The Unintended Consequences of IBT Pricing Policy in Urban Water[1]

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Abstract

We exploit a unique data set to estimate the degree of economies of scale in water consumption, controlling for the standard demand factors. We found a linear Engel curve in water consumption: each additional household member consumes the same amount regardless of household size, except for a single person household. Our evidence suggests that the IBT (increasing block tariffs) structure, which is indifferent to household size, has unintended consequences. Large households, which are also likely to be poor given the negative correlation between income and household size, are forced to pay higher price for water. The degree of economies of scale found here erodes the logic of using an IBT price structure as a way to introduce an equity consideration. This implication is important in view of the global trend toward the use of IBT.

JEL classification: D63, Q25

Keywords: Water Pricing Policy, Increasing Block Tariff, Urban Water Demand.

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Introduction

The main goal of this paper is to estimate the degree of economies of scale in urban water consumption exploiting a unique data set. We uncover the water demand structure with regard to household size. In particular, we explore what is the additional water consumption, as a result of additional family member, for various household sizes. We then compare our estimates to the implicit economies of scale that is embedded in pricing policy of urban water.

Water utilities and regulators in many countries are moving toward IBT (increasing block tariff) pricing. IBT price structures set two or more prices for water, each price pertaining to consumption within a defined block. Estimates of economies of scale in household water consumption are becoming more important in light of the global trend toward the use of IBT.

When an IBT pricing structure is used, policymakers have to determine the range of water consumption at which the lowest price applies. This range may be a constant quantity of water or a function of household size. It seems natural to demarcate the first block in accordance with household size. The optimal structure, however, depends on the assumptions underlying the normative model.

Although there are considerable variations in water-pricing structure among the OECD countries, there is a general move away from fixed-price and decreasing block tariff (DBT) pricing structures toward volumetric charging and increasing block tariffs (OECD, 1999). As Table 1 shows, there has been a significant shift to increasing block tariffs in the United States over the past two decades. Only 4 percent of American utilities used IBT pricing policies in 1982; 36 percent did so in 2004. A survey of urban water utilities in Asia found that the majority of utilities in the sample used an IBT pricing structure (Asian Development Bank, 1993).

A large variation exists among OECD countries that use IBT pricing policies in the way they treat household size in determining the first block. Typically, in the United States and other OECD countries that use IBT pricing structures, the first block is the same for households of all sizes. This feature of IBT pricing, contrasts sharply with the equity consideration, if water consumption varies with household size. Large households tend to belong to the lower income classes. In an IBT pricing scheme that uses the same first block regardless of household size, large households are pushed to pay a higher average price for water. Obviously, the more important economies of scale in water consumption are, the weaker the inequity effect is.

Table 1: U.S. Residential Public Water Supply Rate Structure, 1982–2004

Rate structure	**1982**	**1991**	**1997**	**2004**
Flat fee	1%	3%	2%	0%
Uniform volumetric charge	35%	35%	33%	39%
Decreasing block	60%	45%	34%	25%
Increasing block	4%	17%	31%	36%
Number of utilities	90	145	151	266

Source: Cavanagh et al. for 1982–1997, AWWA and Raftelis Environmental Consulting Group for 2004.

Spain (Barcelona), Belgium (Flanders), and Greece (Athens), which use IBT pricing policies, do take household size very partly into account in setting the price of the first or second block. However, it is hard to explain in terms of economies of scale why the first block is indifferent to household size for households of four individuals or less and increases at a linear rate for larger household sizes, as is the case in Spain (Barcelona). No empirical study known to us shows this pattern of economies of scale in water consumption. Thus, insofar as economies of scale exist in water consumption, this pricing policy reflects cross-subsidization among households of different sizes.

In general, most households consist of four or fewer members. In Jerusalem, for example, more than 75 percent of households fall into this size cohort. In a typical developed city, the share of households of four or less is even larger and tends to exceed 90 percent. It follows that the mentioned pricing policy reflects a very incomplete handling of the equity consideration.

Taking household size into account in setting the first block price in an IBT structure is an administrative challenge. It imposes a cost on water utilities by forcing them to update their databases continually as people move in and out. Therefore, policymakers have to weigh the administrative cost against the equity consideration. The tension between these two considerations is dictated by the economies of scale in water consumption.

Metering is an essential part of IBT pricing policy. Two large water companies in England and Wales have withdrawn metering expansion due to stiff opposition occasioned by the possibility of negative effects on low-income households with children. This example highlights the importance of the equity consideration in shaping water-pricing policy.

Most empirical work on urban demand for water focuses on estimating price and income elasticities. These studies differ in the types of data used (aggregate or disaggregate household-level data), model specification, and estimation technique.[4] More recently, price elasticity has been estimated using more advanced estimation tools that deal with the endogeneity problem associated with IBT pricing.[5]

These studies estimate the price elasticity while controlling for various demand factors such as spatial variables (e.g., temperature and rain), geographic variables, and demographic variables. A key demographic variable in many of these studies is household size. In those papers that include household size as one of their explanatory variables, it appears in a linear specification. Linear specification, however, ignores the potential of economies of scale in water consumption. This paper aims to fill the gap by estimating the economies of scale of water consumption.

For this purpose, we use a unique data set composed of disaggregated data on households' water consumption, size, and other characteristics. The data pertain to *all* households in Jerusalem. The demographic structure of the population of Jerusalem is propitious for the estimation of economies of scale due to its large variation in the size of households.

[4] Danielson (1979), Jones and Morris (1984) Chicoine, Deller and Ramamurthy (1986), Nieswiadomy and Molina (1988, 1989, 1991).

[5] Hewitt and Hanemann (1995), Cavanagh et al. (2002), Nauges and Blundel (2002).

The next section briefly reviews the theory of consumer demand that faces piecewise linear budget constraints and the associated econometric issues. Section 3 describes the data. Section 4 presents the estimation results. Section 5 offers policy implications and concludes.

2. Theoretical Background

Some water uses are family shared consumption (housecleaning, dishwashing, cooking and outdoor consumption) while other uses are private (such as toilets, showers, and drinking). The existence of economics of scale is seemed to be trivial, but the degree is an open empirical question.

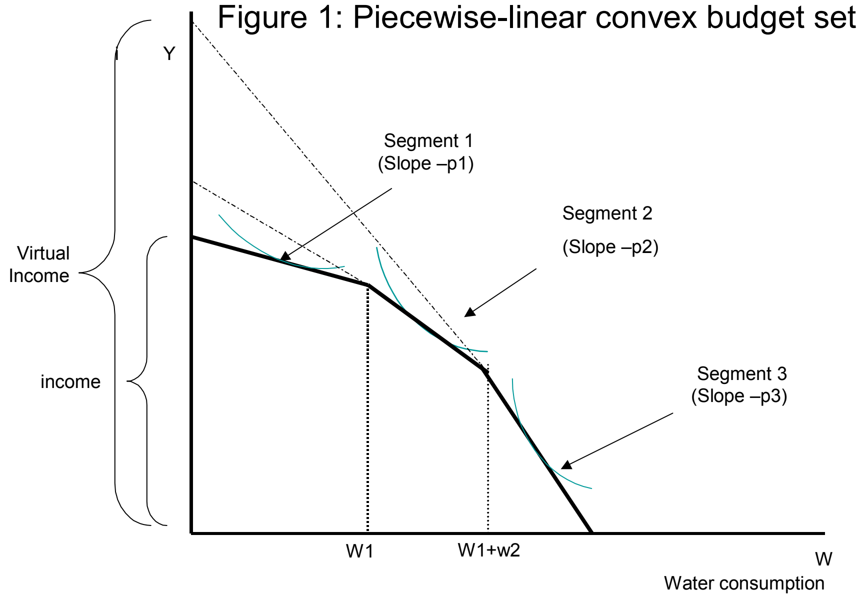
2.1 The Demand for Urban Water

Consider a utility-maximizing household with income Y and a piecewise-linear convex budget such as that in Figure 1. For simplicity, assume that the consumer utility comes from water consumption, denoted by w, and from a composite good, c, the price of which is normalized to 1. The consumer faces three increasing price blocks. We define p_i as the price of water in the i^{th} block, w_1 as the range of the first block, and w_2 as the range of the second block. The budget constraint consists of three segments that are described by the following equations:

$$
\begin{aligned}
&Y = p_1 w + c && \text{if } w < w_1 \\
&Y + (p_2 - p_1)w_1 = p_2 w + c && \text{if } w_1 < w < w_1 + w_2 \\
&Y + (p_3 - p_2)w_2 + (p_3 - p_1)w_1 = p_3 w + c && \text{if } w > w_1 + w_2
\end{aligned}
$$

Where three block tariffs exist, there are two *differences*. It is by now common to define $d_1=(p_2-p_1)w_1$ as a *difference* for households that face p_2. Therefore, the virtual income of these households is equal to their actual income plus this *difference*. For households in the third block, the *difference* is equal to $d_2=(p_3-p_2)w_2+(p_3-p_1)w_1$.

Figure 1: Piecewise-linear convex budget set

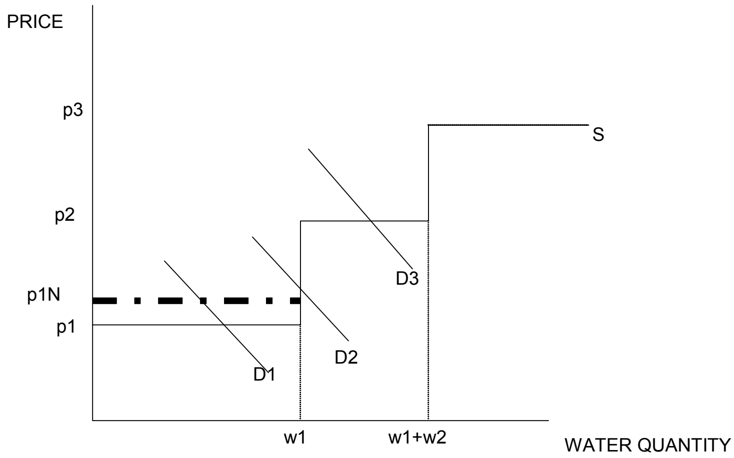


The consumer may be located within one of the three segments or at one of the two kinks. A household's demand for water is determined, among other things, by its taste for water and its size. Since it is natural to expect larger households to have higher demand for water, large households are pushed into higher price segments unless the block range is related to household size. In this regard, the economies of scale are a key factor in shaping the demand for water, which is the focus of this paper.

Increasing block tariffs generate a non-conventional demand curve (may be kinked, exhibiting non-differentiability). A price change in the first block, for example, affects households in the first block but may have no effect on all other households (Figure 2).[6] Therefore, the magnitude of price elasticity depends on the distribution of households along the water-consumption continuum.

[6] The price change reduces these households' income.

Figure 2: The effect of price changes



2.2 *Econometric Issues*

Maximum Likelihood has become a standard tool in estimating the demand for water in the case of increasing block tariffs. Demand for water is a combination of choice of block (discrete choice) and choice of the level of water consumption within the block chosen (continuous choice). The following equation describes the demand for water:

$$w = \begin{cases} w^*(p_1, y_1) & \text{if } w^*(p_1, y_1) < w_1 \\ w_1 & \text{if } w^*(p_2, y_2) \le w_1 \le w^*(p_1, y_1) \\ w^*(p_2, y_2) & w_1 \le \text{if } w^*(p_2, y_2) \le w_2 \\ w_1 + w_2 & \text{if } w^*(p_3, y_3) \le w_1 + w_2 \le w^*(p_2, y_2) \\ w^*(p_3, y_3) & \text{if } w^*(p_3, y_3) \ge w_1 + w_2 \end{cases}$$

See Burtless and Hausman (1978), Moffitt (1986), and Hewitt and Hanemann (1995) for a detailed derivation of the demand for water.

Following Burtless and Hausman (1978), we consider two possible sources of error: heterogeneity of taste and optimization error that reflects the difference between desired and observed levels of water consumption. Thus, actual water consumption may deviate from the chosen level.

The joint probability includes the probability of continuous choice of water consumption and the conditional probability that the desired level of water consumption, given the existence of choice, lies at a particular kink or block. Use of a maximum-likelihood method to maximize the joint probability elicits parameter estimates. The derivation of the log-likelihood function that we use in the empirical section of this paper is shown in the Appendix.

The maximization of likelihood function solves both endogeneity and the clustering of observations around the kinks. However, the likelihood function is not globally concave and may be sensitive to starting values in the computation. Several other problems are covered by Moffitt (1986).

3. The Data

The data used in this study cover all households in Jerusalem for the year 2003 (115,887 households).[7] Our data set comes from three main sources: Hagihon, the only water-supply company in Jerusalem; the Municipality of Jerusalem; and the Israel Ministry of the Interior. Most of the data originate with the Municipality of Jerusalem and were merged with household water-consumption data from Hagihon and household-size data from the Ministry of the Interior. Table 2 reports descriptive statistics.

Table 2: Descriptive Statistics

Variable	**Mean**	**S.D.**
Consumption (m^3/year)	205	150
Household size	3.65	2.41
Apartment size (sq.m.)	79	30
Lawn size (sq.m.)	123	122
Share of households at Price A	0.08	0.27
Share of households at Price B	0.60	0.49
Share of households at Price C	0.32	0.47
Number of units in building	23	25
Share of households below poverty line	0.12	0.32

[7] We excluded 64,720 observations for several reasons (commercial consumers, shared meters, household larger than twelve individuals, household metered during part of the year).

Most studies on demand for water tend to use samples rather than a whole population. Our database, composed of the entire population, allows us to estimate economies of scale in the demand for water. Jerusalem's highly diversified household structure makes this data set very attractive. It contains enough large households to permit precision in estimating the parameters—22,658 observations of households with six individuals or more, including 692 households with twelve persons (Table 3). The average household size in Jerusalem is 3.65.

Average per-capita water consumption in Jerusalem is 56 m^3/year, ranging from 125 m^3/year for single-member households to 33 m^3/year for households of twelve members (Table 3). The overall average is 7% lower than that in the OECD countries, 60 m^3/year (Figure 3).

Table 3: Households Characteristics by Household Size

Family size:	1	2	3	4	5	6	7	8	9	10	11	12
Average consumption per capita	125	80	62	54	51	47	43	39	37	35	34	33
Apartment size	68	77	80	83	87	88	86	85	86	87	88	90
Below "poverty line"	2.3%	3.6%	7.0%	8.0%	9.8%	17.8%	32.3%	45.7%	55.4%	63.5%	69.0%	73.7%
Lawn size (sq.m.)	139	135	129	121	115	118	122	117	96	76	75	83
Number of units in building	27	25	23	22	20	18	17	17	17	18	18	18
Marginal price A	0.32	0.15	0.09	0.06	0.06	0.08	0.12	0.16	0.19	0.25	0.27	0.28
Marginal price B	0.39	0.44	0.36	0.28	0.23	0.24	0.28	0.29	0.30	0.28	0.30	0.28
Marginal price C	0.28	0.41	0.55	0.66	0.71	0.68	0.60	0.55	0.51	0.47	0.43	0.45
Number of observation	23512	23784	16806	15925	13202	8385	5008	3413	2409	1640	1111	692

One of the limitations of our data is the absence of information on household current income. However, other characteristics in the set, such as apartment and lawn size, may be viewed as indicators of wealth. The wealth indicators, coupled with those of residential neighborhood and poverty line, may provide better information about households' permanent income.[8] As Table 2 shows, the average size of an apartment in Jerusalem is 79 square meters.

As noted, the price structure is crucial in choosing the estimation technique. Israel is one of the pioneers in using IBT pricing, reflecting the shortage of water in its region (efficiency consideration) and negative correlation between household size and income (equity consideration). Israel's IBT structure was determined thirty years ago and has hardly been changed since then. All municipal authorities in the country use the same pricing policy.

Jerusalem uses a three-block IBT pricing structure. In 2003, the average price in the first block, applying to the first 96 cubic meters (m^3), is $1.2/$m^3$ including a sewage surcharge (hereinafter: Price A). The price in the second block, for additional consumption up to 84 m^3, is $1.5/$m^3$ (hereinafter: Price B). The charge for all extra consumption is $1.9/$m^3$ (Price C). The price of water in Jerusalem is slightly below the median in the developed countries (Figure 4).

The pricing structure in Israel has two additional features. Households larger than four persons are entitled to an additional 36 m^3 per person per year at a low price. Households with irrigated lawns are allowed an additional 0.6 m^3 per square meter per year, up to 300 m^3, at a low price (excluding sewage surcharge).

The use of yearly data raises the question of whether marginal or average price should be used in the estimation. Following Williams (1985) who found that marginal price estimates are more reliable and Nieswiadomy and Molina (1991), who conclude that urban water consumers respond to marginal price when faced with IBT, we chose to use the marginal price. The marginal price in our study is defined as the highest price paid by the household during the year, even if it applied to one billing period (usually two months) only.

[8] In this paper, a household is below the poverty line if it is entitled to municipal tax deduction. This

4. Estimation Results

To estimate the extent of economies of scale in water consumption, the central question in this paper, we control for various factors of demand for water that are common in the literature. Those factors include the price of water, wealth indicators (apartment size, lawn size, number of apartments in the building, entitlement to municipal-tax discounts), and geographical regions within Jerusalem. Obviously, the wealth indicators may capture additional demand factors, such as taste for water in the case of lawn size.

The dependent variable in our regressions is yearly household water consumption in absolute terms (cubic meters). One expositional advantage of this specification is that the estimators are expressed in units of cubic meters. We also use a Log-Log specification to test the sensitivity of the scale-economies estimates to the particular specification. These regressions appear in table 4 in the Appendix.

The way we specify economies of scale in the regression is by using eleven dummy variables for each household size up to twelve members. The omitted variable is a single-person household. This specification permits a non-linear relationship between water consumption and household size. We are particularly interested in the marginal consumption at each household size. To date, the literature on water demand shows household size in a linear specification. This assumes zero economies of scale.

Table 4 presents the results of three estimations: OLS, 2SLS, and Maximum Likelihood. As the table shows, in the OLS estimation the additional consumption occasioned by an additional household member is roughly linear for households with more than four members. The economies of scale for households of four persons or less, in contrast, seem to be immense.

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tax deduction is means-tested and it is closely related to the formal poverty line in Israel.

Table 4: Estimates of the Water Demand Model

Variable	OLS	IV	ML
Constant	-5.60 (0.1285)	43.26 (0.0001)	1946 (0.36)
Household size:			
1			
2	1.19 (0.2048)	23 (0.0001)	175 (0.41)
3	5.75 (0.0001)	43 (0.0001)	357 (0.44)
4	13.93 (0.0001)	66 (0.0001)	424 (0.37)
5	34.35 (0.0001)	90 (0.0001)	344 (0.26)
6	59.47 (0.0001)	109 (0.0001)	320 (0.22)
7	83.16 (0.0001)	124 (0.0001)	344 (0.30)
8	106.99 (0.0001)	139 (0.0001)	320 (0.31)
9	138.17 (0.0001)	166 (0.0001)	323 (0.26)
10	170.67 (0.0001)	191 (0.0001)	283 (0.13)
11	193.40 (0.0001)	206 (0.0001)	225 (0.006)
12	221.48 (0.0001)	232 (0.0001)	171 (0.006)
Apartment size+d	0.64 (0.0001)	1.17 (0.0001)	2.49 (0.11)
Lawn size	0.37 (0.0001)	0.32 (0.0001)	-0.52 (0.6)
Private house	34.31 (0.0001)	41.50 (0.0001)	285 (0.48)
Below poverty line	-3.74 (0.0001)	-13.29 (0.0001)	58 (0.77)
Price b	60.46 (0.0001)	-6.58 (0.0001)	-315 (0.11)*
Price c	171.09 (0.0001)	-9.98 (0.0001)	
σ_η	99.88 (0.0001)	116.91	312 (0.14)
σ_ε			60 (0.0006)
Adjusted R^2	0.55	0.39	
F test	696.42 (0.0001)	357.29 (0.0001)	
Mean ll			-5.06
Number of observations	115,887	115,887	115,886

*Continuous price
P values are shown in parentheses.
The full list of explanatory variables includes 178 regions within Jerusalem, twelve types of municipal tax relief, and number of apartments in the building. For expositional purposes we do not present their estimators.

However, the sign of marginal price is positive in the OLS model due to the endogeneity that IBT pricing policy in Jerusalem causes. This endogeneity generates a bias not only in the price estimator but also in all other estimators, including those of household size. The interaction between that endogeneity and pricing policy, regarding the additional quantity of water that households receive at a low price for each additional member, exacerbates the bias of the household-size estimator. It produces artificial economies of scale for households of four members or less, as mentioned above.

In 2SLS, we instrument the marginal price and the *difference* in the first stage by the observed characteristics of households. In the second stage, predicted marginal price and *difference* are used as explanatory variables in the estimated demand function. The 2SLS method solves the endogeneity problem and tends to remove these biases. Under certain conditions, 2SLS may be an even better technique for describing household behavior than the Maximum Likelihood method that we present below.

In the 2SLS estimation, the sign of the marginal price estimator becomes negative, as theory would predict. The absolute effect of Price C (the highest price) is greater than the effect of Price B (the intermediate price), which is also consistent with the standard theory of demand.

The sign of the marginal price is negative in the Log-Log specification as well (Table 5 in the appendix). The calculated price elasticity, based on this specification, is -0.18, falling into the lowest range that appears in the literature.

The 2SLS estimation also produces plausible signs and magnitudes for all other estimators. Wealth indicators such as apartment and lawn size have a positive and quantitatively large coefficients . A ten square-meter increase in apartment size results in additional water consumption of 12 cubic meters. Households below the poverty line consume 13 cubic meters less than households that share the same characteristics but are over the poverty line.

The main focus of our paper is on estimating the extent of economies of scale in water consumption. The general picture that arises from Table 5 is rather clear. Except for single-member households, there are no economies of scale in water consumption. The marginal water consumption of households of two or more members follows a linear pattern.

Marginal consumption, although by no means constant, fluctuates around 20 cubic meters. The estimator of two persons implies additional consumption of 23 cubic meters compared with a single-person household. The marginal consumption of very large households is more volatile, ranging from 15 cubic meters for an eleven-member household to 27 cubic meters for households of nine members.

Note that the estimated consumption pattern reflects no economies of scale in households larger than two. The implied pricing policy in Israel is consistent with infinite economies of scale up to a household of four persons. No additional quantity of water is given at a low price as the household expands. For households larger than four persons, the policy means zero economies of scale. Each additional member is entitled to 36 cubic meters, much more than the estimated marginal consumption.[9]

The partial consideration of household size in determining the range of water consumption at which the low price applies results in unintended cross-subsidization among households of different size. It is also has unintended redistribution consequences due to the interaction between household size and income. The share of households that pay a marginal low price follows an inverted-U shape (Table 3). Single-member households that pay a low price at the margin are the highest (32%). The share decreases in inverse proportion to household size up to five members. From that point on, the share rises commensurate with household size.

We also estimated the economies of scale using the Maximum Likelihood method, as is common in the more recent literature on demand for water. Convergence was achieved by means of the dual Quasi-Newton optimization. The marginal price estimator carries the expected negative sign but the magnitude is too large by any standard. It turns out that many of the estimators have both an opposite sign and or extremely large quantitative effect.

In particular, the effect of household size follows a peculiar pattern. The estimator implies additional consumption of almost 200 cubic meters due to the addition of one more member (for a household that began with two members). Note that as household size increases, the marginal consumption exhibits an increasing and then a economies of scale decreasing(!) relationship with each additional person.

Thus, the results elicited by the Maximum Likelihood method are not convincing. Unfortunately, maximization of the likelihood function appears to be difficult in some cases, including ours. We speculate that these peculiar results trace mainly to the lack of clustering around the kinks. Bear in mind that Israel's water-pricing policy generates a large number of kinks. A kink depends on both household size and lawn size. As a result the kink is almost a continuous variable. This, of course, reduces the likelihood of clustering.

The two-stage least-square method is not appropriate for the estimation of economies of scale in the presence of kinks. For our purposes, however, it seems to be the method that is least limited by the lack of clustering around the kinks. The results of the 2SLS estimation turn out to be much more plausible than those elicited by the maximum likelihood estimation. Therefore, we draw our conclusions on the basis of the estimate brought forth by the 2SLS technique.

5. Policy Implications and Conclusions

We used a unique data set, composed of disaggregated data on water consumption and household size, to estimate the economies of scale. We found that water consumption exhibits no economies of scale (with regard to household size) for households of two persons or more.

Our study suggests that IBT pricing policy used in OECD countries clashes sharply with the equity consideration. We have shown that IBT pricing structure forces large households to pay higher average prices for water. This outcome is inconsistent with the equity consideration because large households tend to belong to the lower income classes.

One of the main motives for the use of an IBT pricing structure and, in particular, the low price range is to reflect the equity consideration. Our evidence implies that ignoring household size is self-defeating in this regard. It becomes more important in view of the general move away from fixed-price and decreasing block tariff (DBT)

[9] As noted above, other countries (e.g., Spain-Barcelona) use a similar pricing structure that implies infinite scale economies for small households and zero scale economies for large households.

pricing structures toward volumetric charging and increasing block tariffs (OECD, 1999).

A natural policy implication of our findings is that the IBT pricing structure should take household size into account in determining the range at which the low price applies. This, however, is an administrative challenge because the need to continually update databases as people move in and out inflicts a cost on water utilities. Therefore, policymakers have to weigh the administrative cost against the equity consideration.

In cases where the administrative cost are important factor that it outweighs the equity consideration, a larger question arises: is IBT the right pricing policy in the water market? In view of the real increase in household expenditure on water as a result of price rises in many OECD countries, the importance of the equity consideration is on the rise.

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Figure 3: Per Capita Yearly water consumption (1995-1997)

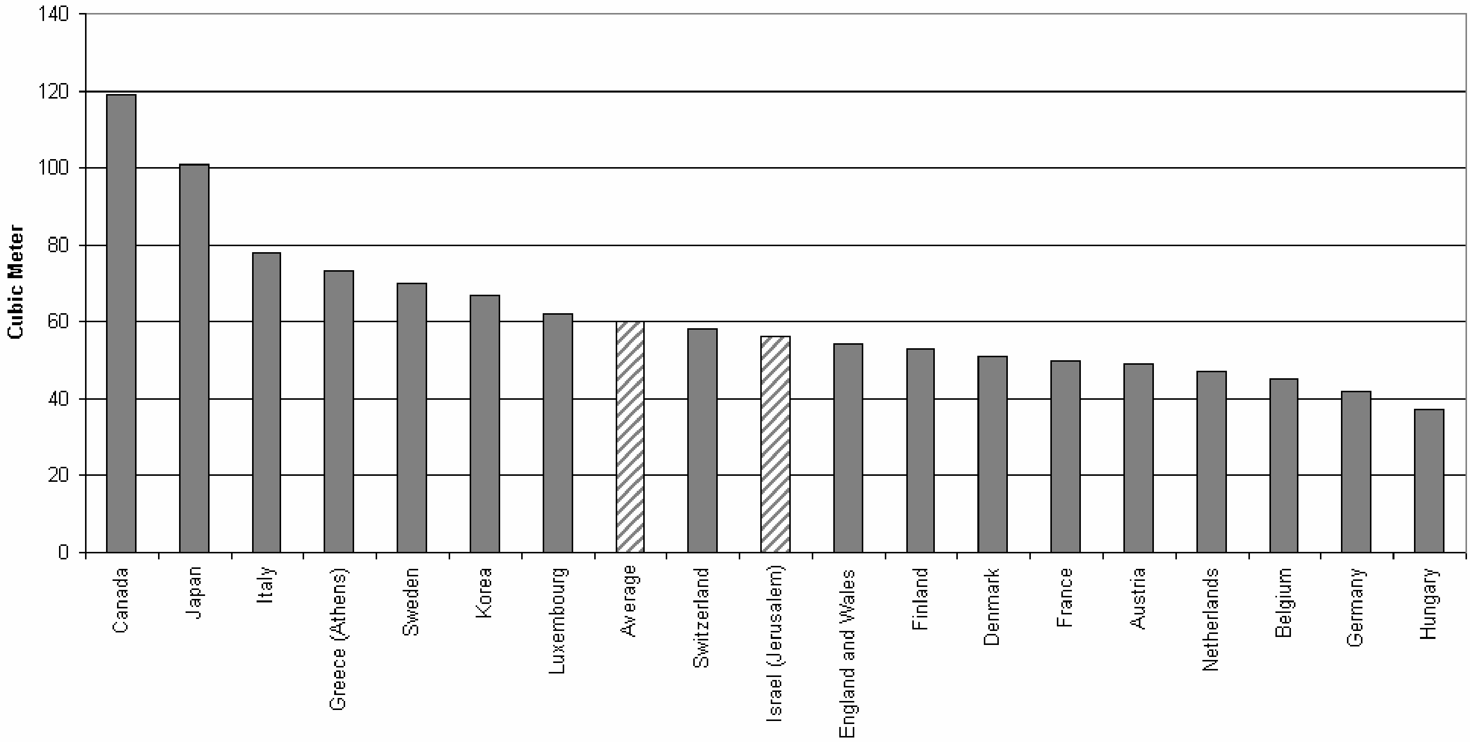

Figure 4: Average Water Tariffs in OECD Countries (urban)

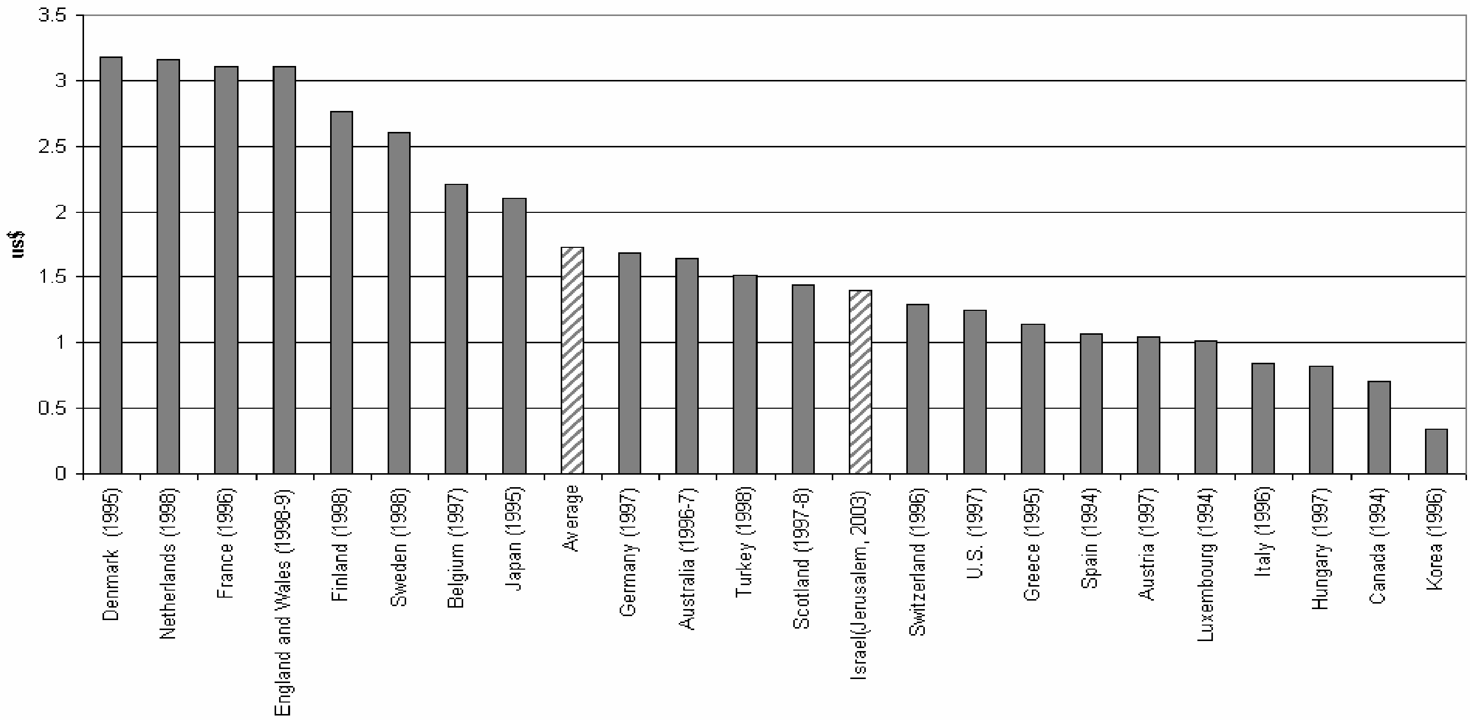

Table 5: Estimates of Water Demand Model—Log-Log Specification

Variable	**OLS**	**IV**
Constant	-0.70 (0.0001)	4.51 (0.0001)
Household size:		
1		
2	0.09 (0.0001)	0.26 (0.0001)
3	0.13 (0.0001)	0.40 (0.0001)
4	0.18 (0.0001)	0.54 (0.0001)
5	0.27 (0.0001)	0.65 (0.0001)
6	0.39 (0.0001)	0.72 (0.0001)
7	0.50 (0.0001)	0.77 (0.0001)
8	0.60 (0.0001)	0.80 (0.0001)
9	0.72 (0.0001)	0.90 (0.0001)
10	0.84 (0.0001)	0.97 (0.0001)
11	0.93 (0.0001)	1.00 (0.0001)
12	1.01 (0.0001)	1.06 (0.0001)
Apartment size+d	0.0025 (0.0001)	0.0062 (0.0001)
Lawn size	0.0011 (0.0001)	0.0006 (0.0001)
Private house	0.04 (0.0001)	0.07 (0.0001)
Below poverty line	0.049 (0.0001)	-0.004 (0.0001)
Price	2.66 (0.0001)	**-0.18** (0.0001)
$\sigma_{\acute{\eta}}$	0.38	0.55
$\sigma_{\acute{\varepsilon}}$		
Adjusted R^2	0.71	0.39
F test	1357.82 (0.0001)	364.67 (0.0001)
Mean ll		
Number of observations	115,887	115,887

P values are shown in parentheses.
The full list of explanatory variables includes 178 regions within Jerusalem, twelve types of municipal tax relief, and the number of apartments in the building. For expositional purposes, we do not present their estimators.

Appendix 1: Derivation of Log-Likelihood

This appendix describes the derivation of the likelihood function in a three-block setting that corresponds to our data set. The discrete continuous choice model is based on the Hausman model and the generalization of Moffitt. A linear form is chosen for the conditional demand.

The econometric model follows:

$$
q = \begin{cases}
Z\delta + \alpha p_1 + \mu y_1 + \varepsilon + \eta & \text{If } \varepsilon < l_1 - Z\delta - \alpha p_1 - \mu y_1 \\[2ex]
l_1 + \eta & \text{If } l_1 - Z\delta - \alpha p_1 - \mu y_1 \le \varepsilon \\ & \text{and } \varepsilon \le l_1 - Z\delta - \alpha p_2 - \mu y_2 \\[2ex]
Z\delta + \alpha p_2 + \mu y_2 + \varepsilon + \eta & \text{if } l_1 - Z\delta - \alpha p_2 - \mu y_2 < \varepsilon \\ & \text{and } \varepsilon < l_2 - Z\delta - \alpha p_2 - \mu y_2 \\[2ex]
l_2 + \eta & \text{if } l_2 - Z\delta - \alpha p_2 - \mu y_2 \le \varepsilon \\ & \text{and } \varepsilon \le l_2 - Z\delta - \alpha p_3 - \mu y_3 \\[2ex]
Z\delta + \alpha p_3 + \mu y_3 + \varepsilon + \eta & \text{if } \varepsilon > l_2 - Z\delta - \alpha p_3 - \mu y_3
\end{cases}
$$

where:

Z—a vector containing the following variables in addition to a constant: number of persons per household, low-income households that are entitled to discounts on municipal taxes, ownership of a lawn, lawn size, number of tenants per building, and geographical region.

q—water consumption
(p_1, p_2, p_3)—prices in the three blocks
(y_1, y_2, y_3)—virtual apartment sizes in the three blocks
(l_1, l_2)—kink points
ε—heterogeneity error
η—measurement error
(δ, α, μ)—unknown parameters

Assumptions:
$\varepsilon \sim N(0, \sigma_\varepsilon^2), \eta \sim N(0, \sigma_\eta^2), E(\varepsilon\eta) = 0$
$v = \varepsilon + \eta$
$f_{v,\varepsilon}(v, \varepsilon)$ is binormal.

The log-likelihood is:

$$\ln L = \sum_i \ln \left\{ \frac{\exp(-w_1^2/2)}{\sigma_v} \Phi(r_1) + \frac{\exp(-u_1^2/2)}{\sigma_\eta} \left[\Phi(t_2) - \Phi(t_1) \right] + \frac{\exp(-w_2^2/2)}{\sigma_v} \left[\Phi(r_3) - \Phi(r_2) \right] \right.$$
$$\left. + \frac{\exp(-u_2^2/2)}{\sigma_\eta} \left[\Phi(t_4) - \Phi(t_3) \right] + \frac{\exp(-w_3^2/2)}{\sigma_v} \left[1 - \Phi(r_4) \right] \right\}$$

where:

$$w_k = \left[q - Z\delta - \alpha p_k - \mu y_k \right] / \sigma_v$$
$$u_1 = \left[q - l_1 \right] / \sigma_\eta$$
$$u_2 = \left[q - l_2 \right] / \sigma_\eta$$
$$t_1 = \left[l_1 - Z\delta - \alpha p_1 - \mu y_1 \right] / \sigma_\varepsilon$$
$$t_2 = \left[l_1 - Z\delta - \alpha p_2 - \mu y_2 \right] / \sigma_\varepsilon$$
$$t_3 = \left[l_2 - Z\delta - \alpha p_2 - \mu y_2 \right] / \sigma_\varepsilon$$
$$t_4 = \left[l_2 - Z\delta - \alpha p_3 - \mu y_3 \right] / \sigma_\varepsilon$$
$$r_1 = \left(t_1 - \rho w_1 \right) / \sqrt{(1-\rho^2)}$$
$$r_2 = \left(t_2 - \rho w_2 \right) / \sqrt{(1-\rho^2)}$$
$$r_3 = \left(t_3 - \rho w_2 \right) / \sqrt{(1-\rho^2)}$$
$$r_4 = \left(t_4 - \rho w_3 \right) / \sqrt{(1-\rho^2)}$$
$$\sigma_v = \sqrt{\sigma_\varepsilon^2 + \sigma_\eta^2}$$
$$\rho = \sigma_\varepsilon / \sigma_v$$