RESIDENTIAL WATER CONSERVATION: SEASONAL RATES AND NON-LINEAR TARIFFS

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Residential Water Conservation: The Effectiveness of Seasonal Rates. (May 2014)

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With drought conditions and climate change creating an increasingly pressing issue, water conservation has become profoundly important. This work quantifies the effectiveness of residential water conservation programs, namely non-linear tariff functions and seasonal rates, at inducing household water customers to conserve water.

The analysis of non-linear tariffs and seasonal rates commences through a clustering study, measuring consumption at certain kink points in pricing. If customers respond to prices by reducing consumption, then one should observe a bunching of customers who consume just below kink points where the marginal price of water increases. I use detailed customer-level data on monthly water consumption from a water utility in Texas to test for the behavioral response to discrete increases in the marginal price of water. This work concludes that consumers in this region do not respond to price changes at the kink points in non-linear tariff functions in a statistically significant way.

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CHAPTER I

INTRODUCTION

Due to increasing population and drought conditions, conservation has become an extremely important part of meeting demand. Retail utility companies meet the vast majority of residential water demand by purchasing water wholesale and selling it directly to customers. These retail utilities are responsible for conservation programs at the residential level. This work informs the conservation efforts of retail utilities by analyzing the effectiveness of price schemes in encouraging water conservation. Economists generally argue that pricing strategies are the most efficient way to encourage behavior changes. However, this depends on prices being salient to consumers and consumer being responsive to price changes.

Residential water markets face serious supply issues. In Texas specifically, the Texas Water Development Board projects water demand to increase by 22% between now and 2060, while supply is projected to decrease by 10%. A severe drought, such as the one plaguing the state in recent years, could prove disastrous for the economy. The TWDB estimates that a record drought (similar to that experienced in Texas during the 1950s) would cost the state economy $116 billion, up from the approximately $10 in losses from drought in 2010. Even in absence of drought these conservation issues remain serious—but drought conditions made more severe by climate change could cripple the state economy. Reducing demand stands as the easiest, most cost effective way to mitigate this problem (TWDB 2012).

The work delves into the effectiveness of seasonal rates in terms of encouraging water conservation. Prior to looking into seasonal rates directly, research focuses on economic theory and existing literature to explain the residential water market. With seasonal rates, during high-usage months (typically Summer months) prices increase with the goal of reduced consumption.

The residential water market functions in a distinct way. High fixed costs to set up distribution structures create a natural monopoly typically managed by the public. Political pressure encourages municipal providers to keep prices as low as possible, not always pricing based on the cost structure of the market. Sibly (2006) shows that water is almost universally not priced as high as it should be to encompass environmental and opportunity costs.

The first chapter of the work looks at economic literature to establish how the residential water market functions. Examination focuses on pricing structures (marginal cost pricing, increasing block rate pricing, seasonal rates, etc.) and the price elasticity of demand for water. Following the pricing discussion, focus shifts to non-price strategies, explaining how alternative methods typically stand up to their pricing counterparts. The first chapter concludes with a short discussion of methodology and data gathering.

The second chapter revolves around the effectiveness of a particular pricing method—seasonal non-linear rates. Seasonal rates increase prices during peak months and by comparing consumption levels and using econometric tools, one can establish whether and how effective seasonal rates are at reducing consumption. The second chapter represents data-driven section that explains the methodology and approach to the problem.

The third chapter provides results and discusses the importance of the results in terms of reducing consumption.

Structure of the residential water market and current trends

Because of the basic structure of the local water distribution system, the market functions as a natural monopoly (per Goetz 2006). A natural monopoly is defined as an economy of scale, whereby one firm can most efficiently (at the lowest long-run average cost) supply the entire market. High fixed costs associated with purchasing and distributing water, along with the political sentiment that drinking water represents a public good, historically created the existence of local municipal water providers that meet demand. While privatization of the residential water market became popular in the 1980s and 1990s in certain parts of the world, nearly all local water distribution is managed by a municipally owned utility in the United States.

The pricing of water at the residential level has changed dramatically over the past 10-15 years. In the past, it was very common for water to be priced using a Decreasing Block Rate (DBR) structure, whereby the marginal price of water fell when consumption rose. Recently, utilities have flipped the script, pricing water in an Increasing Block Rate (IBR) structure, or more generally called a non-linear tariff function. To visualize this, the following graphics demonstrate the prices faced by consumers during the recorded time period. The table below shows a tabular organization of the tariff function, Figure One graphically depicts the price scheme during peak months (May to October). In this scheme, the price per thousand gallons is \$3.55 for the first 15,000 gallons, but then increases to \$5.15 per thousand gallons, and so on. See below:

Each household pays a Base Fee of $12.95. In addition, consumers pay a dollar amount per thousand gallons according to the following rate structure—

Table One

Water Usage (Per Gallon)	Price Per Thousand Gallons (November to April)	Price Per Thousand Gallons (May to October)
0-15,000	$3.55	$3.55
15,001-30,000	$3.55	$5.15
30,000-50,000	$3.55	$6.65
50,000+	$3.55	$8.40

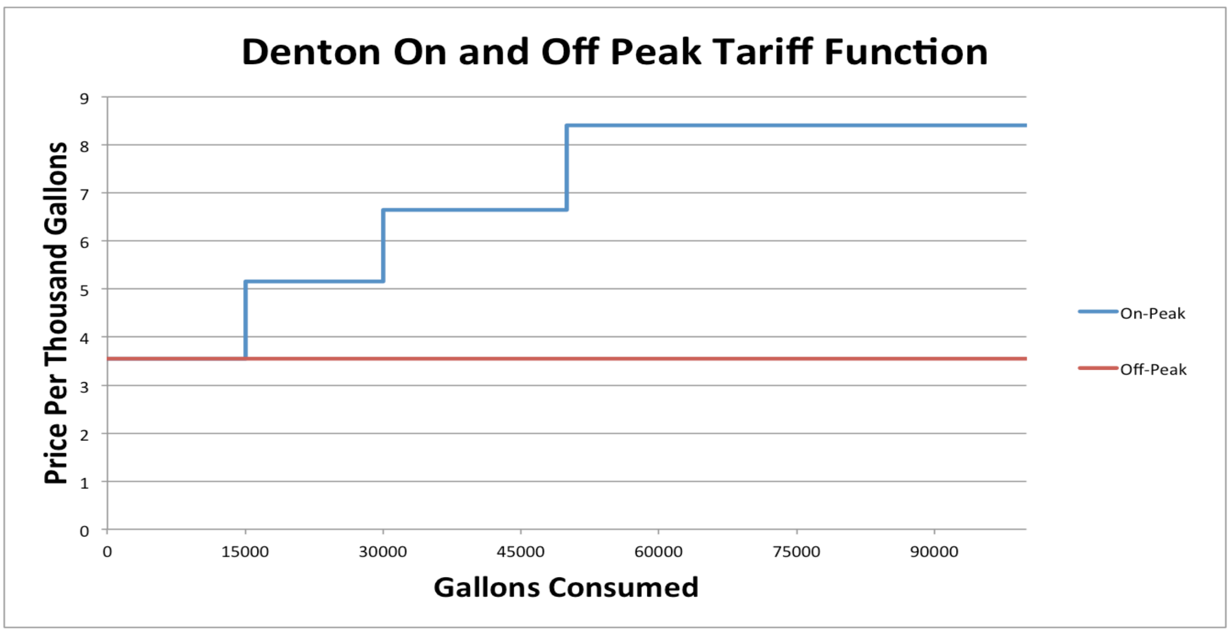

Figure One: Non-Linear Tariff Function Depicted Graphically—vertical portions represent kink points Note: The prices in Denton changed over the time the data was collected. However, the kink points in the tariff function did not change, the prices were simply shifted upward.

Relatively few utilities utilize constant pricing for residential customers, and the prices are typically not set at true marginal costs (including opportunity and environmental costs). Seasonal Rates, or raising prices in some fashion during hotter months, has picked up some steam in recent years. Seasonal rates increase marginal prices for all consumers during times of peak usage (usually between April and October).

IBRs (or non-linear tariff functions) are the single most common water-pricing scheme utilized today for two reasons. One, they tend to increase revenue streams by pricing high levels of consumption much higher than before; two, IBRs are assumed to encourage conservation by adjusting consumer behavior. Simply put, since IBRs are so overwhelmingly common, policymakers are interested in learning whether these programs have any effect on conservation. This work quantifies the effectiveness of these non-linear tariff pricing programs, as well as the effectiveness of seasonal rate structures at reducing water consumption.

A common metric of the sensitivity of water consumption to the price is the "demand elasticity". Demand elasticity for water is relatively low, meaning that as prices increase, the quantity demanded decreases as a percentage by less than price. Olmstead's (2007) recent estimate of the Price Elasticity of Demand for water held around -.31. This elasticity implies that an increase in price by 10% would lead to a reduction in consumption of 3.1%.

Many residential water providers have moved towards what economists denote as "Command-and-Control" policies—essentially incentives and rules that promote conservation. CACs include watering restrictions, rebates on efficient appliances, etc. Economists generally believe that command and control policies are a poor instrument to encourage behavior changes because they don't act on market forces to change behavior. In the case of watering restrictions, they're often ineffective (Dixon et al. 1996). CACs, however, have the distinct advantage of being for more politically feasible because it's much more palatable to residents to ask for everyone to pitch in and reduce consumption than to raise prices, even if the evidence indicates that CACs are less effective.

Methodology introduction and data considerations

In quantifying the effectiveness of non-linear tariff functions in terms of reducing water consumption, this work utilizes a clustering analysis to estimate the degree to which consumers respond to prices. One possible empirical strategy is to conduct a randomized controlled trial where some customers are exposed to high marginal prices and others are exposed to low marginal prices. Absent a randomized experiment, field data using existing tariffs can be used if the tariffs have particular characteristics.

In this case, the non-linear tariff function provides the opportunity to analyze the bunching behavior of consumers around pricing kink points (where the marginal prices increase). By using a regression discontinuity approach, this work indicates that consumers do not respond to marginal prices.

CHAPTER II

MODEL SPECIFICATION

This section describes the data and the methodology of the study.

Study region

The study constitutes an examination of the effectiveness of non-linear tariff functions in residential water pricing programs. Thus, consumer level data become essential. For this purpose, this study focuses on one residential utility provider in particular, the City of Denton (a suburban area in the Dallas Fort-Worth region).

I utilize a quasi-experimental circumstance distinct to the particular service region in question. This work takes advantage of a natural experiment in which prices change during the course of the year. During half of the year (non-peak consumption periods), consumers face a constant rate for each 1000 gallons of water. During the other half of the year (peak consumption periods), consumers face more expensive prices across the board in addition to an increasing block rate tariff function. That is, consumers pay more per gallon during peak consumption periods and the price per 1000 gallons increases and consumption increases.

Data description

The dataset in question includes 25,800 unique consumers (accounting for all consumers in the Denton region). The consumption records for these customers were gathered for three years, with monthly consumption totals documented and assigned to each water connection. Each water connection was given a randomized identification number for privacy purposes. Each individual data point (indexed by i and t) indicates a unique water connection at a specific time interval. In this case:

i = Individual connection identification number ($i = 1, 2, 3 \dots 25{,}800$)

t =Time period or monthly billing cycle ($t = 1, 2, 3 \dots 36$)

Note: the time period indexed by t runs for 36 months, or three years.

Within the context of the statistical test, a particular observation is a unique customer at a given time period.

Model description

Economically speaking, this study focuses on the implications of what is known as bunching at kink points around a certain price change. Essentially, I analyze whether or not consumers respond to price changes by studying their behavior at the kink points. Whether the change in behavior is due to lack of knowledge regarding the change, consumer's inability to monitor their usage, etc. plays no role in the analysis. This work tests whether or not consumers respond to the price changes, not why or why not. The why or why not, however, remains a very interesting question.

In an attempt to analyze this question I analyze the behavior of consumers at the kink points (in this case, at consumption levels of 15,000 gallons, 30,000 gallons, and 50,000 gallons) during all months in which they face non-linear tariff functions. That is, one can analyze whether consumers tend to consume more on one side of the kink or the other. The intuition here is relatively simple: if a person believes that people respond to price changes, one would expect consumers to cluster on the “left” side of the kink point to avoid higher prices. If a person believes that people do not respond to price changes, one would expect to find that consumption patterns do not change significantly when prices change.

To study this phenomenon I utilize a regression discontinuity model to estimate to statistical effect of the price change on consumption patterns, effectively testing for bunching behavior around the primary kink point. I follow Nataraj and Hanemann’s work on the subject, where they noted the ability to utilize regression discontinuity to analyze price response behavior in residential water demand. Notably, Nataraj and Hanemann’s methodology tests whether consumers respond to average or marginal prices. This work focuses more directly on whether consumers respond to marginal pricing at all, taking no position on average pricing.

Another study that utilizes a similar research design is Wichman’s work on residential water demand. However, by utilizing a regression discontinuity model to estimate the effect of price changes on consumer behavior, this work can calculate a price elasticity of demand for water in the given region. This information indicates to policymakers exactly how much they would have to raise prices to achieve certain conservation outcomes, which becomes particularly important when considering alterations to the price structure. These two works represent the theoretical model framework for the study. This model utilizes a slight alteration of the traditional regression discontinuity framework by analyzing a histogram instead of typical data. In this case, the histogram captures the kink points by looking at bunching behavior around the price changes.

For the regression discontinuity approach, the null and alternative hypotheses are as follows: the null hypothesis is that consumption does not bunches around the kink points, indicating that consumers do not respond to price changes in a statistically significant way; the alternative hypothesis being that consumption bunches at the kink points and consumers respond significantly to price changes.

CHAPTER III

RESULTS

This section shows results of the methodology described above. Simply put, the results indicate that consumers do not respond to marginal prices. The methodology tests whether consumers would exhibit "bunching" behavior around the kink points, or whether consumers would gather at the lower side of the price break. If consumers were truly responding the prices significantly, one would expect a frequency histogram to show that consumers gather at a consumption level just below 15,000 gallons, with the frequency dropping off significantly at a consumption level just beyond 15,000 gallons (as this is where the marginal price shifts).

Graphical Results

The histogram below (Figure Two) depicts the behavior described above, capturing all non-peak consumption during the three year period. The x-axis measures consumption (separated by bin size), the y-axis captures the frequency of occurrence. Notice that the red shaded frequency bars indicate consumption just above and below the price breaks.

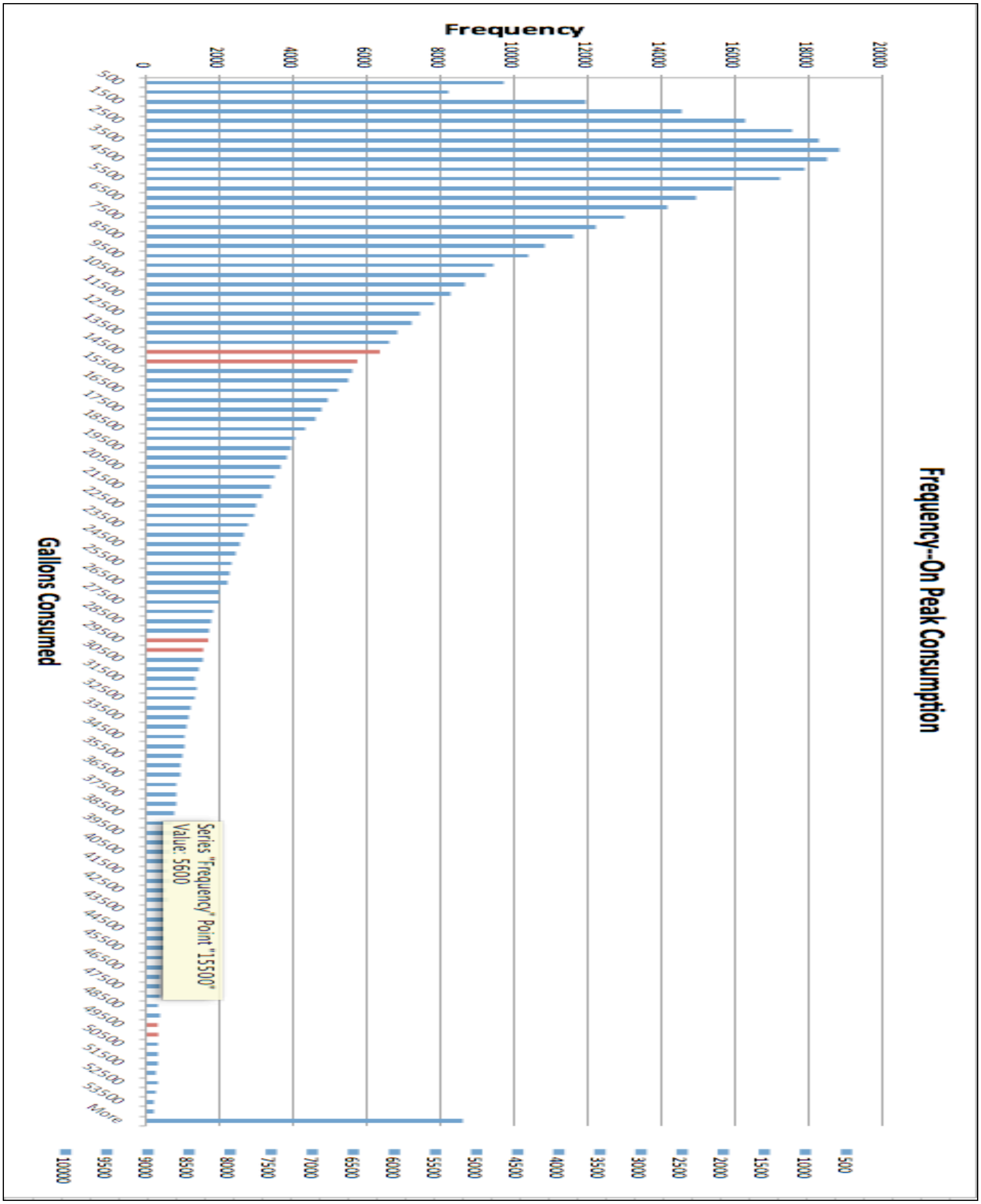

Figure Two: Figure depicts the aggregate consumption of all non-peak bills during three-year period

The graphic above indicates very little bunching activity at the given price breaks of 15,000, 30,000 and 50,000 gallons. The graphic captures a compilation of all consumer activity during all on-peak months for the given observation period, or when the non-linear tariff scheme is active. Simply put, there is very little bunching activity to indicate consumers are responding to price signals. Visually speaking, at a price break of 15,000 gallons, there's very little if any bunching that occurs. At the 30,000 and 50,000-gallon price breaks, there's no visual evidence of consumption bunching to indicate that consumers respond to marginal prices.

Statistical Output

To this point, the analysis has been limited to an eyeball-test of the histogram. Next, I utilize the regression discontinuity approach to estimate statistically whether or not consumers respond to the price changes at the primary kink point (15,000 gallons). The following table depicts the regression output. Intuitively, the regression fits a polynomial on both the left and right sides of the kink in the tariff function. A "jump" in the estimated density function at the kink point is evidence of bunching. Recall that the bills included in this dataset includes those during on-peak months (May-October).

Table Two:

	Full Regression (All Data)	Linear Regression (Limited Data)	Full Regression (Limited Data)
Bin	1.194629**	-.6745626**	1.194629*
	(.52459)	(.17392)	(.5395)
Bin^2	-.000124**		-.0001246**
	(.00003)		(.00003)
Treat	-961.723	-7084.351**	-3535.623
	(1968.2)	(1828.2)	(2053.2)
Treat-X	1.668143**	.3719521*	-2.054234**
	(.52485)	(.17427)	(.54115)
$Treat\text{-}X^2$	.0001297**		.0001376**
	(.00003)		(.00003)
Constant	12282.99**	17111.74**	12282.99**
	(1947.4)	(1812.2)	(2002.9)
N	108	56	56
R^2 Adjusted	.9499	.8341	.9059

*P<.05; **P<.01

That statistic of interest is the "Treat" variable, which estimates the bunching behavior (to the extent that it exists). This variable captures the gap in consumption outside of what's expected by plotting the polynomial function (bunching) at the 15,000-gallon price change. There are three separate regression outputs listed above—the first contains the full histogram, including the second two kink points. Because it contains price changes, the other two regressions ignore all consumption above 28,000 gallons (just prior to the second kink point). This more realistically captures the consumer behavior. The second regression plots a linear model onto the data—by looking at the histogram above, one can easily tell that a linear fit is not appropriate. The third regression, the one of most interest, plots a quadratic function onto the data. The statistic associated with the "Treat" variable is not statistically significant at the 5% level. Thus, this work does not rejects the null hypothesis.

In order to interpret the estimated coefficient on "Treat", recall that the regression is plotted against three-year consumption data plotted on a histogram with frequency on the y-axis. The coefficient essentially measures the number of water bills (or monthly cycles) in which consumption dropped more than predicted by the polynomial equation fitted to the data on the left side of the kink point. That is, the coefficient is measured at approximately -3535, indicating that 3,535 bills were estimated to have cut water consumption as a result of the kink point. In context, the data includes 25,800 customers over three years, with each observation representing a unique customer's bill during one particular month during the on-peak periods. Note: this result is NOT significant at the 5% level. It is statistically zero for practical purposes. The result is not statistically significant and the coefficient is not economically robust despite the lack of significance considering the large number of observations in the set and the relatively small drop in consumption. The following graphic visually depicts the regression discontinuity.

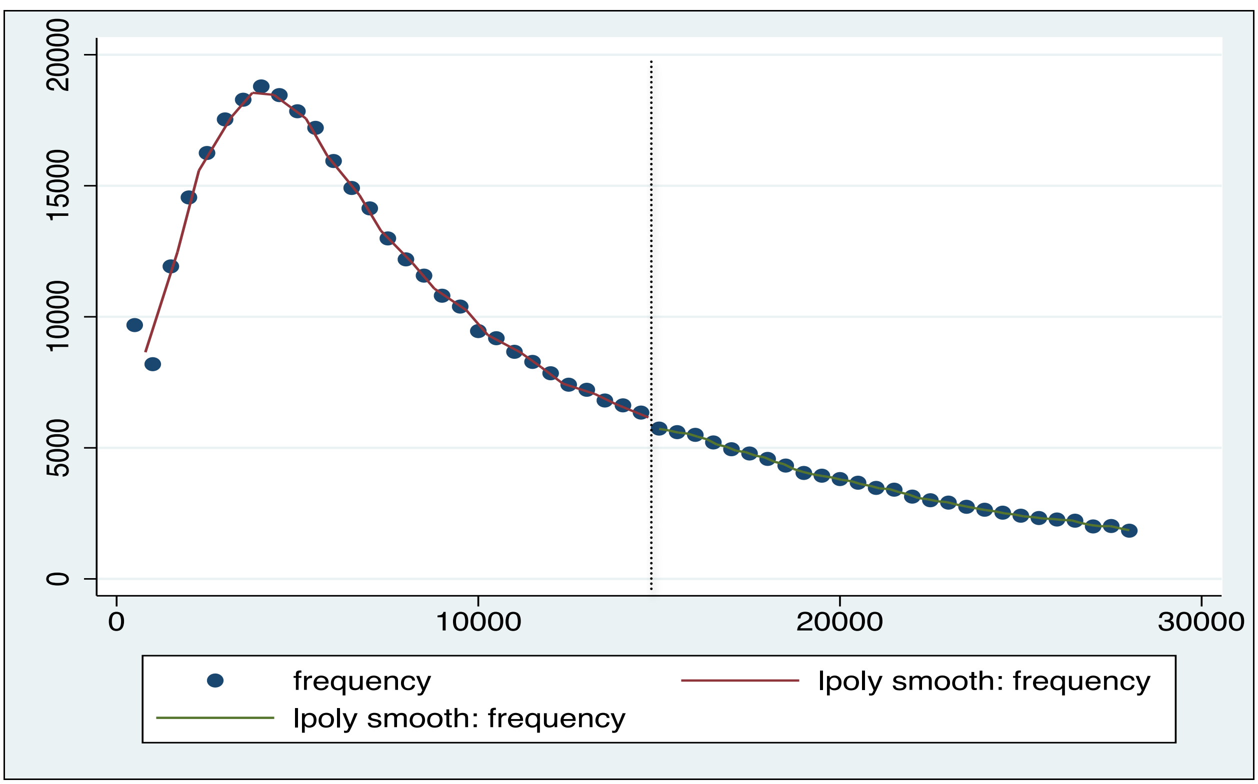

Figure Three: Figure shows regression discontinuity. Red line represents left side of kink point, green line represents right side of the kink point. Figure shows slight drop in consumption also seen in full histogram, recall not statistically significant.

These results indicate a few possible outcomes. First, it's possible that consumers simply do not respond to price signals that they're given. That is, it's possible that consumers do not regard the price change as significant enough to alter their behavior. From a policy standpoint, this indicates that non-linear pricing schemes of this sort cannot induce conservation at the margin as intended. Second, it's possible that consumers do not internalize the price signals available to them, or that price signals are not salient to consumers. This could be the case if the consumers are simply unaware of the price changes or have no reasonable way of tracking their consumption. These results indicate that regardless of the reasons, consumers are not responding to marginal prices in a way that indicates that prices should be used as a policy lever to encourage conservation. These results cannot take a position as to whether consumers are instead responding to the higher average prices presented to them—it's certainly possible that consumers do cut back on consumption overall because they face higher average prices. This would counter economic theory that states that consumers respond rationally to marginal prices. For a more in depth look at average and marginal prices, see Nataraj and Hanemann's work on the subject.

Conclusion

Water conservation has become increasingly important for local municipalities over the years. The water utility in question uses seasonal rates with a non-linear tariff function to establish prices. This work utilizes a regression discontinuity approach to test for bunching behavior at pricing kink points in a particular residential water utility. Essentially, this approach quantifies the degree to which consumers respond to price changes at the margin. If consumers did respond to marginal prices, one would expect to observe a sharp increase in consumption on the left side of the kink point (or just before prices change). The graphical approach, as well as the statistical analysis, confirms that consumers simply do not respond to marginal price changes.

This work takes no position on whether consumers respond to average prices instead of marginal prices. It's certainly possible that consumers are reducing consumption with the knowledge that prices are higher on average. This would suggest, though, that a non-linear tariff function is not necessary to induce that activity. It's also possible that price and quantity are not salient to consumers—or that consumers are not made aware of prices and cannot readily measure their consumption during a month to respond. This study suggests that consumers do not respond to marginal prices in non-linear tariff functions. Another approach to this problem could randomly provide consumers with different information in their bills that explains the rate scheme and statistically test for and control for consumer information. This requires random assignment of treatment, however, which was not possible here.

In terms of policy implications, this work suggests that adjusting marginal prices is not a valid policy lever to induce conservation. However, it's possible that in this case the prices are simply not salient to consumers. Further research in this area could test the notion that simply providing consumers with more information about their prices (i.e. making the prices more salient) could improve conservation outcomes.

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