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# Do Households Respond to the Marginal or Average Price of Piped Water Services? **FREE**

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## Summary

Water utilities commonly use complex, nonlinear tariff structures to balance multiple tariff objectives. When these tariffs change, how will customers respond? Do customers respond to the marginal volumetric prices embedded in each block, or do they respond to an average price? Because empirical demand estimation relies heavily on the answer to this question, it has been discussed in the water, electricity, and tax literatures for over 50 years. To optimize water consumption in an economically rational way, consumers must have knowledge of the tariff structure and their consumption. The former is challenging because of nonlinear tariffs and inadequate tariff information provided on bills; the latter is challenging because consumption is observed only once and with a lag (at the end of the period of consumption). A large number of empirical studies show that, when asked, consumers have poor knowledge about tariff structures, marginal prices, and (often) their water consumption.

Several studies since 2010 have used methods with cleaner causal identification, namely regression discontinuity approaches that exploit natural experiments across changes in kinks in the tariff structure, changes in utility service area borders, changes in billing periods, or a combination. Three studies found clear evidence that consumers respond to average volumetric price. Two studies found evidence that consumers react to marginal prices, although in both studies the change in price may have been especially salient. One study did not explicitly rule out an average price response. Only one study examined responsiveness to average total price, which includes the fixed, nonvolumetric component of the bill.

There are five messages for water professionals. First, inattention to complex tariff schedules and marginal prices should not be confused with inattention to all prices: customers do react to changes in prices, and prices should remain an important tool for managing scarcity and increasing economic efficiency. Second, there is substantial evidence that most customers do not understand complex tariffs and likely do not respond to changes in marginal price. Third, most studies have failed to clearly distinguish between average total price and average volumetric price, highlighting the importance of fixed charges in consumer perception. Fourth, evidence as of late 2020 pointed toward consumers' responding to average volumetric price, but it may be that this simply better approximates average total price than marginal or expected marginal prices; no studies have explicitly tested this. Finally, although information treatments can likely increase customers' understanding of complex tariffs (and hence marginal price), it

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is likely a better use of resources to simplify tariffs and pair increased volumetric charges with enhanced customer assistance programs to help poor customers, rather than relying on increasing block tariffs.

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**Keywords:** water demand, price perception, tariff design, conservation, efficiency

**Subjects:** Behavioral Science & Health Education, Environmental Health, Public Health Policy and Governance

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## Introduction

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If a water utility changes its tariff for services, how will customers respond? This question is key to predicting how successful a revised tariff will be in meeting multiple objectives, such as financial (revenue) stability, efficiency, and equity (Whittington & Nauges, 2020). If tariffs are adjusted in part to spur water conservation in the face of a drought, how customers respond will determine whether conservation goals are likely to be met and supply is able to meet demand. This is a core question for studies of demand for piped water supply. These studies estimate price elasticities as well as uncover nonprice determinants of water demand, such as household size, income, yard size, etc. Since the late 1960s (Howe & Linaweaver, 1967), researchers have generated dozens of these studies. (For a useful review of the conceptual and empirical dimensions of this literature for piped supply, primarily in wealthy countries, see Arbués et al., 2003; for a review of the literature in low- and middle-income countries, see Nauges & Whittington, 2010; and for meta-analyses, see Dalhuisen et al., 2003, and Sebri, 2014.)

Given the ubiquity of complex, nonlinear tariff schedules, namely increasing block tariffs, most consumers do not face a single volumetric price for water. A key question is what price customers perceive and react to. Economic theory suggests they will optimize water consumption by reacting to the marginal price. But this requires that the customer understand the tariff structure and know their own consumption. These are strong assumptions where tariffs involve fixed charges and complex volumetric charges with multiple blocks. Furthermore, a household doesn't learn about its consumption until the end of the billing period, making it difficult to connect the effect of changes in water use with changes in the bill. More recent evidence casts doubt on both of these assumptions, and newer quasi-experimental studies suggests that customers are more likely to react to "average" prices.<sup>1</sup> Interestingly, authors rarely specify whether they mean average *volumetric* or average *total* price, with the latter including fixed (nonvolumetric) charges. With one exception, empirical tests of price perception focus on average volumetric price. Most evidence suggests consumers perceive changes in average price, although there is evidence from two studies that marginal price may be salient when nonlinear tariffs are relatively simple (single

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volumetric or two-tier rate structures). Recent field experiments suggest that consumers can be taught to perceive marginal prices, although it is not obvious that this is preferable to simplifying complex nonlinear tariffs.

This article draws largely on research on the economics of water demand to address the current state of knowledge around consumer price perceptions. Nonlinear price schedules are also used by electricity service providers, governments (i.e., progressive income taxation), and mobile phone service providers, and the question of consumer price perceptions has also received considerable attention in those fields. Therefore, the article also draws on literature in these areas, although the review is not as comprehensive.

The article begins in Part One with an illustration of the primary question with an example before sketching some basic behavioral questions related to the example. It then discusses a brief history of the earlier literature (roughly 1970–2010) in the field before turning in Part Two to more recent studies, focusing mainly on those with causal identification.

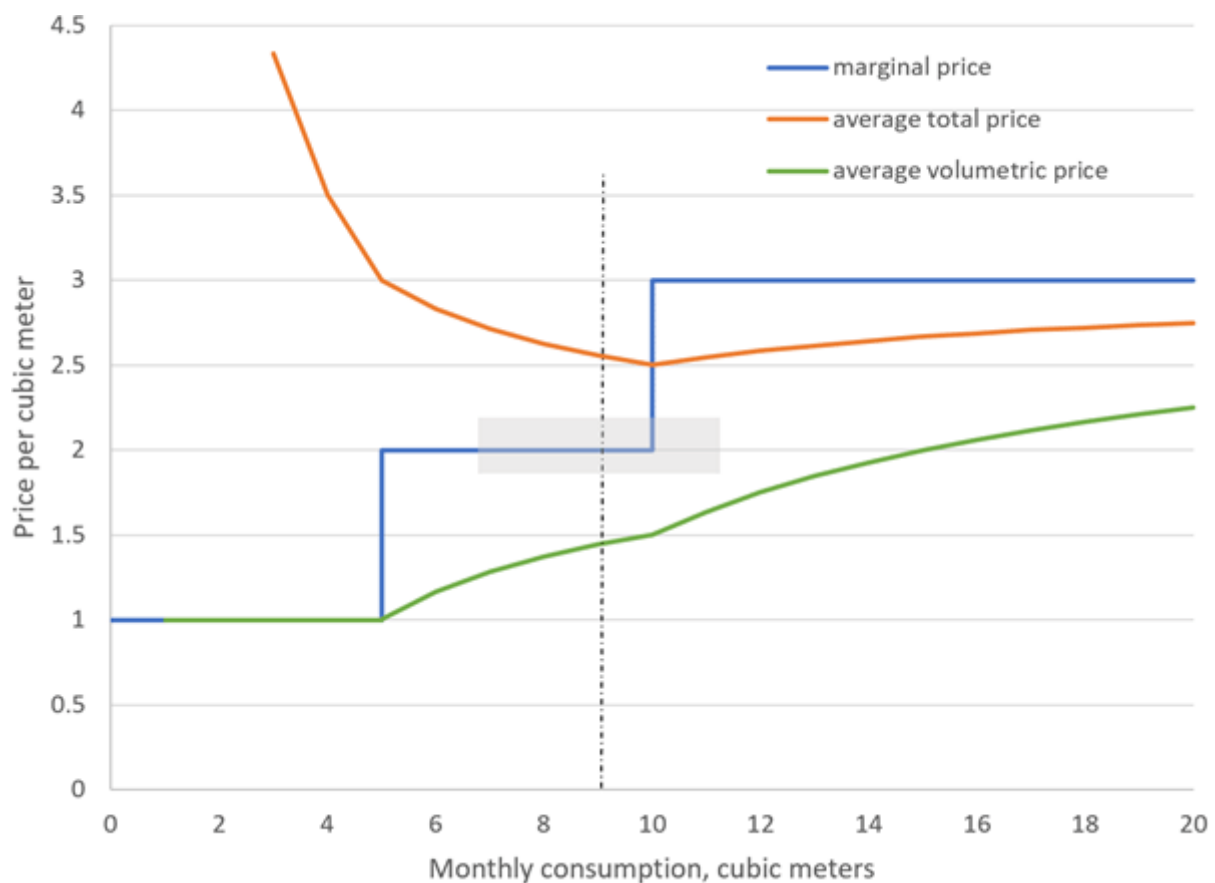
## Part One

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### A Price Perception Example

Imagine a consumer faces the following hypothetical tariff schedule. She pays a fixed (nonvolumetric) charge for access to water and sewer services of \$5.<sup>2</sup> The volumetric component of the tariff depends on the quantity used, with the volumetric price rising with larger quantities used (an increasing block tariff, or IBT). She pays \$1 per cubic meter ( $\text{m}^3$ ) for the first 5  $\text{m}^3$  used. She pays \$2 for the sixth through ninth cubic meter. If her consumption is ten cubic meters or more, she pays \$3 for each additional cubic meter. For simplicity, assume sewer services are also assessed as an additional \$5 fixed charge, for a total fixed charge of \$10.<sup>3</sup>

The IBT schedule for volumetric use is shown by the blue line in figure 1. This corresponds to a consumer's marginal price. The orange line in figure 1 shows the average total price calculated as the total bill (including fixed charges plus volumetric charges) divided by total consumption. The average volumetric price is also plotted (shown in green); it is calculated as the total volumetric charges divided by consumption. This measure overlaps marginal price for the first tariff block and will always be lower than marginal price for subsequent blocks in an IBT.



**Figure 1.** Price perception with increasing-block tariffs.

The central question is: to which price is the customer responding? Economic theory holds that consumers will use water up to the point at which the marginal benefit of consuming an additional unit of water is equal to its marginal cost to the household. The dashed line shows that our hypothetical customer consumed nine cubic meters in one particular billing period (typically a month). The marginal cost of her last unit consumed was \$2, but if she chooses to consume an additional cubic meter, her marginal price for the tenth cubic meter jumps to \$3. If many customers respond to marginal price, one would expect to see them “bunching” at kinks in the tariff schedule: plotting a histogram of consumption would show spikes right before a price jump. Bunching in water and electricity is discussed in the next section, and it is noted here that there is evidence that most taxpayers do not bunch at kink points in the marginal income tax; only the self-employed do (Saez, 2010).

What are the necessary pieces of information the water consumer needs in order to behave in an economically rational way and to equate her marginal water use to her marginal cost of \$3? We begin by listing them, and then describe the evidence supporting whether each requirement is met. First and most simply, she must have knowledge of the tariff schedule. This could come from the most recent bill if the tariff is printed in the bill, or from independent research. This knowledge need not necessarily include the entire tariff schedule, but perhaps only the prices in the vicinity of her normal consumption (her “local” marginal prices). This leads to the second requirement: she must have a sense of her water consumption and where it fits in the tariff schedule. Her consumption will of course fluctuate from month to month. Some customers’ monthly consumption may fluctuate more than others, perhaps because of seasonal water use or visitors. Finally, to believe customers are fully

optimizing their water behavior, we would want to be confident that they also have a sense of the water intensity of different activities. Understanding how much water is used in flushing the toilet, running the dishwasher, etc., is difficult. Quantity information is only received in one large monthly total, and with significant delay between the activity and the arrival of the bill.

What is the likelihood that most consumers have this information? Readers might stop and ask these questions of themselves before proceeding. What was your last water bill? How much water did you use? Could you explain the tariff structure? For your last water bill, what was the volumetric price for the last unit of consumption or the volumetric price for consuming a little more? You are probably a water professional, but you are also likely not to have answers to all of these questions. You can probably remember your total bill, and perhaps have a sense of how much your bill has varied in the recent past, particularly if it increased over a period with seasonal water use. You would not be the only one.

Gaudin (2006) examined the information content of water bills in 387 water utilities in the United States, finding that marginal price information was included in only 17% of bills. Nearly 80% of bills only reported the total amount due. (Gaudin also found that price elasticity estimates increase 30% when price-related information is included.) In a survey of households in three utilities in Florida, Carter and Milon (2005) found that only 6% of customers correctly identified their marginal price. Only 7% of customers surveyed in three Texas utilities reported that they use either marginal or average price in making water consumption decisions (Stratus Consulting, 1999). More recently, Brent and Ward (2019) showed that Australian water consumers are generally unaware of the marginal price but have better information on the total bill. Wichman (2017) attributed the increase in consumption caused by a transition to more frequent billing to a decrease in the wedge between perceived and actual prices. Binet et al. (2013) found that surveyed households in Reunion Island, a French overseas territory, underestimated the price of water. Surveying customers after a transition from a uniform rate to a two-tier IBT in Kyrgyzstan, McRae and Meeks (2016) found one third of consumers could not identify the quantity threshold for the second tier and two thirds did not know the second-tier price. Shaffer (2020) found that energy consumers on an IBT in Canada included a set of “confused” households who responded as if the high marginal price in a two-tier IBT applied to all units of consumption. Nor is there evidence that customers understand how best to adjust their water consumption to lower their bills: both Attari (2014) and Brent and Ward (2019) found that consumers have poor knowledge of the water intensity or “cost per use” of activities. It is also possible that “budget-based” rates, where each customer’s tariff schedule has block sizes that are specific to the household and change depending on weather conditions, require even more effort to understand. This could explain the heterogeneity in price responses observed in Pérez-Urdiales and Baerenklau (2019).

A lack of detailed tariff knowledge might be rational, however, in a situation where the combined water and sewer bill is a relatively small fraction of income. The marginal costs of discovering this information (in time spent) may well exceed the marginal benefits of adjusting behavior (Shin, 1985). This is a type of bounded rationality (Stigler, 1961) and “rational inattention” (Dellavigna, 2009; Sallee, 2014) that has been discussed in the water demand literature (e.g., Carter & Milon, 2005). The search costs may exceed benefits even in the face of large changes in the water bill. Note that since even large increases in the marginal price often apply only to the highest tiers, they tend to apply to relatively few units

of water and may not lead to big changes in total bills. However, some consumers have poor knowledge of tariffs even when facing large financial consequences, as is shown by the failure of consumers to take advantage of significant savings by signing up for a transitional tariff during the shift to volumetric billing (Ornaghi & Tonin, 2018).

A slightly less restrictive view of the information needs of consumers assumes that the person has knowledge of “local” marginal prices and has a prior estimate of the range of consumption values her monthly water use will fall in. Without detailed knowledge of the tariff schedule and without precise quantity information, she can act as if she is responding to the “expected” marginal price (see Saez, 1999, on expected income in the tax literature and Borenstein, 2009, on electricity). In figure 1, the gray box surrounding her consumption of  $9 \text{ m}^3$  shows the range of monthly water use values she expects she will use. Suppose she thinks there is a 50% chance that her use will fall within  $8$  to  $9 \text{ m}^3$ , and a 50% chance it will fall within  $10$  to  $11 \text{ m}^3$ . Her expected marginal price would therefore be  $0.5 \times 2 + 0.5 \times 3 = \$2.5$  per cubic meter.

Relaxing informational requirements still further, consumers might not have knowledge of the marginal price schedule at all. Suppose the customer in the example knows the total bill but differentiates between the fixed and total volumetric components, which are commonly reported on bills. With knowledge of approximate consumption, consumers might behave as if they are reacting to average volumetric price (orange line in figure 1). However, calculating the average volumetric price is more complicated than finding the relevant marginal price in most cases.<sup>4</sup>

With knowledge of only the total bill amount and total consumption, consumers might also be reacting to average total price. Because of the presence of positive fixed charges, this average total price will initially fall over successive units of consumption, as the fixed costs are spread over more units. However, this type of price perception is not consistent with standard economic theory, because any fixed costs should drop out of the solution of any consumer’s utility maximization. This is like asking if customers react to changes in fixed charges on their utility bills.

The shape and position of the average and marginal price curves will of course depend on the tariff structure, including the magnitude of the fixed charges. But two things are apparent from figure 1. First, in an IBT with fixed charges, average total price (ATP) and marginal price will move in opposite directions over low quantities of consumption, with ATP falling and marginal price rising. Second, once ATP reaches its minimum, both average and marginal price move in the same direction (upward). If most customers consume quantities to the right of this point, it is econometrically challenging to disentangle whether consumers perceive ATP or marginal price because the prices move together. This is even more econometrically challenging with average volumetric price, since it always varies with marginal price, absent changes to the tariff schedule. This example also illustrates the opportunity that became available once electronic billing data were more available in the 1990s. With customer-level data and changes in tariffs, one can exploit kink points in the schedules where the change in marginal price and change in average price move in opposite directions. Several researchers have combined this opportunity with quasi-experimental approaches for causal identification, namely spatial discontinuity approaches generated by adjacent water or electricity utilities or differences in billing zones within a utility. (The studies are described in more detail in Part Two.)

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## A Brief History of Price Perception in Water Demand Studies

Early water demand studies, such as Howe and Linaweaver (1967), used marginal price mainly by assumption. Before the advent of electronic billing records, these early water demand studies also relied primarily on cross-sectional variation in price to estimate models. Cross-sectionally, marginal and average price also typically move together: cities with higher marginal prices for an average consumer are also likely to have higher average prices for an average consumer. Complex IBTs were less common than today.

Following work in electricity by Taylor (1975) and Nordin (1976), the issue of how to accurately estimate demand and price elasticities in the presence of complex nonlinear rates and piece-wise linear budget constraints attracted attention in the water demand literature in the late 1970s and early 1980s (Foster & Beattie, 1979, 1981; Griffin et al., 1981; Opaluch, 1982). Early studies used the “Taylor-Nordin” approach of including in the demand model marginal price, the difference between average price and marginal price, and an income effect (the windfall associated with inframarginal units’ being charged at lower marginal prices, i.e., what the bill would have been if all units had been billed at the last final marginal price). The latter income term is positive for IBTs and negative for decreasing block tariffs, and it is added as “virtual income” or a “rate-structure premium” to observed income data. Many studies followed Foster and Beattie’s (1981) suggestion to treat perception of marginal or average price as an empirical question to be investigated econometrically rather than assumed. Charney and Woodward (1984) argued for using lagged average price, since consumers would logically be reacting to their prior month’s consumption and prices in deciding how much water to use in the current period. Shin (1985) introduced a price perception parameter that could be directly estimated, finding evidence for average price perception (in a decreasing block tariff for electricity). Note that Shin (1985) and the earlier studies examined average *total* price, not average volumetric price, although this was not always explicitly defined. Nieswiadomy and Molina (1991) applied the Shin approach to water, finding somewhat weaker evidence than Shin (1985) that customers responded to average prices in a decreasing block tariff but that they responded to marginal prices under IBTs.

With nonlinear tariffs, marginal and average price are chosen endogenously by the consumer when they choose how much to consume. IBTs gained popularity and increased in complexity during the late 1980s and early 1990s. Rather than relying on more “reduced form” econometric approaches to deal with the simultaneity problem, Hewitt and Hanemann (1995) introduced a structural approach for modeling demand. Consumers first make a discrete choice (which tariff block to consume in) and a continuous choice of how much to consume within that block. This discrete/continuous choice (DCC) model is estimated using a maximum likelihood approach. Hewitt and Hanemann acknowledged that their model cannot be used to test which price customers respond to, since it assumes by construction knowledge of the entire tariff structure. They noted empirical evidence at the time casting doubt on this assumption, but they argued (à la Friedman, 1953) that if applying the model to high-quality data produced estimates “consistent with the second-order conditions for utility maximization, then we may conclude that on average households do behave *as if* they knew the rate structure.”

Olmstead et al. (2007) applied the discrete-continuous model on a larger data set of households in 11 U.S. urban areas, with cities employing two-tier IBTs, four-tier IBTs, or uniform rates. They found evidence of bunching that suggests consumers react to marginal prices: among households facing IBTs, 40% of demand observations in their sample lay within 5% of a kink point in the tariff. The Olmstead paper also pointed out that elasticity estimates must be developed and interpreted carefully in the presence of nonlinear rates. In simultaneous equations approaches (like two-stage least squares), the elasticity estimates report the effect of a 1% increase in marginal price conditional on the consumer's remaining in the same consumption block. Elasticity estimates in discrete-continuous models (a 1% increase in marginal prices in each block) account for changes along both dimensions of choice. Accounting for this, and using less restrictive data, Olmstead et al. (2007) found price elasticities that were much more comparable to the means of meta-analyses than those that were found by Hewitt and Hanemann (1995). They also found demand is more elastic under IBTs than under uniform tariffs, noting the possibility that the choice of tariff structure might be endogenous to the utility and its customers.

Wang et al. (2018) evaluated the DCC model for water demand in the face of growing evidence of inattentive or imperfectly informed consumers. Wang et al. (2018) modeled consumers as following a simple heuristic that uses only the prior month's total bill and total water quantity to decide whether to use more water, less water, or the same amount. They found the heuristic, which does not require knowledge of the full tariff structure, generated more accurate out-of-sample predictions than the DCC approach. Roseta-Palma et al. (2020) also reviewed the literature on price perception and discussed the possibility that customers facing nonlinear water and electricity tariffs may show reference dependence, reacting differently to increases and decreases in price away from that reference price (i.e., loss aversion). They theoretically extend the DCC model of Hewitt and Hanemann (1995) to include reference dependence.

Finally, it may also be instructive to review how the revealed preferences of researchers have changed over time. The choices they have made in existing demand studies are revealed here by describing three existing meta-analyses. First, Espey et al. (1997) examined 124 elasticity estimates from 24 demand studies between 1967 and 1993. Specifications using average and marginal price are equally predominant (note that most studies include both price specifications), with other studies using a difference variable (the difference between the actual volumetric bill and what the customer would pay if all units were priced at the final marginal price) and "Shin" prices. Espey et al. (1997) spent relatively little space in their article discussing the issue of price perception. Based on meta-analysis results, elasticity estimates derived from models using average, Taylor-Nordin "difference," or Shin prices were found to be more elastic than estimates using marginal prices.

The meta-analysis in Dalhuisen et al. (2003) covered 314 elasticity estimates in 64 studies published through 2001. The paper did not report the fraction of estimates that used various price specifications, but, like Espey et al. (1997), Dalhuisen et al. found that elasticity estimates are higher in absolute value when average or Shin price is used rather than marginal price. Finally, in a meta-analysis of 100 studies and 638 price elasticities available as of 2012, Sebri (2014) found that 38% of elasticity estimates were derived from demand studies assuming customers' perceived marginal price, 57% from studies using an average price specification, and 6% from studies using a Shin price specification (see Table 1 in Sebri,

2014). Price elasticities were not statistically different between studies using marginal or average price, although studies using a Shin price or other specification showed more elastic demand.

## Part Two: More Recent Studies of Price Perception

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### Quasi-experimental Studies of Average Price vs. Marginal Price

Nataraj and Hanemann (2011) provided causal evidence suggesting customers respond to marginal prices. In an early natural experiment, they examined the impact of the addition of a new tariff block in Santa Cruz, California, using a regression discontinuity (RD) design. In an RD framework, the control and treatment groups are customers whose average monthly water use before the tariff change was just above and below the volumetric cutoff for the new tariff block (40 ccf [hundred cubic feet]). The price for this new, third tariff block was approximately double the price in the second block, so the jump in marginal price was likely to be especially salient. In addition, the utility printed a warning on water bills alerting high-use households to the new, more expensive tariff block. A difference-in-difference design was used to compare billed water use in two summer months before and after the tariff change among the treatment and control groups.

Focusing their analysis on only one water use record that covered two summer months, they found that doubling the marginal price led to a 12% decrease in water use. The local elasticity estimate for this large (nonmarginal) price change was  $-0.12$ , somewhat lower than typical elasticity estimates found in meta-analyses. However, the elasticity estimates in Nataraj and Hanemann's study applied not to average water users but to high water users. Furthermore, Wichman (2014) noted that average and marginal prices moved together in the natural experiment, making it difficult to rule out that customers were responding to increases in average prices. Using back-of-envelope calculations (see footnote 2 in Wichman, 2014), he noted that the corresponding increase in average price in Nataraj and Hanemann's study was only on the order of 10%, implying a larger elasticity ( $-1.16$ ) that would be more consistent with other estimates for high users.

Ito (2014) provided a compelling empirical case that customers respond to average volumetric price, not marginal price or expected marginal price, in electricity. Interestingly, the paper never clearly defined average price. It is clear, however, from Ito's figure 1 (Panel A) and figure 3 that the focus was average volumetric price: "average" price was always lower than marginal price, and it was equal to marginal price for the first block. The paper overcame identification challenges with a spatial discontinuity design in electricity service areas: two customers in the same city can be served by one of two providers. Substantial variation in prices both over time and across utilities allowed robust estimation of the effect of prices. Nonparametrically, he tested for evidence of bunching at kink points in the price schedule. The intuition was that if customers, like our hypothetical customer in figure 1, were aware that their consumption placed them near a jump in marginal price, they would act to keep consumption below the threshold of the next tariff. In aggregate, customers should bunch just below that threshold if they act on marginal prices. Ito found no graphical evidence of bunching, even when marginal prices jumped 84%. Using predicted prices as instruments, he found no evidence that customers respond to marginal or expected marginal prices in an

“encompassing” test, which essentially includes both marginal and average prices in regressions jointly and separately.<sup>5</sup> This result also held for lagged prices. Finally, Ito (2014) outlined a weighting function that consumers might use to construct a “perceived” price. Estimating the parameters of the function empirically, he found again that the shape of the weighting function was consistent with response to average prices. Finally, using simulations, he highlighted the idea that IBTs can discourage conservation compared to a single marginal price set at marginal cost. Compared to a single marginal price, an IBT presents some lower-consumption households with lower prices, and they increase their consumption. This is not outweighed by the slight decrease in consumption among higher-usage customers because their average price does not increase that much.

In an unpublished working paper, Ito (2013) employed many of the same analytical approaches in Ito (2014) but using data on household water consumption in Irvine Ranch Water District. The water provider used a five-tier “budget-based” rate that based the pricing tier on a baseline allocation of water that depended on weather and household characteristics. Marginal prices increased steeply, doubling in the third, fourth, and fifth tiers. Despite this, Ito (2013) again found no nonparametric evidence of bunching near kink points in the distribution. The RD design that he used exploited the reduction in the baseline allocation from the summer to the winter months. The intuition was that households at the upper end of a consumption tier were more likely to be pushed into a higher marginal price tier when allocations were reduced in the winter than households at the lower end of the tier. This analysis provided no evidence that consumers responded to changes in marginal price resulting from being pushed into higher price tiers during the winter. Finally, using a spatial discontinuity design analogous to the design in Ito (2014), he examined water use of households in a service area that moved from a single rate to the five-tier tariff when they were consolidated into the utility that serves the surrounding households (the control group). Comparing households within one mile of the border of the service area, he found that average volumetric price had the expected and statistically significant effect, while marginal price did not.

Another strong piece of causal evidence that customers respond to average volumetric price came from a natural experiment in billing periods exploited by Wichman (2014). Like Ito (2013, 2014), Wichman never defined average price, but the tariff schedule in his Table 1 made it clear that average volumetric price was being used. The paper formalized the common empirical approach of using lagged prices by modeling a household’s decision of how much to consume as a function of last month’s consumption and prices. The city of Chapel Hill, North Carolina, moved from a single uniform volumetric price to a five-tiered IBT. The utility informed customers of the tariff change on their water bill. Because the utility delivered bills to some meter routes early in the month and some adjacent meter routes late in the month, Wichman (2014) used this spatial discontinuity for quasi-experimental identification. The intuition was that a customer who received notice of the new tariffs in their October 4 bill would incorporate that information into their consumption decision for the remainder of October. A neighboring household in a different meter route that received word of the new tariffs in their October 30 bill would not have been able to react to the new prices until November. Thus, Wichman could compare October water use of the October 4 group (treatment) with water use of the October 30 group (control), eliminating time-varying confounders like October’s weather.

Furthermore, the tariff change led average volumetric prices and marginal prices to change in opposite directions for many customers. For customers using more than 7,000 gallons, marginal prices increased but average prices decreased, creating a clear test of price perception. If customers respond to the (increasing) marginal price, this should have led to a decrease in consumption. If they respond to (decreasing) average price, consumption should have increased. Wichman (2014) showed clear nonparametric difference-in-difference evidence that consumption increased, confirming that customers perceived average price. This was confirmed with statistical evidence from the application of the RD design (as in Nataraj and Hanemann) around the kink in the distribution of 7,000 gallons.

Ito and Zhang (2020) provided the only empirical test, to our knowledge, of whether customers respond to ATP (including fixed charges) or marginal price. They found evidence that customers react to changes in marginal price, not ATP. They examine the 10-year roll out of a heating reform policy in northern China that moved customers from a single fixed (nonvolumetric) electricity charge that was based on the square footage of the dwelling to a two-part tariff with a fixed charge and a single volumetric price. Because the reform was rolled out over time and because households were metered for several months even before the tariff reform, Ito and Zhang used an event-study framework. They found that electricity consumption fell by 13% after the first year of the reform, 25% after the second year, and 34% after the third year.

Although they labeled it simply “average price,” it is clear from the figures and a conceptual sketch that Ito and Zhang defined average price as average *total* price. Therefore, their nonparametric and encompassing tests were testing whether customers responded to marginal price or were “schmedulers” (Liebman & Zeckhauser, 2004) who were responding to fixed charges. For low-usage customers, the marginal price increased, but the ATP decreased. For high-usage customers, marginal price increased, but ATP changed relatively little. (Note that in this case the change in average volumetric price and change in marginal price were identical and couldn’t be identified.) If customers react to ATP, low-usage customers should increase their usage. Ito and Zhang found no evidence of this; all quartiles of consumption decreased in response to the policy. An encompassing-test regression confirmed that customers reacted to changes in marginal prices.

Finally, while not a quasi-experimental study, the study by Clarke et al. (2017) estimated water demand in Tucson, Arizona, and found evidence in support of using lagged average price. The definition of average price was not clear in the paper, but it was average volumetric price.<sup>6</sup> Using 10 years of data encompassing numerous changes to the four-tier tariff structure, the authors estimated a Stone-Geary demand function. They instrumented for both lagged average and lagged marginal price by using total annual water expenditures and rate information. Using an encompassing test similar to the one used by Ito (2014), they found that the effect of instrumented marginal price had the wrong sign, while lagged average price was statistically significant and negative. The estimated elasticities showed seasonal patterns, with households less sensitive to prices during summer months than winter months. The long panel also showed evidence of “demand hardening,” with the seasonal variation attenuating and overall elasticity trending downward (less sensitive to price).

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## Field Experiments: Can We Make Consumers Respond to Marginal Price?

The evidence, including papers that found a response to average price, led to studies that used field experiments to improve price information and to study the effect on consumption. An implicit, but often unstated, goal was that informed consumers would stop responding to average price and begin responding to marginal price. Making the tariff structure clearer and more salient, however, improves only one aspect of a household's decision-making; they may still struggle to connect water usage to specific activities throughout the month because consumption information comes monthly and with a lag. Brent and Ward (2019) randomly invited a subset of households linked with billing records to a survey informing them of features of the tariff as well as the cost of different water activities. They found an aggregate increase in consumption for survey participants. Since consumers generally overestimated marginal price, the increase in consumption could be interpreted as consumers' response to a decrease in the perceived price, although other mechanisms are possible. In energy, two studies found similar results, where information on an electricity IBT increased consumption for households in the lowest pricing tier (where average price exceeded marginal price) and decreased consumption for households in higher tiers (where marginal price exceeded average price). Kahn and Wolak (2013) found this effect for an online experiment in California, and Stojanovski et al. (2020) found similar results for an in-person intervention in Mexico. One interpretation is that, armed with adequate information, an average-price consumer can turn into a marginal-price consumer.<sup>7</sup> One challenge with this interpretation is that, within a utility, the marginal price in an IBT increases monotonically with consumption, so the pattern of heterogeneity seen in the experiments might be due to average energy use as opposed to the specific marginal price they face. There are also a host of experiments in energy that show evidence for greater response to peak prices with the use of "enabling technologies," such as in-home displays and programmable thermostats (for a review, see Faruqui & Sergici, 2010).

## Conclusions

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This article has five messages for water professionals.

First, consumers do respond to changes in the price of water and sewer services. Studies from Howe and Linaweaver (1967) onward, including many dozens of demand-estimation studies, have found that consumers will react when their bills change. Prices should remain an important tool for utilities to use in managing demand. One should not mistake consumers' inattention to complex tariffs and marginal prices for an insensitivity to *some* price.

Second, it seems clear that for nearly all customers facing nonlinear tariffs in water and electricity, the "some" price they are sensitive to is not the marginal price. In both sectors, the evidence has amassed over several decades that most consumers (or taxpayers) do not have a clear knowledge of the tariff structure and have an imperfect sense of their own consumption level in relation to that tariff. Two modern, well-identified studies did find that consumers react to marginal prices (Ito & Zhang, 2020; Nataraj & Hanemann, 2011), but in both cases the salience of the marginal price was unusually high. In the study by Nataraj and Hanemann (2011), the utility introduced a new tariff block with a marginal price twice as high as the second block, and it sent mailers alerting users to the change. (As noted, Nataraj and

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Hanemann did not explicitly rule out an average price response.) In the study by Ito and Zhang (2020), consumers faced a large change from a fixed, nonvolumetric bill to a relatively simple two-part tariff with a single volumetric price.

Third, existing studies have not carefully defined which average price they used. A typical study simply described, rather than defined, average price, leaving the reader to deduce from context, tables, and figures whether the subject was average total price or average variable price. It seems clear that most early studies on price perception through the 1980s used average *total* price. More recent studies (Ito, 2013, 2014; Wichman, 2014) used average *volumetric* price, except for Ito and Zhang (2020).

Fourth, based on more recent and well-identified studies, the current state of the evidence suggests that consumers respond to average *volumetric* prices rather than marginal prices or “expected” marginal prices. But the informational requirements to calculate average volumetric prices seem nearly as onerous as those for calculating marginal prices. It seems most likely (and as it seemed to earlier authors like Shin, 1985) that consumers respond to changes in average *total* price, with information only on their total bill and their total consumption. This is also supported by the better out-of-sample predictions for the heuristic decision rule used in Wang et al. (2018) that uses information only on changes in total bill and changes in consumption compared to the DCC model. But, to our knowledge, there have been no clear tests in the more recent econometric literature of whether customers perceive average volumetric or average total price (for example, tests applied by exploiting rate changes that only affected fixed charges). It may be that average volumetric price is simply a better econometric approximation than marginal price of what consumers are really reacting to. Allowing consumers to change consumption based on changes in the fixed cost of their water bill would defy conventional utility optimization. But one can imagine at least a subset of households that might wish to hold expenditures on water and sewer services within a fixed interval. When their total bill increases because of an increase in fixed charges, they may reduce consumption to lower their bill back to their preferred expenditure level. Of course, this would also be possible if people were unaware of why their bill increased.

Finally, recent field experiments have demonstrated in both water and electricity that utilities can increase the salience of marginal prices through educational materials and more dynamic information from smart meters (Jessoe & Rapson, 2014; Strong & Goemans, 2015). This may be desirable in some situations, particularly in the electricity sector, where peak loads vary during the day. If consumers respond to marginal real-time prices, peak pricing coupled with “smart” meters and in-home displays or energy use apps can induce consumers to flatten those peaks, lowering production costs and environmental externalities. Such time-of-day pricing is less useful in the water sector, where managing water demands seasonally is the typical concern. Rather than expending effort to educate their consumers to react “as expected” to their complex, increasing block tariff policies, utilities and their tariff consultants are likely better off focusing their efforts on simplifying tariffs. Marginal prices will be easier for customers to understand (without help) when tariffs have only one or two consumption blocks, perhaps with a seasonal component. Then, simpler tariffs might achieve their efficiency goals at a lower cost than information interventions. Given recent evidence on the poor performance of IBTs in meeting their equity goals (Whittington & Nauges, 2020), simplification might also spur creativity among tariff consultants. Rather than relying on complex IBTs, they can set volumetric prices in the simplified block(s) closer to long-run

marginal cost and use targeted “customer assistance programs” to help the poorest customers afford their bills (Cook, 2020; Cook et al., 2020) while still complying with zero-profit constraints.

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## Notes

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1. This article refers throughout to the “prices” faced by the consumer. They could also be described as marginal or average “costs” to the consumer, but we want to avoid any confusion with the average and marginal costs of *supplying the water* to the consumer that are common to the tariff design literature.
2. Howe and Linaweaver (1967) correctly argued that the correct conception of price is “what charges can be avoided or changed in magnitude by the decision now being made by the decision-making unit (household, builder, commercial establishment).” We ignore situations where households may be able to affect their “fixed” charges through some type of action, such as installing a permeable driveway to decrease a stormwater assessment.
3. Many utilities assess sewerage services on a volumetric basis, linking the quantity of water treated in the sewer system to the quantity of potable water delivered to the household. Because outdoor water use does not contribute to load on the sewer system, many utilities calculate summer sewer charges based on an average of water use during winter months. The discussion here ignores the possibility that trash collection services are bundled into the bill as another fixed charge. It also leaves aside stormwater charges in the simple example, although both add to the total bill faced by consumers in many places and would thus impact their perception of the average price.
4. To calculate average volumetric price, a consumer has to subtract the fixed charge from the total bill and then divide the volumetric charges by the units of consumption.
5. Note, however, that it is possible that the encompassing test is biased toward average prices because average price is more highly correlated with consumption than marginal price.
6. Personal communication with Bonnie Colby, July 2, 2020.
7. There is also a parallel in the tax literature. In an experimental study with 125 MBA students at New York University, De Bartolome (1995) found that roughly half of the participants treated the average tax rate as if it were the marginal rate when the tax schedule was presented in the standard “tax table” format used in U.S. income tax instructions. This table simply lists the total tax due at various levels of income. When given information explicitly identifying the appropriate marginal tax rate, virtually all students behaved as if they were responding to the marginal rate.

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