Teaching and Educational Methods

Teaching Price Elasticity of Demand and Marginal Analysis using Household Water Pricing

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Abstract
Understanding the economics of urban water pricing is fundamentally about the concepts of price elasticity of demand and marginal analysis. Recent advances in our understanding of consumer response to water pricing, emerging discussions of equity issues, and water utility interest in innovative pricing approaches make this topic important to integrate into any class on natural resources or water economics. To aid instructors, we highlight current issues in the field and emerging research, and present materials used to teach urban water pricing to both undergraduate and graduate audiences. We present a variety of activities and resources to integrate concepts of price elasticity of demand, conservation pricing, utility considerations, and equity issues. After using these materials, students are expected to know how to calculate prices and elasticities and explain these values in the broader context of conservation and equity.

1 Introduction

Water shortages in major urban centers across the globe and recent droughts across the western United States have pushed water issues into the forefront of natural resources policy issues (Kummu et al. 2016; Brown, Mahat, and Ramirez 2019). Climate change, growing populations, and drought have intensified coverage of water scarcity to the point most students are aware of challenges to urban water delivery, either in their local areas or through national and international media coverage. How urban water utilities price water and how consumers respond has emerged as an increasingly important issue in natural resources economics.

While water remains a topic in most natural resources classes, teaching students water economics today requires a broader understanding that extends beyond traditional concepts of balancing supply and demand across multiple time periods (Grafton 2017). To address these challenges, students must bring together foundational economic concepts while understanding the accounting structure of water delivery systems and how users respond to price signals. Finally, to satisfy students' desire for real-world examples and topical application of concepts, instructors must address current pricing strategies, behavioral economics, and equity issues.

The topic of water pricing links key fundamental concepts from economics such as marginal price and elasticity of demand to emerging issues like equity and behavioral economics. We present a multi-modal approach to teaching a module on the economics of water pricing with a focus on residential consumers. We draw on our experience teaching a wide array of topics in water economics to students from both economics and interdisciplinary backgrounds at a variety of academic levels to provide a set of key concepts that emphasize: price elasticity, conservation pricing, utility accounting, and equity. These concepts highlight the relevant economic theory and provide a targeted treatment of current literature to provide students a basis for understanding the challenges of meeting water demand in the 21st century.

In the discussion below, we present an overview of the emerging issues in consumer water pricing as context for preparing instruction or leading a discussion. Then, we provide classroom-ready material organized around teaching the four key concepts. This material is intended to help students understand the complexity of water demand by different user groups. After utilizing the materials given below, students should be able to:

1. Understand and calculate the marginal price, average variable price, and total average price of water.
2. Define different water pricing strategies and explain how water pricing can motivate conservation.
3. Apply the concept of price elasticity of demand qualitatively and through numerical calculation.
4. Explain some of the complex issues in water pricing, equitable access, and tradeoffs facing water managers in the 21st century.

The paper first discusses the key economic concepts in residential water pricing and understanding demand response. We then introduce our module's materials and approach, referencing assignments, lectures, and case studies, which we make available as supplementary material. We then document our expected learning outcomes from the module and discuss some of the frequently asked questions in the classroom before concluding.

2 Economic Concepts and Framework

Addressing water scarcity from the lens of an economist requires an understanding of incentives faced by water providers and users, and the economic framework under which they operate. In this section, we provide a background on the basics of water pricing, key economic concepts, and emerging areas of research.

Water utilities construct and operate water distribution systems and charge consumers some price via a combination of fixed fees and per-unit pricing. While utilities deliver water to a variety of industrial, single-family, multi-family, and agricultural water users, our class material follows the bulk of the literature on consumer response to water pricing by focusing on residential single-family consumers. Throughout this paper, we use "price" to refer to the charges consumers face and "cost" to refer to those incurred by utilities. Water utilities are characterized by high fixed and low marginal costs. Consumer water price is often low because the average private cost (APC) of water delivery is typically low and, for utilities, setting residential prices at levels near APC allows consumers to meet their essential uses at a low cost (Grafton, Chu, and Wyrwoll 2020).

The goal of a profit-neutral utility would be to set average consumer price to APC.[1] From an economic perspective, however, this is not ideal when new water sources have a higher marginal cost than existing sources. For instance, a key challenge associated with urban growth is finding water. If a utility sets the price at APC, then the consumer sees a marginal price below marginal cost. Economically,

[1] Theoretically, there are several interesting considerations for how a regulated utility should set a tariff to pay back fixed costs. Ramsey pricing, the result of the work of Ramsey (1927), sets a tariff for a single good with a markup necessary to recover the full cost, but when multiple goods are present, like water for indoor and outdoor use, price is set following the inverses-elasticity rule. This rule maximizes total utility (consumer plus producer surplus) but is unlikely to be palatable for utilities and regulators when low elasticity and low incomes coincide, as in water pricing. Feldstein (1972) addresses this concern with a fixed fee weighted by the marginal utility of income, and other authors have considered efficiency, equity, and financial payback considerations in setting tariffs (e.g., García-Valiñas 2005). This material is beyond the scope of the module we typically teach on water pricing.

the volumetric charge for water should equal its long-run marginal cost, but this can be difficult for utilities to achieve because it creates a situation where total revenues exceed costs.[2]

Where water is scarce, the value of water exceeds the cost of delivering it. This is typical in arid regions, but acute drought or misalignment between infrastructure and short-run demand can make water scarce in wet regions as well. To ensure water demand and supply are equal (i.e., no shortages), water utilities may employ demand management strategies or invest in new supply. Supply-side management can involve building new dams or canals, or purchasing water from other municipalities or farmers. In many arid areas, opportunities for increasing supply are extremely limited. Demand management strategies may involve price or non-price approaches to encourage water conservation. Non-price strategies can include subsidies for conserving technologies, reminders or other behavioral nudges, or rationing. Rationing can involve absolute quantity restrictions but more often limits certain behaviors (e.g., car washing or lawn watering) entirely or to certain days/times. These noneconomic instruments can misallocate scarce water where high surplus activities are curtailed, but may be undertaken for political or logistical reasons. For instance, utilities may find it is easier legally and in terms of public opinion to impose a watering ban due to a severe drought instead of doubling water rates.

Volumetric pricing offers several advantages over rationing. First, because elasticity of demand is less than one, increasing price conserves water *and* increases revenue. Second, volumetric pricing provides the utility the opportunity to increase allocative efficiency, although this comes at the expense of higher transaction costs for utilities creating and consumers interpreting prices, and makes utility revenue more uncertain (Grafton et al. 2020). Utilizing price strategies requires knowledge of the relationship between the price of water and quantity demanded. Students should be aware upon entering the class that the degree of responsiveness of consumers to changes in price is the price elasticity of demand—for instance from a course in the principles of microeconomics—and lessons on water pricing can reinforce this crucial concept. Understanding elasticity is a prerequisite for understanding the use of price as a tool to influence water consumption.

Elasticity of demand is influenced by many factors. Demand tends to be relatively inelastic when there are few substitute goods and for goods that occupy a small portion of the overall consumer budget—where price increases are less impactful on the consumer's overall spending power—which are both generally true of water. Demand also tends to be less elastic when the good is a necessity. Consumers need water to do very basic things such as drink, cook, and bathe, and there are few, if any, substitutes to using water for these activities. In 2010, the United Nations passed a resolution recognizing access to clean drinking water and water for sanitation as an essential human right.

In contrast, most outdoor water use including landscaping and swimming pools is not essential, and therefore would not be considered a necessity. Additionally, if water becomes very expensive, in the long run, consumers can install alternative forms of ground cover such as drought resistant vegetation, rocks, or mulch in place of traditional turf and reduce water use (Brent 2016). For these reasons, both outdoor water use and water use in the long run are more elastic than indoor and short-run water use, respectively. Most literature estimates urban water price elasticity of demand to be between -0.1 and -0.76, suggesting overall demand for urban water is relatively inelastic (Bruno and Jessoe 2021). Outdoor demand elasticity estimates range from -0.67 to -1.2, with elasticities depending on the seasons because most outdoor water use in many locations occurs during the summer (Mansur and Olmstead 2012).

[2] In California, for instance, utilities may be found to be in violation of proposition if rate increases exceed to cost of providing the water service.

There are three primary rate structures used by utilities—flat rate, uniform rate, and block rate—along with more complex budget-based rates. Each structure provides consumers with a different price signal, and this offers instructors an opportunity to build student understanding of behavioral responses to price. Flat rates charge consumers the same amount regardless of usage.

Uniform rates charge the same per unit rate for all units of consumption. Increasing block rates (IBRs) charge an increasing marginal price of water at discrete intervals as consumption increases. IBR pricing is quite unusual except in the case of water and energy pricing, and many economic papers have been written about behavioral response. The complex information conveyed by IBR pricing, however, has led some researchers to question whether consumers are responding to changes in the marginal or average price of water (Ito 2014; Wichman 2014). There is evidence that high-use consumers respond to large increases in the marginal price of water (Nataraj and Hanemann 2011), but recent work suggests demand is more responsive to changes in average price than marginal price (Browne, Gazze, and Greenstone 2021).

Budget-based pricing is an alternative water pricing scheme used to cater water prices more specifically to individual household characteristics. When used in the context of increasing block rates, block sizes may differ based upon environmental conditions, household characteristics, or other metrics determined by the regulator (Baerenklau, Schwabe, and Dinar 2014). To provide affordable water for essential uses, the lowest tier or block of water has the lowest marginal price. Low-income households are more likely to have a high number of occupants per house or live in inefficient homes, and consequently, have a higher rate of essential water use. Varying the size of the lowest-priced, first block can help ensure that the pricing structure does not put an excess burden on low-income households (Borenstein 2012; Smith 2022).

Understanding what price consumers are responding to links this topic to key concepts from behavioral economics like rational inattention and decision biases. Assuming consumers respond to marginal price requires fairly strong assumptions on the ability and interest of households. Generally, consumers know much less about their water use and the price they pay than these assumptions would require (Brent and Ward 2019). Utilities vary in what information is displayed on consumer utility bills. The bill may contain information on marginal or average price, or not.

Another emerging area of economics where urban water pricing has formed a key part of the literature is around equity. Equity is a normative concept used to describe the allocation of resources in society. In the context of discussing equity and water pricing in the classroom, we broadly describe a water pricing scheme as equitable if the pricing system does not disproportionately harm low-income households or benefit high-income households and provides all individuals with access to water for essential use. Water used for drinking or sanitation is considered essential while outdoor water use, which is typically landscape irrigation, is considered discretionary.

Water affordability is particularly important for low-income households where water expenditures make up a relatively large percentage of total income (Cardoso and Wichman 2020; Teodoro and Saywitz 2020). In the United States, the price of water and wastewater services is increasing faster than inflation, and 10 percent of households face water affordability issues (Cardoso and Wichman 2020). Households within the lowest income bracket earning less than $15,000 per year are spending nearly 6.8 percent of income on water and sewer services. The use of fixed or user fees can have implications for affordability because their burden is decreasing with income; price setters concerned about equity may opt for lower fixed fees and higher marginal prices (Beecher 2020; Levinson and Silva 2022). IBRs and budget-based rates are considered more progressive because lower end essential units of water are more affordable and higher use discretionary units are more expensive (Smith 2022).

To ensure the lowest block is large enough, block size can be adjusted to account for household size or other characteristics (Mayer et al. 2008; Barberán and Arbués 2009). Smith (2022) examines the use of average winter consumption (AWC) as the basis for the size of the lowest or essential water tier. The justification for using AWC to determine the size of the lowest tier is that winter usage likely incorporates only essential use because outdoor watering does not take place. This type of budget-based pricing may violate concepts of horizontal equity because households consuming the same amount of water face different prices.

Price-based approaches to reducing water demand can be made more progressive by returning utility profits to lower income households in the form of rebates (Olmstead and Stavins 2009). Research on electric utilities finds evidence that utilities located in areas with more unequal income distribution use more redistributive tariffs (Levinson and Silva 2022). Some municipalities have used other tools to address equity, including income-based rates and low-income water rate assistance programs (Cardoso and Wichman 2020).

For equity or other reasons, some utilities have chosen to forego price interventions in favor of mandates and information campaigns. Complicated rate structures have higher administrative costs, which are often reflected in increased fixed fees. The increased fixed fees tend to be regressive, disproportionately paid by minority, lower income, and rental households (Smith 2022). Restrictions on outdoor water use tend to induce a more uniform response in water usage than do price controls (Wichman 2014). Other nonprice interventions include social comparisons in which a user is provided information on peer usage and technology standards (e.g., low-flow or efficient appliances). Although more equitable, nonprice mechanisms are generally less efficient (more costly) and more difficult to monitor and enforce (Olmstead and Stavins 2009).

The adoption of some form of real-time pricing has also begun to emerge as an option for some urban water pricing agencies. Energy can account for up to 40 percent of operating costs for drinking water systems, and pumping in high demand periods requires the use of additional pumping resources. As utilities adopt advanced metering infrastructure, new options to price water at high temporal resolution and accuracy are possible. If effective, pricing to flatten peak hour water demand can reduce the magnitude of peak energy consumption and the cost of distributing water. In electricity consumption, consumers that are more accurately able to receive energy price through real-time availability of price data are more responsive to short-term price increases (Jessoe and Rapson 2014).

3 Materials and Details

To elucidate our approach to teaching elasticity of demand and marginal analysis in the context of an urban water utility, we break the subject into four topics: elasticity of demand, conservation pricing, utility considerations, and equity issues. These topics can be taught as an integrated whole or broken down into the four topic areas. Table 1 provides a description of the four topic areas and the modalities we use to engage students and convey information. The table also provides descriptions of the materials used to teach these topics. Additional information on teaching approaches, suggestions for delivery, and the materials can be found in the Teaching Notes.

Elasticity of demand (EOD) can be a challenging concept for students to apply. A lecture on the basics of elasticity in the context of water pricing is a good kickoff to water pricing and should focus on reviewing key concepts from earlier classes as well as the literature on elasticity of demand in urban water. Papers have estimated the elasticity of demand in numerous countries and settings using various approaches. We use two meta-analyses to provide students an idea of the range of elasticities that have been estimated. Espey, Espey, and Shaw (1997) perform a meta-analysis of the water pricing literature and provide a nice summary of the studies they use and the potential factors that change elasticity of demand. However, their econometric approach may not be easily interpretable to students. We typically show results from the meta-analysis by Dalhuisen et al. (2003), which reviews 314 price elasticity estimates. Figure 1 in the paper is compelling for students because it shows the wide range of price elasticity of demand estimates. In our classes, we encourage discussion of why elasticity of demand estimates vary so widely.

Table 1: Topics and Associated Materials

Topic	Modalities	Description	Materials
Elasticity of Demand	Lecture Coding	Elasticity of demand for water lecture slides Regression coding exercise using data from a Utah water facility	EOD slides.pdf Water rate regressions.pdf Utah Water Datat.csv IBR Slides.pdf
Conservation lecture Pricing	Spreadsheet	Urban water conservation pricing lecture slides Spreadsheet for group activity calculating rate changes and elasticity of demand from IBR schedule	IBR_Group.xlsx IBR_Group_Instruct.pdf IBR_Group_instruct.pdf
Utility Considerations	Reading	Extension reading of conservation pricing geared for water utilities	Municipal_conservation.pdf
Equity Issues	Discussion Lecture Supplement Discussion	Comparison of water bills from different utilities in different locations Supplemental slides for including equity in discussion of IBR/EOD Supplemental materials to engage students in discussion of human right to water and water availability/price for low-income users	Bill_Handout.pdf Equity_slides.pdf Colonias_handout.pdf
Learning Evaluation	Assignment	EOD/IBR assignment where students fill in marginal and average prices	IBR_pricing.xlsx IBR_assignmnet.pdf

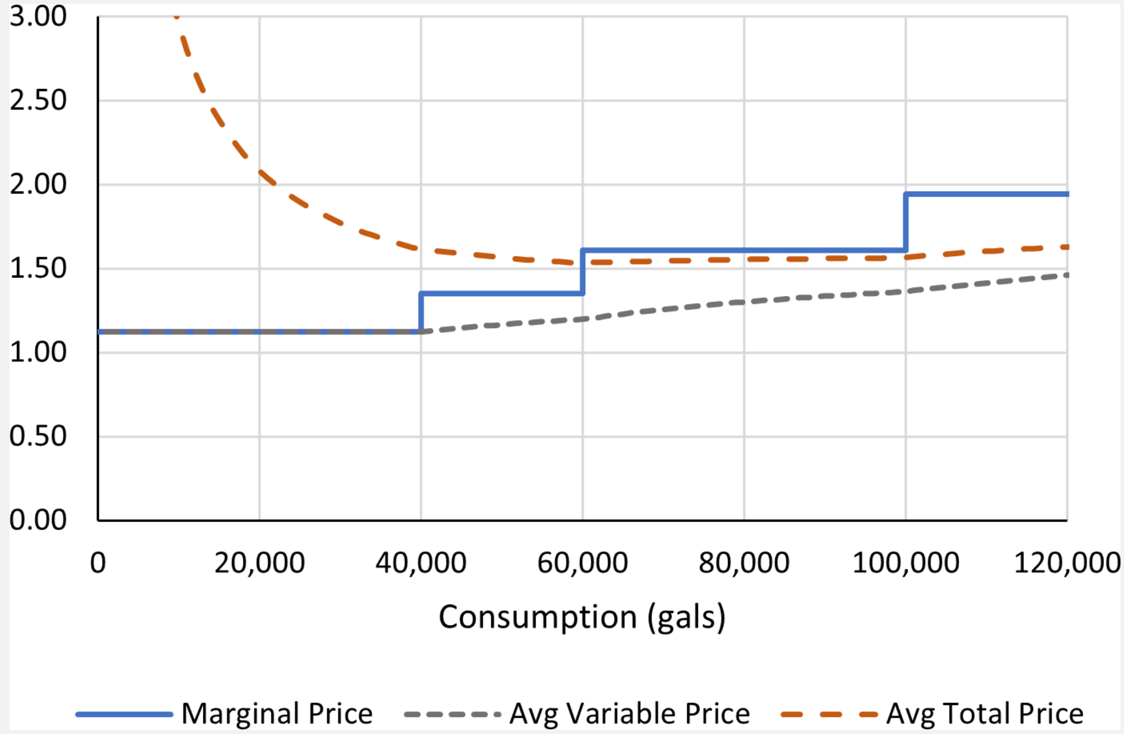


Figure 1: Consumer Prices from Example Utility in Teaching Notes

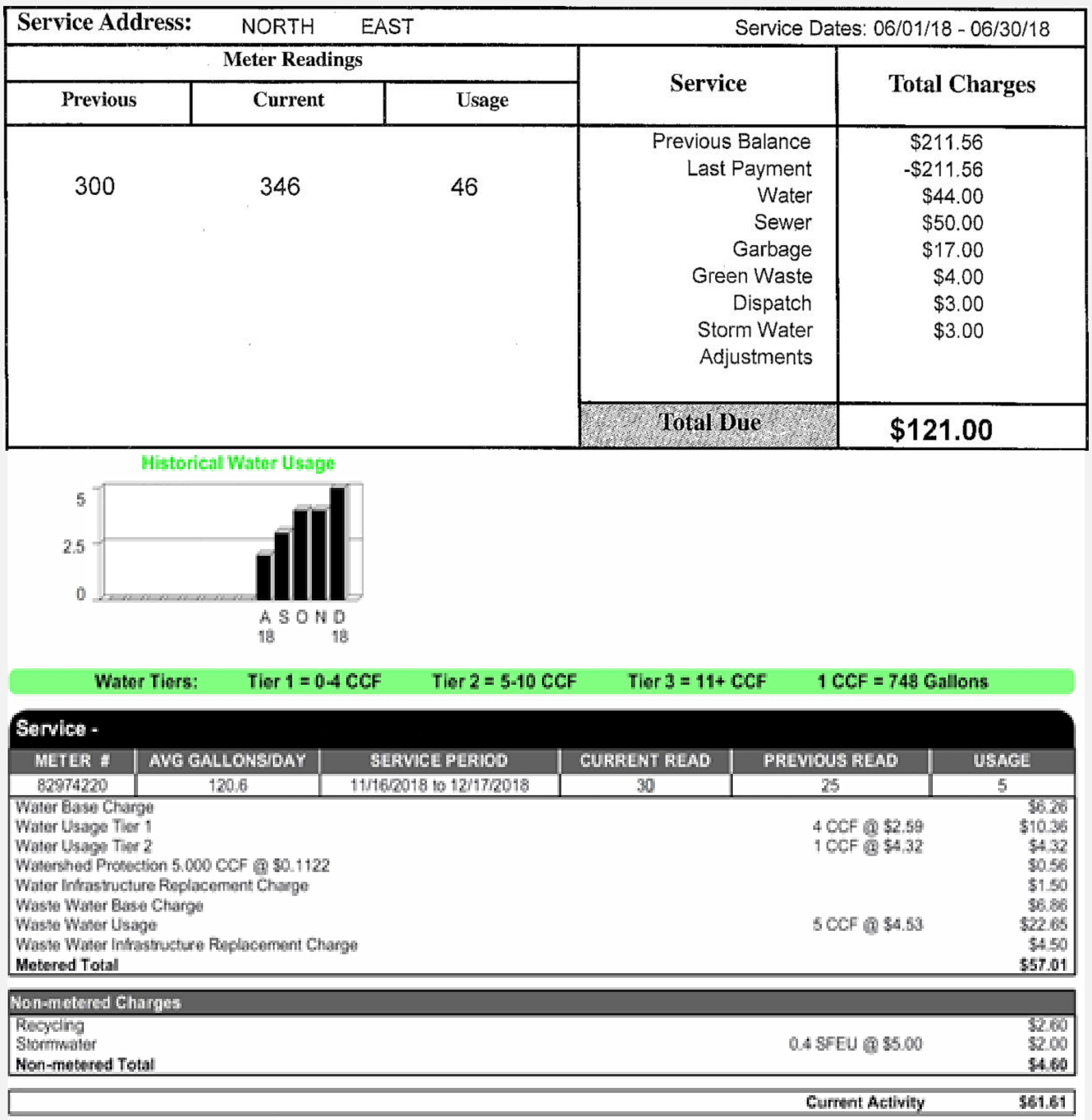
For advanced students who have taken econometrics, using real price and rate data to estimate elasticity of demand is an exciting exercise with a myriad of possible extensions to complement other course content and build on students' existing econometric background (see Teaching Notes). For all students, having a solid grounding in what the elasticity of demand for water is and what it means is crucial. We typically use a point estimate of price elasticity of demand for urban water of -0.41 (Dalhuisen et al. 2003).

As the material transitions from EOD to IBR pricing, students often encounter a key barrier in understanding the difference between marginal and average price. In a standard principles class, students would have worked with graphs of marginal and average cost curves. Water pricing offers a unique application of these ideas because IBR pricing is such an unusual pricing structure. Although IBR pricing has become popular among utilities, recent work has emphasized that consumers may know little about the marginal price they pay for water, and little about their water use in general, and so may not respond in their behavior to marginal price (Wichman 2014; Brent and Ward 2019). We spend substantial in-class time training students to take a marginal IBR pricing schedule and compute the average variable cost and average total cost, as shown in Figure 1, for the example utility described in the Teaching Notes. We emphasize that researchers look at all three costs as potentially affecting behavior. The complexity of the calculations is important for students to understand because demand management via pricing requires consumers to know the price they pay for water.

Building on EOD and IBR concepts, we typically transition into discussions of the motivation of water utilities in using different pricing strategies. Most water utilities are not-for-profit and may have rules requiring revenues to not exceed costs. (This may also allow for discussion of monopolies and public oversight or regulation.) As such, IBR pricing allows them to charge high marginal prices to high-volume users while offering prices below marginal costs for low-volume users. Utilities may or may not choose to display pricing information on consumer bills. One way to clearly demonstrate this to students is through the comparison of bills with marginal price information and without. Figure 2 shows a bill comparison we apply in class where the left bill has higher water consumption, less information, and a lower price (see Teaching Notes for additional discussion).

One key sticking point for students beginning to study water economics is the treatment of water as a good with monetary value. For this reason, water pricing is a great opportunity to discuss issues of equity in natural resources use. While water is essential to human life, the concepts from economics still apply to its allocation and use. Studying water as a market-allocated good does not change its essential nature, our moral obligation to allocate it fairly, or the need to preserve water for the natural environment.

The case we provide to study equity in water pricing (see Teaching Notes) focuses on colonias, unincorporated subdivisions along the U.S.–Mexico border without access to urban water supplies. We emphasize two approaches to understanding the problem. The standard policy approach suggests the municipalities are failing because they are not providing water service to these communities.



Service Address: NORTH EAST — Service Dates: 06/01/18 - 06/30/18

Meter Readings: Previous	Current	Usage	Service	Total Charges
300	346	46	Previous Balance	$211.56
			Last Payment	-$211.56
			Water	$44.00
			Sewer	$50.00
			Garbage	$17.00
			Green Waste	$4.00
			Dispatch	$3.00
			Storm Water	$3.00
			Adjustments	
			Total Due	$121.00

Water Tiers: Tier 1 = 0-4 CCF Tier 2 = 5-10 CCF Tier 3 = 11+ CCF 1 CCF = 748 Gallons

Service -

METER #	AVG GALLONS/DAY	SERVICE PERIOD	CURRENT READ	PREVIOUS READ	USAGE
82974220	120.6	11/16/2018 to 12/17/2018	30	25	5

Water Base Charge		$6.26
Water Usage Tier 1	4 CCF @ $2.59	$10.36
Water Usage Tier 2	1 CCF @ $4.32	$4.32
Watershed Protection 5.000 CCF @ $0.1122		$0.56
Water Infrastructure Replacement Charge		$1.50
Waste Water Base Charge		$6.86
Waste Water Usage	5 CCF @ $4.53	$22.65
Waste Water Infrastructure Replacement Charge		$4.50
Metered Total		**$57.01**

Non-metered Charges		
Recycling		$2.60
Stormwater	0.4 SFEU @ $5.00	$2.00
Non-metered Total		**$4.60**

Current Activity **$61.61**

Figure 2: Example Bills from Comparison Exercise

A paper by Olmstead (2004) focuses on the economic incentives facing municipalities, which are legally limited in what they can charge for water. This limitation makes it impossible for municipalities to recoup investment in extending water service to these communities. The case demonstrates the importance of economic analysis in understanding the underlying mechanisms behind policy failures and leads to a nice discussion of potential solutions.

The colonias case study could be fit into a more thorough treatment of equity and affordability in water delivery either through a more elementary discussion of current affordability metrics and indexes (Patterson and Doyle 2021) or more advanced discussion of the unintended consequences of block rates (Agthe and Billings 1987) and theoretical efficiency discussions around marginal users (Schoengold and Zilberman 2014). A more in-depth discussion on equity, emigration in urban areas, and the complex challenges of water delivery with aging infrastructure (Swain, McKinney, and Susskind 2020) and declining population (Faust, Abraham, and McElmurry 2016) could also be included and potentially reference other urban water crises such as Flint, Michigan (Sadler and Highsmith 2016).

4 Discussion and Outcomes

Urban water pricing is an intuitive topic that many audiences easily relate to. A modified version of the material presented in this article has been presented to nonstudent audiences to introduce EOD and conservation pricing. Students and nonstudents alike relate to receiving utility bills, assessing the costs and benefits of various water uses, and making decisions on use. The contrast between a low-cost, low-information bill in arid Utah and a high-cost, high-information bill in humid North Carolina (Figure 2) always spurs interesting discussions. A paper by Luby, Polasky, and Swackhamer (2018) can enhance classroom discussion in its findings that this single observation is an empirical regularity.

In gauging student learning outcomes, we use two quantitative and three qualitative measures. The ability to calculate and apply a concept like elasticity of demand varies depending on the level of the course, so the exact expectation of the calculations can vary, but generally our two quantitative learning outcomes are:

1. Calculate total average price, average variable price, and marginal price for water;
2. Calculate price elasticity of demand for water using the midpoint method.

The first objective is achievable for all student levels, although undergraduates struggle with average price calculations using an IBR pricing schedule. While all undergraduate students can apply elasticity of demand to go from a change in price to change in quantity demanded, only advanced students have the experience in using econometric tools to calculate elasticity of demand using data. For this reason, the qualitative objectives associated with elasticity of demand become critical in evaluating undergraduate learning outcomes. We define three qualitative learning outcomes:

1. Understand determinants of price elasticity of demand and use the concept of price elasticity of demand to explain how water consumers will respond to a change in the price of water.
2. Define different water pricing strategies and explain how water pricing can motivate conservation.
3. Explain some of the complex issues in water pricing, equitable access, and tradeoffs facing water managers in the 21st century.

Student level sets the criteria for mastering these topics. For graduate students, items one and two should be fully and easily addressed. Undergraduates, especially in lower-level courses, will still struggle with elasticity concepts. Mastery of the topic requires they be able to identify urban water demand as inelastic and explain why.

Undergraduate students may or may not fully master the complex and emerging policy issues related to water pricing, but efforts should be made to at least engage them on these topics. Graduate students, however, can be evaluated on how well they can articulate the inherent tradeoffs in conservation and equity related to water allocation: providing cheaper water reduces barriers to access but encourages use. These discussions can be extended to include water pricing choices under increasing scarcity and subsequent management choices for water policy makers.

In advanced undergraduate and graduate courses, the cutting edge of economic research on demand response, real-time pricing, peer effects, and equity can be presented depending on instructor interest and expertise. Students interested in causal empirical analysis will be particularly interested in the quasi-experimental settings offered by rate changes, and how these have evolved (e.g., Nataraj and Hanemann 2011; Ito 2014; Wichman, Taylor, and Von Haefen 2016). Students interested in behavioral economics will enjoy papers that think about what information users receive or what knowledge is required for them to act on price signals (e.g., Brent and Ward 2019).

5 Conclusion

In this paper we present an overview of urban water pricing for an instructor of a class in natural resources and environmental economics or water economics. The basic concepts of EOD and IBR pricing are framed within the context of emerging issues in urban water pricing and equity. We provide classroom-ready material intended to help students understand the complexity of water demand by different user groups. The topic and material enhance prior concepts of marginal analysis and elasticity of demand by providing an intuitive and interesting setting.

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