Residential water demand in Durham, NC, at the onset of the 2007 drought

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1 abstract

Understanding patterns of residential water use is important for designing and assessing demand-oriented policies on water conservation. Using the City of Durham's water consumption data for July 2007, this study attempts to quantify the effects of socio-demographic variables (e.g., income, household size, age of the house) on household water consumption using regression analyses. We found that the block group average per capita income and the fraction of newly constructed housing units in a block group are positively related to household water consumption. Ultimately, this paper comments on the feasibility of policies such as water reduction targets and the possible effects of these policies on different income groups.

2 introduction

During the past few months, the city of Durham has implemented several stages of water restrictions in response to the continuing drought condition. Durham's two main sources of water, Lake Michie and Little River Lake, have experienced a constantly decline in water due to the high household water use and the scarce amount of rainfall this year. According to officials, we are fortunate that the situation this year is significantly better than the record drought in 2002. However, this does not mean that we all can ignore the problem and let Mother Nature take care of it.

From the perspective of economists and policy makers, information on the determinants of consumer demand is of pivotal importance for the efficiency and efficacy of public and private water management programs. A proper cost-benefit assessment of sustainable water use programs is only feasible on the basis of a thorough understanding of consumer responses to price and income changes. Moreover, understanding usage pattern is important for forecasting the future and designing water use reduction policies.

Typically there are two different types of policy responses to the water scarcity problem. The supply-oriented policy focuses on the utilization of new resources and expansion of the infrastructure. The other approach is a demand-oriented policy that focuses on the development of water conservation and management programs to influence water demand and water use. In the short-run, demand-driven solutions are increasingly viewed as a necessary complement to, or even substitute for, supply-oriented policies. As seen in the opening quotation, the policies mandated by the City of Durham in response to the continuing drought are primarily demand-driven solutions. Therefore, it is important for policymakers to understanding how consumer water demand responds to income changes in order to evaluate the cost-benefit of the proposed water management program.

Acknowledging the importance of the information on income elasticity of water demand in terms of policy implications and realizing that no prior studies existed on this topic, this paper attempts to measure the income elasticity of residential water demand for the city of Durham.

3 Literature Review

There are various studies on price and income elasticities of residential water demand both within the United States and outside. However, the results vary significantly due to the different functional specifications, aggregation level, and data characteristics. Three of the prior studies on price and income elasticities of residential water demand are reviewed here. First, a study by Mazzanti[3] presents empirical evidence on the determinants of residential water demand for one Italian region, Emilia-Romagna. The measured income elasticities of Mazzanti's study ranges from 0.40 to 0.71. The second study by Renwick and Archibald[5] estimates income elasticity of water demand in two municipalities in California to be 0.36. The third study by Nauges and Thomas[4] estimates a model of water demand using a sample of French municipalities. Nauges found income elasticity estimated to be 0.1. These figures are consistent with various other studies and to the general consensus among economists that water demand with respect to income is inelastic.

Mazzanti uses a panel dataset consisting of 125 municipalities observed over four years (1998-2001.) The dependent variable is annual water consumption per capita. Independent variables include a tariff (water price), per capita income, household size, share of population age 19 and younger, share of population age 65 and older, and population density. Mazzanti bases his analysis on a fixed effects specification. The signs and magnitudes of the estimated coefficients on income and tariff (water price) are statistically significant and consistent with the theory. However, coefficients on household size and other demographic variables are not statistically significant.

Renwick and Archibald also use panel data on two communities in California to estimate the effects of difference demand side management (DSM) policies and other factors on residential water demand. Data were collected on a representative random sample of 119 single-family households in two communities: Santa Barbara and Goleta over a six-year period. Explanatory variables of interest are gross monthly household income, number of household members, dummies for low and medium lot size, and cumulative monthly rainfalls. Dummies for different DSM policies are also included in the model. However, they are not of interest for our purposes. They base their estimation on a two-stage least squares (2SLS) model. Regression results show that the coefficient for monthly household income, number of household members and lot size are statistically significant, while cumulative monthly rainfalls seem not to play an important role in determining water demand.

Nauges and Thomas estimate water demand using a panel sample of 116 French municipalities during 1988 to 1993. Explanatory variables include proportion of inhabitants aged more than sixty years old, proportion of households composed of one or two members, average household income, population density, proportion of single housing units in the community, proportion of homes with a bath, proportion of homes that owns one or more cars, total rainfall, rainfall during summer, and proportion of houses built before 1949 and 1982 respectively. Nauges estimates his model based on the Generalized Least Squares (GLS) method. Only regression coefficients for household income, rainfall during summer, proportion of residents aged more than sixty, and proportion of single housing units, car ownership, and the age of the house turn out to be statistically significant.

Mazzanti's and Nauges' studies are done at the community level, while Renwick's study utilizes data at the individual household level. Using aggregate level data can prevent the problem of sampling bias while forgoing accuracy of individual household economic and demographic characteristics. On the other hand, using a representative random sample of individual households can give a more accurate picture of household characteristics, but bias is also easily introduced from either over- or under-sampling some group in the population. All three studies utilize panel data sets, which is a much more powerful regression method compared to the cross-sectional data. Panel data typically allow researchers to control for some unobserved fixed and random effects that could introduce regression biases.

Relative to the prior studies on income elasticities of residential water demand, this paper aims to estimate water demand function and income elasticity for the City of Durham using a similar model for water demand.

The data on residential water consumption have not been made available for public access unless requested. Thus, no prior study has been done on water consumption in Durham. The estimation will be done using data at both individual household level and at block group level. These two results will be compared. On top of estimating demand and income elasticity for water use, the study will also estimate the amount of water saved under different scenarios such as when extreme users (those who use more than 40 units of water) are excluded from the sample, or when everyone is forced to consume their fair allocation (which is the amount on the regression line).

This paper is organized into six sections. Section III describes data sources and the model used for estimating residential water demand and income elasticity. Section IV and V display empirical results using data at the individual household level and at the block group level, respectively. Section VI provides a detailed discussion and policy implications of the result.

4 Data

Data for Durham city water consumption was obtained from the Customer Billing Service Division. Out of 110,792 total housing units in Durham, we randomly selected 97 streets that represented 97 block groups within Durham. All housing units locating on these 97 streets were included. The data set contained records of water consumption for July 2007. Housing units with missing data for water consumption were dropped out, leaving a total of 5,140 observations as our full sample. This study conducted regression analyses on two consumption levels: the block-group (aggregate) level and the individual household level. At the block-group level, all 5,140 observations were assigned to their respective block group and regressed on block-group specific socio-demographic variables. At the individual level, approximately 300 households will be randomly sampled for the analysis. We then regressed the water consumption of these 300 households on household-specific variables (such as lot size and house value).

One unit of water consumption is equal to one hundred cubic feet (ccf) or 748 gallons of water. The City's current water pricing structure is a flat monthly charge at the rate of $1.56 per unit.

A census block group is a geographical unit used by the United States Census Bureau which is between the census tract and the census block. It is the smallest geographical unit for which the bureau publishes sample data, i.e data which is only collected from a fraction of all households. The population of each block group generally ranges from 600 to 3,000 people. Most block groups are defined by local participants as part of the U.S. Census Bureau's Participant Statistical Areas Program[1].

Data for block-group specific socio-demographic characteristics were obtained from the 2000 Census[2]. Block group-specific information included in this study are 1) the fraction of small families (1-3 people per household), 2) the fraction of large families (7 or more people per household), 3) the fraction of housing units having more than 5 rooms, 4) the fraction of owner occupied housing units, 5) the fraction of housing units having more than 1 occupant per room, 6) per capita income (in $1,000)[3], 7) the fraction of population that is white, 8) the fraction of housing units owned by householders age 15-34, 9) the fraction of housing units owned by householders age 55 and above, 10) the fraction of housing units built after 1998, and 11) the fraction of housing units built in 1969 or earlier.

Data for socio-economic characteristics at the individual household level were obtained from the online Tax Administration Record . The source offers information on 1) housing value, 2) heated area, 3) lawn size, 4) number of rooms, 5) ownership status, 6) year built, and 7) sale history.

The major limitation of this study is the inability to run a panel data regression. Although there are three-year records for water consumption of individual households, information for socio-economic characteristics is not year-specific. Data from the Decennial Census, as the name suggests, are collected once every ten years, while data from the online Tax Administration Record are collected every five years.

5 Framework and Model

5.1 General Model

The demand expression for residential water is derived from the Stone-Geary utility function for two necessity goods. The general expression for the utility

[1]More information on block group definition on http://www.census.gov/geo/www/cob/bg_metadata.html

[2]http://factfinder.census.gov/servlet/CTGeoSearchByListServlet?ds_name=DEC_2000_SF3_U&_lang=en&_ts=214736820128

[3]in the Census 2000 dollars

function can be written as:

$$U(x,y) = (x - \bar{x})^{\alpha} + (y - \bar{y})^{\beta}$$

Where x = amount of water demand
$\bar{x}$ = minimum amount required for x
y =demand for all other goods
$\bar{y}$ = minimum amount required for y
I = income
P_x = price of water
P_y = price of other goods

Assuming that $P_y = 1$ (regard other goods as numeraires) and $\alpha + \beta$ yields the demand expression for water (x):

$$x = \bar{x} + \frac{\alpha(I - \bar{x}P_x - \bar{y})}{P_x}$$

This Stone-Geary demand function is useful for our water study because it reinforces the nature of residential water as a necessity, which requires some nonzero minimal amount of consumption. Here, the consumer is given some level of income (I) and price of water (P_x). The consumer needs to purchase a minimum amount of water ($\bar{x}$) and other goods ($\bar{y}$). The leftover income will thus be allocated to water consumption according to its preference parameter (α).

Since the price of water does not vary across observations, $P_x$is going to be constant in the model. Thus, having P_x as a constant, the model implies a positive relationship between water demand and income. From this expression, we derive the income elasticity of water demand (ϵ) as:

$$\epsilon = \frac{\alpha I}{P_x x}$$

From this expression, we can predict the value in which the elasticity of income would converge to. Assuming as income goes to infinity, the minimum requirement for both water and other goods ($\bar{x}$ and $\bar{y}$) becomes negligible. Therefore, the elasticity expression implies that as income approach infinity, the elasticity will asymptotically approach unity. The assumptions and the resulting elasticity expression are especially suitable for water demand because they suggests that elasticity is non-negative and less than 1 for everyone. It is consistent with many empirical studies that the income elasticity of water demand almost all the time is inelastic.

5.2 Block Group (Aggregate) level Analysis

In this section, we derive an estimable linear model for residential water use as a function of block-group socio-demographic characteristics, which includes:

1. *Per capita income* Residential water is regarded as a normal good. Therefore, we expect water demand to rise as income goes up. However, the rate in which water demand rises with income might not be linear. In fact, most prior studies found that at higher income levels, one additional unit of income induces less than one additional unit of water use. In other words, the income elasticity of residential water demand is positive but inelastic.

2. *Fraction of small and large households* Since the dependent variable is water consumption per household, it is reasonable that water consumption rises with household size. However, some studies suggest that there are economies of scale in water consumption. [2] This implies that in the increase in household size induces a less than proportional increase in water use. Therefore, the relationship between residential water demand and the fraction of smaller and larger households can go either way. Another possibility is that there could be some optimum household size beyond which the economies of scale vanish. [1] In this study, we define a small household as an occupied housing unit with 3 or fewer occupants, and a larger household as those with 7 or more occupants.

3. *Fraction of housing units with few rooms or many rooms* Number of rooms in a housing unit is a proxy for house area, which in turn would highly correlate with its lawn size. Here, we intend to use number of rooms as a proxy for lawn size since getting individual household lawn size for all 5,140 observations will be highly demanding. Generally, a house with a larger lawn would require more water to maintain the grass and any flowerbed and trees. Therefore, we expect that a higher fraction of housing unit with many rooms (7 or above) will lead to a higher demand for residential water.

4. *Fraction of crowded families* We define a crowded family as any family that has more than one occupant per room. This feature is used to deliberate correlation on housing space. We expect this variable to correlate with several other characteristics such as age and income and thus there might not be a strong, direct relationship between the fraction of crowded families and household water consumption. One possibility that having a lot of crowded families would reduce household water use is that in general, people who live in a crowded environment tend to be a migrant labor or impermanent residents of Durham. Controlling for income, we expect these people to have preferences that are less water intensive.

5. *Fraction of white population* The fraction of white population is included in the regression model as a demographic control.

6. *Fraction of housing units owned by young householders or old householders*
   Young people might use water less carefully, while older people might be more cautious. This relationship is mentioned in the Nauges study. However, the pattern of water use can also go in the opposite direction as older people spending more time at home tend to do more gardening. Therefore, the direction of water use determined by age of the householder is unclear. We define young householders as householders between ages 15 and 34, and old householders as those above 55.

7. *Fraction of new and old housing units* We define newer housing units as those constructed after 1998, and older housing units as those constructed in 1969 and earlier. Newer housing units are likely to be equipped with more efficient appliances and are less subject to leaks from the municipal system mainlines. Therefore, we expect to see water consumption rising with the fraction of older housing units.

8. *Fraction of owner occupied housing units* Ownership of a housing unit could be highly correlated with pattern of water use especially for gardening. An owner of a house would certainly care more about maintaining his garden compared to a renter. Thus, we expect water use to rise with the fraction of owner occupied housing units.

5.3 Individual Level Household level Analysis

In this section, we use the same regression model defined in the previous section. Dependent variable used here is the unit of water use per person per month, where one unit consumption is equal to 748 gallons. Household-specific socio-demographic characteristics included in the regression are:

1. *House values* Due to the confidentiality issue, it is impossible to acquire the information on individual's household income. Since income is generally highly correlated with house values, we select house value as a proxy for household income. Information on house values in Durham are published every 5 years on the online Tax Administration Record. According to the rationale in the previous section, we expect per person water consumption to go up with house value.

2. *Heated area* Heated area is the floor area of the housing unit that is enclosed from the weather and heated.

3. *Average household size*

4. *Lot size* Lot size potentially dictates the pattern of water use for the purpose of gardening. Therefore, we expect water consumption to go up with the lot size.

5. *Ownership status* We define ownership status as a categorical variable which takes on the value of 1 if it is an owner-occupied house, and 0 if it is renter-occupied. The argument goes in the same way as discussed in the previous section: an owner of a house tend to spend more water maintaing flower and trees in the garden, and thus would use more water than a renter.

6. *Sale history* A house with a sale history generally has a higher house value than its counterpart without a sale history. We included this categorical variable for the sale history as a control for the house values.

6 Block Group level analysis

6.1 Summary Statistics

Summary statistics for the samples included in the block-group level analysis are presented in table1.

Table 1: summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
water (in consumption units)	5140	13.695	14.860	0	197
% small household (≤ 3)	5140	0.792	0.079	0.624	0.944
% large household (≥ 7)	5140	0.014	0.017	0	0.108
% house with 5+ rooms	5140	0.422	0.238	0.021	0.964
% owner occupied housing unit	5140	0.548	0.266	0.023	0.971
% house with 1+ occupants per room	5140	0.050	0.048	0	0.247
income (in 1,000 dollars)	5140	22.719	10.871	7.806	91.275
% white population	5140	0.479	0.270	0	0.948
% house occupied by owner age 15-34	5140	0.289	0.143	0.070	0.662
% house occupied by owner age 55+	5140	0.277	0.121	0.045	0.609
% house constructed after 1998	5140	0.102	0.152	0	0.786
% house constructed before 1969	5140	0.457	0.273	0.025	0.953

6.2 Regression Results

Table 2 shows the OLS estimation result for the block group level analysis. The only three statistically significant variables are per capita income, the proportion of newly constructed housing units in the block group, and the proportion of smaller households. The effect of income is very strong as the coefficients for the per capita income (income) show up to be positive and highly significant in all specifications. The coefficients for the proportion of smaller households (smallhhz) are negative and significant in all 4 specifications. Simple interpretations for these results are when controlling for all other variables 1) for every $1,000 in per capita income, estimated water use per household rises by 0.252 units or 188.496 gallons per month, 2) for every ten percent increase in newly constructed housing units in a block group, estimated water use per household rises by 0.38 units or 284.24 gallons per month, and 3) for every ten percent increase in small households (1-3 people) in a block group, estimated water use per household drops by 1.11 units or 830.28 gallons per month.

There is, however, a lot of variations on the socio-economic characteristics within the sample. As shown by the R^2 value, our estimated model can only explain 2.87% of the variation in the sample. This variation in water consumption pattern could be separated into i) variation within a block group and ii) variation across block groups. Variation across block groups is

Table 2: Durham residential water use: Block-group level analysis
OLS regressions

	(1) water	(2) water	(3) water	(4) water
% small household (≤ 3)	-9.539*	-11.66**	-12.42**	-11.14*
	(-2.37)	(-2.76)	(-2.64)	(-2.29)
% large household (≥ 7)	-12.04	-10.23	-8.656	-9.850
	(-0.76)	(-0.65)	(-0.54)	(-0.61)
% house with 5+ rooms	-0.670	-1.772	-1.047	-2.686
	(-0.29)	(-0.73)	(-0.41)	(-1.00)
%owner occupied houseing units	-0.652	-0.546	-0.207	0.968
	(-0.33)	(-0.28)	(-0.10)	(0.42)
% house with 1+ occupants per room	6.908	7.050	6.285	7.742
	(0.87)	(0.89)	(0.74)	(0.89)
per capita income (in 1,000 dollars)	0.266***	0.249***	0.244***	0.252***
	(8.86)	(7.87)	(7.53)	(7.59)
%white population		2.024	1.906	1.805
		(1.63)	(1.51)	(1.43)
%house occupied by owner age 15-34			3.218	1.599
			(0.85)	(0.39)
%house occupied by owner age 55+			1.968	0.395
			(0.56)	(0.11)
%house constructed after 1998				3.791*
				(2.09)
%house constructed before 1969				1.778
				(1.55)
_cons	15.67***	17.13***	15.95***	14.51***
	(4.07)	(4.33)	(3.74)	(3.36)
r2_a	0.0281	0.0284	0.0281	0.0287
N	5140	5140	5140	5140
F statistics				14.81

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

estimated by the adjusted R^2 from regressing the dependent variable (water use) on block-group dummies (1 to 96), which shows to be only 8% of the overall variation. Variation within a block group is thus calculated as 92% of the overall variation.

Of all significant determinants of residential water use in our model, only the fraction of newly constructed housing units (those built after 1998) shows an unexpected relationship with water use. As mentioned before, we expected a higher fraction of old housing units to exhibit a higher demand for water, rather than the fraction of new housing units. The coefficient we obtained suggests that new housing unit characteristics might be correlated with income or other household characteristics that lead to higher demand for water.

Using specification (4) as our main estimation model from this point onward, several analyses are presented in the next section.

7 Findings (for the block group level analysis)

7.1 Identifying the biggest water users

Table 3 lists out the five block groups with the biggest predicted average water demand. The highest predicted average water demand is 30.59 units per household per month, or 22,881.32 gallons. This is 123.44% higher than the predicted average for the entire sample.

Table 3: Block groups with highest average predicted water use

Block group	Street Name	Predicted	Actual	Obs
Block Group 1, Census tract 20.08	Devon	30.6	31.2	43
Block Group 2, Census tract 17.05	Medford	18.1	25.8	48
Block Group 1, Census tract 20.17	Lochnora	18.1	20.4	36
Block Group 3, Census tract 20.14	Cedar Grove	18	18.3	57
Block Group 2, Census tract 20.08	Sunningdale	21.2	17.8	67

7.2 Identifying block groups with the largest and smallest residual

We obtain this information from fitting a regression line through the data points, then calculate an average positive residual and an average negative residual for each block group. We then rank these block groups' average residuals and pick out the five block groups with the highest average residuals and the five block groups with the lowest average residuals. The results are reported in table 4.

Residuals measure how much the actual water consumption for each household in a block group deviates from the fitted regression line. Therefore, the larger average residual (either positive or negative) implies a larger unexplained variation in pattern consumption within the block group.

Table 4: Block groups with highest average positive and negative residuals

Block group	Street Name	residual	Predicted average	Obs
Highest average positive residuals				
Block Group 2, Census tract 20.12	Eagle View	13.5	16.3	49
Block Group 2, Census tract 7	Beverly	10.6	16.6	27
Block Group 1, Census tract 1.02	Acadia, Leon	10.5	12.8	114
Block Group 2, Census tract 6	Pinecrest, Perkins	8.2	14.6	89
Block Group 2, Census tract 17.05	Medford	7.7	18.1	48
Highest average negative residuals				
Block Group 2, Census tract 20.17	Stoneridge	-9	16.2	50
Block Group 1, Census tract 17.07	Hawthorne	-8.1	17.9	43
Block Group 2, Census tract 20.18	Beechnut	-8	16.9	56
Block Group 1, Census tract 18.05	Bungalow	-6.4	13.5	25
Block Group 1, Census tract 4.02	Hale	-5.6	12.2	43

7.3 Predicted average water use and per capita income

Figure 1 shows a relationship between predicted average water consumption and per capita income. Here, the scatter plot shows the predicted average water consumption in each block group calculated using block-group specific values for socio-economic characteristics. The straight line shows the predicted average water consumption calculated at each level of income conditional on the average values of all other independent variables. Clearly, the graph suggest that water consumption goes up with income.

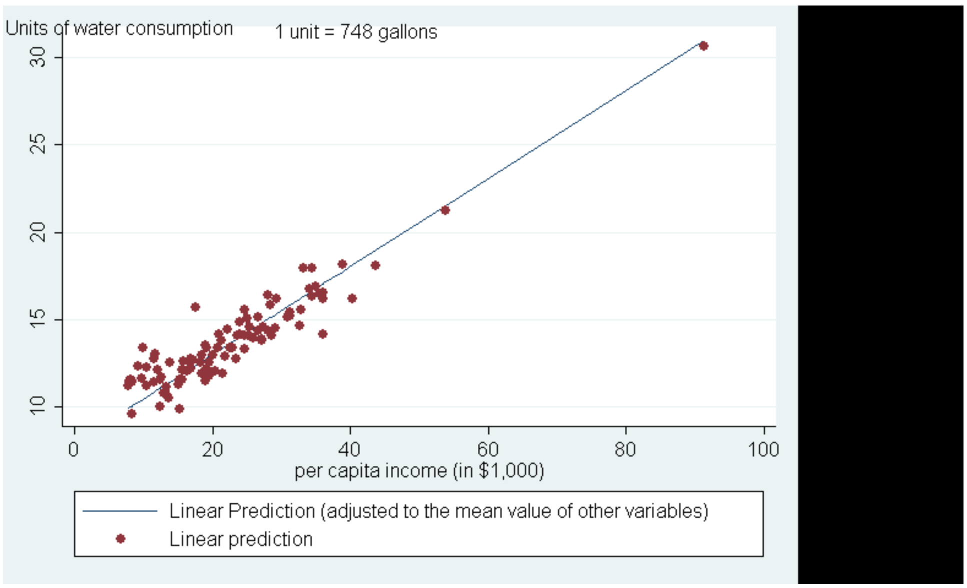

Figure 1: Predicted average water use *vs* income

7.4 Predicted average water use and percentage of newly constructed housing units

The fraction of newly constructed housing units in a block group was shown to drive up household residential water use. Figure 2 shows a relationship between predicted average water consumption and the fraction of new houses (those constructed in 1998 and after). Again, the straignt line shows predicted average water consumption conditional on the average values of all other variables in the model while the scatter plot was calculated using block-group specific values. The one outlier belongs to Stardust street in Block Group 2, Census Tract 16.01. Again, the graph suggest that water consumption goes up with the fraction of newly constructed housing units in a block group.

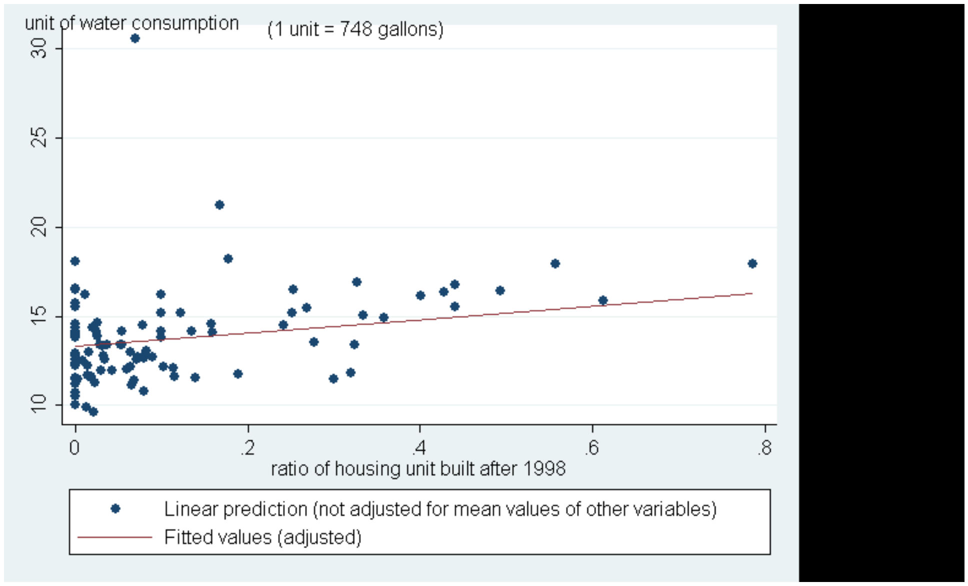

Figure 2: Predicted average water use *vs* income

7.5 Amount of water saved if restriction is placed on the maximum water allowance

Figure 3 shows the percentage of water saved if everyone in the sample is forced to consume at or under some speficied amounts. As the graph suggests, in order to reach a 30% water reduction target, approximately a 9 units maximum allowance seems reasonable for the average households.

7.6 Predicted income elasticity of water demand

Using specification (4) estimated in the previous section, we derive an expression for the income elasticity of water demand as

$$\epsilon = \frac{0.252I}{wateruse}$$

The relationship between income and the income elasticity of water demand is shown in figure 4. As income increase, the predicted income elasticity rises but with a slower and slower rate. The predicted income elasticity of water demand in this sample ranges from 0.18 to 0.75. It is consistent to the prediction by the Stone-Geary Model that suggests a positive and inelastic demand.

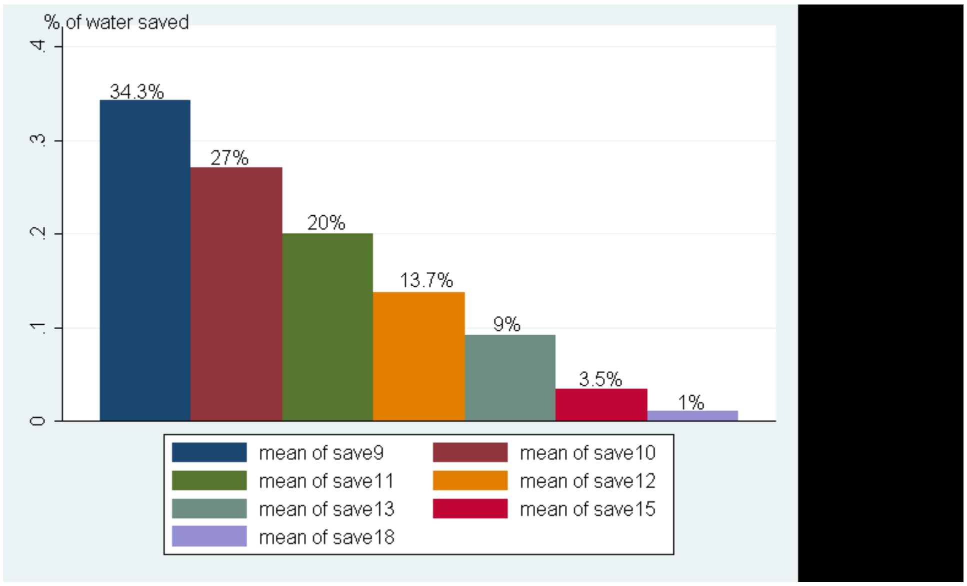

Figure 3: % of water saved at each maximum allowance

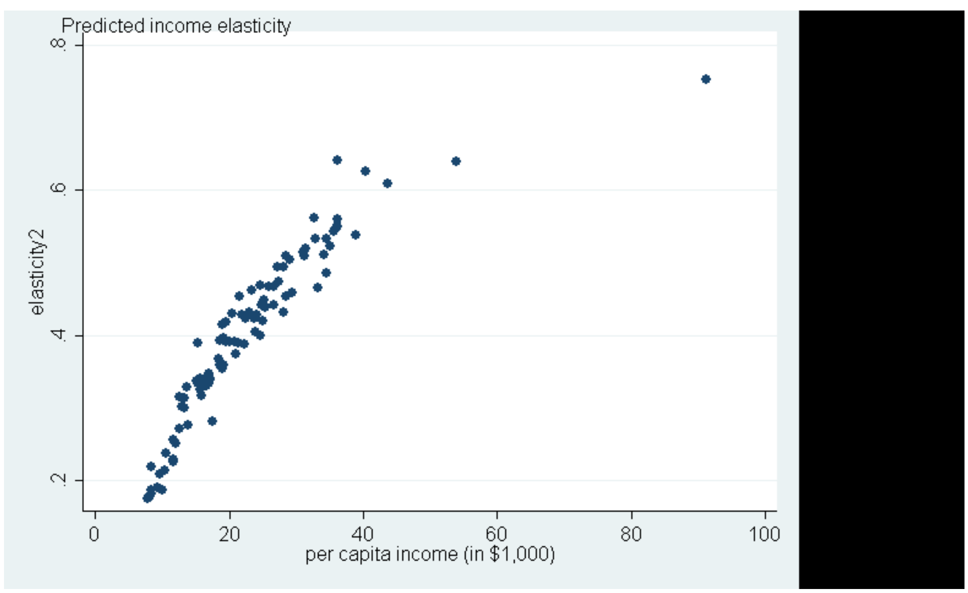

Figure 4: Predicted income elasticity of water demand at each level of income

8 Individual Level Analysis

8.1 Summary Statistics

Table 5: Summary Statistics for the Individual Household

Variable	Obs	Mean	Std. Dev.	Min	Max
per capita water use	329	8.6	8.8	0.3	81
housevalue (in 1,000 dollars)	329	194	160.8	30.3	1217.2
household size	329	2.4	0.4	1.4	3.5
heated area	329	1831.6	896.6	630	5627
lot size	329	0.4	0.3	0.03	2.5
ownership status	329	0.8	0.4	0	1
sale history	329	0.03	0.2	0	1

Summary statistics for the observations included in the individual household level analysis are displated in table 5. The average water consumption per person per month for this sample is 8.71 units or 6,515.08 gallons per month. The interpretation for the individual level analysis is slightly different from the block-group level analysis since water consumption is measured as a per person, as opposed to per household. Additionally, the values for all independent variables are household-specific as opposed to the fractions within a block group.

8.2 Regression results for the individual household level analysis

Table 6 shows the regression results for the individual household level analysis. The only variable that is statistically significant with expected sign is the house value. The coefficient for heated area is also statistically significant but in an opposite direction from what we expected. Using specification (2) which better captures the variation in our observations, two simple interpretations can be drawn. First, controlling for other variables, for every $1,000 increase in house value, the water consumption increase by 34.782 gallons per person per month, and second, per person water consumption decreases with larger heated area. An interesting implication from specification (2) is that the relationship between per capita water use and housevalue is not linear.

Table 6: Durham Residential water use: Individual-level analysis
OLS regressioins

	(1)	(2)
	per capita water	waterperson
house value	0.0258***	0.0465***
(in 1,000 dollars)	(4.47)	(3.98)
household size	-2.051	-1.431
	(-1.61)	(-1.09)
heated area	-0.00143	-0.00236*
(in S/F)	(-1.50)	(-2.25)
lot size	0.206	0.0569
(in Acres)	(0.11)	(0.03)
ownership status	1.258	0.747
	(0.99)	(0.58)
sale history	2.748	2.898
	(1.09)	(1.15)
housevalue2		-0.0000188*
		(-2.03)
_cons	9.965**	7.821*
	(2.84)	(2.14)
N	329	329
adj. R^2	0.146	0.154
F statistics	10.35	9.54

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 5 shows the relationship between predicted per capita water use versus house value. In fact, the model implies a positive relationship between water use and house value up to a certain level before the relationship becomes negative. It also implies that the house value elasticity of water demand is a decreasing function of house value–that is, it becomes more inelastic as house value goes up. Figure 6 shows the relationship between the elasticity of water demand and house value. This elasticity value is estimated using specification (2) of table 6. The demand function from specification (2) is in a quadratic form of:

$$water = \alpha_0 + \alpha_1 housevalue^2 + \alpha_2 housevalue + \sum(\alpha_i \vec{z_i})$$

Thus the house value elasticity of water use is derived from

$$\frac{\partial water}{\partial housevalue}\frac{housevalue}{water} = (2\alpha_1 housevalue + \alpha_2)\frac{housevalue}{water}$$

where α_1= -0.0000188 and α_2= 0.0465.

Compared to the block-group level model, the models constructed using the individual household level characteristics perform much better in capturing the variations in the (15.4% compared to 2.87%).

9 Conclusion

Of all the relevant socio-economic characteristics, only per capita income and house value turn out to have strong and expected relationships with the pattern of water use. This finding is consistent with the prior studies by Renwick, Nauges and Thomas, and Mazzanti. Surprisingly, newly constructed housing units seem to drive up household water consumption. What accounts for the higher demand for water might not be a feature of the house itself, but rather the characteristics and preference of the occupants. Living in a new housing unit could imply a higher income and that the person is likely to be a permanent resident in Durham. Compare to a non-permanent resident, a permanent resident would spend more time at his home and thus tends to invest more in luxuries and maintaining the garden. These two factors suggest more water intensive preferences of the occupant. Another interesting finding is that there are huge variations in socio-economic characteristics within a block group, rather than between block groups. Thus, even though our block-group level model can capture some variation in the

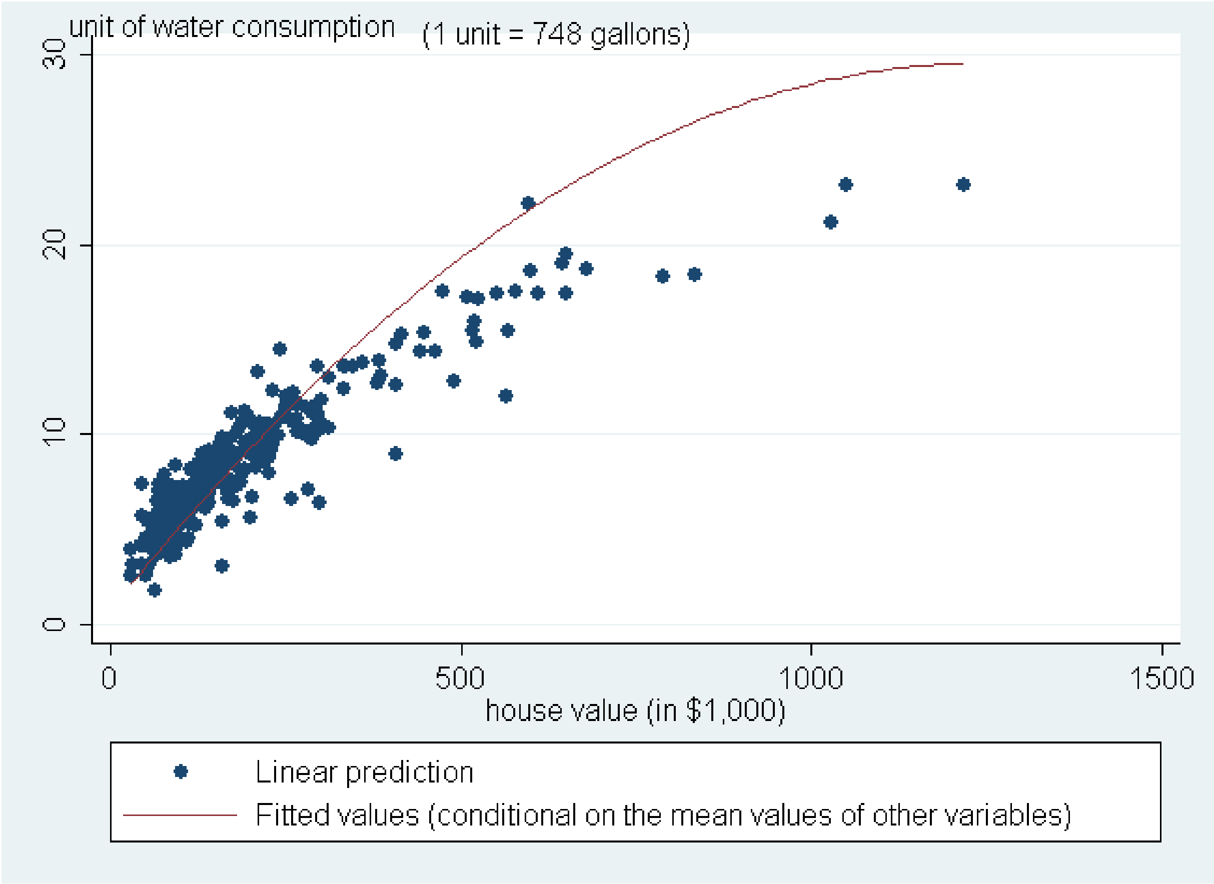

Figure 5: Predicted per capita water consumption *vs* house values

observation, the model could be improved further to capture variation with in a block group.

There are several limitations to this study. The most important of all is the availability of the data on water consumption. The household water consumption record is not publicly available and the only data set we could obtain was for July 2007. Having only cross-sectional data, we are unable to control for the weather variable such as rainfall and other unobservable variables that are unchanged over time. Second, even though the regression model done at the individual household level performs much better than the block group level in terms of capturing variations within the sample, match-

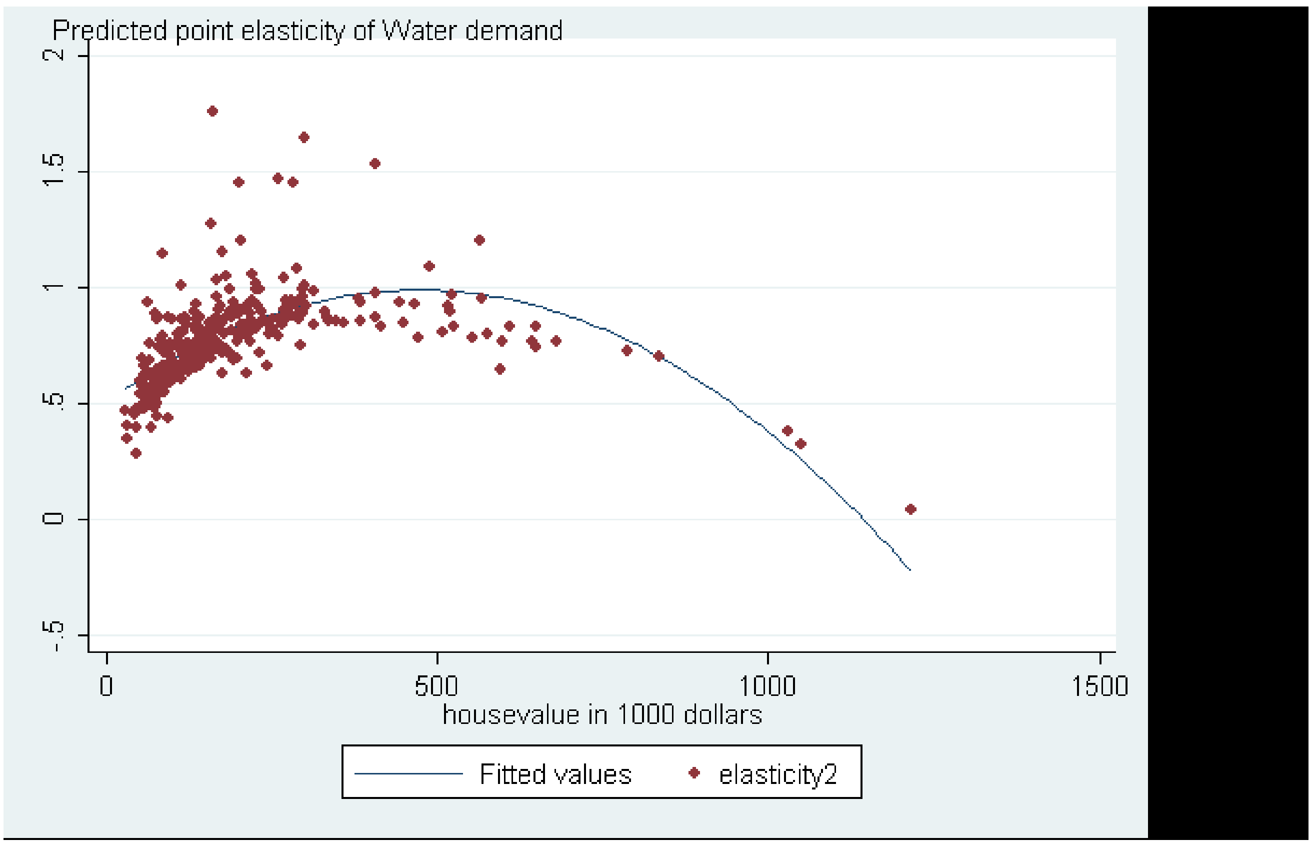

Figure 6: House value point elasticity of water demand

ing information on individual household characteristics to each observation is highly demanding. Given a limited amount of time, we were unable to include more than 300 observations.

Future work should be made using a more extensive set of data spanning several years, if available. Utilizing panel data not only allows us to control for seasonal and unobservable effects, but also enables us to evaluate the effect of each water restriction policy placed on the City of Durham over the past several months.

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