Residential Water Usage

Price Perceptions and Behavioral Nudges

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Overview

- Price Responsiveness
  - Price certainly matters in consumers' decision making, but most studies find an inelastic demand elasticity between 0 and -1
  - The complicated bills result in uncertainty about consumers' perception of the price of water
  - The complicated pricing results in econometric debate about model specification which still persists
- Behavioral Nudges
  - Reactions to price changes have led to many attempts at non-pecuniary measures to reduce water usage
  - Appeals to pro-social preferences, comparisons, and technical advice have all been used to reduce water usage

What's so complicated about water bills?

- Most water utilities charge a two-part tariff, with fixed fees and volumetric rates on delayed bills, where consumers cannot readily observe quantity purchased
- Increasing block rates are the most common form
- Bills are "lumpy": ccf (748 gallons) and 1000 gallons in integer amounts
- Billing periods are of uneven length
- Sewage bills are often based on winter water usage, adding a "shadow price" to water usage

Severin Borenstein (2000)

It seems safe to say that not only do most consumers not know how much power or water they have used since their current billing period began, most consumers don't know when their current billing period began

Theory of Optimal Consumption with Block Rates

- Taylor (1975) and Nordin (1976) solved the utility maximization problem with block pricing
- As usual, set $MB = MC$
- Vertical segments of block rate structure could result in $MB > MC$ at the optimum
- If they are not consuming at the first tier, inframarginal units at a different price act as an income effect
- The changing block rates results in kinks in the budget curve

The Debate

- Early papers made a choice and modeled Taylor and Nordin "rate structure premium" aka "difference variable" and marginal price, or average price
- Foster and Beattie (1979) used average price
- Griffin et al. (1981) argue that the average price, as calculated over the entire utility company, is "not closely related to the marginal price faced by consumers"
- Foster and Beattie (1981) quote Taylor's proviso "provided that consumers are well informed." As economists the two of them do not know their marginal water rate, so it seems likely that consumers are equally uninformed
- Lastly, Foster and Beattie stated that it was time to stop arguing and let empirical results decide the matter.

The Tests

- Opaluch (1982) suggests an econometric test for linear demand models, by modeling

$$Q = \beta_0 + \beta_1 MP + \beta_2 (AP - MP) + ... + \epsilon$$

  - $\beta_2 = 0$ implies MP is the correct price
  - $\beta_1 = \beta_2$ implies AP is the correct price
- Shin (1985) offers a log-log test, by defining a "price perception parameter"
  - $P^* = MP \left(\frac{AP}{MP}\right)^k$
  - $k = 0$ implies MP is correct, $k = 1$ implies AP is correct
  - Unlike the Opaluch model, this model allows for perceived price to be a mixture

The Results

- Foster and Beattie found that AP models have higher R^2 than MP models
- Chicoine and Ramamurthy (1986) cannot reject either price perception using Opaluch model
- Shin (1985) finds a k around 0.9-1.0, indicating AP dominates
- Ito (2013) finds strong evidence that consumers respond to average price, not marginal (or expected marginal) price

Digging their own grave

- Billings and Agthe were among the top proponents of of the Taylor-Nordin specification with marginal price and the rate structure premium/difference

Billings and Agthe (1980)

We conclude that most water customers in Tucson during the two winters during which these implicit marginal prices were in effect were unaware of them and did not respond to the high implicit price.

Billings (1987)

consumers frequently ignore income effects arising from changes in [the difference variable]; or consumers are unaware of the true nature of the pricing scheme for water and therefore do not respond as predicted by demand models which assume well-informed consumers.

Another nail in the coffin

- The Taylor-Nordin model specifies that the coefficient on the "rate structure premium" should be equal in magnitude and opposite in sign to the coefficient on income

Difference vs. income elasticities (Table 2 of Arbues et al. 2003)

Study	Difference elasticity	Income elasticity
Agthe and Billings (1980)	-0.112 to -0.412	1.33 to 7.829
Billings and Agthe (1980)	-0.123	
Billings (1982)	-0.075 to -0.14	1.68 to 2.14
Agthe et al. (1986)	-0.14 to -0.25	
Nieswiadomy and Molina (1989)		0.10 to 0.14
Billings and Day (1989)	-0.21	0.36
Hewitt and Hanemann (1995)		0.15
Kulshreshtha (1996)	-0.069 to +0.435	0.051 to 0.123
Renwick and Green (2000)	-0.01	0.25

Why don't you just ask households?

- Agthe et al. (1988) surveys Tucson residents, only 21% were aware water was billed on an increasing block rate
- Carter and Milon (2005) use a 1997 survey of Florida customers and report that only 6% of respondents knew their marginal price of water
- A Stratus Consulting (1999) survey found that 7% of households reported using average or marginal price in making water consumption decisions.
- Gaudin (2006)
  - In 1995, 17.2% of water companies reported the household's marginal rate next to the consumption on the bill
  - Only 2.9% included the full rate schedule
  - Finds that price elasticities are 30% higher for utilities that report marginal price (-0.5) than those that do not (-0.3)

Other Econometric Issues

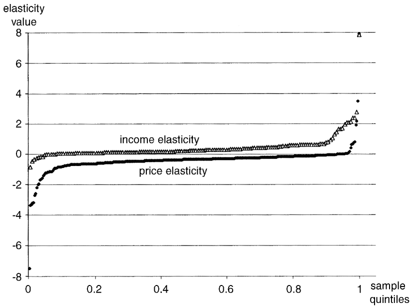
- Block rate price structures imply simultaneity bias since price is a function of quantity
  - Early literature focused on IV solutions to this problem
  - Billings (1982) "Linear approximation" IV
  - Agthe et al. (1986) simultaneous equations model
- Charney and Woodard suggest lagged price, since consumers receive the bill AFTER the cycle, addressing both simultaneity and perception
- Hewitt and Hanemann (1995) pioneered the use of Discrete/Continuous models which estimate which block a consumer will be in separately from their consumption within that block
- Strong and Smith (2010) employ a structural model, estimating a utility function instead of a demand function
  - Elasticity values are similar across the two models (-0.40 and -0.48)
  - Primarily concerned with welfare analysis (CV/EV)

Summary of Elasticities

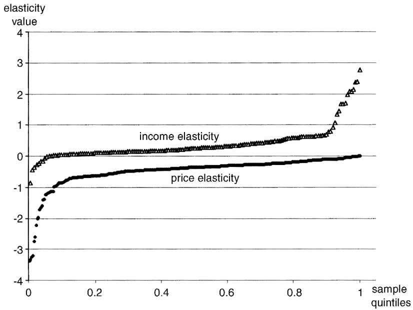
- Since most data sets are unable to distinguish indoor and outdoor usage, the estimated elasticity is a composite
- Demand is price inelastic, and income inelastic

Dalhuisen et al. (2003) Figure 1

(a) All Observations



(b) Excluding Outliers



Odds and Ends

- Weather
  - Temperature has a non-linear relationship with water usage
  - Evapotranspiration is the preferred weather measurement
  - Number of days with rainfall is more explanatory than amount of rainfall (Maidment and Miaou 1985, Martìnez-Espiñeira 2002)
  - To my knowledge, nobody (else) has interacted weather and yard size
- Demographics
  - Price elasticities decrease steadily as income rises (Agthe et al. 1988, Ito 2010, Mieno and Braden 2011)
  - Percentage of residents over 60 y.o. negatively correlated with water use (Nauges and Thomas 2000, Martìnez-Espiñeira 2003)
  - Children under 10 add the most to water use, then adults, followed by teens 10-20 (Lyman 1992)

The Problem with Prices as a Management Tool

Sample Monthly Water Bills

Usage	Current Bill (All Variable)	Proposed Rates: January 1, 2017 (Fixed and Variable)	Proposed Rates: January 1, 2021 (Fixed and Variable)
4 HCF	4 x $4.40/HCF = $17.60	$5 + (4 x $4.83/HCF)= $24.32	$10 + (4 x $6.56/HCF)= $36.24
9 HCF	9 x $4.40/HCF = $39.60	$5 + (9 x $4.83/HCF)= $48.47	$10 + (9 x $6.56/HCF)= $69.04
14 HCF	14 x $4.40/HCF = $61.60	$5 + (14 x $4.83/HCF)= $72.62	$10 + (14 x $6.56/HCF)= $101.84

Demand-Side Management

- Given the legal framework of utility pricing, temporary reductions are better accomplished through non-price channels
- Over-reaction to increases in rates makes it difficult for pubicly operated utilities to raise rates
- Therefore a myriad of non-price management tools have been employed and economically tested
  - Subsidies for costly water-saving investments (low-flow toilets, free showerheads, xeriscaping)
  - Appeal to social norms through comparison on bills
  - Providing technical advice regarding water saving strategies
- But causing demand to decrease with a constant price always reduces revenue, leading to more price increases to remain solvent

Early Work

- While information campaigns and conservation pleas were common, economists long relegated them to “control variables”
  - Early engineering research used before-and-after study designs, incorrectly calling the result the causal estimate
  - Billings and Day (1989) used a binary variable for public information programs and found little effect on water demand
  - Nieswiadomy (1992) analyzed a large national data set and found non-price programs reduced demand in the Western U.S. but not in other regions and were not significant in the combined model
- Michelsen, McGuckin, and Stumpf (1999) aggregate all varieties of demand-side campaigns and find they lead to a 1-4% reduction in usage

Social Norms and Comparisons

- Goldstein et. al. (2008) *Using Social Norms to Motivate Environmental Conservation in Hotels*
  - Field experiment involving hotel guests and appeals to re-use towels
  - found that social norms ("the majority of guests reuse their towels") worked better than the traditional ("reusing towels saves water and energy")
  - but direct comparisons ("the majority of guests *in this room* reuse their towels") worked even better, so-called provincial norms.
- Ferraro and Price RCT reports that social norms and comparisons are effective at reducing short-run demand, but their studies primarily focuses on long-run effects
- There is more information in the energy economics literature on this topic, mostly finding similar results of about 4% short-term reductions

Longitudinal Work on Persistence of Effect

- Ferraro and Price (sometimes others) organized a randomly controlled trial using an array of non-price management techniques in metropolitan Atlanta and measured results over the years
- Ferraro, Miranda, and Price (2011) show that while appeals to pro-social preferences affect short-run patterns, only messages augmented with social comparisons have a lasting impact
- Ferraro and Price (2013) show that the comparison message reduces usage by the most price-inelastic households, highlighting a complementarity in strategies, but the effect wanes over time
- Bernedo, Ferraro, and Price (2014) find that the effect size declines about 50% after 1 year, but remains detectable and policy-relevant six years later, as households also change long-lived habits and capital along with making temporary behavioral modifications

Which non-social programs work?

- The following is a test in the aggregate for the efficacy of five strategies in eight California Water Agencies (Renwick and Green 2000)
- Results are from a log-log IV demand model

REBATE	−0.004
	0.02
RETRO	−0.09
	0.02***
RATION	−0.21
	0.03***
RESTRICT	−0.34
	0.04***
COMPLY	0.003
	0.03

- Low-flow toilet rebate programs
- Low-flow shower head/tank displacement devices
- Rationing programs
- Use restrictions
- Compliance affidavit

Comparisons of Price and Non-Price Management

- Price inelasticity implies that reducing demand by increasing price will result in increased profits for the utility company; thus price increases are better than even "costless" nudges
- Bernedo, Ferraro, and Price (2014) incorporate the persistence in their cost-effectiveness calculation and report that the nudge costs approximately $0.25 per 1000 gallons reduced
- Lavee et. al. (2013) reports that a smooth increase in tariffs was ineffective, while a drought surcharge and educational tools were effective in reducing demand in Israel
- Studies comparing rationing/watering restrictions with price policies report dead-weight loss figures of 25-50% of the average annual water expenditure (Mansur and Olmstead 2007, Brennan et al. 2007, Grafton and Ward 2008)
- When California instituted rationing, more than half of customers violated the restrictions (Dixon et al. 1996)

Why use Demand Side Management?

- Price-based approaches are more cost-effective, similarly difficult to predict, with similar equity and distributional concerns (Olmstead and Stavins 2009)
- It is the political cost of raising water rates which leads to inefficient policy adoption
- Investments in demand-side management may be cheaper than other infrastructure projects and realize more benefits from such programs than households would via cost savings
    - Low-flow showerhead programs saved 1.7 and 3.6 gallons per capita per day (gpcpd) in East Bay, CA and Tampa, FL respectively (Aher et al. 1991, D.L. Anderson et al. 1993)
    - Low-flow toilet program savings range from 6.1 gpcpd in Tampa, FL to 10.6 gpcpd in Seattle, WA (US GAO 2000)
    - Monthly water bills (30 days) at increments of 748 or 1000 gallons may not show evidence of this savings for households, but have significant effects at the aggregate utility level