zone fixed effects. Furthermore, we note that calculated affordability metrics are, by construction, non-linear functions of income distributions, household sizes, and rate schedules. We include indicators of prices and poverty to control for the linear association of these factors with affordability metrics (see Section 2 and Supporting Information S1 for our detailed statistical methodology).

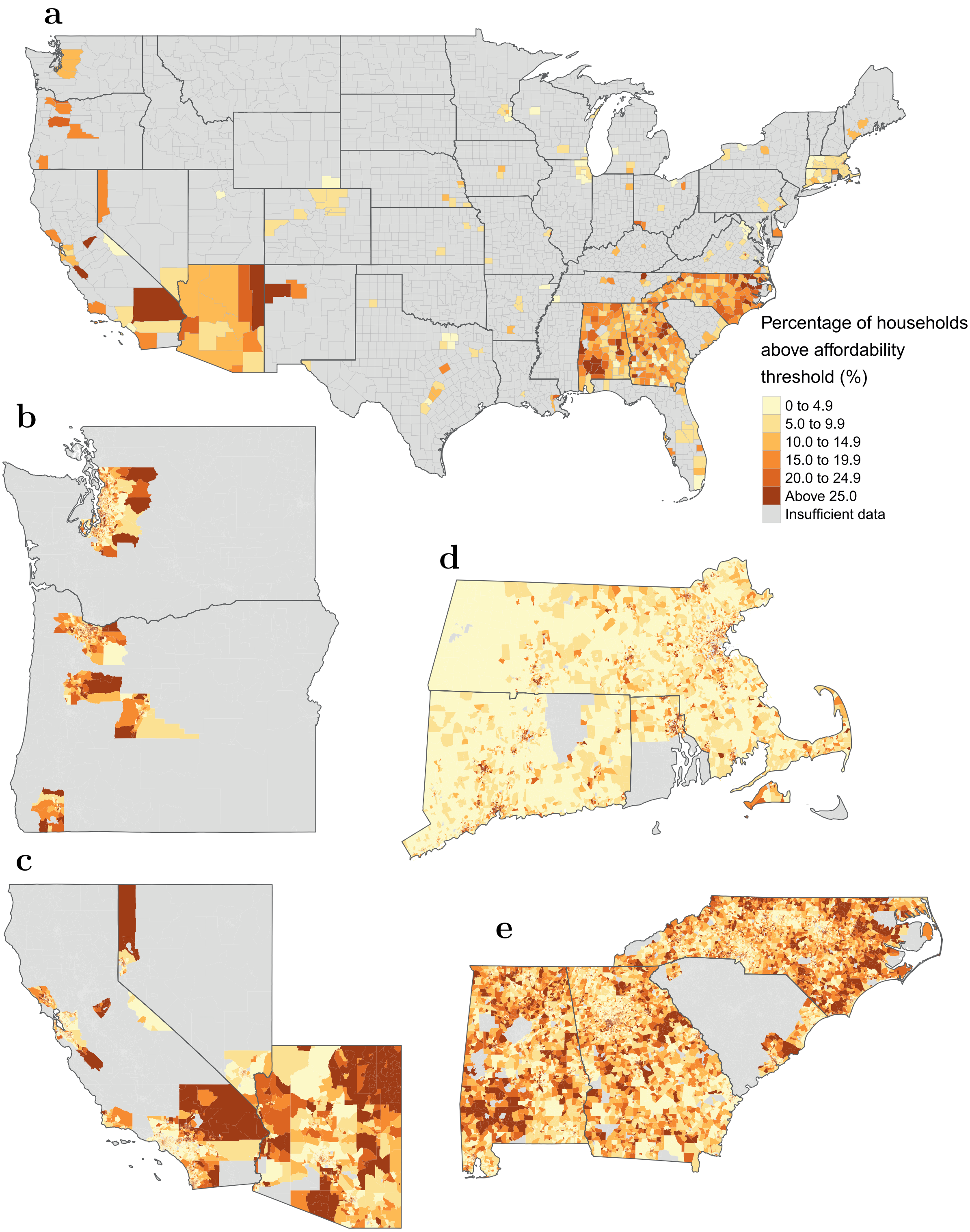

Figure 4. Geographic distribution of water affordability within regions. Shaded colors show the percentage of households within each county (in a) and census block group (in b–e) that have combined water and sewer bills (CWSBs) above 4.5% of annual household income. CWSBs are calculated at the essential consumption level of 50 gallons per person-day.

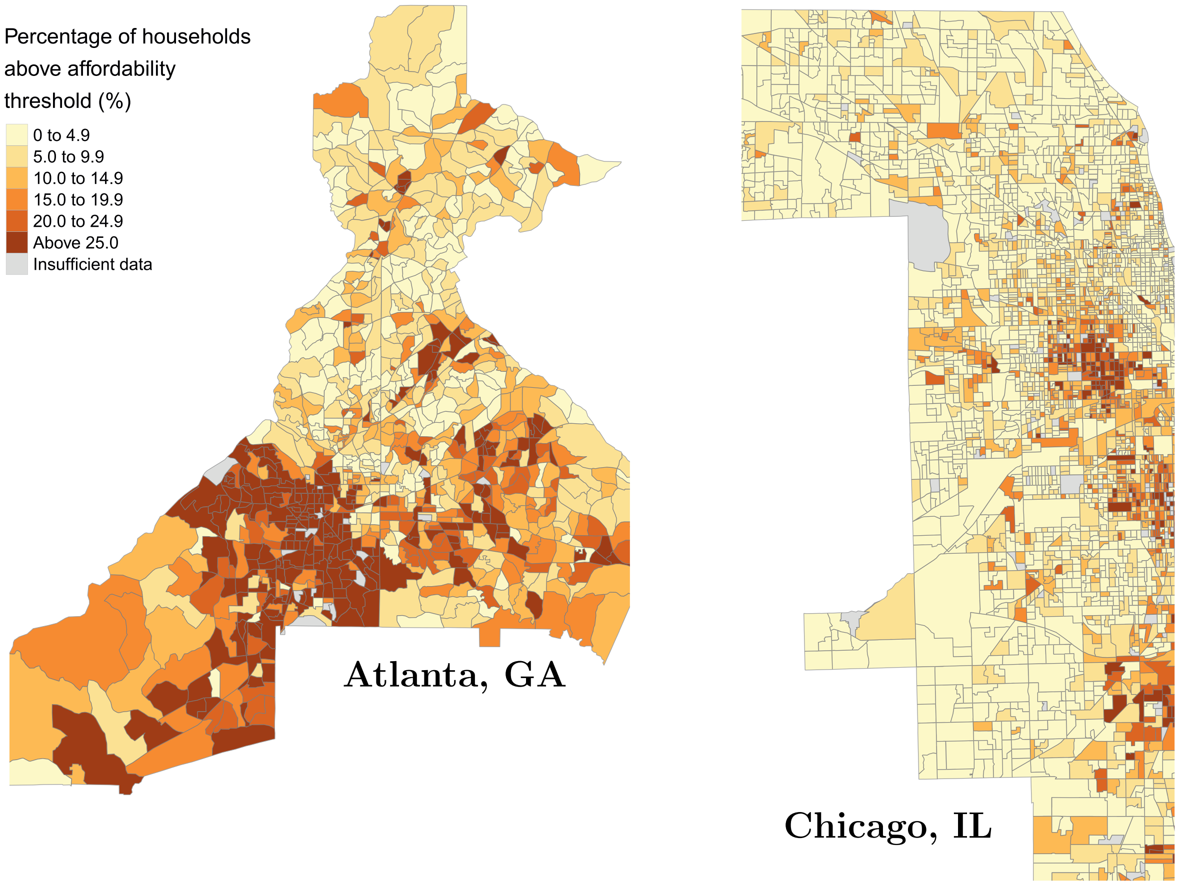

Figure 5. Geographic distribution of water affordability in block groups within urban areas. Results are presented for Atlanta, GA (DeKalb and Fulton counties) and Chicago, IL (Cook county). Shaded colors show the percentage of households within each Census block group that have combined water and sewer bills (CWSBs) above 4.5% of annual household income. CWSBs are calculated at the essential consumption level of 50 gallons per person-day.

Table 3 shows the estimated conditional correlation coefficients between the proportion of households facing unaffordable CWSBs and select community characteristics. Confidence intervals are based on standard errors clustered at the county level. The percentage of the population below the federal poverty limit is strongly associated with the prevalence of water affordability concerns. A one percentage point increase in the number of households below the poverty limit is associated with a 0.492 [0.448, 0.536; 95% CI] percentage points increase in the number of households above the affordability threshold. Additionally, we report a significant positive relationship between water affordability concerns and the proportion of black households within a community (0.019 [0.002, 0.036; 95% CI]) even after controlling for poverty levels. However, results indicate the opposite for the relationship between affordability and the proportion of Hispanic residents (−0.023 [−0.043, 0.004; 95% CI]). We also find a small positive correlation between affordability concerns and the proportion of renters within a block group and the median cost of rent relative to income. However, this correlation has limited economic significance since we do not observe whether renters directly pay for their water bills.

Additionally, by using the natural log of population density as a proxy of urbanicity, we find that population density has a negative association with the proportion of households above the affordability threshold. A one log-point increase in population density is associated with a −0.507 [−0.711, −0.302; 95% CI] percentage point decrease in the number of households above the affordability threshold. The magnitude of this effect, however, is quite small. In other words, a one-percent increase in population density is associated with a −0.005% point decrease in affordability concerns. Nevertheless, we believe that we are more likely to falsely assign rural households to utilities when they might in fact not receive public water or sewer service (e.g., rural households are more likely to have septic systems and thus not pay for sewer services directly). As a result, we cannot rule out that water affordability might be a concern for both urban and rural areas.

Table 3
Conditional Correlations Between Water Affordability and Select Socioeconomic Characteristics[a]

	Coef.	SE	95% CI
log(Population density) (Persons/Sq. mi)	−0.507	0.104	[−0.711,−0.302]
Average household size (Persons)	0.925	0.367	[0.206, 1.644]
log(Volumetric rate at 5–10 ccf) (USD/1,000 gallons)	8.419	1.257	[5.956, 10.882]
Base charge relative to CWSB at essential level (%)	0.115	0.025	[0.066, 0.164]
Households below poverty level (%)	0.492	0.023	[0.448, 0.536]
Households between 1 and 2× poverty level (%)	0.100	0.014	[0.073, 0.127]
Median gross rent relative to income (%)	0.058	0.008	[0.042, 0.074]
Occupied units that are rented (%)	0.012	0.006	[0.001, 0.022]
Median age of housing unit (Years)	−0.005	0.007	[−0.019, 0.009]
Population identified as Black/African American (%)	0.019	0.009	[0.002, 0.036]
Population identified as Hispanic/Latino (%)	−0.023	0.010	[−0.043, −0.004]
State fixed effects		Yes	
Climate zone fixed effects		Yes	
Observations		76,240	
R^2		0.571	
F-statistic		1693.31	

[a]Dependent variable is the percentage of households in a block group above the 4.5% water affordability threshold calculated at the essential consumption level (50 gallons per person-day). The mean of the dependent variable is 11.49 and its standard deviation is 11.67. Summary statistics for other variables are presented in Supporting Information S1. Standard errors (SE) are clustered at the county level. All variables are defined at the block-group level.

We include two variables that capture the role of water rate-setting practices. One variable captures the mean volumetric price for monthly consumption between 5 and 10 ccf. This variable is positively associated with water affordability concerns. A one log-point increase in average water rates is positively correlated (8.419 [5.956, 10.882; 95% CI]) with the proportion of households above the affordability threshold. Put another way, a one-percent increase in volumetric water rates is associated with a 0.084% point increase in the proportion of households with water affordability concerns. A second variable captures the proportion of a customer's bill (evaluated at 50 gppd) that is composed of the fixed access charge. This variable is also positively correlated with the proportion of households with unaffordable water (0.115 [0.066, 0.164; 95% CI]), which suggests that affordability concerns are not driven entirely by the volumetric price of water and sewer services, but also the fixed service fee.

Overall, the proportion of impoverished households within a block-group and average water prices are strongly associated with unaffordable water. We also find evidence that the proportion of black households is correlated with unaffordable water after conditioning on poverty levels and other socioeconomic characteristics. This correlation, however, is reversed when we consider the proportion of Hispanic residents within a block group. Additionally, we find positive correlations between water affordability concerns and household size as well as median rents as a proportion of household income.

3.6. Affordability Policies That Provide Lump-Sum Rebates for Low-Income Households and Are Funded by Income Taxes Lead to Fewer Unintended Consequences to Total Expenditures and Water Conservation

We compare the effectiveness of four illustrative policies resulting from the combination of two options for the assistance they provide and how they are funded. Assisted households receive either a 50% rate discount or a uniform rebate. Programs are funded by non-assisted households that face either a uniform rate increase or a local income tax increase. Eligible households have an annual income such that a CWSBs at the essential level would represent an income share above 4.5%. While all four programs produce equivalent results in lowering CWSBs at the essential level, they can generate different consequences for total CWSBs and aggregate water consumption.

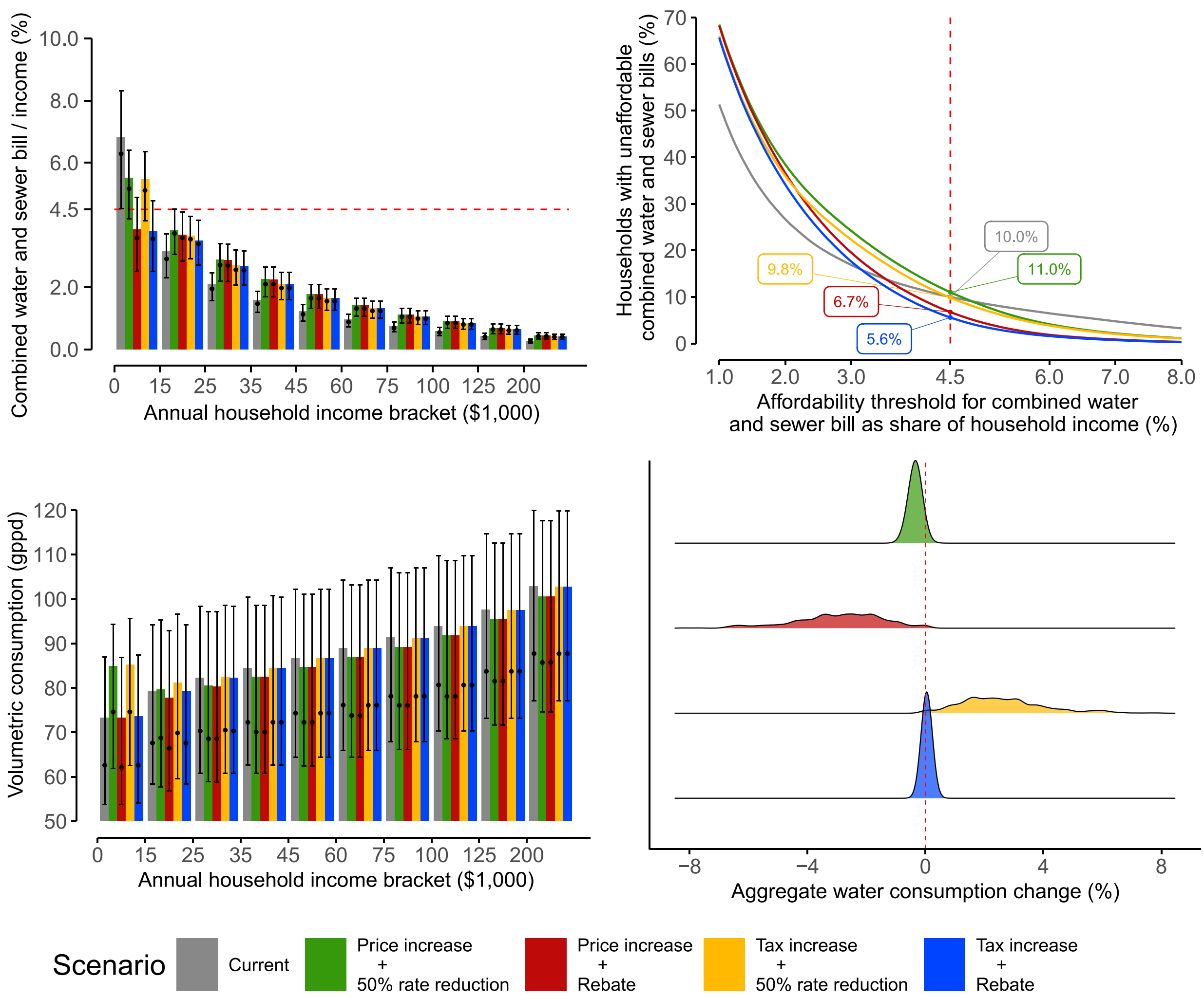

Figure 6. Results of program simulations. Top left panel: Average expenditure shares on water and sewer service by income bracket for business-as-usual and each policy option. Expenditures are based on the estimated level of consumption. Top right panel: Combined water and sewer bill by income bracket for business-as-usual and each policy option. Bottom left panel: Distribution of sample with unaffordable water and sewer expenditures based on affordability threshold for business-as-usual and each policy option. In all bar charts, whiskers show the interquartile ranges and dots represent median values.

Figure 6 shows the relative outcomes of these policies. These comparisons consider initial expenditures in water and sewer services at the estimated level of consumption (an income-based adjustment of average county consumption; see Supporting Information S1 for details). In the top left panel, we show average expenditure shares for the business-as-usual scenario and for each of our four policy options. Each program reduces the average number of households above the affordability threshold, although aid transfers reduce the number of households above the affordability threshold in the lowest income bracket more than rate reductions. For example, at the 4.5% threshold, all programs considered reduce the 75th percentile of CWSBs to less than 7% of annual income, with transfers reducing it further to approximately 5%.

In the top right panel of Figure 6, we plot the change in the number of households above the water affordability threshold for each program. Programs designed with income transfers rather than rate reductions can reduce the number of households with CWSBs above 4.5% of annual income from 11.0% to 6.7%, if funded by rate increases, and from 9.8% to 5.6%, if funded by income taxes. For programs of a similar size, structuring water affordability aid as an income transfer funded by income taxes dominates policy options that alter the unit price of water and sewer consumption. As a practical matter, an income transfer could take the form of individual-specific credits on customer bills (so long as they are not misperceived as a reduction in the price of water (Wichman, 2017)) or

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a rate structure in which households pay different fixed access fees for water and sewer services. This finding is a result of the relative sensitivity of water and sewer consumption to changes in price and income.

Additionally, the bottom panels of Figure 6 show the distribution of changes in household (bottom left) and county-aggregate (bottom right) volumetric water consumption for each policy. Together, these panels illustrate how a narrow focus on affordability at the essential level can produce unintended consequences. Programs that modify the marginal price of water incentivize higher total consumption in assisted households, thus partially undoing the intended affordability effect. This effect is seen in the bottom left panel, where the distribution of assisted household consumption shifts up and can substantially exceed the status quo when 50% discounts are offered, thus also raising their CWSBs due to higher consumption above the essential level. These responses raise a concern about consequences of these programs for water conservation. To examine such consequences, the bottom right panel displays the distribution of percent changes in aggregate water consumption for each county in which we simulate policies. We observe that a policy that offers rate discounts funded by rate increases tends to slightly decrease aggregate water consumption due to reductions from non-assisted households. Nevertheless, if discounts are funded by a mechanism that does not affect the marginal cost for non-assisted families, aggregate water consumption can increase substantially. On the other hand, if both the funding and offered benefit of a policy do not affect marginal incentives for water consumption—as in the tax increase and rebate scenario—changes to aggregate consumption are close to zero.

Our baseline program simulations follow previous findings that the price elasticity of water and sewer demand is greater in absolute magnitude than the income elasticity of water and sewer demand (Dalhuisen et al., 2003; Havranek et al., 2018; Klaiber et al., 2014; Olmstead et al., 2007; Wichman, 2014; Wichman et al., 2016). We report a sensitivity analysis on these parameters in Supporting Information S1. Among other results, our sensitivity analysis shows substantial differences in program performances even when both elasticities have equal magnitude; these findings are due to the fact that price reductions are, in relative terms, a bigger shock than their corresponding lump-sum income increase. Because rate reductions distort marginal incentives for households to consume water more than income transfers do, low-income households tend to consume more water as a result of affordability policies that make additional water use cheaper. This feedback counteracts the goal of the affordability program and may have unintended consequences for water conservation. As a result, it is important to understand the demand implications of water affordability policies.

4. Discussion

In this section, we discuss some limitations of our analysis and their implications; a detailed explanation of robustness checks that explore these implications is presented in Supporting Information S1. First, our sample covers only 45% of the US population, which skews toward urban areas and is not representative of the US. Our population of interest, however, is US residents who receive water and sewer service from public or private water utilities, which mitigates this sample-selection concern. As we show in Supporting Information S1 (Figure S8), the income distribution in our sample is virtually identical to that of the nation as a whole. Moreover, although our sample is not comprehensive, our analysis is based on a large-scale sample that has very strong coverage in a few states and a broad snapshot of utilities of multiple sizes across the US.

Second, our results rely on a metric that has received increasing scrutiny as a useful tool for measuring affordability concerns, in part because the 4.5% of median-household income threshold is arbitrary and median income poorly captures the full income distribution. We have shown empirically the substantial difference that using MHI and the full income distribution can have when measuring affordability. Additionally, two alternative metrics of affordability have been proposed recently and are gaining traction as useful policy tools (Teodoro, 2018). The first is an "affordability ratio" that captures the ratio of essential water and sewer expenditures to a subjective measure of disposable income, evaluated at the 20th percentile of income within a service area. The second is essential water and sewer expenditures in units of hours worked at the minimum wage. Our focus in this analysis is not on contrasting alternative metrics, but we perform a simple comparison in Supporting Information S1. For the 20 overlapping cities in our sample and in Teodoro (2018), our preferred metric correlates strongly with these new metrics, which suggests these alternatives may not dominate an income-based threshold affordability metric at face value (see Table S7 Supporting Information S1). This result is important as income-based thresholds are used in the vast majority of other means-tested assistance programs (e.g., the Supplemental Nutrition Assistance Program, the Low Income Home Energy Assistance Program, and California's proposed statewide Low-Income

Water Rate Assistance Program). Additionally, our affordability metric is readily scalable and can be used holistically in two ways: (a) to identify communities with a high burden of water and sewer expenditures and (b) to establish household-level eligibility in low-income water rate assistance programs.

Third, we calculate household essential consumption using block-group average rather than individual household sizes. Moreover, we assume that household consumption scales linearly with household size (Equation 1). These choices reflect available data limitations, as we are not aware of microdata linking household size, income, and water consumption at scale. However, this approach can bias our estimates of affordability in either direction. If low-income households tend to be larger than richer households within the same block group, our calculations would underestimate the essential household water consumption level and its respective expenditure for poor households. In this case, we would underestimate the proportion of households facing unaffordable water in that block group. Conversely, we would overestimate unaffordability in block groups where poor households tend to be smaller. Census data show that the relation between household income and size is not monotonic: income may increase or decrease with household size depending on the range of size and these ranges vary substantially across states. Therefore, we cannot ascertain a priori the direction of the resulting error that follows from using average household sizes.

Fourth, we do not know whether the representative customers in our sample are homeowners or renters (who may not pay for water and sewer services directly). If the costs of water and sewer services are passed-through to renters fully in the cost of their rent, affordability is still a concern, but it changes the incentives for efficient water use. We know of no large-scale data set that contains this information at the scale of our analysis. To mitigate this concern in our regressions, we control for the proportion of renters within a Census block group and housing rental rates as a proportion of income.

Fifth, our data set construction requires several assumptions to match demographics with utility service areas. We aggregate water rates to the county level, which may not precisely represent the price signal that customers face in counties with multiple utilities. Since we calculate county-average rates weighted by the number of accounts for each utility, this estimation error is likely larger in block groups served by smaller utilities. More recent research (i.e., Patterson and Doyle (2021)) has made great strides in matching water rates data with spatial utility boundaries, which is a useful and necessary advancement to better understand how local demographics interact with utility rate-setting practices.

Lastly, many utilities have existing programs and rate structures for low-income customers across the US. We know of no large-scale database of these types of rate structures or a synthesis of what the eligibility requirements are. Many of these rate structures lower the marginal price for water consumption for customers with low income. In our policy simulations, we show that lowering the marginal price of water counteracts the effectiveness of low-income water rates, which suggests that these "lifeline" rates may be inefficient policies. Exploring ways to address affordability issues for renters and understanding the dynamics of local or more aggregate policies (e.g., state or national) are fruitful areas for future research.

5. Conclusions

Provision of affordable water and sewer service is a growing concern in the United States, although the extent of the problem is not known and the effectiveness of corrective policy options are underexplored. In this paper, we have compiled a database of water and sewer prices for approximately 45% of the United States population to estimate annual expenditures on water and sewer service. We find that nearly one in ten households spend more than 4.5% of their annual household income on essential water and sewer services, and that affordability concerns are significantly correlated with race after conditioning on poverty levels. Our analysis shows the importance of incorporating geographically resolute information on the local income distribution of residents. Results from policy simulations demonstrate that redistributive water affordability policies that do not distort marginal incentives to consume water achieve the same goal of reducing unaffordability at the essential level of consumption as distortive policies but introduce fewer unintended consequences for non-essential expenditures and water conservation.

Our analysis provides a consistent framework to evaluate the extent of the water affordability burden. Importantly, this framework also facilitates the assessment of policies to ameliorate the worst consequences of unaffordable water as municipalities and regulators grapple with alternatives to fund water infrastructure improvements equitably. Ultimately, affordability metrics rely on judgments about what is essential consumption and what defines low-income customers. As illustrated in Figure 3, our framework is easily adaptable to inform and account for the decisions of policymakers over affordability thresholds and essential water consumption.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

The data used to generate all results is available at Zenodo via https://doi.org/10.5281/zenodo.6991563 (Cardoso & Wichman, 2022).

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