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A Statistical Estimation of a Demand Function for Residential Water

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SOCIAL SCIENCE SERIES NO. 11
(Résumé en français)

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Abstract

The objective of this report is to define and statistically test factors that are felt, on an *a priori* basis, to affect significantly the residential demand for water. Using "ordinary least squares" regression, cross-sectional models are constructed on the basis of 1971 data for 57 urban centres with populations over 10,000. Essentially the influence of climatic factors, population, household size, income and price are tested. Whereas consumers under a flat-rate system are faced with a marginal price of zero, consumers in metered consumption areas face a positive marginal price. As a result, separate models are tested for centres imposing flat-rate charges and for metered centres. To test the impact of metering *per se*, a composite model in which all centres are included is constructed. Consumers in flat-rate areas do not have an economic incentive to regulate water use, and as a result, their consumption patterns exhibit wide random variance. The model for metered centres is capable of explaining more of the variation in interurban area consumption, although the commodity price variable itself does not show the relationship to consumption that is hypothesized. The author concludes that the model is not suitable for determining the effects of unit price charges; the extreme significance of the metering dummy variable, however, does suggest that water consumption is subject to some economic consideration. Then, of course, there are obvious policy implications. A negative relationship between consumption and average rainfall for 1971 suggests that consumers are responsive to water conservation efforts during seasonal peak periods.

Résumé

L'auteur tente de définir et de vérifier de façon statistique les facteurs qui, sur une base *a priori*, semblent influés considérablement sur la demande en eau à domicile. À l'aide de la régression basée sur la méthode des moindres carrés, des modèles de coupe instantanée sont élaborés d'après les données de 1971 relatives à 57 centres urbains dont la population dépasse 10,000 habitants. Essentiellement, on vérifie l'influence des facteurs climatiques, de la population, du nombre de personnes dans une famille, du revenu et du prix. Tandis que les consommateurs soumis à un système de taux uniforme doivent faire face à un prix marginal de zéro, ceux qui vivent dans des secteurs où la consommation est calculée payent un prix marginal positif. Résultat, des modèles séparés sont mis à l'essai pour les centres qui imposent des frais uniformes et ceux qui calculent la consommation. Pour vérifier l'impact du calcul de façon intrinsèque, on construit un modèle combiné qui inclut tous les centres. Les consommateurs des secteurs au taux uniforme n'ont pas de stimulant économique pour régulariser leur utilisation d'eau, et il en résulte que leur mode de consommation montre de grandes variations attribuables au hasard. Le modèle réservé aux centres soumis au calcul permet d'expliquer une plus grande partie de la variation dans la consommation des secteurs interurbains, bien que la variable du prix du produit ne montre pas le rapport avec la consommation, qui est émis en hypothèse. L'auteur conclut que le modèle ne permet pas de déterminer les effets de l'imposition d'un prix unitaire. Toutefois, la grande importance de la variable factice de calcul révèle que la consommation d'eau est soumise à certaines considérations économiques. Dans ces conditions, il y a donc des implications de politiques évidentes. Le rapport négatif entre la consommation et les précipitations moyennes en 1971 suggère que le consommateur réagit favorablement aux efforts de conservation d'eau durant les périodes saisonnières de pointe.

A Statistical Estimation of a Demand Function for Residential Water

Harry M. Kitchen

INTRODUCTION

In essence an individual's demand for residential water is conditioned by a number of aspects of his environment. Although at least a certain minimum of water is required for sustenance, the residential consumer also uses water for such non-essential purposes as sprinkling lawns, washing automobiles, and supplying water-using appliances, e.g., air conditioners. Intuitively one can see justification for believing that these non-essential uses are not stable, either over time or space, but rather are responsive to influence. The key to using water resources in the most efficient manner, then, involves identifying and interpreting those aspects of the consumer's environment that significantly affect his demand for water. The objective of this study is to define the determinants of the economic demand for residential water, and to estimate, where possible, the parameters associated with these determinants. If these relevant variables can be identified and the extent of their influence estimated, planners can use such information to advise policy-makers better of the real needs of a community and the most efficient allocation of available supplies. If, for example, a city is considering annexing an adjacent community, which would be hooked up to the city's water system, it may not be realistic to estimate the increased demand for water as a function of the increased population alone, since it may also be a function of other factors, such as lot size or the socio-economic level of the individuals involved. Thus it is the purpose of this study to derive a demand function for residential water by selecting and evaluating those factors that are likely to have the greatest effect on the quantity of water used.

GENERAL MODEL

The general model employed in this paper is an attempt to test statistically the various factors that are felt on an *a priori* basis to have a significant effect on the quantity of water demanded per residential dwelling unit. Essentially, these independent variables are designed to test whether climate, density, average household size, average income, and price significantly affect the residential demand for water. Although one might include a number of further variables, such as the age of the dwelling and plumbing, the distribution system pressure, the irrigable area per dwelling unit, the number of billing periods and other social and economic variables that may be non-observable or nonquantifiable[1*] as having an important effect, the lack of sufficient and accurate data eliminated any possibility of analyzing these variables in our study.

No uniform pricing policy exists for public water, and it has frequently been observed that municipal water rates are "the most unscientifically determined price in the public utility field."[2] In competitive markets, prices determine the optimal allocation of the scarce resources of an economic system by equating the consumer's valuation at the margin with the cost of producing the marginal unit. In those industries generally referred to as public utilities, including water supply, it is highly uneconomical to have a number of firms serving one consuming area. The forces of competition are absent, and regulation partially supplants them. The competitive results, however, can still be obtained if the utility is required to set its rates equal to the marginal costs of serving its customers. If marginal costs are less than average costs over the relevant range of output because of scale economies, such a pricing scheme may produce revenues from the commodity charges that are less than full cost,[3] but this discrepancy can usually be made up by imposing fixed charges (such as a service charge) on the customer.

In practice, however, scant consideration has been given to fundamental principles. In accordance with the requirements approach, price has not been considered to have any significant effect on water demands. If consumers are not thought to adjust their consumption in an economically rational way to price, then price is not taken as a measure of value at the margin of use, and the equating of marginal value and marginal cost simply does not occur. The design and operation of a water supply system becomes a matter of attempting to meet nearly all demands, with no attempt to consider the value of water at the margin. Pricing decisions by utility managers are consequently concerned with only two objectives: 1) to generate suffi-

*Footnotes are on pages 7, 8 and 9.

cient revenues from the sale of water to cover costs and 2) to raise these revenues in accordance with some principle of "equity" among customers.[4] The notion, prevalent in most engineering and utility literature, that rates should be equated with average cost, is evidence of the lingering doubt that price has any significant effect on quantities demanded.

Our definition of price should be clarified at this point. Most systems have several types of charges that they impose on customers, among them a fixed service charge per billing period, minimum charges, front-foot assessments, charges linked to the number of fixtures or water-using appliances, installation charges, charges linked to lot size, *ad valorem* taxes; and water and sewerage charges, which vary with the quantity of water used. Any combination of charges that do not vary with the quantity of water used are "flat-rate" charges; charges varying with the quantity used are referred to as "commodity" charges.[5] Water system pricing exhibits wide and persistent price variance. Among other things, this variance can be attributed to the differential costs involved in the following:

1) the treatment and purification of the water,
2) the transmission of water from the plant to the customer,
3) whether water is purchased or produced,
4) if water is distributed by force or gravity, and
5) the source of supply (wells, springs, rivers, etc.).[6]

Rate variance may also occur where rates of urban growth are unequal, since public water systems commonly frame rates to permit improvements or extensions to be financed out of operating incomes.

The study of the pricing practices of urban water systems reveals some differences between the policies adopted in the United States and the policies adopted in Canada. From 90-95 per cent of all urban service in the United States is metered,[7] but this proportion is not as great in Canada where there appears to be less concern over the conservation of existing water supplies.[8] Although the remaining centres operate under flat rates, the flat rates frequently apply only to residential users other than apartment buildings. These apartment dwellings and industrial and commercial users are generally subject to metering.

In view of these two approaches, our study was divided into metered and flat-rate centres on the assumption that flat rates do not discourage excessive water use, whereas metering gives the consumer some control over his total water bill. In the case of a flat rate, the marginal price of water to the consumer is zero, and hence the price variable can be excluded from such a study. In the case of metering, however, the marginal price is a positive amount, and consequently there may be an incentive to repair leaks and to reduce non-essential uses of water such as lawn sprinklers and car-washing. The price variable, which is the price applicable to average consumption per dwelling unit, is included in the latter study on the hypothesis that the higher the price, the lower the quantity of water demanded.

The amount of water demanded is likely to be related to the standard of living as measured by the number and variety of water-complementary appliances and fixtures in the dwelling unit. Such information, however, is not available for a study of this scope. Since similar income levels are likely to have a similar number of water outlets and water-using appliances regardless of the geographical location, we used average income as the variable reflecting the standard of living.[9] In the North American cross-sectional studies surveyed, family income was found to have a significant positive relationship with residential water demand.[10]

If there is a variation in the number of persons per dwelling unit, one would expect an increase in domestic consumption and therefore a direct relationship between this variable and the quantity of water demanded per dwelling unit.[11]

On an *a priori* basis, it was felt that in metered centres, the greater the percentage of apartment dwelling units or flats that were rented per municipality,[12] the greater would be the demand for water. Essentially this should occur because individual tenants of an apartment are seldom metered (although the building is metered) and consequently treat the price per unit of water consumed as a fixed price, i.e., not dependent on the quantity consumed. As a result, they tend to be less conscious of the quantity of water consumed and therefore may use more per dwelling unit.

Climatic factors may have a significant influence on water demand. In regions where irrigation is necessary for vegetation, sprinkling forms a large proportion of residential water use during the summer months and has been found almost to obscure normal household uses in flat-rate areas.[13] In a study covering different climatic regions one would expect differences in patterns of water use.[14] To evaluate the climatic influences on water demand, use is made of both the average summer temperature (i.e., June, July, August) and average summer rainfall in each centre. While these variables may be criticized,[15] it is our impression that they most accurately reflect the sprinkling demand in the following manner; the lower the average summer rainfall and/or the higher average summer temperature, the greater should be the quantity of water demanded.

Although this study concerns annual water demand and not fluctuations in consumption throughout the year, the question of peak loads and peak-load pricing is important and deserves brief mention. Although water utilities always maintained some extra standby capacity for fire protection and for future urban growth, the fact that there might be a predictable and systematic element in the pattern of seasonal, daily, and hourly use has only recently been appreciated. Variation in the level of water consumption is not just a random process; different classes of users may consistently place differing maximum actual demands on the system.[16] This means that water systems as currently operated may have excess capacity or at the same time be short of capacity, depending on the pattern of peak use. Much more must be learned about these patterns of variation. Daily and seasonal variation in residential water demand follows a well-marked pattern, and peak demands are primarily a product of lawn-watering.[17] Maximum simultaneous demand in a residential area can be about six times the average use, as compared with maximum industrial demand of nearer twice the average use, and this phenomenon has been used to justify the heavier burden of demand charges falling on domestic users.[18] Nevertheless, current pricing practices show little or no recognition of the peak-load problem and, in fact, may aggravate the peaks by application of promotional rates even during the seasonal and daily peaks. Some cities have responded with the imposition of restrictions on water use. Given the right data, the sprinkling component of residential consumption can be isolated and a separate demand function estimated.[19] That option, however, was not available to this study, so the demand function was confined to total annual residential water demand.

The theoretical model of residential water demand described would then be formulated as:

$$Q = f(X_1, X_2 \ldots X_6) \qquad (1)$$

where Q = average annual quantity consumed per dwelling unit

X_1 = price charged for average annual consumption per dwelling unit (in metered study only)

X_2 = average family income, 1971

X_3 = number of persons per dwelling unit

X_4 = percentage of total dwelling units which are rented apartments or flats

X_5 = average summer temperature (June, July, August)

X_6 = average summer rainfall (June, July, August).

EMPIRICAL RESULTS

Metered Model

Given the theoretical model (1), it is now possible to derive a residential demand function for water. In this case a statistical model based on "ordinary least squares" is tested for 31 municipalities with a population in excess of 10,000 for the year 1971. The final selection of 31 places represents municipalities for which data were available and reliable.[20]

For the 31 communities[21] in our sample, the following regression equation was obtained (figures in brackets are the standard errors of the regression coefficients).[22] The underlined variables have regression coefficients significantly different from zero at the .05 level:

$$\begin{array}{l} Q = -53681.14 + \underline{261.2888X_1} + .1060930X_2 \\ \qquad\qquad\qquad\qquad (106.0330) \qquad (1.483603) \\ \quad + \underline{13945.18X_3}\text{[23]} + \underline{348.1718X_4} \\ \qquad (7626.176) \qquad (158.4595) \\ \quad + 427.6411X_5 + 1551.060X_6 \\ \qquad (524.3283) \qquad (1327.950) \end{array} \qquad (2)$$

Coefficient of multiple determination = .5084758

Adjusted coefficient of multiple determination = .3855947.

Table 1 gives the correlation matrix for this model.

Table 1. Correlation Matrix for the Metered Model (based on equation 2)

	Q	X_1	X_2	X_3	X_4	X_5	X_6
Q	1.0000						
X_1	.2191	1.0000					
X_2	.2896	- .3816	1.0000				
X_3	.4460	- .1232	.5803	1.0000			
X_4	.2178	- .3200	.2626	- .2087	1.0000		
X_5	.0612	- .1420	.4265	.0039	.1390	1.0000	
X_6	.4307	.1644	- .1152	.3801	.0193	- .3974	1.0000

An examination of the regression analysis yields some interesting and unexpected results. First, our price variable (X_1) indicates a highly significant positive relationship, exactly opposite to our hypothesis. Initially, one might question such a statistical result; on further investigation, however, such a value seems plausible. Our model is cross-sectional relating the average consumption per dwelling unit to price. Since this involves a number of different centres at one period of time rather than a specific municipality over a period of time, it is not effectively analyzing the impact of changing prices upon the quantity demanded. Rather, it is simply observing the relationship between the price in a municipality with the quantity consumed in that municipality, without any knowledge of whether this price has prevailed for a considerable period of time or whether it has recently changed. Consequently, the true impact of price changes may be obscured.[24] Furthermore, in each of the centres in our study where average consumption per dwelling unit is high, it appears that the average cost of supplying water to each dwelling unit is high,[25] and if the rates are fixed to cover the total cost, then price per unit will necessarily be high. Finally, the price per unit of water demanded is so low that it is possible that most customers ignore cost when making water consumption decisions,[26] but this behaviour is probably not so widespread that water consumption violates the general law of demand. In other words, the price per unit of water consumed is lower than the marginal value of water to the consuming unit, and hence price will not show the hypothesized negative relationship.[27] Second, average income (X_2) was found to have an insignificant, but, as was expected, positive relationship with consumption. The income elasticity of demand was .026, which indicates an incredibly small change in the demand for water as income changes.[28] Third, both an increase in the number of people per household (X_3) and the percentage of multi-unit dwellings which were rented (X_4) yielded a significant positive relationship with consumption. Fourth, the failure of average summer temperature and average summer rainfall to prove significant is somewhat more difficult to explain. Immediately we questioned the use of these variables and re-specified our model by 1) substituting actual evapotranspiration for both climatic variables; 2) substituting potential evapotranspiration and average summer rainfall for both variables; and 3) substituting average summer temperature and number of summer days in which a measurable amount of rain fell for both climatic variables. In none of the cases were the results noticeably different from the results previously reported. Indeed, the substitution of these other variables simply supported the usefulness and accuracy of our original regression equation. Although rainfall and temperature are insignificant, rainfall and consumption are positively related, i.e., the greater the average summer rainfall, the higher the consumption per dwelling unit. Indeed, this was the case even when we substituted the other variables listed. The explanation for such a result is not difficult. In cities with a low average rainfall, the frequency of imposing controls (when they exist) or the frequency of warnings (through the media) with regard to the serious consequences of excessive use of water for sprinkling, etc., appear to be higher and the controls or warnings tend to be effective. While it is virtually impossible to verify statistically such a conclusion, many water policy-makers have stated that warnings and controls have a noticeable impact on the rate of consumption.

Although only a little more than 38 per cent (adjusted for degrees of freedom) of the variation in average consumption can be explained by the previous equation, it contained two highly insignificant variables (X_2 and X_5).[29] After dropping these two variables, the equation was subsequently reworked, yielding the following relationship:[30]

$$Q = -28396.27 + \underset{(102.4787)}{\underline{263.8143}}X_1 + \underset{(4712.889)}{\underline{15388.81}}X_3 + \underset{(130.3961)}{\underline{379.7871}}X_4 + \underset{(1063.469)}{1021.659}X_6 \quad (3)$$

Coefficient of multiple determination = .4916306
Adjusted coefficient of multiple determination = .4134199.

With the gain in degrees of freedom, almost 42 per cent of variation in average consumption is now explained. The statistical significance of the variables X_1, X_3 and X_4 has increased, while X_5 has decreased. Although three variables account for most of the variation, we are not quite certain of the meaning of the price variable. Can one state that the higher the price, the greater the quantity consumed? This seems highly implausible for as we earlier indicated, the price, although lower than the marginal value of water consumed, essentially reflects the cost of supply. Our feeling, then, is that there must be certain peculiarities of demand in high cost centres that have not been included in our model and for which the price variable is acting as a proxy. It would be folly to use this model as a basis for making any policy suggestions on the impact on demand of altering the per unit price of water. This could only be done if price actually measured the marginal value of water to the consumer.

Flat-Rate Model

In this case, a statistical model is tested for 26 Canadian municipalities with populations in excess of 10,000 for the year 1971. Since this model concerns a fixed price over which the consumer has no control, he will not adjust his consumption according to price. Hence the exclusion of the price variable from the regression analysis.

The underlined variables have regression coefficients significantly different from zero at the .05 level.[31] The standard errors are in brackets:

$$Q = 348507.1 - .8571805X_2 - 15365.88X_3$$
$$(10.25938) \quad (31272.21)$$

$$+62129.04X_4 - 4247.992X_5 + \underline{27921.82X_6} \quad (4)$$
$$(111601.8) \quad (3146.439) \quad (11057.58)$$

Coefficient of multiple determination = .3388361
Adjusted coefficient of multiple determination = .1735451.
The correlation matrix for this model is given in Table 2.

Table 2. Correlation Matrix for the Flat-Rate Model (based on equation 4)

	Q	X_2	X_3	X_4	X_5	X_6
Q	1.0000					
X_2	- .0958	1.0000				
X_3	.1581	- .4132	1.0000			
X_4	.0393	.2593	- .4047	1.0000		
X_5	- .3311	.0943	- .4265	.1680	1.0000	
X_6	.5158	- .2583	.3899	- .1373	- .2456	1.0000

As in our metered model, an examination of the regression analysis yields some interesting and peculiar results. Our income variable (X_2) and our number of persons per dwelling unit variable (X_3) both act in a negative direction. Although this is different from what was expected, little attention should be paid to the importance of these variables. Indeed, about all one can say is that they are extremely insignificant, and consequently the direction of impact is virtually meaningless.[32] The percentage of multi-unit dwellings that are rented (X_4) is statistically insignificant in affecting the quantity consumed. This is different from our metered study, but what one might expect. Average summer rainfall appears to be important as a determinant of average consumption. This positive relationship is explained in the same manner as in the metered model, i.e., the imposition of controls or even warnings against excessive use of water tend to curtail the demand for water. Consequently, a centre receiving less rainfall and more frequently resorting to controls or warnings consumes less water per dwelling unit. Average summer temperature yields a negative, although insignificant, relationship with average consumption. This result is different than we expected and different from our previous model. Explaining such a relationship is considerably more difficult than in the other cases. Indeed, a further analysis of the data indicated that those cities with lower temperatures and higher average consumption tended to be located in certain regions of the country. Hence, the temperature may be disguising a regional variable. Rainfall, on the other hand, did not show this kind of regional variation.[33]

Although this model only explained about 17 per cent (adjusted for degrees of freedom) of the variation in average consumption, it contained three extremely insignificant variables. After dropping these three variables (X_2, X_3, X_4) and reworking our equation, we obtained the following results:[34]

$$Q = 252875.1 - 3367.716X_5 + \underline{25551.00X_6} \quad (5)$$
$$(2765.454) \quad (9870.150)$$

Coefficient of multiple determination = .3105058
Adjusted coefficient of multiple determination = .2505498.

A re-examination of the regression results indicates that the t-statistic for each variable changed very marginally.

In summary, the two climatic variables explain over 25 per cent of the variation (after adjusting for degrees of freedom) in the average consumption of water per dwelling unit. The most interesting point to note here is that rainfall becomes extremely important in terms of its explanatory powers. In fact, the t-ratio has risen from a value of .96 in our metered model to 2.59. Why such a difference should exist is not immediately obvious. Perhaps one explanation may be that in flat-rate centres as opposed to metered centres average consumption tends to absorb a greater percentage of the capacity of the utility plant. This, combined with the notion that controls or warnings appear to be effective, may account for our results; that is to say, if rainfall tends to be low, then the capacity of the plant is reached more quickly in flat-rate centres and hence controls or warnings are implemented sooner than in metered areas.[35] Although this explanation appears to have some statistical validity, it is our feeling that further analysis should be done in this area.

CONCLUSION

Evolving from this analysis are a number of rather interesting comparisons among centres using metered rates and those using flat rates. Although most of the variables yielded the hypothesized results, some were considerably different. For example, in the metered model, price and consumption were significantly related in a positive direction. This may be explained in terms of the extremely low rates charged for water consumption and the fact that municipalities set rates to cover costs. As well, income tends to be statistically insignificant in explaining the variation in demand for water in both the flat-rate and metered study. Such a result is probably indicative of the fact that annual water expenditures comprise an extremely low percentage of the family's total disposable income. Finally, rainfall tends to be highly significant in the flat-rate study and not in the metered study.

These results leave us with one further possibility in our analysis, that is, to run a regression including all 57 municipalities and variables X_2, X_3, X_4, X_5 and X_6 from our previous studies. The rationale for including the metered centres and excluding the price variable is based upon the peculiar results yielded by this variable and the fact that in its present form price explains really nothing in terms of its importance as a means of allocating the consumption of water. A further variable (X_7) reflecting whether or not the centre was metered or flat rate was included.[36] Essentially this is designed to indicate, among other things, the significance of metering on the consumption of water. Our model, then, yielded the following results. All underlined regression coefficients are significant at the .05 level. Standard errors of the regression coefficients are in brackets:

$$
\begin{aligned}
Q = {} & 189893.5 + \underset{(4.329857)}{1.577591X_2} + \underset{(16770.15)}{2793.703X_3} \\
& + \underset{(571.3071)}{348.7405X_4} - \underset{(1762.003)}{2145.654X_5} + \underset{(5109.039)}{\underline{11198.99}X_6} \\
& - \underset{(12155.12)}{\underline{78672.97}X_7}
\end{aligned}
\qquad (6)
$$

Coefficient of multiple determination = .6308878
Adjusted coefficient of multiple determination = .5865944.
Table 3 gives the correlation matrix for this model.

Our model explains over 58 per cent of the variation in average consumption per dwelling unit. An examination of the individual regression results indicates that we have two statistically significant variables. Average summer rainfall is significant and positive as would be expected from our separate models. Finally, the variable reflecting flat rate versus metered rate proves to be by far the most important variable in our analysis. As hypothesized, metering, when compared with flat rates, tends to lead to lower consumption per dwelling unit. Finally all highly insignificant variables were dropped,[37] and the relationship was recalculated yielding the following results:

$$
\begin{aligned}
Q = {} & 206078.4 - \underset{(1641.661)}{1892.351X_5} + \underset{(4648.847)}{\underline{11291.98}X_6} \\
& - \underset{(9756.249)}{\underline{76803.64}X_7}
\end{aligned}
\qquad (7)
$$

Coefficient of multiple determination = .6256608
Adjusted coefficient of multiple determination = .6044718.

This model indicates that three variables can explain over 60 per cent of the variation in the average consumption with the variable reflecting flat-rate centres versus metered centres having the most noticeable impact. An examination of our raw data indicated that the average consumption per dwelling unit in flat-rate centres was more than twice as high as in metered centres. Although it is particularly difficult to say anything about the impact of price per unit in a study such as ours, one can make some rather definitive statements on the impact of metering *per se*. Many of the studies surveyed that have attempted to analyze flat rates versus metered rates have dealt with an analysis of the impact on water consumption of changing from a flat rate to a metered rate.[38] While water consumption is reduced in these cases, it is not certain if the initial reduction was sustained indefinitely. Such studies have been concerned with the change from a marginal price of zero to a positive figure. Our study, on the other hand, has attempted to discuss the differential impact when the respective centres have been accustomed to either a flat rate or metered rates for a number of years. Essentially, one can conclude that metering reduces the consumption per dwelling unit even though prices may be too low to have any influence on water consumption.[39]

Some of the results of this study should be of particular concern to policy-makers, for example, the fact that income does not have a significant impact upon the consumption of water. The importance of metering and its implications for conservation of water are obvious. The impact of controls or warnings against the unnecessary use

Table 3. Correlation Matrix for the Complete Model (based on equation 6)

	Q	X_2	X_3	X_4	X_5	X_6	X_7
Q	1.0000						
X_2	- .4285	1.0000					
X_3	.2904	- .0898	1.0000				
X_4	- .0197	.2536	- .3261	1.0000			
X_5	- .4291	.4003	- .3400	.1690	1.0000		
X_6	.1672	- .0805	.3297	- .0422	= .2501	1.0000	
X_7	- .7453	.5589	- .2452	.0714	.3648	.1047	1.0000

of water seems to be effective. Perhaps a study specifically designed to test the validity of this hypothesis would be of particular use.

While this study has some useful and some peculiar results, it is our belief that a further analysis along these lines based upon such aggregative data would yield very little that is new. Although it is true that a further significant variable or a slightly higher explanatory value may be obtained, the usefulness of such an exercise is far from clear. What is now needed is a model based upon disaggregated data, for example, detailed information on the actual consumption per household broken down into seasonal demands, demands at particular times of the day, number of taps, bathroom facilities, size of family, assessed value of house, size of lot, the existence of a vegetable garden and/or swimming pool, etc. An in-depth, detailed analysis of the demand per dwelling unit both in a specific city operating under a flat rate and in a specific city operating under a metered rate should be undertaken. Although this would yield no information in terms of the impact of climatic variables, it would provide us with better information on the decision-making process within a specific household.

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FOOTNOTES

1. For summaries of factors affecting residential water demand, for both domestic and sprinkling purposes, see B. Larson and H. Hudson, August 1951, "Residential Water Use and Family Income," *Journal of American Water Works Association,* p. 604; S.H. Hanke, October 1970, "Demand for Water under Dynamic Conditions," *Water Resources Research,* Vol. 6, pp. 1255-1259; C. Howe and F. Linaweaver, 1967, "The Impact of Price on Residential Water Demand and its Relation to System Design and Price Structure," *Water Resources Research,* Vol. 3, pp. 19-20.
2. S. Wong, February 1972, "A Model on Municipal Water Demand: A Case Study of Northeastern Illinois," *Land Economics,* Vol. 48, No. 1, pp. 35-36.
3. For evidence of economies of scale in water production, see L. Hines, 1969, "The Long Run Cost Function of Water Production for Selected Wisconsin Communities," *Land Economics,* Vol. 45, and H.M. Kitchen, 1973, *A Statistical Estimation of an Operating Cost Function for Municipal Water Provision,* C.73.5, External Research, Ministry of State for Urban Affairs, Ottawa.
4. Howe and Linaweaver, *op.cit.*, p. 15.
5. Howe and Linaweaver, *op.cit.*, pp. 13-14. For a general idea of the diversity of charges in Ontario, see "Municipal Water Rates of Ontario," *Water Works Digest,* Stanton Pipes Ltd., Toronto, April 1971, Vol. 12, No. 1.
6. A description of factors causing rate differentials is found in M. Gottlieb, 1963, "Urban Domestic Demand for Water: A Kansas Case Study," *Land Economics,* Vol. 39, pp. 204-205, and in P. Garfield and W. Lovejoy, 1964, *Public Utility Economics,* Prentice-Hall, p. 229. For a summary of the statistical impact of these factors on the cost of supplying residential water, see Kitchen, *op.cit.*
7. J. Milliman, 1963, "Policy Horizons for Future Water Supply," *Land Economics,* Vol. 39, p. 117.
8. Note later that 26 out of 57 Canadian municipalities in this study employed flat-rate residential charges.
9. For an illustration of the relationship among income, water-using appliances and fixtures and water consumption, see G.M. Quraishi, April 1963, "Domestic Water Use in Sweden,"

Journal of the American Water Works Association, Vol. 55, Tables 3 & 4, p. 454.

10. Gottlieb, *op.cit.,* p. 209; C.J. Headley, 1963, "The Relation of Family Income and Use of Water for Residential and Commercial Purposes in the San Francisco-Oakland Metropolitan Area," *Land Economics,* Vol. 39, p. 448; Wong, *op.cit.,* pp. 43-44. A further variable which has been used in a number of studies as a proxy for the standard of living was a variable reflecting some measure of residence value (market or assessed value). See Howe and Linaweaver, *op.cit.,* p. 28; A. Grima, 1972, *Residential Water Demand,* Toronto, University of Toronto Press, pp. 102 & 104; D.F. Dunn and T.E. Larson, 1963, "Relationship of Domestic Water Use of Assessed Valuation, with Selected Demographic and Socio-Economic Variables," *Journal of the American Water Works Association,* Vol. 55, No. 4, p. 442. For a cross-sectional study covering centres of different sizes across a large geographical area, however, it was felt that equalized property values may not be a reliable indicator of the building values, which are more likely to reflect the number and kind of water-using devices. A high assessment in a large city might be concentrated on the building, whereas an identical equalized assessment in a small city might reflect a modest building but a large lot.
11. Grima, *op.cit.,* pp. 86-87. See C.R. Weeks and T.A. McMahon, April 1973, "A Comparison of Urban Water Use in Australia and the U.S.," *Journal of the American Water Works Association,* Vol. 65, Table 1, p. 234, for evidence of the importance of the bathroom component.
12. Either population density or dwelling unit density might be considered an important variable which could have some impact on the consumption of water. A simple rank correlation between density and this variable in each centre, however, indicated a direct and significant relationship (at the .05 level of significance) and suggested, therefore, the inclusion of one or the other. We chose the percentage of multi-unit dwellings (i.e., percentage of apartment dwelling units or flats that were rented).
13. Milliman, *op.cit.,* p. 121.
14. American Water Works Association, May 1973, "Water Use Committee Report, Parts 1 and 2," *Journal of the American Water Works Association,* Vol. 65, Table 2, pp. 297 & 299.
15. Some authors have used potential evapotranspiration as a climatic variable; for example, see Howe and Linaweaver, *op.cit.,* pp. 20-21. A further approach was adopted by S.H. Hanke who used a combination of effective rainfall, mean monthly temperature, monthly percentage of daylight hours and an empirical crop coefficient to calculate the ideal quantity of lawn-sprinkling (see Hanke, *op.cit.,* p. 1255). Although we accept the scientific nature of these variables since some of them incorporate the factors of air humidity, soil moisture conditions, wind conditions, etc., and hence reflect a fairly accurate measure of the need for sprinkling, we believe that individuals use a much less sophisticated approach in making a decision with regard to sprinkling. For a further criticism of some of these points, see American Water Works Association, *op.cit.,* p. 301. Essentially, it is our impression that individuals make a decision based on nothing more than the temperature and rainfall variables that we have included in our model.
16. J. Hirshleifer, J. DeHaven and J. Milliman, 1966, *Water Supply: Economics, Technology and Policy,* University of Chicago, p. 102.
17. Milliman, *op.cit.,* p. 121.
18. Hirshleifer, DeHaven and Milliman, *op.cit.,* p. 103.
19. Empirical demand functions for sprinkling were able to be completed by Howe and Linaweaver, *op.cit.,* pp. 20-32, and Hanke, *op.cit.,* pp. 1255-1261.
20. Perhaps a few examples of some of the problems we faced in selecting our final list of municipalities would suffice. First, many communities, upon further check, provided either incomplete or suspect data on their questionnaires and were subsequently removed from the sample. Second, many communities did not have the information that was requested. Finally, a number of communities simply did not return the questionnaire and hence were excluded. In the end, this left us with 31 places of more than 10,000 people.
21. Data were obtained from a number of sources. Census data, 1971, were used for average income (X_2), number of persons per household (X_3), percentage of total units that are rented apartments or flats (X_4). Questionnaires received from the municipalities provided us with the total residential consumption for 1971. The municipalities supplied us with rate schedules (X_1). Data for average temperature (X_5) and average rainfall (X_6) were obtained from *Monthly Records: Meteorological Observations,* June, July, August, Department of Transport, 1971.
22. The relationship in this study measures the average demand per dwelling unit per municipality per year (Q).
23. We used average household size, since the definition of household size applied in the 1971 Census is the number of people occupying a single dwelling unit.
24. It is virtually impossible to collect consumption figures over a number of years for any municipality.
25. A rank correlation between the average cost of supplying dwelling units and the average consumption per dwelling unit is significant at the .005 level.
26. In our study, the yearly average expenditure per dwelling unit per city ranged from $14.08 to $57.00.
27. In this model, most centres for which we could obtain reliable data used a declining block rate (meter) schedule which included a fixed minimum charge. This charge varies from centre to centre, but is fixed for a certain minimum quantity of water consumed. Consequently the customer, although metered, can only control his expenditures on the gallonage consumed over and above the stipulated minimum. In all centres except for two, the variable rate actually paid by each customer for average consumption never exceeded the first variable rate; for example, if the variable rate (over and above the minimum) was 22¢ per 1000 gallons for so many gallons and then 18¢ per 1000 gallons for a further number of gallons, the average consumption was not large enough to move away from a rate of 22¢. This variable charge which exists further complicated our statistical analysis, since one can say virtually nothing about the relationship between quantity and price. A further analysis on the price variable was attempted by subtracting the fixed minimum quantity consumed from the total gallonage consumed and by subtracting the yearly fixed charge from the total yearly dwelling unit expenditures on water and rerunning our regression. It was hoped that this would provide some information on whether consumption is influenced by price. Our results were highly insignificant and actually provided no reliable indication of the importance of price. This was mainly attributed to the fact that in many cases average consumption only marginally exceeded the basic minimum quantity (this was generally quite high) for which consumers were required to pay a basic minimum rate. Hence,

one can say nothing about price except that it is not being effectively used to control the supply of water.

28. This result tends to be lower than a number of U.S. studies. For a brief summary of price and income elasticities, see Wong, *op.cit.,* Table 2, p. 42.
29. Each of the t-ratios was less than one.
30. The standard errors are in brackets. All underlined variables are significant at the .05 level.
31. All data sources are the same as listed in Footnote 21 and the problem of selecting the final sample is the same as listed in Footnote 20.
32. The t-ratios are −.08 for X_2 and −.49 for X_3.
33. As in the case of the metered study, 1) actual evapotranspiration, 2) number of rainy days and average temperature, and 3) potential evapotranspiration and average rainfall were substituted for the climatic variables. In none of the cases were the results noticeably different.
34. We dropped all variables from our initial run that yielded a t-ratio less than one. All underlined variables are significant at the .05 level.
35. An analysis of plant use in the centres in our study revealed that average consumption represented a greater percentage of plant capacity in flat-rate centres than in metered centres. For a discussion of this concept of plant use and a statistical analysis of its impact on costs, see Kitchen, *op.cit.*
36. Metered centres had a value of one and flat-rate centres had a value of zero.
37. All variables (X_2, X_3, X_4) yielding a t-ratio less than one were dropped. Standard errors of the regression coefficients are in brackets. All underlined variables are significant at the .05 level.
38. Gottlieb, *op.cit.,* p. 206; J.J. Warford, 1966, "Water Requirements—The Investment Decision in the Water Supply Industry," *The Manchester School of Economics and Social Studies,* Vol. 34, pp. 97, 104; American Water Works Association, *op.cit.,* p. 289; Dunn and Larson, *op.cit.,* p. 442; Hanke and Boland's study of Boulder, Colorado, revealed that not only did sprinkling demands decline immediately after the introduction of meters, but continued to decline. Furthermore, domestic use was reduced initially by 36 per cent and later never returned to the original level, S.H. Hanke and J.J. Boland, November 1971, "Water Requirements or Water Demands?" *Journal of the American Water Works Association,* Vol. 63, p. 680, Table 3, p. 681.
39. This result is contrary to that cited by Grima, *op.cit.,* p. 189, where he concludes that only a high marginal price, not metering *per se,* influences customers' total use.