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Residential Demand for Water in Israel

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Abstract

The paper is a study of the demand for urban water in Israel employing data for close to 100 municipalities and 25 years. The analysis is a maximum likelihood estimation of the discrete-continuous choice model for a regime of increasing block pricing. The model is expanded, its technical aspects are elucidated, and the estimation is followed by simulation analyses of price and income effects. Estimates of both individual and market elasticities are presented. The main empirical findings are that the demand is highly price and income inelastic and, consequently, changes in household welfare following price reforms—and expressed in monetary terms—will be almost identical to changes in payment for water. Given the structure of water tariff in Israel, a price reform of a move to a uniform rate will adversely affect poor (and large) families, while having only a minor effect on richer and smaller households.

Key words: urban water demand, increasing block rate, maximum likelihood estimates, welfare analysis, price reform, Israel.

1. Introduction

Most recent studies of the demand for urban water have followed the pioneering work of Hewit and Hanemann [9] applying the discrete-continuous choice model where, as is often the case, prices are of the increasing block structure (Arbues [1]). The authors of these modern demand studies have relied mostly on Moffitt's [13, 14] exposition of a model due to Burtless and Hausman [2]. This paper reports an estimation of the residential demand for water in Israel; the discrete-continuous model is expanded; and the analysis, and the simulations that follow it, are explained in detail. In contrast to several recent reports, we found very low price and income demand elasticities. These findings can be justified by the small share of household expenditure on water: 1.2 percent in the lowest income decile and even less for families with higher income.

The paper starts with a short description of the urban water sector in Israel and moves to Moffitt's model and to the empirical estimations. We conclude with simulations of the demand under alternative price regimes and a welfare analysis of a price reform.

2. Urban water in Israel[1]

Israel is a small country with a population of close to 7 million; most live in urban communities. There are 210 municipalities in the country; of these, 64 are cities and the others are local councils. The population of seven municipalities—among them the largest cities—is mixed: Jews and Arabs; in the rest, the population is either Jewish or Arab. For historical and political reasons, the latter have less developed water and sewerage systems than the more recently established Jewish communities. The services, water supply and sewage removal, are provided by municipal departments (under a newly enacted reform the services are gradually being transferred to independent utilities). Consumers—

[1] For a more detailed survey, see Kislev [11].

households and other urban users—pay development charges when connected to the water or the sewer system and a bimonthly volumetric fee. The household price for water is an increasing block rate tariff, set by the government, and it is the same rate for all municipalities. The tariff is made of three blocks: the first block is 16 CM for a bimonthly bill,[2] currently priced at NIS 3.042 per CM; the second block is 14 CM, priced at NIS 4.342 per CM; and the price of the third block is NIS 6.132 per CM. Other urban users pay different prices. For large households the first block is extended by 6 CM per bill for each person above 4 inhabitants. Households with watered yards are credited by up to 300 CM "garden water" per season at the price of the first block. Time series of household water price by block are depicted in real terms in Figure 1.

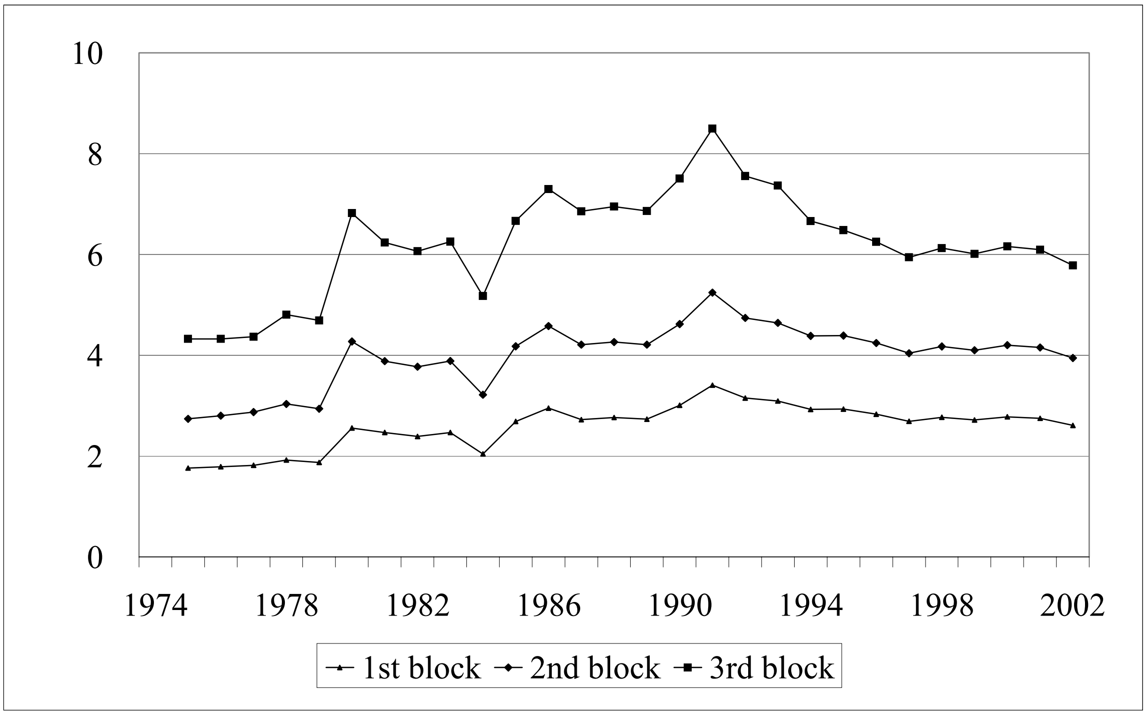

Fig. 1. Household block rate prices, NIS per CM.
(Modified by the Consumer Price Index to October 2002 prices)

[2] Water is measured in CM (cubic meters), the currency is NIS (New Israeli Sheqel) and the current exchange rate (September 2005) is NIS 4.50 per US dollar.

Sewerage charges (not in the diagram) were introduced with the construction of modern sewage collection and treatment systems in the localities; they are uniform, not block rate, but vary between municipalities: NIS 0.25- 3.00 per CM of water used, garden water is exempt.

3. Block rate prices

A step-function of three increasing blocks is depicted in Figure 2 where the first block, up to the quantity X_1^*, is priced at P_1, the second and the third blocks are priced P_2 and P_3, respectively (the price P_{11} is considered below). In the figure, household 1, with demand D_1, chooses the first block and in it a quantity of water to use—a discrete-continuous choice; similarly, household 2 with demand D_2 is located on the second block.

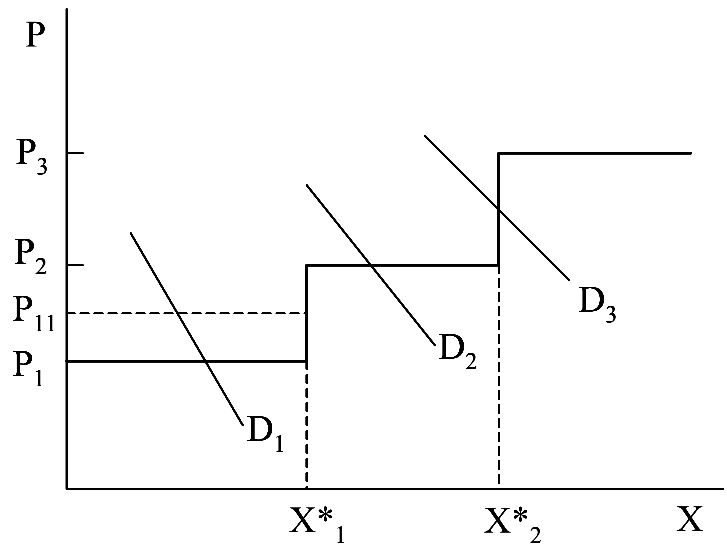

Fig. 2. Increasing block rate.

With block rate pricing, not only the price schedule is kinked, but the household's budget constraint is also kinked (not shown here). Notice household 3: its demand crosses the vertical section of the price scheduled and its consumption quantity is X_2^*, at the kink.

It is sometimes useful to define the highest block the household has reached as its marginal price; thus, P_1 is the marginal price of household 1 and P_2 is the marginal price of households 2, 3.

Household 2 can be visualized as consuming water with a uniform price P_2 and receiving a subsidy of $X_1^*(P_2 - P_1)$. The subsidy is termed the difference in income between block rate tariff and the corresponding uniform price. Evidently, household 3 also enjoys the difference. Virtual income is the sum of the nominal income and the difference.

Consider a change in the price of water. In Figure 2, the price of the first block rose to P_{11}; household 1 reduced its consumption, households 2 and 3 may have not been affected. (To be precise, the functions D_2 and D_3 may have shifted due to the income effect of the price change since the difference is now smaller. But we are disregarding this effect for the moment.) Non-uniform reaction of households to changes in price means that the market demand function is not a simple horizontal sum of the individual functions—the market elasticity of demand will in general be lower than the elasticity measured for the individual household.

A household, choosing a quantity of water to use, chooses a block and its price. Hence, with a block rate tariff, the price too, not only the quantity, becomes endogenous and is correlated with the regression error. Ordinary least squares estimates of the demand will therefore be biased. Moreover, in an increasing block regime, the samples are censored since observations for households with true demand at the kink may not respond to price changes; standard simultaneous equation procedures are therefore inadequate here.

The Maximum Likelihood Estimation (MLE) of the discrete-continuous choice model overcomes both the simultaneity and the censoring problem. It is presented below.[3]

4. Discrete-continuous choice with two errors

This section and the next reconstruct with slight modifications three of Moffitt's [13] equations. Eq. (1) is Moffitt's (12), it specifies the discrete-continuous choice model of demand for a two-block tariff. The quantity demanded, X_i, can be either in the first block, the second, or at the kink. (The household index i is dropped here and everywhere else in the paper, except from X_i.)

$$\begin{aligned} X_i &= D_1\left[g\left(P_1, M;\beta\right) + Z\delta + \alpha\right] + D_2\left[g\left(P_2, \hat{M};\beta\right) + Z\delta + \alpha\right] \\ &+ \left(1 - D_1 - D_2\right)X^* + \varepsilon \end{aligned} \tag{1}$$

The expression $g(\ ) + Z\delta + \alpha$ is termed the true demand.

In equation (1),

$D_1 = 1$ if the true demand is in the first block; $D_1 = 0$ otherwise;

$D_2 = 1$ if the true demand is in the second block; $D_2 = 0$ otherwise;

When not in either of the blocks $(D_1 = D_2 = 0)$, the true demand is at the kink.

In the model, the household demand function for water is made of three components:

a. A function of price and income

$$g(P_1, M;\beta), \quad g(P_2, \hat{M};\beta)$$

where P_j is the price at block j, M is the nominal income of the household, $\hat{M}$ is its virtual income in the second block—including the difference. The vector β is the parameter

[3] For a general discussion of demand for water, see Renzetti [17]. For alternative estimation methods, see Dalhuisen, Florax, de Froot, and Nijkamp [5], Nauges and Blundell [15], and Williams [19].

vector; for example, a linear $g()$ may take the form $\beta_0 + \beta_1 P_1 + \beta_2 M$ ($P_2, \hat{M}$ for the second block).

b. A household specific shifter, a function of several variables: the size of the house, number of family members, the location of the household (dry or rainy region), and

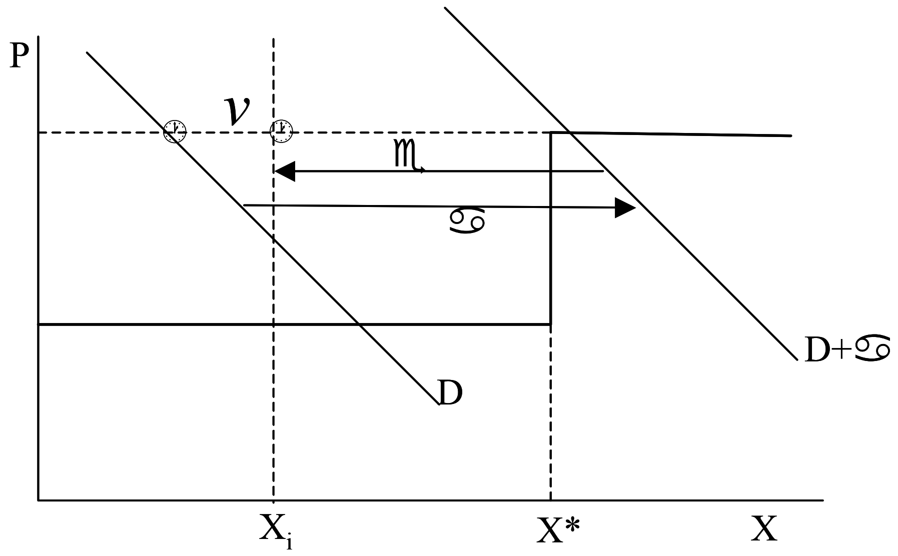

Fig. 3. The errors in action.

similar factors. The shifter is written as $Z\delta$, where Z is the vector value of the variables and δ is the vector of parameters. While the variables P and M in the $g(\ )$ functions are block-specific, the shifter is not; it assumes the same household value whatever the block the demand is on.

c. A random component, made of two error terms, and added to the deterministic part of the model, to $g(\ ) + Z\delta$. The error terms are independent and assumed to be distributed normally around zero. The first, α, is the heterogeneity error. It represents errors in the demand function as captured by the econometrician and, in particular, the household specific shifter. The second error, ε, is a measurement error; it may represent an error of the household in setting the exact desired water consumption level or error of the observer who recorded the consumption ε units away from the actual value.

Figure 3 depicts a realization of the errors. In the figure, X_i is the observed water consumption of household i. The line D represents the deterministic part of the demand. With the realization of the errors in the diagram, α points to the true demand function of the household, D+α, and the measurement error, ε (<0 in the diagram), shifts it back to the observed X_i.

Consider household demand functions spread evenly along the X-axis. The quantities consumed will then also spread evenly along sections of the quantity axis; however, consumption for all the true demand functions intersecting the vertical part of the price step function (such as D_3 in Figure 2) will be at the kink, X^*. In reality, because of measurement errors, the probability of observing a household exactly at X^* is of measure zero (households may be found at X^* if the measurement of water is in discrete units). The spread of X_i on both sides of the kink, for households with true demand at X^*, is affected only by ε and not by α. This property facilitates the identification of the distributions of the two errors, α and ε.

5. <u>Maximum likelihood estimation</u>

The maximum likelihood function is defined in the first sub-section in the fundamental form of integrals and, making use of the properties of the normal distribution, it is simplified in the second sub-section.

5.1 The likelihood function

This section deals with a single likelihood contribution, equation (A.2) in Moffitt [13]; it is repeated here slightly modified:

$$
\begin{aligned}
L(X_i \mid \theta) &= \int_{-\infty}^{u_1} h[v_1 = X_i - g(P_1, M; \beta) - Z\delta, \alpha] d\alpha \\
&+ \int_{u_2}^{\infty} h[v_2 = X_i - g(P_2, \hat{M}; \beta) - Z\delta, \alpha] d\alpha \\
&+ \int_{u_1}^{u_2} \frac{1}{\sigma_\varepsilon} f\left(\frac{X_i - X^*}{\sigma_\varepsilon} \right) \frac{1}{\sigma_\alpha} f(\alpha) d\alpha
\end{aligned}
\tag{2}
$$

where θ stands for the set of the parameters in the equation, $u_1 = X^* - g(P_1, M; \beta) - Z\delta$, $u_2 = X^* - g(P_2, \hat{M}; \beta) - Z\delta$, $f(\ )$ is a the normal density, and $h(v, \alpha)$ is a bivariate normal density.

Equation (2) specifies the likelihood of observing X_i, given the demand parameters. It is formulated for a two-step price function where the probability sought is the sum of three components corresponding to the three integrals in (2): the probability of observing X_i when the true demand intersects the price P_1 in block 1, the corresponding probability when the true demand intersects P_2 in block 2, and the probability of observing X_i when the true demand is at the kink.

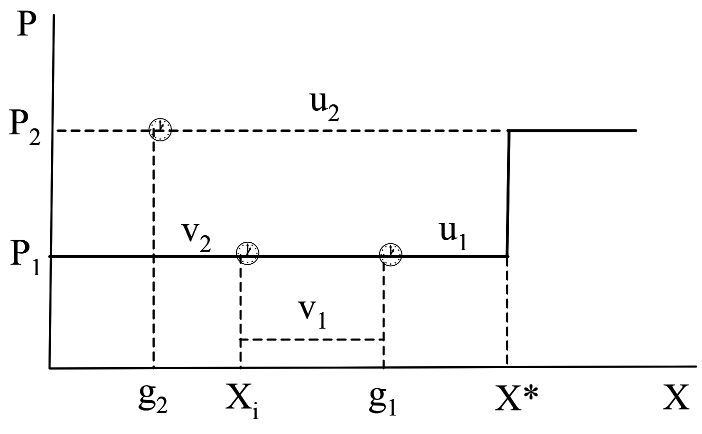

Fig. 4. Block prices and demand.

The probability of observing X_i when the true demand is in block 1 is the probability of realizing the error v_1 (recall $v = \alpha + \varepsilon$) and it is calculated in (2) as the integral of the joint density $h(v,\alpha)$ over α up to u_1. The magnitudes v_1, u_1—and the corresponding magnitudes for block 2—are depicted in Figure 4 for a household with observed water consumption in the first block. Two shorthand definitions are made in the figure for convenience $g_1 \equiv g(P_1, M; \beta) + Z\delta$ and $g_2 \equiv g(P_2, \hat{M}; \beta) + Z\delta$; these are quantities on the demand function for a set of parameters β, δ, the exogenously given prices P_1 and P_2, and the corresponding virtual income. Since $\hat{M} > M$, the points $(g_1, P_1), (g_2, P_2)$ are not on the same demand curve.

For α in the range (u_1, u_2) the true demand is on the vertical section of the price schedule. For this case, the probability of observing X_i can be obtained by integrating the density of α and ε over the appropriate range. Highlighting the independence of the two error terms, their joint density is written in (2) as the product of their marginal densities.

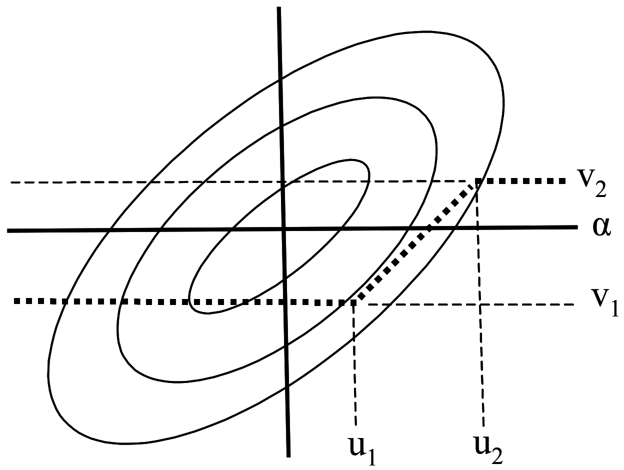

Fig. 5. Joint distribution of v and α.

Continuing from Figure 4, Figure 5 presents the level counters of $h(v,\alpha)$ and the path of integration (the dotted line sections). The first integral in (2) is for v_1 up to u_1, the second integral is for v_2, and its lower bound is u_2. The third integral is on the 45º line connecting u_1 and u_2.

5.2 The algorithm

Using Bayes Low, $h(v,\alpha)=h(v)h(\alpha\mid v)$, (2) can be written as Moffitt's [13] (A.3):

$$
\begin{aligned}
L(X_i\mid\theta) = {} & \frac{1}{\sigma_v} f(z_1)F(r_1) \\
& + \frac{1}{\sigma_v} f(z_2)[1-F(r_2)] \\
& + \frac{1}{\sigma_\varepsilon} f(s)[F(t_2)-F(t_1)]
\end{aligned}
\tag{3}
$$

where *f*( ) and *F*( ) are, respectively, the normal density and the distribution. An EView program of (3) for the empirical study reported below is available from the first author.

The three expressions in (3) correspond to the three integrals in (2). The variables of (3) are standardized values of the variables in (2) (and in Figure 4) defined as,

$$z_j = v_j/\sigma_v \quad j=1,2 \tag{4}$$

$$s = \varepsilon/\sigma_\varepsilon \tag{5}$$

$$t_j = u_j/\sigma_\alpha \quad j=1,2 \tag{6}$$

Eq. (6) is the standardized value of $\alpha = u_j$ (the denominator in Moffitt is mistakenly written σ_v). The last definition is of the standardized $\alpha\mid v$ evaluated at u_j,

$$r_j = \frac{t_j-\rho z_j}{\sqrt{1-\rho^2}} \quad j=1,2 \tag{7}$$

where $\rho=\sigma_\alpha/\sigma_v$. Eq. (7) is proved in the Appendix.

6. Estimation

6.1 Sample and variables

The data for the analysis were available for 97 municipalities for the 25-year period 1975-1999.[4] Since a lagged variable was used, the first year, 1975, was not included in the sample [except as y(t-1)] and, also, quite a few cases of missing information were encountered. All in all, the sample analyzed included 1580 observations. The data were at the municipality level and, where needed, averages per household in municipality and year were calculated. Before turning to the description of the variables, we offer a comment on family size.

The number of persons in the household appears in the analysis twice. Income is calculated per person but, assuming intra-family economies of scale, income was divided by the number of standard person per household (average for the municipality). Moreover, data on monetary income were not available and we therefore used the number of passenger cars[5] per standardized person as a proxy for average income in the municipality. Virtual income is defined here as a weighted sum of the proxy and the monetary value of the difference. The estimation of the weights is explained below.

The second way family size enters the analysis is in affecting water use in the household. Experience indicates economies of scale in water consumption, similar to the corresponding economies in income; but in an analysis of the demand for water the effect of household size is not taken as given, it is estimated. Hence the argument in the demand function is the actual number of person, not the standardized number.

The variables in the analysis were (time and municipality index are omitted):

X_i water per household, CM per year;

[4] The data are described in detail in Cohen [3] and are available from the corresponding author.

[5] First suggested by Darr [6].

P_1, P_2, P_3 price in block 1, 2, 3, including the sewage removal charge, NIS per CM;

X_1^*, X_2^* quantity of water in block 1, 2, CM per year;

m_1, m_2, m_3 difference in income due to increasing block tariff, NIS per year, $m_1 = 0$;

C number of passenger cars per standard person in municipality (standardized person were calculated as in CBS, [11] Chapter 5);

L water loss (leakage and not collectable charges) in the municipal system, percent of total supply;

N number of persons in household;

H municipality specific index of heat burden;

Dummy variables:

D86, D91 dummy variables for the exceptionally dry years 1986, 1991;

DE ethnic composition, Jewish and mixed municipalities (0 for Arabs);

DL form of the municipality, local councils (0 for cities);

DC interaction effect, cars and prices, *AC* =average *C* in sample, *DC*=0 for municipality with $C \leq 0.25AC \text{ or } C \geq 0.75AC$, 1 otherwise.

Remarks:

The quantities X_1^*, X_2^* were calculated according to the average number of persons in household in municipality;

The quantity in block 2, X_2^* is measured from 0, it includes block 1, and similarly for X_3^*;

Information on garden water was not available.

The particular definition of *DC* was chosen after testing for different forms of interaction.

The variables are described in Table 1.

Table 1
Variables in the analysis

	Average	Minimum	Maximum	St. Deviation
Person in household	4.06	2.10	14.53	1.54
Water per household (cm per year)	199.78	94.17	541.77	45.38
Block 1 (cm per year)	117.34	96.00	475.08	44.32
P_1 (NIS per CM)	3.38	1.79	7.23	0.81
P_2	4.85	2.80	9.07	0.90
P_3	7.22	4.32	12.33	1.15
Marginal price	5.80	1.79	12.33	1.78
Cars	0.17	0.01	0.47	0.08
Difference (NIS per household)	115.33	0.00	291.87	79.17
Heat index	35.74	6.00	82.00	11.20
Water loss	15.69	0.27	50.42	8.74

6.2 Empirical specification

The equation estimated was (2) in the form specified by (3). The dependent variable was, X_i, water consumption per household per year. Four adjustments were made in the specification of the $g(\ )$ function. The first two accounted for the interaction between price effect and income (cars), and the combination of the cars—proxy for income—and the income difference due to the increasing block tariff. With these two adjustments the function was formulated as

$$g(\ ) = \beta_1 P_j + \beta_2 DC * P_j + \beta_3 \left(\beta_4 C + m_j\right) \quad j = 1,2,3 \tag{8}$$

In equation (8), β_2 is the magnitude by which the price effect differs for municipalities with around average number of cars; and, since m_j is measured in NIS, β_4 translates cars to monetary units; in terms of (2), $\beta_4 C + m_j = \hat{M}_j$, the virtual income. The parameter β_3 is the income effect.

The third adjustment was generalizing the estimated model by Box-Cox transformation (Greene [7] p. 173)

$$X^{(\lambda)} = \left(X^{\lambda} - 1\right)/\lambda \tag{9}$$

So also for the other variables. With the definition in (9), the estimated demand function is linear for $\lambda = 1$, it is log-linear for $\lambda = 0$, and it is reciprocal, $1/X = f\left(1/P,...\right)$, for $\lambda = -1$. A value $-1 < \lambda < 1$ indicates an intermediate functional form. The transformation parameter received two values, λ_1 for all variables except virtual income, and λ_2 for the combined cars-difference: $\left[\left(\beta_4 C + m_j\right)^{\lambda_2} - 1\right]/\lambda_2$. The MLE estimation of the transformation parameters was conducted jointly with the other demand parameters.

The last adjustment was to add lagged water use, $X_i(t\text{-}1)$, on the right hand side of the estimated equation to take account of the long run effect of the explanatory variables (distributed lags, Greene, [7] p. 565).

6.3 Findings

The MLE findings are reported in Table 2; because of the functional form, most coefficients do not have immediate interpretation and they will be discussed below. At this stage notice that the estimates have the expected signs; for example, the sign of the price coefficient is negative and income's is positive. Also, all the estimates are significant at 10% and less (not in the table). The only coefficient with immediate meaning is β_4, the value of cars in NIS. The average, standard, number of persons per household is 3.7; hence the value of β_4 in Table 2 is that the estimated monetary value of a car is NIS 16,365. The negative values of the λ parameters indicate that the estimated function is a combination of a log-linear and a reciprocal formulation.

Another estimate of interest is of β_2, the interaction term. Its positive sign indicates that the elasticity of demand for poor families (municipalities) and for rich ones is lower than for middle-income households. Evidently, the poor consume as much as they must, the rich do not really care.

Table 2
The estimated demand function

Variable	Coefficient	Estimate	Z-stat.
Intercept	β_0	1.083	3.46
Price	β_1	-0.047	-2.93
Interaction	β_2	0.005	1.82
Income	β_3	0.246	1.62
Cars	β_4	4,423.33	2.89
X lagged (t-1)	β_5	0.498	32.73
Persons	β_6	0.232	5.23
Water loss	β_7	-0.027	-4.51
D86	β_{86}	-0.053	-3.77
D91	β_{91}	-0.054	-3.53
Variance α	σ_α	-3.042	-10.17
Variance ε	σ_ε	-3.599	-6.22
Box-Cox	λ_1	-0.086	-1.85
Box-Cox	λ_2	-0.205	-2.11
Log likelihood		-6698.180	

Note: The estimated model included 96 municipality dummy variables (one omitted).

The model estimated and reported in Table 2 included individual municipality effects (not in the table); they were utilized to gauge the influence of three group and municipality characteristics. This was done by calculating a regression of the estimated coefficients of the municipality dummy variables on the two dummies—ethnic composition and form of municipality—and on the continuous variable index of heat burden. By this estimate, the consumption per household is larger in a Jewish and mixed community by 22.3 CM per year than in an Arab community; the consumption in local municipality, mostly of rural nature, is larger by 6.8 CM per year than in a city; and the elasticity of water consumption with respect to the heat index is 45%. As an example, the average value of the heat index is 37.74; in a municipality where the index is larger by 10%, consumption per household will be larger than the sample average by 9 CM per year.

7. Simulations

7.1 The distribution of the dependent variable

Given the estimated parameters of the model and the value of the exogenous variables for an observation, the density of the distribution of the dependent variable, X, can be computed by (3). Figure 6 depicts such a distribution for observation 825 in the sample; a single household (municipality) for a single year. The distribution was simulated by calculating the likelihood (density) of (3) for 100 values of X spread evenly between 0 and 700 CM. Changing to a more delicate partition—700 steps of 1 CM—did not affect the simulation. The distribution in the diagram approaches zero for quantities lower than 100 CM; this demonstrates that, as indicated above, it was appropriate to disregard the truncation of the distribution at 0 CM.

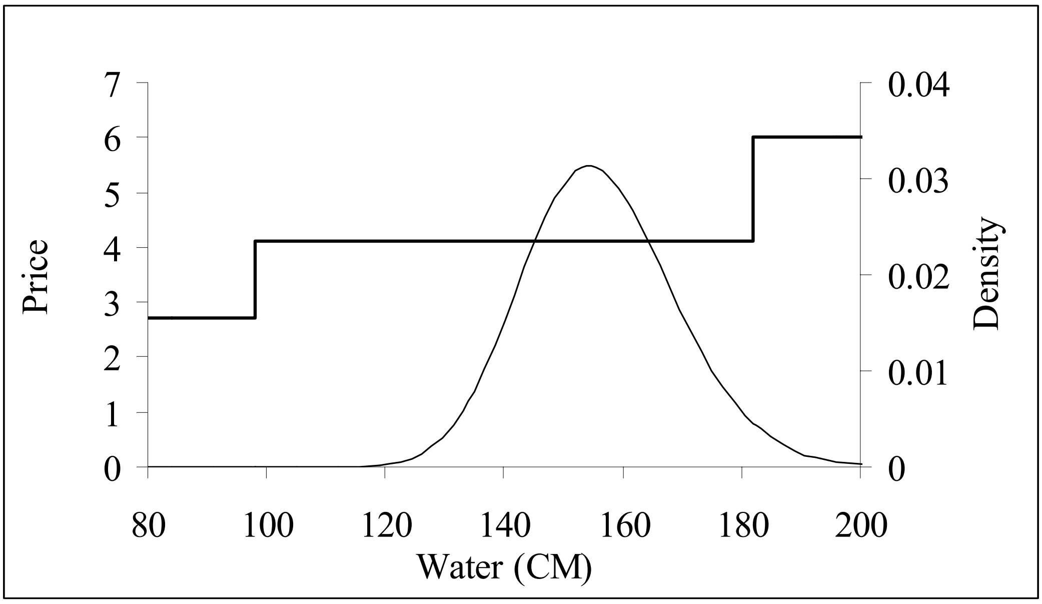

Fig. 6. Block rate prices and the distribution of X for observation 825.

In the MLE of the discrete-continuous model, the prediction $\hat{X}$, is the expected value of X for each household

$$\hat{X}_i = \int_{-\infty}^{\infty} XL\left(X \mid \theta\right) dX$$

In the simulation, $\hat{X}$ was computed numerically as

$$\hat{X}_i = \sum_{j=1}^{100} X_j [7L\left(X_j \mid \hat{\theta}\right)] \quad X_1 = 7, X_2 = 14, ..., X_{100} = 700 \tag{10}$$

where $\hat{\theta}$ is the set of the estimated parameters. The sample average X was calculated as

$$\bar{\hat{X}} = \sum_{i=1}^{1580} \hat{X}_i / 1580 \tag{11}$$

For the observation in Figure 6, $X_{825} = 153.4$, $\hat{X}_{825} = 152.7$; for the sample, $\bar{\hat{X}}$ was 199.75 CM and this compares with 199.78 CM in Table 1. Equations (10), (11) are the tool of the simulation analysis to follow.

7.2 Estimated coefficients and behavioral parameters

We are moving now from the estimates in Table 2 to the market demand elasticities. Two dimensions of this shift, presented in terms of price elasticity, are considered. The first is that with Box-Cox transformation, the elasticity is not constant—it is household specific and given by (index omitted)

$$\frac{\partial X}{\partial P}\frac{P}{X} = \left(\beta_1 + \beta_2 DC\right)\left(\frac{P}{X}\right)^{\lambda} \tag{12}$$

Accordingly, we define the individual price elasticity of the sample as the weighted average

$$\eta_P = \sum_{i=1}^{1580}\left(\beta_1 + \beta_2 DC\right)\left(\frac{P}{X_i}\right)^{\lambda} Q_i \Big/ \sum_{i=1}^{1580} Q_i \tag{13}$$

In equation (13) the quantity Q_i is total water use in the municipality (not per household). In Table 3, the individual sample elasticity is –0.0633.

The individual elasticity will tend, however, to exaggerate the market reaction since the quantity taken by households with true demand at the kink may not change with price. Accordingly we computed the market elasticity using (11) to find the predicted sample quantity demanded twice; once for a price 1% higher than the observed price (the same proportional change in each of the blocks) and once 1% lower. The elasticity was then calculated as arch elasticity. The simulated market elasticity in Table 3 is –0.0497. The individual and market elasticity of demand with respect to income were calculated in a similar fashion.

As expected, the market price and income elasticities are smaller than the corresponding individual elasticities. The relative difference, the gap in Table 3, is 21.5 and 37.2 percent, respectively. The gap is a function of the distribution of the estimated demand functions along the quantity axis—whether they are concentrated close to the kinks or not—and the elasticity; the lower the elasticity, the fewer demand curves will cross the vertical section of the price schedule.

Table 3
Individual and market elasticity

Elasticity	Individual	Market	Gap
Price	-0.0633	-0.0497	21.5%
Income	0.1389	0.0873	37.2%
Water loss	-0.0336	0.0335	0.3%
Persons (linear)	18.0	17.5	2.8%

With block rate pricing, a proportional change of all prices in the step function changes the difference in the same proportion. To eliminate this effect, the elasticity was calculated by changing the prices by ±NIS 0.01 and taking the arch elasticity. Indeed, the "linear" price elasticity thus calculated was 20% higher than the "proportional" elasticity in Table 3 and the gap between its individual and market version was markedly smaller.

In Table 3 we also report the elasticity of water use with respect to water loss. As indicated, we take this effect as a supply parameter. The other effect reported in the table is of the number of persons per household. It is reported here in a linear form: at the sample average, an additional person adds 17.5 CM of water per year. Dahan and Nissan [4] found for individual household in Jerusalem that marginal water use with household size is constant, approximately 20 CM per year per person, not far from our estimate. However, given the general formulation of the estimated demand function in our study, the marginal water use we estimate is decreasing.

The effect of the explanatory variables on water consumption is not immediate: an increase in price may entail a move to smaller gardens or water saving devices. Such changes take time. Given β_5, the long run price effect, B_1, is

$$B_1 = \beta_1/(1-\beta_5) = \beta_1/(1-0.498)$$

That is, the long run elasticities are twice as large as the short ones reported in Table 3. For the price effect, the long run elasticity is approximately 10%, anyhow not a large value.

8. Block rate and uniform pricing

The effect of block rate pricing was analyzed in two dimensions: the effect of price spread on water use and a welfare analysis of a move to a uniform price. To be as concrete as possible, the analysis was done with data for the last year of the sample, 1999. There are 95 observations for this year and the tariff was

First block	P_1=NIS 3.74 per CM
Second block	P_2=5.12
Third block	P_3=7.04.

The observed average water use in 1999 was 218.95 CM per household, the predicted (simulated) was 210.911 CM per household.

8.1 Price spread

To examine the effect of price spread, we defined Δ=NIS 0.50 and calculated predicted water use for changes in the rates:

P_a-Δ, P_c+Δ	210.98 CM
P_a-2Δ, P_c+2Δ	211.08 CM
P_a-4Δ, P_c+4Δ	211.35 CM.

Increasing the spread increases water consumption, the reduction in the price of the first block more than compensated for the increase of the price in the third block.

8.2 A uniform price

The abolition of block rates and the move to a uniform price regime in the urban sector is now under consideration in Israel. We therefore study this possibility. Given block rate tariff, we define the equivalent uniform price as the price for which the predicted average quantity per household is the same as under the block rate regime. For 1999 data, the equivalent price is NIS 5.035 and the predicted household average quantity with this price [simulated as in (10) and (11)] is 210.912 CM.

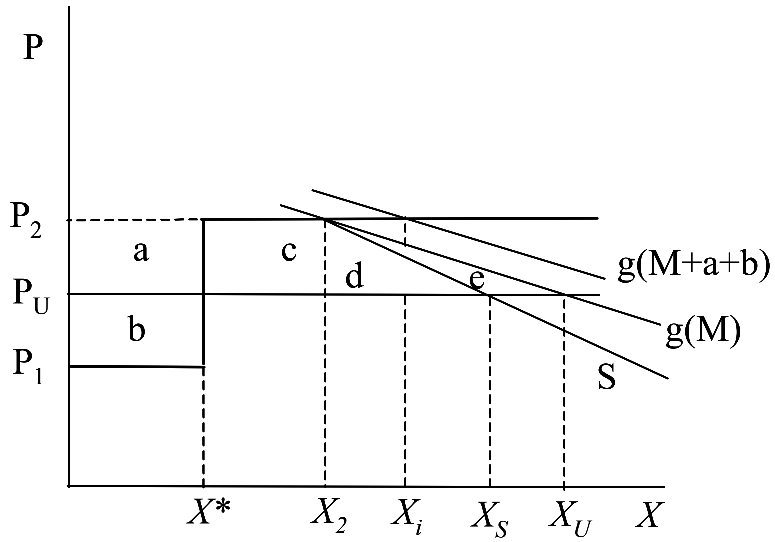

Fig. 7. The move to a uniform price.

To analyze the change, consider in Figure 7 a household consuming X_i CM at a price P_2. The move to the uniform price, P_U, and to the corresponding quantity can be seen as made in two steps. In the first, visualize removal of the difference, a+b; that is, the household faces now the price P_2 as if it were a uniform price. This reduction in income is depicted in the diagram as a shift of the demand curve from g(M+a+b) to g(M); on the new demand, the quantity consumed, on the second block, is X_2. In the second step, the household moves along the demand g(M) from P_2 to P_U and from X_2 to X_U. (The line marked S is the Slutsky demand and will be explained below.)

The magnitudes in the diagram were arrived at, for each household in the sample (for 1999), in the following way: the quantities under block rate regime and a uniform price were calculated as $\hat{X}_i, \hat{X}_U$ by simulation as in (10). The quantity X_2 was calculated first by (a, b are from the figure)

$$\left(X_2^{\lambda_1}-1\right)/\lambda_1=\left(\hat{X}_i^{\lambda_1}-1\right)/\lambda_1+\left\{\beta_3\left[(\beta_4 C)^{\lambda_2}-1\right]/\lambda_2-\beta_3\left[(\beta_4 C+a+b)^{\lambda_2}-1\right]/\lambda_2\right\} \tag{14}$$

$$\beta_3=0.246,\ \beta_4=4{,}423,\ \lambda_1=-0.086,\ \lambda_2=-0.205$$

and then retransforming the Box Cox expression to X_2. The calculation of X_S will be explained below.

The effect of the move from the block rate regime to the equivalent uniform price is reported in Table 4 for four income quartiles (measured by number of private cars per standard person in average household in municipality). There are three sections in the table: the number of persons in the household, information for the block rate regime, and the effect of price reform—the move to a uniform price.

First examine the block rate regime. Lower income households (municipalities) have larger families and more persons per household than higher income groups[6]. With larger families, water use is larger; but, as the data indicate, the quota for the first price block is even larger[7]. Consequently, households in the first quartile paid the lowest price for 55.2% of their consumption; the share of first block in the water consumption of the fourth quartile was 44.9%. And, the average household in the first quartile—while

[6] The number in the table is average per quartile, individual observations (municipalities) differ significantly.
[7] Recall, the additional quota to the first block is 36 CM per year for each person in households of over 4 persons, much larger than the marginal consumption reported in Table 3.

consuming 98% of the quantity consumed by a household in the fourth quartile—paid for water only 70% of the payment of the richer household.

Turning to the move to the equivalent uniform price (the third section in Table 4), one observes that, the demand being price inelastic, the change in water use, the difference $\hat{X}_i - \hat{X}_U$, is small: a reduction of 3 and 1 CM in yearly consumption in lower income households and a parallel increase in water use in the richer families. Total sample payment for water increased by 10% with the move to the uniform price P_U. Different income quartiles were affected differently; the payment changes were +30% and -6% for the first and fourth quartiles, respectively. A move to a uniform price, with total quantity unchanged, hurts the poor families markedly and it benefits the rich families only marginally.

Table 4
Water use, payment, and welfare by income quartile

Income Quartile	Persons per Household	Block Rate			Move to Uniform Price		
		Share in first block (%)	Quantity (cm)	Payment (NIS)	Quantity (cm)	Payment (NIS)	Welfare (NIS)
First	4.6	55.2	215	818	-3	248	-267
Second	4.1	54.2	204	845	-1	175	-186
Third	3.3	48.7	205	1,007	1	28	-18
Fourth	3.0	44.9	220	1,200	3	-76	88
Sample	3.7	50.7	211	969	0	93	-97

Notes:
a. The data are for 1999;
b. The monetary values are in October 2002 prices, the corresponding exchange rate is NIS 4.74 to US dollar.

8.3 Welfare effects

The last column in Table 4 reports the change in the welfare of the households with the move to a uniform price. This is the area under the Slutsky demand function, S in Figure 7 (taken as linear). It was calculated as the change in the consumer surplus for each household individually. We first calculate X_S, the quantity of the Slutsky demand function for the uniform price. To this end define, in Figure 7,

$$\phi = a + c + d + e$$

and now

$$\left(X_S^{\lambda_1} - 1\right)/\lambda_1 = \left(\hat{X}_U^{\lambda_1} - 1\right)/\lambda_1 - \left\{\beta_3[(\beta_4 C)^{\lambda_2} - 1]/\lambda_2 - \beta_3[(\beta_4 C - \phi)^{\lambda_2} - 1]/\lambda_2\right\} \quad (15)$$

The move to a uniform price, "deprived" the household of the difference in income, a+b in the figure, and added the consumer surplus a+c+d. The net effect is the welfare change

$$\Delta W = c + d - b$$

This change in welfare may be positive and, alternatively, it may be negative (or zero).

The welfare change, averaged per quartile, is reported in the last column of Table 4. With an inelastic demand function, the change in the welfare of the households, associated with the move to the uniform price, is of the same magnitude as the change in payment (with opposite sign).

Unlike in Israel, in Indonesia the block rate structure does not change with household size; large families consuming more water are paying higher marginal prices. Under these circumstances, Rietwelt, Rouwendal, and Zwart [18] found that the move to a uniform price (average of the block rate) would have improved the welfare of all four income quartiles but would have worsened the welfare of small families and improved the welfare of large households.

9. Concluding remarks

Using maximum likelihood estimates we found that the price and income elasticity of the demand for water in the residential sector in Israel is small in absolute value. Even in the long run, prices will not affect consumption markedly. This conclusion contradicts the reports presented, among others, by Olmstead, Hanemann, and Stavins [16] that under block rate regime price elasticity is relatively large. We do not have the information for a comparative analysis of the determinants of the elasticity estimates in different studies, but we do accept our findings and wish to defend them: in Israel, the expenditure on water and sewage removal is only 1.2% of total household expenditures of the lowest income decile. The share is even lower for higher income families. For comparison, the share of expenditure on telephone service in the lowest decile is 4.4% (of this, 2.5% on cellular phones). Even for low-income families, one can hardly expect prices to have a large effect on the use of water.

Price reform, the shift from block rate to a uniform price, affects the welfare of the households. With low price elasticity, the change in welfare—measured in monetary units—is similar in magnitude to the change in payment for water. These changes are not identical, poor and large families will be harmed by the reform, the welfare of rich families will be affected just slightly.

Several explanations were offered for the adoption of block rate pricing, some were presented by Hewitt [8]. It seems that in Israel, the main reason was social, to reduce the price to poorer families. And indeed, particularly with the first block expanding for larger households, most of the poor families pay the lowest price for all the water they consume. The difficulty, often overlooked, is that many of the poor reside in poor localities and then, where cost is recovered locally, the “rich” of the town subsidize the poor of the place. The elaboration of the economic and political determinants of the price regime and its consequences is, however, beyond the scope of this paper.

Appendix

To prove eq. (7) in the text, write the density of $\alpha \mid v$,

$$f(\alpha \mid v) = N(\bar{\alpha} - \rho^2 \bar{v} + \rho^2 v, \sigma_\alpha^2 (1-\rho^2)) \qquad \text{(a.1)}$$

[eq. (B-80) in Greene [6] p. 868) in terms of the present variables].

Using the text equations (5)-(8), for j=1, 2,

$$\begin{aligned} r_j &= \frac{t_j - \rho z_j}{\sqrt{1-\rho^2}} = \frac{(\alpha_j - \bar{\alpha})/\sigma_\alpha - \rho(v_j - \bar{v})/\sigma_v}{\sqrt{1-\rho^2}} \\ &= \frac{\alpha_j - (\bar{\alpha} - \rho \bar{v} \sigma_\alpha / \sigma_v) - \rho v_j \sigma_\alpha / \sigma_v}{\sigma_\alpha \sqrt{1-\rho^2}} \\ &= \frac{\alpha_j - (\bar{\alpha} - \rho^2 \bar{v}) - \rho^2 v_j}{\sigma_\alpha \sqrt{1-\rho^2}} \\ &= \frac{u_j - (\bar{\alpha} - \rho^2 \bar{v}) - \rho^2 v_j}{\sigma_\alpha \sqrt{1-\rho^2}} \end{aligned} \qquad \text{(a.2)}$$

Given (a.1), the last term in (a.2) is the standardized value of $\alpha \mid v$ evaluated at u_j.

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