Measuring Household Affordability for Water and Sewer Utilities

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Rising costs and recent high-profile crises have brought renewed and increasing attention to the affordability of water and sewer service. Meaningful, accurate assessment of affordability is critical as utility leaders seek to serve low-income customers while also raising the revenue necessary to maintain and advance public health and conservation. Unfortunately, the predominant conventional method of measuring household affordability is fundamentally flawed and often misleading. This article advances a more accurate and meaningful method for measuring the affordability of water and sewer service for low-income households. The proposed method accounts for essential household water needs, income disparities, and core nonwater/sewer costs. After detailing the method, the new approach is used to measure water and sewer service affordability in the 25 largest US cities. The article concludes with a discussion of the new method's limits and general guidelines for its use in policymaking and rate design.

This article advances a new method for measuring the affordability of water and sewer service for low-income households. Rising costs and recent high-profile crises have brought renewed and increasing attention to the affordability of water and sewer service for utilities that rely upon rate revenue to meet operating and capital needs. Consequently, communities across the United States and elsewhere are under increasing pressure to ensure that the most economically vulnerable can afford to pay for these essential services in an era of rising costs. Meaningful, accurate assessment of affordability is more critical than ever as utility leaders seek to serve low-income customers while raising the revenue necessary to maintain and advance public health and conservation (LaFrance 2017).

As with any organizational goal, getting affordability right requires measuring affordability accurately; unfortunately, the predominant method of measuring household water and sewer affordability is fundamentally flawed. The conventional approach measures affordability as a community's average cost of water and sewer service as a percentage of that community's median household income (%MHI), with values <2.0 or 2.5%—4.0 or 4.5% combined—deemed "affordable" (Mack & Wrase 2017). Originally intended as a means of gauging a community's overall financial capability for purposes of negotiating regulatory compliance, this standard has been widely misapplied to household affordability. As a result, evaluations of household water and sewer utility affordability are inaccurate at best and misleading at worst.

This article offers a more meaningful and accurate method for measuring the affordability of water and sewer service at the household level. Unlike the conventional approach, the proposed affordability ratio (AR) accounts for essential household water needs and core nonwater/sewer costs. Further, because the main concern for affordability in the United States and other developed countries is for low-income households, the proposed method assesses affordability at the 20th income percentile (AR_{20}), rather than at median income. Basic household water and sewer cost is expressed in terms of hours of labor at minimum wage (HM) and offered as a useful complementary affordability measure. Together, these two metrics offer a more defensible and practically useful way of assessing utility affordability for purposes of budgeting, planning, rate-setting, and policy design.

This article begins by summarizing the current conventional %MHI approach to measuring affordability and the ways in which it fails. The proposed new and improved method is then presented, along with a discussion of its advantages over the conventional approach. As an illustration, the new method is used to measure water and sewer affordability in the 25 most populous US cities. The article concludes with a discussion of the new method's applicability, limitations, and general guidelines for use in budgeting and rate design. Significant portions of the current article draw on Davis and Teodoro (2014), which first introduced the AR method.

THE CONVENTIONAL APPROACH AND WHY IT IS WRONG

As noted previously, the most widely applied method of measuring water and sewer affordability in the United States is to calculate the average residential water and sewer bill for

a given utility as a percentage of the community's MHI. Usually, this percentage is calculated for an entire utility, but sometimes it is calculated for a subset of customers, such as a neighborhood or a census tract. Typically, this percentage is compared with a set affordability standard, most often 2.0% or more, recently, 2.5%. A simple binary declaration follows this standard: if a utility's average bill as %MHI is less than this standard, then it is deemed "affordable"; if it is greater, then it is "unaffordable." Sometimes these %MHI standards are applied separately to water and sewer rates; at other times, they are combined water plus sewer costs. Often used but rarely considered carefully, the 2.0 or 2.5%MHI (4.0 or 4.5%MHI combined) standard has become the default basis for analyzing water and sewer affordability in recent published research (Mack & Wrase 2017, Janzen et al. 2016), with no other rationale than that it is convenient and conventional. Utility rate analysts typically follow suit; the University of North Carolina Environmental Finance Center's Water and Wastewater Rates Dashboard uses the %MHI method to guide rate design, for example (https://efc.sog.unc.edu/reslib/item/north-carolina-water-and-wastewater-rates-dashboard).

Despite its widespread use, the %MHI approach is seriously flawed. The main trouble with using it as a measure of affordability is that it does not measure affordability—at least not at the household level, in the way that most interested observers typically think of affordability. The %MHI method and accompanying 2.0% standard as developed by the US Environmental Protection Agency (USEPA) were intended as a gauge of a community's financial capability for purposes of negotiating regulatory compliance by its utilities. The idea of %MHI as a measure of financial capability can be traced to the USEPA's *Financial Capability Guidebook* (USEPA 1984). Identifying specific %MHI thresholds for determining financial capability appears to emerge from the agency's 1995 guidelines on Water Quality Standards (USEPA 1995) and Combined Sewer Overflow compliance schedule (USEPA 1997). For purposes of assessing financial capability, %MHI values for water and sewer would be calculated separately, with the sum of the two held up against the standard. For example, a 2.0%MHI standard for water and 2.0%MHI standard for sewer implies a 4.0%MHI combined standard. None of these USEPA documents offers a theoretical rationale for the 1.0, 2.0, or 2.5%MHI standards.

It is not clear when or how analysts began to conflate these utility-level financial capability metrics with household-level affordability, but as noted previously, %MHI is now widely used as a household affordability metric. Unfortunately, as a method of measuring household affordability, the %MHI method is flawed in at least four ways.

Average versus essential water use. Using average residential demand as a basis for affordability analysis inflates the cost of water and sewer service for purposes of affordability analysis. In nearly all US utilities of significant size, average residential water consumption is considerably higher than its median—that is, relatively conservative customers greatly outnumber high-volume customers. Consequently, in most utilities, a minority of high-volume customers drive up the average demand that the conventional method uses as the basis for affordability analysis. Further, most American water utilities exhibit significantly greater demand during summers because of residential outdoor irrigation, indicating that much of the "average" water bill is for usage that is not serving basic health needs. Public policy discussions of water and sewer affordability seldom are concerned with the cost of maintaining large lawns, swimming pools, or other discretionary outdoor use. Rather, affordability is typically thought of as the ability of customers to pay for water and sewer services that are adequate to meet their basic needs for drinking, cooking, health, and sanitation. For most US utilities, then, evaluating affordability as a function of average consumption implies an unduly high demand.

Median versus low income. Perhaps the most frequent criticism of the %MHI standard is that its focus on median income misses the real subject of affordability concerns: poor households (Stratus Consulting 2013, Baird 2010, Rubin 2001). The median-income household is unlikely to face serious water and sewer affordability problems in any but the smallest or most desperately poor communities. For low-income households, however, water and sewer services may force important economic tradeoffs. Measuring affordability as a function of an entire community's MHI obscures the effects of rate-setting on low-income customers, for whom utility leaders presumably have the greatest affordability concerns. Certainly the tenor of public policy debates surrounding utility affordability suggests that low-income residential customers are the focus of alarm. As income stratification in a community increases, the degree to which %MHI masks potential affordability problems increases.

Essential costs of living. Water and sewer services are vital, but are not the only vital goods and services customers must purchase. Housing, food, health care, home energy, and other essential goods and services also affect water and sewer affordability to the extent that they constrain households' financial flexibility. These nonwater/sewer costs vary widely across utilities. Water and sewer bills may be low as a percentage of income, but much higher as a percentage of disposable income if the costs of housing or health care are high, for example. In such cases, water and sewer bills that are nominally low or are a small percentage of MHI may force serious sacrifices for low-income customers. The conventional approach to affordability measurement is insensitive to these differences in costs of living.

An arbitrary, binary standard. Whether the affordability standard is set at 1.0, 2.0, 2.5, or any other %MHI, the standard represents a value of water and sewer service that is rarely (if ever) rooted in any philosophical reasoning

or as a result of a deliberative process. Instead, analysts simply cite precedent and invoke the standard. Whatever its origins, the 2.0 (or 2.5) %MHI affordability threshold has evolved into a "golden number" (Socolow 1976), now held up as a definitive measure of household-level affordability, apparently for no other reason than its familiarity and convenience.

The simple binary nature—either affordable or unaffordable—of the %MHI standard is also problematic. The affordability of anything is rarely a strictly yes/no phenomenon—in microeconomics, things are more or less affordable relative to the costs of other things. Although informal rules of thumb can be useful, the %MHI standard has become a crutch that causes simplistic and misleading analyses. For example, simplistic application of the %MHI standard to census tracts led one recent study to report that "water rates are currently unaffordable for an estimated 11.9% of households" (Mack & Wrase 2017), with no attention to the validity of %MHI standard or the distribution of water consumption within the census tracts in which water was declared unaffordable. By the same token, leaders of a utility that satisfies the %MHI threshold can use the standard as an excuse not to address affordability, even if many of its customers struggle to pay their bills.

A BETTER WAY

This article offers a method for measuring water and sewer utility affordability that proceeds from an understanding of affordability as the ability of individual customers to pay for water and sewer services to meet their basic needs while maintaining the ability to pay for other essential costs (Davis & Teodoro 2014). This definition is similar to what the USEPA's National Drinking Water Advisory Council called "household relative affordability" (NDWAC 2003). The method aims to retain the intuitive appeal of the conventional approach while remedying its shortcomings. Specifically, the proposed method: (1) measures household-level affordability (rather than the entire utility's financial capability); (2) provides for basic water needs (rather than average consumption); (3) focuses on low-income households (not average- or median-income customers); and (4) accounts for essential costs other than water and sewer. The proposed method involves two complementary metrics: the AR and basic costs expressed as HM.

The AR. Household-level affordability (sometimes called micro-affordability) can be measured as the percentage or ratio of basic water and sewer costs to disposable household income for low-income customers. This measure may be calculated for an individual customer or aggregated statistically for any defined group of customers. For a given customer c, the AR (AR_c) is

$$AR_c = \frac{p_c(W + S)}{I_c - E_c} \qquad (1)$$

where I is household income, E is essential household expenses (other than water and sewer services), p is the number of persons in the household, and W and S are the per capita cost of essential water and sewer services, respectively. The relevant time frame for calculating AR depends on the billing cycle used by the utility (e.g., monthly, bimonthly, quarterly).

The numerator in Eq 1 is the price of basic service to customer c, which varies according to the water volume considered necessary to maintain health, the utility's rates, and the number of people in the household. The denominator is c's disposable income, which depends on the customer's income and the cost of essential nonwater/sewer household expenses. The definitions of basic water needs and essential household expenses may vary from one utility to another, depending on local values and conditions. The resulting AR_c reflects the economic tradeoffs that customer c faces because of the costs of basic water and sewer service.

AR can be calculated for any customer, group of customers, or hypothetical customer. An assessment of AR_{20} provides a meaningful look at affordability for low-income customers. This focus on the 20th percentile household aligns the analysis of water and sewer affordability with mainstream assessments of welfare economics, which typically identify the 20th percentile as the lower boundary of the middle class. At this income level, "working poor" households have very limited financial resources, but may not qualify for income assistance programs. Public assistance programs vary considerably across the United States and across the world, and the absolute income level at the 20th percentile may qualify for significant assistance in some places. Still, the 20th percentile standard is a useful benchmark level for assessing the economic conditions of lower-middle-class and working-poor households. Analysts might choose to focus on a different income percentile when assessing affordability depending on the economic conditions or distribution of incomes in a particular community.

The ease and precision with which the AR can be calculated depend on the availability of household-level customer data. Calculating the numerator is straightforward, requiring only information about the utility's rates (or proposed rate). Ideally, the AR's denominator would be calculated using a comprehensive household-level consumer survey of the utility's customer base. Because such data are unlikely to be readily available, in most cases analysis will depend on estimates of household income and expenditures. Those estimates can draw from a variety of sources; the analysis presented in this article uses regression-based estimates, but a simpler approach could be to use more readily available data on local housing, food, medical, home energy, and tax costs for a given community.

Basic service costs as HM. A complementary way to measure affordability is to calculate the HM that would be necessary to pay for basic water and sewer service. As with the AR, the HM may be calculated for an individual

customer or aggregated statistically for any defined group of customers. For a given customer c, basic service costs as HM (HM_c) is

$$HM_c = \frac{p_c(W + S)}{A} \qquad (2)$$

where p is the number of persons in the household; W and S are the per capita cost of essential water and sewer services, respectively; and A is the minimum wage in c's labor market. HM represents the cost of basic water and sewer service for low-income households, many of which work at or near minimum wage. HM is not sensitive to other essential costs as AR is, but it is intuitively appealing because minimum wage is a familiar economic touchstone.

Analytical assumptions. The AR and HM methods are generally applicable metrics flexible enough to accommodate specific conditions that apply in any utility. The definitions of basic service and (nonwater/sewer) essential expenses may vary depending on local community values, and the analyst should adjust assumptions as necessary. Basic service is a moving target because consumption patterns vary across utilities and are broadly trending downward in the United States (Rockaway et al. 2011). For purposes of this analysis and as a guideline for affordability analysis in the United States, basic service is defined as 50 gpcd. This standard is a typical assumed minimal residential wastewater flow for purposes of sewer system design (Bowne et al. 1994) and is meant to reflect indoor, nondiscretionary water use to maintain health in a contemporary US home. In a similar vein, the Texas Water Development Board (2004) recommended 50 gpcd as its standard for indoor water use in crafting a water conservation plan. Significantly less than average consumption of 91 gpcd (DeOreo et al. 2016) but greater than the 35.6 gpcd standard that Chenoweth (2008) identifies as the "minimum water requirement for social and economic development," the 50 gpcd assumption represents a reasonable, conservative level of basic service for purposes of evaluating affordability across large numbers of utilities. Values of AR can be calculated for any household size, but a four-person household is assumed for this analysis. This is significantly greater than the average household size in the United States, which is 2.64 people (ACS 2015). As such, an assumed four-person household yields a conservative measure of affordability.

Essential household expenses in the present analysis include the costs of taxes, housing, food, medicine, health care, and home energy. These categories are considered essential because they are either inevitable (taxes) or at least as important as water for maintaining health. Any of these elements may be adjusted to reflect local conditions and values. For example, if the analyst believes that 50 gpcd is too high or too low a standard for basic service, then the AR_{20} formula can be adjusted accordingly. Similarly, essential household costs may be expanded to include other expenses (e.g., child care, transportation, telephone service) as appropriate according to local preferences and conditions. The definition and measurement of essential costs should be based on the needs of low-income households locally. Local organizations that provide assistance to low-income households can provide useful information about these costs.

AFFORDABILITY IN MAJOR US CITIES

Water and sewer utility affordability in the 25 most populous US cities are analyzed here with the new affordability measurement as an empirical demonstration of the method and to provide a descriptive profile of affordability in the country's largest cities. Capital costs, operational expenses, rate structures, demographics, and economic conditions change frequently within and across utilities; therefore, the following information should be considered a snapshot of affordability in early 2017.

Data. To calculate basic service costs, water and sewer rates were gathered from utility websites during spring 2017. Because rate structures vary considerably across utilities in ways that affect the prices that individual customers pay, to maintain comparability and capture affordability, basic service costs were calculated assuming a single-family residential customer with a ⅝ in. meter connection, billed monthly. For utilities that bill bimonthly or quarterly, volumes and charges were converted to monthly to maintain comparability. A four-person household and 50 gpcd were assumed. In cases in which rates vary seasonally or across geographic zones, the highest seasonal and/or zone rates were assumed. Although it might be argued that these assumptions lead to unduly high basic costs, they actually result in a conservative, worst-case scenario test of affordability. Utilities that use seasonal and/or zone rates might opt to calculate basic costs by averaging across time and/or space. However, the current analysis uses a worst-month scenario to calculate affordability because a low-income household is most likely to be stressed by a single high bill than its average bill. Because basic service is assumed to include indoor use only, the same volume is applied to both water and sewer charges.

In most cases, water and sewer services are provided by a single organization (e.g., a city government). In cases in which different entities provide water and sewer services, costs were calculated using the rate structures from both organizations. Some of the utilities in this analysis calculate bills in thousand gallon units, whereas others use hundred cubic foot units; in each case, bills were calculated in the appropriate units for the utility being analyzed.

Many utilities (including several analyzed here) offer discount, subsidy, or other assistance programs aimed at improving affordability. Crucially, the current analysis does not account for such assistance programs in assessing affordability because the analytical goal is to measure affordability in the absence of policy intervention. In this sense, accurate affordability measurement helps gauge the need for assistance programs. Including assistance programs would complicate attempts to measure affordability across large numbers of utilities because such programs

vary widely in scope, structure, and implementation. When using AR_{20} and HM to analyze rates in a utility, calculations can be made with and without assistance programs to understand their potential effects.

Income data—including 20th percentile household income—were drawn from the 2015 American Community Survey five-year estimates. Essential nonwater/sewer expenses were estimated on the basis of the Bureau of Labor Statistics' 2015 Consumer Expenditure Survey (CEX), which includes a probability-weighed national sample of 23,683 households that reported several categories of expenditures as well as income and demographic information. The American Community Survey and CEX data include public assistance programs in determining net income. These data were used to develop regression models that estimate essential expenditures (e.g., taxes, health care, food, housing, home energy) for low-income households. The CEX includes intentional oversamples of several metropolitan areas. Where the CEX included more than 200 households from a given utility's service area, those data were used to calculate essential expenditures for that utility. For all other utilities, the full national sample was used to estimate essential expenditures. These regression models are reported in the appendix. CEX sampling is based on metropolitan areas, whereas the present affordability analysis is based on cities. This sampling unit mismatch limits the accuracy of the essential expenditure estimates used here because expenses can vary considerably within metropolitan areas. Metropolitan area subsamples are used when available because they are likely to be more representative of their respective cities than the full national sample. Coefficients from these models were combined with parameters for each city; the essential expenditures were then estimated at each city's 20th income percentile, assuming a four-person household and single-family home. The legal minimum wages in each utility's political jurisdiction that was in effect on June 1, 2017, were used to calculate HM.

Example: Dallas, Tex. Analysis of affordability in Dallas provides an illustration of how these affordability metrics are calculated. Table 1 shows the monthly basic water and sewer cost calculation for Dallas. Dallas bills water service using units of 1,000 gal; at 50 gpcd, basic service for a four-person household is 6,200 gal monthly. Dallas water rates include a fixed monthly charge of $5.25 for a ⅝ in. meter and increasing block volume charges of $1.90/1,000 gal for the first 4,000 gal and $4.25/1,000 gal for volumes of 4,000 to 10,000 gal. (Dallas water rates include additional blocks that apply for volumes beyond the basic demands analyzed here.) The city's sewer rates include a fixed monthly charge of $4.70 and a uniform $5.31/1,000 gal winter average volume. These rates generate a basic cost of $59.82/month.

Table 2 combines this basic monthly cost with income, essential expenditure, and minimum wage information to illustrate the calculation of AR_{20} and HM values for Dallas, where 20th percentile household annual income is $18,585 ($1,549 monthly) and minimum wage is $7.25/h. A four-person household in Dallas at that income level would have

estimated essential expenses of $864/month, leaving $685 as disposable income. The basic water and sewer cost of $59.82 thus translates into an AR_{20} of 8.74% and an HM of 8.25. In plain language, this result indicates that basic water and sewer service costs a lower-middle class, four-person household in Dallas ~9% of its disposable income, or ~8 h of HM.

A big-city snapshot. The results of this affordability analysis for the top 25 US cities are reported in Table 3, which is arranged by population. The average single-family residential bill at 6,200 gal (8.3 ccf) across these cities is $83.58/month, although costs and rate structures vary considerably across these cities, from a low of $39.68 (Phoenix, Ariz.) to a high of $180.70 (Seattle, Wash.). Incomes also vary widely, with AR_{20} ranging from $9,436 (Detroit, Mich.) to $33,342 (San Jose, Calif.) annually. After accounting for essential nonwater/sewer expenses, disposable income averages $780/month. Hourly minimum wages vary from the federally mandated $7.25 to Seattle's $15.00.

TABLE 1   Basic monthly water and sewer costs, Dallas, Tex.[a]

Monthly basic volume—*gal*	6,200
Water charges	
Fixed	$5.25
Volume (4,000 gal at $1.90/1,000 gal, 2,000 gal at $4.25/1,000 gal)	$16.95
Sewer charges	
Fixed	$4.70
Volume (6,200 gal at $5.31/1,000 gal)	$32.92
Total water and sewer charges	$59.82

[a]Based on 2017 rates

TABLE 2   Affordability metrics for Dallas, Tex.[a]

A. Basic monthly water and sewer cost	$59.82
AR	
B. AR_{20} annual income	$18,585.00
C. Monthly income (B ÷ 12)	$1,548.75
D. Estimated monthly essential expenses[b]	$864.11
E. Monthly disposable income (C – D)	$684.64
AR_{20} (A ÷ E)	8.74%
HM	
F. Minimum wage per hour	$7.25
HM (A ÷ F)	8.25

AR—affordability ratio, AR_{20}—affordability at the 20th income percentile, HM—hours of labor at minimum wage

[a]Based on 2017 rates
[b]Estimates based on regression analysis of 2015 Consumer Expenditure Survey. See appendix.

TABLE 3 Affordability in largest 25 US cities in 2017[a]

| Population Rank | City, State | Monthly Basic Service Cost $ | 20th Percentile Annual Income $ | Affordability Ratio, Four-Person Household | | Minimum Wage $ | HM |
				Estimated Disposable Monthly Income at 20th Percentile $	AR_{20} %		
1	New York, N.Y.	81.78	18,085	579	14.1	12.00	6.8
2	Los Angeles, Calif.	73.11	19,063	888	8.2	10.50	7.0
3	Chicago, Ill.	47.27	17,386	576	8.2	10.50	4.5
4	Houston, Tex.	74.87	19,109	642	11.7	7.25	10.3
5	Phoenix, Ariz.	39.68	21,401	825	4.8	10.00	4.0
6	Philadelphia, Pa.	58.54	13,546	524	11.2	7.25	8.1
7	San Antonio, Tex.	55.16	19,517	933	5.9	7.25	7.6
8	San Diego, Calif.	108.71	26,381	636	17.1	11.50	9.5
9	Dallas, Tex.	59.82	18,585	685	8.7	7.25	8.3
10	San Jose, Calif.	104.47	33,342	1,188	8.8	10.5	9.9
11	Austin, Tex.	91.20	24,438	1,108	8.3	7.25	12.6
12	Jacksonville, Fla.	68.23	19,817	873	7.8	8.05	8.5
13	San Francisco, Calif.	176.85	24,946	658	26.9	13.00	13.6
14	Columbus, Ohio	106.36	18,784	840	12.7	8.15	13.1
15	Indianapolis, Ind.	97.60	17,395	724	13.5	7.25	13.5
16	Fort Worth, Tex.	66.67	21,817	831	8.0	7.25	9.2
17	Charlotte, N.C.	68.84	23,135	1,044	6.6	7.25	9.5
18	Seattle, Wash.	180.70	27,290	961	18.8	15.00	12.0
19	Denver, Colo.	64.91	21,698	884	7.3	9.30	7.0
20	El Paso, Tex.	54.45	17,879	787	6.9	7.25	7.5
21	Washington, D.C.	112.51	22,526	785	14.3	11.5	9.8
22	Boston, Mass.	99.51	14,913	618	16.5	11.00	9.0
23	Detroit, Mich.	92.68	9,436	379	24.4	8.90	10.4
24	Nashville, Tenn.	65.95	21,153	926	7.1	7.25	9.1
25	Memphis, Tenn.	39.53	14,913	618	6.4	7.25	5.5
	25-city average	83.58	20,262	780	11.4	9.19	9.0

AR_{20}—affordability at the 20th income percentile, HM—hours of labor at minimum wage
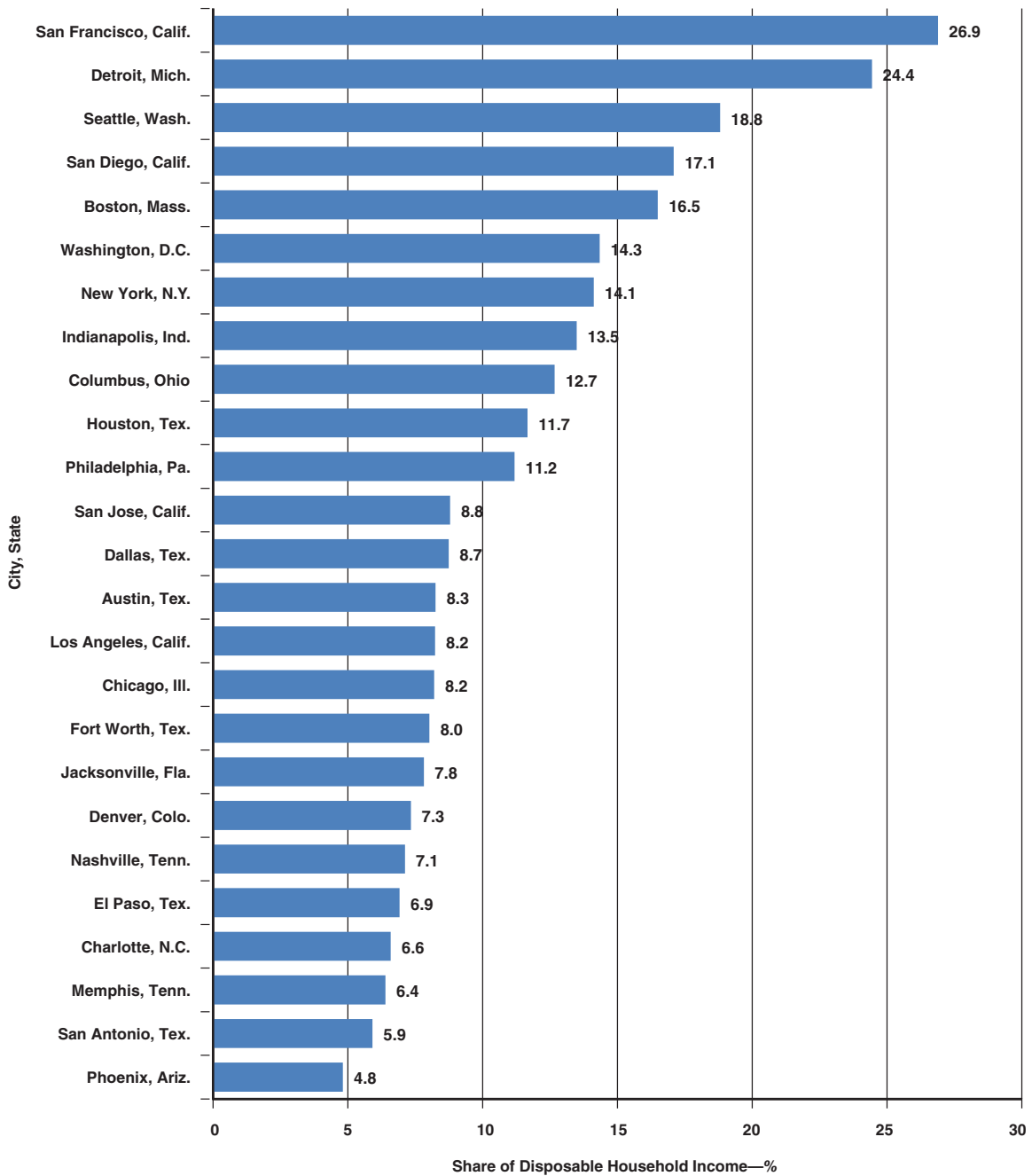
[a]Does not include low-income assistance programs

The resulting AR_{20} values average 11.4%, ranging from a low of 4.8% in Phoenix to a high of 26.9% in San Francisco. In terms of labor, basic monthly water and sewer service in the top 25 cities average 9.0 HM, with Phoenix and San Francisco again at the ends of the distribution (4.0 and 13.6 HM, respectively). Figures 1 and 2 depict these AR_{20} and HM results, with cities arranged from most to least affordable. These results should be considered with some caution because the assumptions underlying the AR_{20} and HM calculations may not be appropriate for all 25 cities and, as noted previously, do not reflect low-income assistance programs that some utilities provide.

The results appear to follow from several factors. Although discussions of utility affordability frequently focus on costs and revenue requirements, a cursory review of these 25 cities suggests that rate structures, particularly the level of fixed charges and rates paid for the first few units of water, also significantly affect affordability for low-income households. Put another way, from a low-income affordability perspective, how a utility collects rate revenue can be as important as how much total revenue it collects. The method applied here reveals the less obvious but critical ways that income distributions and essential nonwater/sewer expenses affect affordability, which are variations not reflected in the conventional %MHI metric.

The significance of these metrics becomes clearer when compared with the conventional %MHI approach to measuring affordability. Consider Dallas (AR_{20} = 8.7, HM = 8.3) and Boston (AR_{20} = 16.5,
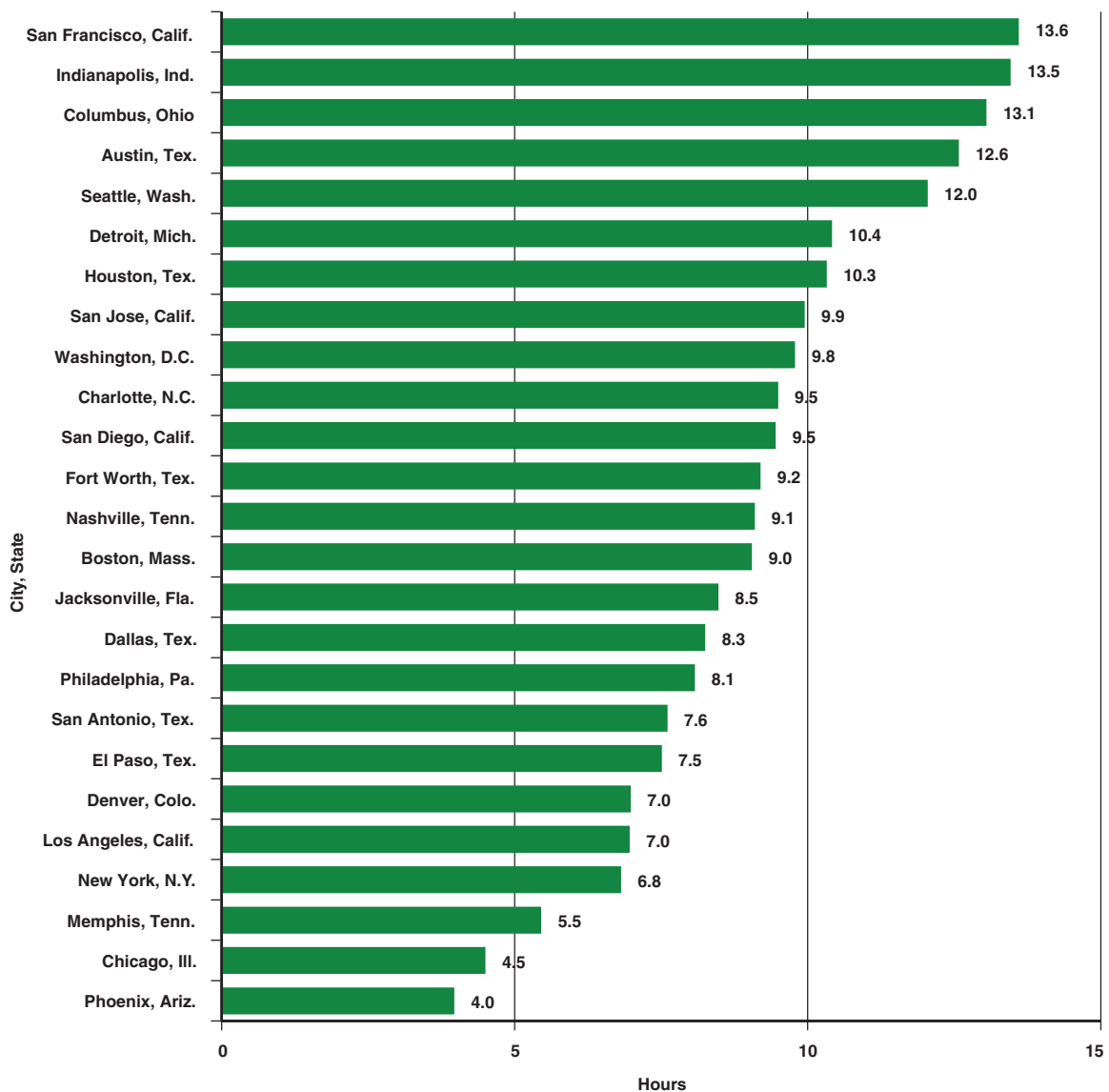
AR_{20}—affordability at the 20th income percentile

HM = 9.0): average single-family residential water consumption in Dallas is 8,300 gal, with billed sewer volume at 5,500 gal, resulting in an average bill of $65.04 (DWU 2016). With a median annual income of $43,781, the conventional metric puts Dallas' water rates at 1.8%MHI, which is well below typical affordability thresholds. Boston's average combined monthly average water and sewer bill is $87.83 and its median income is $62,775, making its average water and sewer cost just 1.7%MHI (BWSC 2017). Naïve application of the conventional standard to Dallas and Boston would lead to the conclusion that these two cities' water and sewer rates are affordable according to USEPA standards, and that they are roughly comparable in terms of affordability. The AR_{20} and HM metrics indicate that the real economic burden of these

FIGURE 2 Basic water and sewer service HM for the 25 largest US cities in 2017

City, State	Hours
San Francisco, Calif.	13.6
Indianapolis, Ind.	13.5
Columbus, Ohio	13.1
Austin, Tex.	12.6
Seattle, Wash.	12.0
Detroit, Mich.	10.4
Houston, Tex.	10.3
San Jose, Calif.	9.9
Washington, D.C.	9.8
Charlotte, N.C.	9.5
San Diego, Calif.	9.5
Fort Worth, Tex.	9.2
Nashville, Tenn.	9.1
Boston, Mass.	9.0
Jacksonville, Fla.	8.5
Dallas, Tex.	8.3
Philadelphia, Pa.	8.1
San Antonio, Tex.	7.6
El Paso, Tex.	7.5
Denver, Colo.	7.0
Los Angeles, Calif.	7.0
New York, N.Y.	6.8
Memphis, Tenn.	5.5
Chicago, Ill.	4.5
Phoenix, Ariz.	4.0

HM—hours of labor at minimum wage

services is markedly greater for low-income households in Boston than in Dallas. (Data necessary for calculation of average sewer bills were not available for all 25 cities.)

DISCUSSION

With improved affordability metrics and a snapshot of affordability in major US cities established, discussion now turns to their limitations, implications, and applications.

Limitations. Although AR_{20} and HM offer major improvements over the conventional method of assessing affordability, they are not perfect. A clear drawback of the AR_{20} is the relative complexity of estimating it with the data typically available to analysts. Although AR_{20} is intuitive, estimating disposable household income in a given community requires a level of effort and/or technical sophistication greater than what is required of the conventional method. For all of its drawbacks, %MHI has back-of-the-envelope simplicity (even if that simplicity is misguided and misleading). Complexity is not an insurmountable barrier to using these metrics for any specific utility, however. Regression analysis of CEX data is not necessary for AR_{20} calculations in a single utility, and, for most, income distribution and reasonably accurate essential household estimates are possible with locally available data.

Two additional limitations are more serious for purposes of advancing the cause of affordability and should be considered when using AR_{20} and HM. First, the metrics

advanced here focus on single-family residential customers. Theoretically, the same metrics could be applied to any class of customer, but measuring affordability for households in multifamily or rental housing is difficult or impossible if those households do not pay their own water and sewer bills. Assessing and addressing affordability for these "hard to reach" customers is a perennial, vexing challenge for utilities (Raucher et al. 2017); unfortunately, the metrics advanced here offer little leverage on that challenge.

Second, and more fundamentally, AR_{20} and HM measure affordability; they do not define it. The metrics advanced here can significantly clarify the scope of the water and sewer affordability issues that utilities face, but they cannot in themselves define affordability.

What is affordable? Water and sewer affordability is a matter of community priorities. When confronting affordability questions, utility leaders and policymakers are actually asking: How much is reasonable to expect households of limited means to pay for these essential services? What economic sacrifices are reasonable to expect low-income households to make in order to pay water and sewer bills?

These are fundamentally normative questions. No metric, however well conceived and executed, can in itself define what is affordable; there is no scientific answer to a philosophical question. Just as incomes and essential expenditures vary from one community to another, so can social and political values: what one community considers affordable may not be considered affordable elsewhere.

As noted previously, one of the main weaknesses of conventional affordability analysis is that it declares utility rates "unaffordable" or "affordable" because they fall above or below a combined 4.0 or 4.5%MHI threshold—golden numbers with no underlying rationale. In the public policy arena, these arbitrary standards tend to preclude or preempt meaningful discussion of affordability. Better measurement of affordability can facilitate clearer thinking and discussion, and the metrics introduced here can serve as a framework.

Beware of cross-utility comparisons. The affordability snapshot of the 25 utilities developed here is interesting in its own right because it depicts the general state of affordability in large US cities; however, this snapshot is not especially useful for setting affordability policy in any given utility. There is a common (perhaps innate?) human tendency to think about performance in comparison with others, so it is tempting to think about a utility's affordability relative to others when developing policy. This kind of comparison distracts from the core issue of affordability. As a metaphor, consider water treatment: no responsible engineer would recommend a treatment technology for Boston based on measurements of average source water quality in the other top 25 cities; for purposes of designing treatment processes, the only relevant measurement is of Boston's source water. Developing affordability policy according to other utilities' affordability metrics is like designing a treatment plant for other communities' average source water. Utility rates and

affordability programs ought to reflect their own communities' needs and values, not those observed elsewhere.

For these reasons, utility leaders and policymakers should resist the temptation to make decisions about affordability in their communities based on affordability conditions nationally or in neighboring communities. The relevant question is not how affordable our water and sewer rates are compared with other communities but rather if they are consistent with the value our community places on affordability.

Rules of thumb. Bearing in mind the dangers of "golden numbers" and cross-utility comparison, some simple rules of thumb for evaluating water and sewer affordability are offered here in response to queries from professionals and policymakers grappling with affordability in their utilities. These guidelines are not rooted in any theory of welfare economics, law, or philosophy; they simply reflect an intuitive answer to what trade-offs low-income households should be expected to make in order to pay for basic water and sewer service. The following double-barreled standard is suggested:

- an AR_{20} value of no more than 10%, so that a four-person household at the 20th income percentile pays no more than 10% of its disposable income on water and sewer service, and
- an HM value of no more than 8.0, so that a four-person household's basic monthly water and sewer bill requires no more than 8 h of labor at minimum wage.

These two standards have some visceral appeal ("10%, one day"), but the intuition behind them is that water and sewer are essential services, so it is reasonable to ask low-income customers to pay up to 10% of disposable income and/or work up to one full day at minimum wage to pay for them. Beyond these levels, water and sewer costs may begin to severely constrain the welfare and economic opportunities of low-income households.

Analysts, utility leaders, policymakers, and interested observers are urged to use these rules of thumb not as new golden numbers to supplant the conventional %MHI standard, but as starting points for discussion and development of affordability policies for their own utilities. These rules can help frame efforts to define affordability locally. Mumm and Ciaccia's (2017) pairwise comparison approach offers promising means of inferring community values about affordability, for example.

Based on the present analysis, 14 of the 25 largest US cities meet the first rule of thumb; only eight satisfy the second. Do these findings indicate that cities that fail to meet these standards have an affordability problem? Not necessarily. Several utilities fall just above or below the 10%/8 h thresholds; therefore, it would be simplistic to declare them "affordable" or "unaffordable" on the basis of rules of thumb. In some cases—most conspicuously, Detroit—high AR_{20} figures are driven more by very low 20th percentile incomes than by utility rates and so may not reflect the range of public assistance programs available to extremely low-income households. In other cases, 50 gpcd indoor water use may be an unrealistically high level of water use. Many of these utilities

use assistance programs to help address affordability concerns in ways that are not captured in AR_{20} or HM. Moreover, utility rates that exceed the rules of thumb may nevertheless be consistent with their communities' understanding of affordability. On the other hand, it is possible that some of these utilities have serious affordability challenges that are underappreciated because they satisfy a %MHI convention. The best solutions for any affordability problems identified with these metrics will vary from one utility to another.

Implications for practice. Better measurement can facilitate better decisions. Utility leaders, policymakers, and regulators should abandon %MHI as a measure of household water and sewer affordability. Instead, better metrics like AR_{20} and HM should be used when setting rates or developing affordability programs, because they capture the kinds of welfare tradeoffs that utility rates force low-income households to make. When considering alternative rate structures, budgets, and affordability programs, policymakers should tailor the AR_{20} and HM metrics to reflect local conditions, compare the AR_{20} and HM that would result under various alternatives, and then set policies to align those results with their communities' priorities. Abandoning the flawed convention in favor of the metrics advanced here can greatly strengthen the way that the utility community thinks about and responds to affordability concerns.

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Appendix: Household Expenditure Estimates

The following tables report the regression models used to estimate essential household incomes using the 2015 Consumer Expenditure Survey (CEX) interview data. Essential expenses were calculated as the sum of average quarterly household expenditures on housing (CEX variable *sheltpq*), food (*foodpq*), health care (*healthpq*), home energy (*ntlgaspq+elctrcrpq+allfulpq*), and taxes (*totxest*), divided by 3 to represent monthly expenditures. Ordinary least squares (OLS) regression models employed robust standard errors to correct for heteroskedasticity, and

applied the CEX's sampling weights (*finlwt21*). Models were estimated for all cities for which the CEX included at least 200 responses; cities with fewer than 200 responses were estimated using the national data set. Regression results are reported in Tables A1 and A2.

The coefficients from these models were used to estimate essential household expenditures at the 20th income percentile for each city, single-family home, and a four-person household. All other variables were estimated at the city's mean values.

TABLE A1   Essential household expenditure estimation models

DV: Log Essential Household Expenditures	National Sample	New York City	Los Angeles	Chicago	Houston	Phoenix	Philadelphia
Household size	−0.035	−0.027	−0.096	−0.019	−0.077	−0.01	−0.095
	(0.005)	(0.019)	(0.023)	(0.015)	(0.036)	(0.029)	(0.091)
Single-family home	0.0332	0.076	0.056	0.148	0.148	0.507	0.125
	(0.017)	(0.050)	(0.057)	(0.064)	(0.197)	(0.109)	(0.027)
High school graduate	0.134	0.194	−0.073	0.015	0.109	0.109	0.205
	(0.020)	(0.062)	(0.076)	(0.101)	(0.132)	(0.134)	(0.103)
College graduate	0.279	0.236	0.227	0.213	0.437	0.319	0.080
	(0.012)	(0.041)	(0.049)	(0.048)	(0.110)	(0.093)	(0.063)
Married	0.208	0.017	0.181	0.185	0.298	0.158	0.292
	(0.012)	(0.044)	(0.060)	(0.055)	(0.090)	(0.085)	(0.070)
Black	−0.122	−0.088	−0.164	−0.264	−0.584	−0.547	0.044
	(0.017)	(0.056)	(0.065)	(0.079)	(0.139)	(0.233)	(0.071)
Native American/Indian	−0.147	0.262	0.156		−0.109	0.145	
	(0.078)	(0.260)	(0.334)		(0.229)	(0.209)	
Asian/Pacific Islander	0.021	−0.091	−0.221	−0.118	−0.008	0.201	−0.040
	(0.022)	(0.062)	(0.072)	(0.079)	(0.108)	(0.206)	(0.133)
Multi-race	−0.075	0.031	−0.287	−0.506	−0.159	−0.526	−1.436
	(0.047)	(0.067)	(0.127)	(0.194)	(0.350)	(0.609)	(0.472)
Hispanic	−0.098	−0.052	−0.250	−0.254	−0.177	−0.118	0.169
	(0.017)	(0.050)	(0.058)	(0.073)	(0.122)	(0.095)	(0.118)
Income (log)	0.558	0.609	0.675	0.555	0.247	0.488	0.575
	(0.011)	(0.031)	(0.047)	(0.033)	(0.090)	(0.044)	(0.030)
Homeowner	−0.018	0.025	−0.025	−0.106	−0.097	−0.104	0.027
	(0.014)	(0.045)	(0.051)	(0.062)	(0.186)	(0.089)	(0.078)
Urban	0.301						
	(0.017)						
Intercept	0.728	0.695	0.307	1.339	4.496	1.495	0.906
	(0.103)	(0.307)	(0.469)	(0.335)	(0.892)	(0.425)	(0.285)
R^2	0.530	0.595	0.544	0.704	0.367	0.601	0.631
N	23,254	1,533	1,166	795	406	300	562

DV—dependent variable

Cells contain coefficients (robust standard errors in parentheses).

TABLE A2   Essential household expenditure estimation models (continued from Table A1)

DV: Log Essential Household Expenditures	Dallas and Fort Worth	San Jose and San Francisco	Seattle	Denver	Washington	Boston	Detroit
Household size	0.008	0.026	–0.004	–0.008	–0.033	–0.116	–0.023
	(0.022)	(0.038)	(0.037)	(0.025)	(0.030)	(0.024)	(0.029)
Single-family home	–0.009	0.167	–0.06	0.181	0.092	0.004	0.336
	(0.113)	(0.091)	(0.134)	(0.108)	(0.098)	(0.113)	(0.128)
High school graduate	0.291	0.327	0.405	0.461	–0.022	0.150	0.049
	(0.113)	(0.183)	(0.219)	(0.225)	(0.198)	(0.175)	(0.260)
College graduate	0.197	0.254	0.281	–0.158	0.239	0.065	0.332
	(0.058)	(0.084)	(0.008)	(0.066)	(0.085)	(0.065)	(0.067)
Married	0.140	–0.080	–0.096	–0.011	0.114	0.325	–0.001
	(0.085)	(0.087)	(0.081)	(0.087)	(0.088)	(0.078)	(0.090)
Black	0.072	–0.651	–0.347	0.172	–0.057	0.566	–0.017
	(0.085)	(0.158)	(0.116)	(0.180)	(0.093)	(0.128)	(0.085)
Native American/Indian	0.341			–0.050	0.079		–0.242
	(0.217)			(0.278)	(0.086)		(0.084)
Asian/Pacific Islander	–0.077	–0.036	0.183	–0.019	–0.115	–0.239	0.242
	(0.010)	(0.089)	(0.101)	(0.146)	(0.104)	(0.367)	(0.098)
Multi-race	–0.334	–0.108	0.302	–0.672	–0.236	–0.714	
	(0.161)	(0.118)	(0.247)	(0.170)	(0.186)	(0.319)	
Hispanic	–0.312	0.126	–0.400	–0.093	–0.155	–0.277	0.301
	(0.079)	(0.097)	(0.260)	(0.115)	(0.094)	(0.152)	(0.096)
Income (log)	0.426	0.638	0.503	0.754	0.641	0.645	0.737
	(0.044)	(0.055)	(0.072)	(0.055)	(0.068)	(0.048)	(0.077)
Homeowner	0.009	–0.231	–0.008	–0.571	–0.112	–0.050	–0.216
	(0.109)	(0.071)	(0.101)	(0.094)	(0.086)	(0.076)	(0.110)
Intercept	2.330	0.264	1.640	–1.015	0.568	0.508	–0.945
	(0.443)	(0.623)	(0.734)	(0.613)	(0.739)	(0.576)	(0.838)
R^2	0.556	0.726	0.521	0.674	0.574	0.704	0.632
N	449	327	280	261	413	285	323

DV—dependent variable

Cells contain coefficients (robust standard errors in parentheses).