Predicting Household Water Consumption Under a Block Price Structure

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Abstract

This study focuses on estimating the variations in per-capita water consumption and predicting the shares of consumption by pricing blocks in eight Kansas regions. Previous studies have considered household or micro-level consumption, but few have focused on aggregate level consumption across different regions. A probit model was used to estimate the consumption shares in individual blocks for each region. Per-capita water consumption varies significantly across the regions and as we move from Western to Eastern Kansas, shares of lower consumption block decrease and higher consumption block likely to increase.

Key words: block share, region, water, consumption.

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Introduction

The indoor and outdoor household water consumption has significant impact on local water use pattern. Since water is used for multiple purposes, the demand for water has multiple dimensions. Competition among households has increased the demand for water and policy makers are compelled to take measures to manage the water demand efficiently and effectively. Research on water demand is gaining momentum throughout the world as it is becoming increasingly scarce. The management of water as a scarce resource resulted in in-depth examinations of demand and supply of this commodity. Since water is traded as a private commodity, the price mechanism seems to be the only option to mange this scarce resource. Previous studies have shown the ability of market prices to manage natural resources, including water, renewable, and other non-renewable resources (Covanagh at el., 2001).

Efficient and effective water use has been a major concern of the policy makers and agents involved in provision and consumption. Either local public or private firms provide water supply in rural water districts and municipal areas. As such, the supply side of water has not been appealing to the economist as much as the demand. According to the US Geological Survey (USGS), domestic water is used for indoor (bathing, toilet flushing etc.) and outdoor (lawn irrigation, pool, car wash etc.). Commercial use may include input for production processes and uses similar to that of a household.

This paper examines the impact of factors such as own block price, per-capita income, population, annual precipitation and annual average temperature on the likelihood of consumption in different blocks. The main contribution of this paper is the estimation of the probabilities/share of household consumption in different block rates in all eight regions. This disaggregates the total consumption into different consumption blocks. Martinez-Espiñeira notes that the procedure or technique is not available to disaggregate the aggregate level consumption (Martinez-Espiñeira, 2002).

One of the assumptions of this study was that the total consumption reported in Kansas Department of Agriculture, Division of Water Resources was considered as the total regional consumption that includes households and firms. In this study we have focused only on per-capita water use and ignored industrial consumption. This paper is organized in seven sections.

Section two provides an overview of past literature on consumer demand for water. Section 3 discusses the theoretical background to estimate a demand function and section 4 focuses on empirical models. The last three sections focus on data, results and discussion, and a conclusion respectively.

Literature Review

Residential water use in municipal areas may constitute over half of the municipal water use in many communities in the USA (Howe and Linaweaver, 1967). Further, Hanke and de Mare (1984) have reported that in industrialized countries, more than 80% of the population lives in the cities and other urban communities. As such, the municipal water usage is considerably higher in a given geographic area. There was no uniformity in methodology in estimating residential or geographic area water demand. Methodology ranges from normal regression to fuzzy logic special decision systems. An important consideration among the researchers was price sensitivity of water demand. The very basic nature of the commodity and household awareness of the marginal price of water are less likely to impact the consumption decisions (Opaluch, 1982). Covanagh (2001) has supported a similar argument and states it is true with complicated price structures.

One of the common approaches in water demand estimation is based on per-capita consumption. Regional and state planning agencies use this approach for policy level decision-making. It was estimated that the average annual domestic per-capita use in the Delaware River Basin was about 79 gal/d with the standard deviation of 21 (Featherstone, 1991). Although the price elasticity for residential water demand varies in magnitude, there is consistency among the research finding that the short run value is lower than long run value. Estimated elasticities rang from –0.01 to –1.63, depending on factors included in the model and nature and frequency of data used (Hanemann, 1997). Often it takes some time for the consumers to adjust their water-using capital stock (durable goods and equipment) and to learn about effects of their use in the following month's bill (Carver and Boland, 1980). Since present consumption is influenced by past consumption, lag variables were often included in the model. Carver and Boland used lagged variables in a static approach, while Nauges and Thomas used lagged prices in dynamic panel data methods.

The price structures are considered to be a very good instrument to manage water demand, pursuing objectives of equity, public health, environmental efficiency, financial stability, simplicity, public acceptability, and transparency (OECD, 1987 and 1999). In the past many studies have focused on the block pricing approach for demand estimation. However, Shin questioned the perception of consumers about the block price structure and doubted the full knowledge assumption. It is interesting to note that several studies have focused on marginal prices (Renwick and Green, 2000; Nieswiadomy and Molina, 1989), average prices (Foster and Beattie, 1979) and combinations of both (Opaluch, 1982; Shin, 1985) under increasing and decreasing block prices. A common consideration among researchers was the consumption adjustment after receiving the previous month's bill that increased the complexity of modeling the demand function. Shin's approach to correct the ex-post measurement error by including the first lag of average price in the perceived price specification. By adopting a similar approach and using monthly data, Nieswiadomy and Molina (1989) obtained mixed results.

In an inverse demand estimation the price is determined by quantity demanded, which may lead to simultaneity, thereby endogeneity, in the model. Often the researchers have used either instrumental variable or two-stage least square approach (Nieswiadomy and Molina, 1989; Renwick and Green, 2000) to overcome the weakness. Hewitt and Hanemann (1995), Cavanagh, et al. (2001), have used discrete to continuous choice models to avoid the endogeneity problem.

Household income (Renwick and Green, 2000) was generally used as an independent variable in the demand estimation. Some other approaches have also used appraised value (Nieswiadomy and Molina, (1989); Hewitt and Hanemann, (1995)) of the home as a proxy to household income. Other variables that have been used to determine the water demand was the household characteristics to capture the variation in the indoor and outdoor use. Nieswiadomy and Molina (1989) included house and lawn size, and Hewitt and Hanemann (1995) used number of bathrooms in addition to house and lawn size and the authors have found bathroom variables were significant, but house size was not.

Many studies included one or two climatic variables to capture the environmental effects on household water demand. The difference between evapotranspiration from Bermuda grass and precipitation was used as a climatic variable (Nieswiadomy and Molina, 1995; Renwick and Green, 2000) excluding all the indoor variables and used the lot size to represent outdoor water use along with dummy variables to capture the effects of demand for irrigation water. Miaou found that the number of days of rain in a billing cycle has a larger impact on consumer demand than evapotranspiration and/or precipitation. Though the precipitation and temperature may have a significant impact on outdoor water use, hardly any studies have primarily focused on those variables impact on consumption. Technically there is not a substitute for household water consumption, but precipitation is a near perfect substitute for outdoor water consumption. Wentworth (1959) developed an equation to convert the rainfall data in a residential area into an equivalent per-capita catchment. The per-capita household catchment is a function of a constant term, roof area and rainfall.

Although the water consumption is continuous variable it becomes discrete when it is priced. The consumption blocks are ordinal and an ordinal discrete choice model will be able to provide a better estimation with the ranked data. Hewitt and Hanemann (1995) suggest that when water is sold according to a block rate there is an issue regarding model specification and whether the authors have used a discrete/continuous model to solve this issue. The discrete choice arises when grouping the household consumption to different block rates. As such, the specified model should be able to address the discrete price structure and continuous consumption. In the discrete choice model the maximum likelihood method can be used on probit or logit models to estimate the distribution of consumers among different blocks and the other regression models can be used to estimate the continuous choice among the consumers. But very few authors have used this approach to address the problem concerning the model specification (Martinez-Espiñeira, 2002).

Model Specification

The concept of aggregate demand is fairly well established in the literature. It exists either in the form of household demand aggregation or aggregate expenditure on consumption of commodities. Aggregation theory provides an important tool and necessary condition to under which it is possible to treat aggregate consumer behavior as if it were the outcome of the single utility maximizing consumer (Deaton and Muellbauer, 1999). Unfortunately the opposite of this argument is absent in the literature. Can the aggregate data be decomposed among the individual members maintaining the variations in the preferences and income? In households consumers are charged according the amount of water that they consume. In our dataset there are five consumption blocks ranging from less than 5000 to more than 100,000 gallons a month, which are listed below. Unfortunately the county level total consumption data does not provide the breakdown of consumption across blocks. The first step of the analysis is therefore to estimate the relative proportion of each block in the total consumption.

Given the average annual average price structure, the relative share of each block can be estimated using probit or logit or ordinal logit/probit model. Let Z_{ij} be the discrete grouping for different consumption block rates for j (5) blocks in the region i. Each block is represented by the amount of water consumed in that category.

$$Z_{ij} = \begin{cases} 5 & = < 5000 \text{ gallons/month} \\ 4 & = 5000 - 10000 \text{ gallons/month} \\ 3 & = 10000 - 25000 \text{ gallons/month} \\ 2 & = 25000 - 50000 \text{ gallons/month} \\ 1 & = 50000 - 100000 \text{ gallons/month} \end{cases}$$

$\pi_{ij}(X_{ij}) = P(Z_{ij} = j \mid X = x_{ij})$ is the share of total consumption in j^{th} block in region i given $X = x_j$. The vector x_j comprises the explanatory variables that are likely to impact the consumption in a given block rate in the region i. In a region the block rates are represented by cumulative probability distribution.

$$\sum_{j=1}^{5} \pi_{ij} = 1$$

Where

$$\pi_{ij} = \exp(\alpha_j + \lambda_i X_{ij}) / [1 + \exp(\alpha_j + \lambda_i X_{ij})]$$

Generally the slope remains the same over a region and the intercept varies across the blocks. This is commonly known as 'equal slope assumption' (Bender and Benner, 2000). This model is referred as the ordinal logistic model (Scott et al., 1997). From this equation one can estimate the proportion or the probability of water consumption in a bock. X_{ij} is the vector of own block price, population, per-capita income, rainfall and average annul temperature in a given region i and block j. Across the blocks only the prices varies and other variables remain the same.

Wentworth (1959) approach allows the household to use the rainfall outdoor water purposes and hence it can be considered as substitute for public water supplies for households. Wentworth (1959) equation converts the inch of rainfall into equivalent gallons of public water supplies, using a conversion factor. Amount of water (in gallons) collected from an inch of rainfall is equivalent to 0.625*roof area of the household. So the total annual per-capita collection is (0.625* roof area*rainfall/household size). Estimated household catchment rain volume depends on the roof area and amount of rain received by households in the respective regions. We assumed the average roof size of a household is about 1500 square feet. Since our interest was to estimate the per-capita consumption, we need to have the average household size data. According the 2000 census, the average household size range from 2.48-2.56 for the state of Kansas (Census, 2000). In our analysis household size was assumed to be 2.52.

Annual per-capita catchment rain volume (Z) = roof area*0.625*rainfall/household

= 1500*0.625*rainfall/2.52

Data

County level consumption data were obtained from publication of Kansas Department of Agriculture, Division of Water Resources over the years 1991-2000. The source data contains annual water use data for all the municipalities in the state of Kansas. A total of 1050 observations (105 counties for 10 years) were obtained from this source. Block price rates were obtained from the Kansas Municipal Water Use Publication for the same period. Average family size data were obtained from census 2000 publication.

Table 1: Summary statistics of data

NAME	Unit	MEAN	ST. DEV	MINIMUM	MAXIMUM
Population	Number	24809.00	61171.00	1539.00	453960.00
Per-capita Income	$	20133.00	3936.60	12908.00	46858.00
Precipitation	Inches/Year	30.95	10.24	11.79	64.26
Average Annual Temperature	℉	55.05	2.28	47.00	61.00
Quantity in Block 1	Mill. Gal/Year	795.46	3064.30	1.32	67027.00
Price in Block 1	$	199.65	52.22	96.12	315.96
Quantity in Block 2	Mill. Gal/Year	603.45	2842.30	2.56	55493.00
Price in Block 2	$	309.52	95.62	136.20	527.88
Quantity in Block 3	Mill. Gal/Year	958.58	7847.20	2.23	232380.00
Price in Block 3	$	640.40	240.21	252.96	1176.00
Quantity in Block 4	Mill. Gal/Year	49.28	304.73	0.01	5805.60
Price in Block 4	$	1166.10	427.81	448.44	2167.10
Quantity in Block 5	Mill. Gal/Year	1.38	9.73	0.00	212.37
Price in Block 5	$	2234.00	830.15	768.60	4184.90
CPI		1.14	0.08	1.03	1.27

Table 1 summarizes the block rate price structure for eight regions in the year 1991. County level household variables such as per-capita income and population were obtained from census data. Precipitation data were obtained from the Kansas State University weather data library. Data on Consumer Price Indices (CPI) for foods were obtained from the International Labor Organization (ILO) statistics for US. This index was used to deflate the prices and per-capita income. Please see the table 1 for the summary of the data used and figure 1 for regional demarcations.

Results

We first tested for the homogeneity of variance in per-capita water consumption in all the regions. PROC GLM procedure in SAS has the facility to test the homogeneity of variance by using the HOVTEST and bf option. This testing is for the one way fixed effect model, considering each region as a distinct group. BF option represents the Brown-Forsythe test for detecting the differences in variance, while protecting the Type I error probability (SAS). The null-hypothesis of this test is that the variance in per-capita water consumption is homogenous across the regions in Kansas. The result for the Brown-Forsythe test is shown in Table 2 and we do not reject the hull-hypothesis. That is to say that the variance per-capita water consumption is homogenous across the regions.

Table 2: **Brown and Forsythe's test for homogeneity of mean variance**

ANOVA of Absolute Deviations from Group Medians					
Source	**DF**	**Sums of Squares**	**Mean Square**	**F Value**	**Pr > F**
Region	7	2.9008	0.4144	0.79	0.5985
Error	72	37.8002	0.525		

After testing for the variance per-capita water consumption, the difference in mean per-capita consumption can be tested either using an ANOVA test or lsmeans test in the PROC GLM procedure. In our estimation PROC GLM procedure was used. The result of this test is presented in table 3. The null-hypothesis was that the per-capita water consumption is equal across the regions. The test indicates that it is not true. Therefore it was concluded that the per-capita water consumption across eight regions in Kansas significantly differ.

Table 3: Homogeneity of mean per-capita consumption

LSMeans test for Homogeneity of mean per-capita consumption					
Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
Model	7	9.33731111	1.33390159	2.44	0.0265
Error	72	39.33815122	0.54636321		
Corrected Total	79	48.67546233			

The result from the ordered probit model of the shares of consumption in each block for the first year is presented in table 4.

Table4: Parameter estimates from logit model

Parameter	DF	Estimate	Standard Error
Intercept1	1	2.969	3.370
Intercept2	1	7.854	0.687*
Intercept3	1	11.941	0.889*
Intercept4	1	14.754	0.998*
Price	1	0.015	0.001*
Population	1	0.000	0.000*
Per-capita Income	1	0.000	0.000*
Mean Annual Precipitation	1	-0.218	0.0287*
Mean Annual Temperature	1	-0.323	0.060*

Except for the intercept1 all the other variables are significantly impacting the individual block effects. Since we have identified (ranked) the increasing consumption blocks with decreasing values (less than 5000 gallons per month = 5 and 50000-100,000 gallons per month =1) the signs are need to be interpreted cautiously. An increasing price would results a move towards a higher ranking block. Thus an increased price in ranked block 4 (5000 – 10,000 gallons per month) altered the consumption in such a way to change the block ranking to a higher order. It is to say that the consumption would be reduced as a result of increased prices. This is consistent with the economic theory. But the coefficients of population, per-capita income and mean annual precipitation indicates a unit increases in those variables results a decline in consumption. An increase in mean annual temperature would result an increase in consumption.

Table 5 gives the results of the shares of consumption by block in the eight regions in Kansas over the 10 year period. This result is the average for the 10 years.

Table 5: Estimated share for the consumption blocks

	Monthly Water Consumption (in gallons)				
Region	**< 5000**	**10,000**	**25,000**	**50,000**	**100,000**
1	0.7751	0.0961	0.1115	0.0168	0.0005
2	0.6749	0.1103	0.1542	0.0563	0.0043
3	0.6015	0.1216	0.2092	0.0635	0.0041
4	0.5846	0.1471	0.2201	0.0467	0.0016
5	0.5695	0.1972	0.2178	0.0154	0.0001
6	0.4235	0.2416	0.3134	0.0214	0.0002
7	0.2600	0.3182	0.4135	0.0083	0.0000
8	0.1596	0.3497	0.4848	0.0058	0.0000

In region one it was observed that about 77 percent of the total consumption is accounted in the first block (<5000 gallons/month), 10 and 11 percent in second and third blocks respectively. In region 2 we tend to observe a lesser amount of total consumption in the first block compared to the same block in region 1. But the proportion of total consumption tends to increase in block 2 and 3. This trend continues as the regional numbers increases in all three blocks.

One of the interesting features of this result is that as we move towards Eastern Kansas (region 8) from the West (region 1) the probability to observe the first block rate decreases. The probability to observe 10,000 and 25,000 gallons per month increases in the same direction. It is to say that proportionately more consumers are likely to be observed in the lower consumption block rates in Western Kansas while less of them in Eastern Kansas. It seems reasonable given the fact that the economic activities and income levels that prevails in those two regions. Western Kansas is predominantly an agriculture economy compared to Eastern part of Kansas where more commercial activities are concentrated. In general the economic activities increase from

West to East where Kansas City is one of the Metropolitan Statistical Areas (MSA), while more farming takes place in western part of the Kansas.

Conclusion

Per-capita water consumption has been an important research area. Location factors could impact the per-capita consumption significantly. The nature of the economic activities and climate may influence the consumption to a grater extent. Disaggregating of aggregate water consumption has constrained the estimation of demand for individual blocks. In this paper it was estimated that the per-capita water consumption varies significantly across eight regions in Kansas and the nature of economic activities tend to influence the share of consumption of a given block in a given region.

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FIGURE 1
REGIONS USED FOR GALLONS PER CAPITA PER DAY (GPCD) ANALYSIS