AN ABSTRACT OF THE THESIS OF

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Title: An Economic Analysis of the Municipal Demand for Water in Kuwait

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Richard S. Johnston

In an effort to estimate the municipal demand for water in Kuwait, it was found that the literature did not single out a unique functional form that best describes the relationship between the quantity of municipal water demanded and other explanatory variables. Moreover, the most widely used functional form (the double-log) is implausible; i.e., it is inconsistent with utility theory. Furthermore, existing demand studies have not taken into consideration the possibility of a minimum amount of water to be demanded regardless of the price of water.

The primary concern in this study was to find a plausible demand function that would take into consideration the minimum amount of water necessary for daily needs, called the domestic base line water use level. Such a function (called the main model) was derived from the Stone-Geary utility function through the assumption of constrained utility maximization.

Since the Stone-Geary utility function has not been previously used to estimate the municipal demand for water, five other functional forms were utilized for comparison. There were the linear, semi-log,

exponential, price-exponential, and double-log forms.

When these six models were estimated using monthly time series data (1973-1981), the resulting regression results indicated the following: First, the main model as well as the other five models explained over 80 percent of the change in the quantity of municipal water demanded in Kuwait. Second, the estimated price elasticity in the main model (-0.771) was very close to that in the other five models, but was greater than that in studies for other countries for the same demand sector (domestic). Third, the estimated income elasticity in the main model (0.211) was greater than that in the other five models, but smaller than that found for other countries. Fourth, contrary to the belief that people in the oil-rich countries do not respond to price changes in public services, this study shows that, at least in Kuwait, people do respond to price changes in municipal water even more than do their counterparts in Canada, the U.K., and the U.S. This is reflected by higher price elasticity estimates for Kuwait than for the other countries (reflecting either different demand relationships or different points on a common demand relationship). Finally, this study estimated the domestic baseline water use in Kuwait to be 21 Imperial gallons per capita per day (IGPCD). This is close to the U.S. estimate (53 IGPCD) if one takes into consideration the price differentials and water use habits in the two countries.

An Economic Analysis of the Municipal Demand for Water in Kuwait

by

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بسم الله الرحمن الرحيم

وَجَعَلْنَا مِنَ الْمَاءِ كُلَّ شَيْءٍ حَيٍّ أَفَلَا يُؤْمِنُونَ

We made from WATER every living thing. Will they not then believe?

The holy QUR'AN (s. XXI:30)

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CHAPTER I

INTRODUCTION

Municipal Water

The story of municipal water supplies started as early as the third centry B.C.[1/] At that time Rome, the capital of the Roman Empire, received its water supplies from adjacent water sources through aqueducts built, for the first time, to transmit water to Rome. However, the modern water works systems did not appear until the early 1800s A.D., especially in the big cities of Europe and North America, e.g., London, Paris, Boston, New York, and Philadelphia.

This era of municipal water supplies was marked by the use of cast-iron pipes, steam engines to pump water into homes, and filtration. The use of chlorination to control water-borne or water-associated diseases (e.g., typhoid, cholera, malaria) was adopted in the early 1900s.

The period that followed witnessed a dramatic development in the system, where water was supplied to almost all villages in the developed countries and many cities in the developing countries.

1/ For a good historical review of the subject see F.E. Tuneaure and H.L. Russell, Public Water Supplies: Requirements, Resources, and Construction of Works, 4th ed. (Wiley, 1940), Chapter 1.

Further, there was enormous engineering progress in equipment and facilities, e.g., plastic pipes, flouridation, taste and odor filters, purification plants, and desalination plants to convert sea water into fresh water on a large scale.

The Area of the Study

The State of Kuwait, the area of the study, is a small country of 1.36 million people (1980) occupying 17,818 square kilometers (6,880 square miles) in the northwestern corner of the Arabian (Persian) Gulf. The major source of the country's gross domestic product (GDP) is oil, contributing more than 60 percent of the GDP in 1981 (at market prices).

In the past three decades Kuwait has been transformed from a rural society depending on fishing, pearling, and trade to a wealthy urban society depending on oil revenues.[2/] This process of development was accompanied by an unusual population "explosion" that could not be matched anywhere in the Middle East or even in Europe.

The population has increased by more than 650 percent in only 23 years, from 206,473 in 1957 to 1,357,952 in 1980. This population "explosion" is attributed in large part to the immigration of labor into Kuwait to fill the jobs that have opened due to oil discovery, and in turn, oil revenues. Comparing the 1957 and 1980 census one finds that the Kuwaiti population grew by more than 497 percent (113,622 to 565,613), whereas the non-Kuwaiti population

2/ It was estimated that per capita income in Kuwait was $21 in the early 1940s [El Mallakh, 1968] compared to $20,578 in 1981.

grew by more than 853 percent (92,851 to 792,339) for the same period.

Water Situation in Kuwait

Water has long been a scarce "item" in Kuwait. In fact, Kuwait's water resources were not able to satisfy Kuwaiti demand as early as the 1900s. For this reason, some Kuwaiti merchants started to make their living by importing fresh water from neighboring Iraq in small ships and then selling it to the public.[3/] These water imports continued to increase until they reached their peak of 80,000 gallons daily in 1947.

The discovery of oil in 1938, and the beginning of exporting oil in 1946 enabled the Kuwaiti government to be "water self-sufficient" through the desalination of sea water from the Gulf (the first country to do so). It therefore stopped its water imports from Iraq in 1950/1951. In the beginning, the Kuwaiti Oil Company, Ltd. supplied Kuwait with fresh water from a disalination plant that was built to provide the company with fresh water. In 1953, the government of Kuwait built its first desalination plant, which provided one million Imperial gallons (MIG) daily. In 1981, Kuwait produced a daily average of 62.8 MIG of distilled water.

However, Kuwait currently secures its fresh water needs from three sources:[4/]

3/ For a historical review on the subject see Fatima H.Y. Al Abdulrazaq, Water and People in Kuwait, 1974 (Arabic).

4/ A third, but minor, source is the imported bottled water which was about 16,737,357 "kilograms" in 1980 (Yearly Bulletin of Foreign Trade Statistics, Ministry of Planning, Kuwait, 1981).

1. Desalination, which constitutes the major source of total fresh water supply of the country. This source provided 89 percent of the total fresh water supply in 1981.

2. Fresh ground water, which provides a small amount of the total fresh water supply (0.7 percent in 1981).

3. An aquifer of brackish water which supplied the country with 14,031 MIG in 1981. Brackish water is used for two purposes:

   a. To mix with distilled water at a rate of 10-20 percent of the total amount of distilled water.

   b. To provide the public with an inexpensive source of water that could be used for agriculture (at the household, business, and public levels), livestock, and industrial purposes.

The Objectives of the Study

With no surface water sources (i.e., rivers, lakes), very limited fresh ground water sources, very small amounts of precipitation (less than 120 millimeters, 4.7 inches, a year), and a very hot and long summer season (over five months) coupled with relative humidity of up to 100 percent, the development of an adequate water supply, while preventing overinvestment, would be quite a challenge for the Ministry of Electricity and Water. Therefore, a careful study of the economic demand for water is a "must" for resolving this issue.

This study is intended to estimate the municipal (urban) demand for water in Kuwait and to analyze whether or not the quantity of water demanded is responsive to price changes in such a wealthy society. More specifically, the objectives of the study are:

1. To identify the variables that affect the demand for municipal water in Kuwait.

2. To estimate a demand equation for municipal water in the study area.

3. To test whether or not water consumption is responsive to price changes.

4. To compare income and price elasticity estimates obtained in this study with results obtained elsewhere, especially in areas with similar weather conditions and income levels.

CHAPTER II

LITERATURE REVIEW

Although water is one of the most important "commodities" (or inputs) for the existence of life on earth, it has received little attention from economists in the past, when compared to other commodities (or inputs). This is especially true of municipal water, at least until recently.

Indeed, the amount of attention given to municipal water has changed since 1970. Wong (1972), reporting on the status of research in this area up to 1972 cited only 17 studies about the estimation of municipal water demand. More than double that number of studies have been published since 1970.

The scarcity of municipal water studies, especially in the earlier period, has been attributed to the difficulties in conducting such studies. The main difficulty is the unavailability of necessary data. In this regard, Wong (1972) lists four problems associated with collecting necessary data: first, the water consumption data are far from perfect; second, there is no uniform pricing policy in public water; third, there are income data problems, mainly, those of obtaining the appropriate data; and fourth, there is the problem of sample reliability due to the length of time for which data are available and other "small sample" difficulties. A more recent study, Danielson (1977), lists five data problems: (1) metering has not been in effect for an adequate period of time to provide a sufficient number of time-series observations, (2) the price changes are not of adequate magnitude nor do they occur frequently enough for statistical analysis, (3) there are socio-economic and climatic collection difficulties, (4) data are such that commercial and other nonresidential use cannot be separated from residential use, and (5) there are econometric problems with the analysis of those time-series data which are available.

However, these problems are handled better than before, as witnessed by the increased number of studies since 1970. Three more reasons are also responsible for this increased attention given to municipal water. The first is the drought conditions that have affected most nations in recent years; second, is the expansion of metropolitan areas which has necessitated an increase in the demand for municipal water; third, is the increased attention given to water pollution and water quality problems which affect municipal water supply sources.

The body of literature covering the estimation of municipal water demand could be looked at in different ways. One way is to review the literature chronologically. Another would be to group the studies according to the type of data used (cross-section, time-series, or pooled) or according to the model(s) employed.

Tables II.1-II.3 summarizes the studies according to the second and third approaches mentioned above. Thus, the present discussion looks at the literature chronologically to provide some notion of how the "evolution" of water demand estimation has taken place.

Metcalf (1926) conducted one of the earliest studies of water demand. Utilizing cross-sectional data for 29 waterworks systems in

Table II.1. Summary of Urban Water Demand Studies Based on Cross-Section Data.[1/]

Investigator	Type of Data and Region Studied	Variables	Type of Model	Price Elasticity	Income Elasticity	R^2
Metcalf (1926)[2/]	Cross-Sectional (29 Waterworks systems, U.S.A.)	Y = average consumption X_1 = average price	Double-Log	-0.65	-----	----
Fourt (1958)[3/]	Cross-Sectional (34 cities, U.S.A.)	Y = residential demand per capita per year X_1 = price X_2 = per capita income X_3 = percentage of dwelling with three or more units per dwelling	Double-Log	-0.387	0.277	0.303
Gottlieb (1963)	Cross-Sectional (Kansas, U.S.A.)	Y = per capita annual consumption X_1 = price X_2 = average household income	Double-Log	-0.656 to -1.238	0.278 to 0.583	0.83 to 0.85
Headley (1963)	Cross-Sectional (14 cities in the Bay Area, California, U.S.A.)	Y = per capita consumption per day X_1 = median family income	Residential Demand:			
			Linear			
			1950	-----	1.49	0.81
			1959	-----	1.24	0.80
			Double-Log			
			1950	-----	1.63	0.77
			1959	-----	1.37	0.69
			Total Demand:			
			Linear			
			1950	-----	1.09	0.65
Gardner and Schick (1964)	Cross-Sectional (6 Northern Utah counties, Utah, U.S.A.)	Y = per capita consumption per day X_1 = average price X_2 = per capita lot area	Double-Log	-0.766	----	0.83
Bain et al. (1966)	Cross-Sectional (41 cities, California, U.S.A.)	Y = per capita consumption X = average price	Double-Log	-1.099	----	----
Howe and Linaweaver (1967)	Cross-Sectional (21 study areas, U.S.A.)	Domestic Demand (equation of best fit): Y = avereage annual quantity demanded for domestic purposes per dwelling unit per day X_1 = market value of the dwelling unit X_2 = the sum of water and sewer charges that vary with water use, evaluated at the block rate applicable to the average domestic use in each study area.	Linear	-0.231	0.319	0.717

Table II.1. Summary of Urban Water Demand Studies Based on Cross-Section Data.[1/] (cont'd.)

Investigator	Type of Data and Region Studied	Variables	Type of Model	Price Elasticity	Income Elasticity	R^2
Howe and Linaweaver (1967) (continued)		Sprinkling Demand (equation of best fit): Y = average summer sprinkling demand per dwelling unit per day X_1 = net evapotranspiration X_2 = summer marginal price X_3 = market value of the dwelling unit	Double-Log	-1.12	0.662	0.729
		Maximum Day Sprinkling Demand (equation of best fit) Y = maximum day sprinkling per dwelling unit per day X_1 = summer marginal price X_2 = market value of the dwelling unit	Double-Log	-0.683	0.591	0.564
		Total Demand: Y = annual average (total) water use X_1 = market value of the dwelling unit X_2 = net evapotranspiration X_3 = the quantity weighted average of the marginal commodity charges applicable during winter and summer seasons.	Double-Log	-0.405	0.474	0.743
Conley (1967)	Cross-Sectional (24 communities, Southern California, U.S.A.)	Y = per capita daily consumption X_1 = average price	Double-Log	-1.025	-----	0.522
Turnovsky (1969)	Cross-Sectional (19 Massachusetts towns, U.S.A.)	Y = planned per capita per day domestic consumption X_1 = variance of supply X_2 = average price of water X_3 = index of per capita housing space X_4 = percentage of population under 18	Linear	-0.049 to -0.406	-----	0.53 to 0.86
Wong (1972)	Cross-Sectional (4 communities, Illinois, U.S.A.)	Y = average per capita municipal water demand per day X_1 = price X_2 = average household income X_3 = average summer temperature	Double-Log	-0.26 to -0.82	0.48 to 1.03	0.30 to 0.53

Table II.1. Summary of Urban Water Demand Studies Based on Cross-Section Data.[1/] (cont'd.)

Investigator	Type of Data and Region Studied	Variables	Type of Model	Price Elasticity	Income Elasticity	R^2
Grima (1972)	Cross-Sectional (Ontario, Canada)	Y = water use per dwelling unit per day X_1 = assessed value of residence (proxy of income) X_2 = number of persons in the dwelling unit X_3 = price X_4 = the fixed bill for one billing period	Double-Log Summer Winter Total	 -1.07 -0.75 -0.93	 0.51 0.48 0.56	 0.55 0.49 0.56
Morgan (1973)	Cross-Sectional (Santa Barbra County, California, U.S.A.)	Y = domestic water demand per year (during winter months, November-February) X_1 = assessed value of the dwelling X_2 = household size	Linear Double-Log	----- -----	0.53 0.43	0.34 0.29
Willsie and Pratt (1974)	Cross-Sectional (Seattle, U.S.A.)	Y = average water use per person per day X_1 = average income per person per year X_2 = average lot size per capita	Linear	-----	0.8	0.62
Berry and Bonem (1974)	Cross-Sectional (16 cities and towns, New Mexico, U.S.A.)	Y = per capita daily water use (equation no. 5)[4/] X = per capita personal income	Linear	-----	0.882	0.393
Andrews and Gibbs (1975)	Cross-Sectional (Miami, Florida, U.S.A.)	Average Price Model: Y = household water consumption per quarter X_1 = average price X_2 = annual household income X_3 = household size X_4 = percentage of households with hot water heat X_5 = seasonal dummy variable	Exponential	-0.62	0.80	0.46
		Marginal Price Model: Y = household water consumption per quarter X_1 = marginal price X_2, X_3, X_4, and X_5 as above X_6 = zero price shifter	Exponential	-0.51	0.51	0.60
Batchelor (1975)	Cross-Sectional (Malvern, U.K.)	Y = annual per capita water consumption X_1 = net annual value of property X_2 = household size X_3 = house garden dummy X_4 = house age dummy	Linear	-0.23 to -0.28	0.38 to 0.93	----

Table II.1. Summary of Urban Water Demand Studies Based on Cross-Section Data.[1/] (cont'd.)

Investigator	Type of Data and Region Studied	Variables	Type of Model	Price Elasticity	Income Elasticity	R^2
Darr et al. (1975)	Cross-Sectional (Urban metropolitan areas, Israel)	Domestic Demand:	Double-Log			
		Y = domestic per capita per year consumption	Master Meter	-----	0.185 to 0.478	----
		X_1 = monthly income per capita per dwelling unit				
		X_2 = number of persons per dwelling unit				
		X_3 = number of rooms per dwelling unit	Metered	-----	0.221 to 0.582	----
		X_4 = age of the head of the household				
		X_5 = education of the head of the household				
		X_6 = cultural origin				
		Sprinkling Demand:	Linear			
		Y = sprinkling per capita per year consumption	Master Meter	-----	-----	----
		X_1, X_2, X_3, X_4, X_5, and X_6 as above	Metered	-----	0.43 to 0.81	----
		Total Demand:	Double-Log			
		Y = total (domestic plus sprinkling) per capita per year consumption	Master Meter	-----	0.172 to 0.431	----
		X_1, X_2, X_3, X_4, X_5, and X_6 as above				
			Metered	-----	0.178 to 0.603	----
Clark and Asce (1976)	Cross-Sectional (22 communities, U.S.A.)	Y = consumption per capita per day	Linear	-0.63	-----	0.45
		X = price	Double-Log	-0.60	-----	0.38
			Inverse	-0.388	-----	0.38
			Exponential	-0.287	-----	0.39
			Inverse Semilog	-0.171	-----	0.31
Morgan and Smolen (1976)	Cross-Sectional (33 cities in Southern California, U.S.A.)	Y = daily per capita municipal water use (total use)	Linear	-0.44	0.30	0.68
		X_1 = average price				
		X_2 = median family income				
		X_3 = temperature				
		X_4 = precipitation				

Table II.1. Summary of Urban Water Demand Studies Based on Cross-Section Data.[1/] (cont'd.)

Investigator	Type of Data and Region Studied	Variables	Type of Model	Price Elasticity	Income Elasticity	R^2
Morgan and Smolen (1976) (continued)		Y = daily per capita municipal water use (total use) X_1, X_2 as above X_3 = potential evapotranspiration minus precipitation	Linear	-0.54	0.38	0.61
		Y = daily per capita municipal water use (total use) X_1, X_2 as above X_3 = monthly dummy variable	Linear	-0.62	0.35	0.59
Grunewald et al. (1976)	Cross-Sectional (rural areas of Kentucky, U.S.A.)	Y = annual water use per dwelling unit X_1 = average water bill X_2 = mean income per year per household	Double-Log	-0.92	0.18	0.67
		Y and X_1 as above	Double-Log	-0.92	-----	0.67
Clark and Goddard (1977)	Cross-Sectional (22 community water supplies, U.S.A.)	Y = average daily per capita consumption X = price	Linear	-0.63	-----	0.45
			Double-Log	-0.60	-----	0.38
Katzman (1977)	Cross-Sectional (Penang Island, Malaysia)	Y = average monthly consumption X_1 = income dummies X_2 = the number of persons per household X_3 = urban dummy	Linear			
			High Income	-----	0.32 to 0.39	----
			Middle Income	-----	0.24 to 0.30	----
			Poor Income	-----	0	----
Gibbs (1978)	Cross-Sectional (Miami, Florida, U.S.A.)	Average Price Model: Y = quarterly household consumption X_1 = average price X_2 = annual household income X_3 = persons per household X_4 = percentage of homes with hot water heat X_5 = seasonal dummies	Exponential	-0.62	0.80	0.46
		Marginal Price Model: Y = as above X_1, X_2, X_3, X_4, and X_5 are as above X_6 = dummy variable for zero marginal price	Exponential	-0.51	0.51	0.60

Table II.1. Summary of Urban Water Demand Studies Based on Cross-Section Data.[1/] (cont'd.)

Investigator	Type of Data and Region Studied	Variables	Type of Model	Price Elasticity	Income Elasticity	R^2
Camp (1978)	Cross-Sectional (288 consumers in northern Mississippi, U.S.A.)	Y = quantity of water demanded by the domestic user	Equation No. 1	-0.24	0.06	0.60
		X_1 = number of persons per household	Equation No. 2	-0.35	0.13	0.58
		X_2 = age of head of household	Equation No. 3	-0.29	0.02	0.57
		X_3 = market value of residence	Equation No. 4	-0.28	0.06	0.55
		X_4 = lawn area	Equation No. 5	-0.03	----	0.58
		X_5 = number of bathrooms per residence	Equation No. 6	-0.40	0.14	0.57
		X_6 = the numbers of clothes washers per residence	Equation No. 7	-0.33	----	0.56
		X_7 = number of dishwashers per residence	Equation No. 8	-0.29	0.07	0.54
		X_8 = existence of a swimming pool at the residence	Equation No. 9	-0.31	0.0006	0.59
		X_9 = race	Equation No. 10	-0.35	0.10	0.59
		X_{10} = average maximum temperature				
		X_{11} = annual precipitation				
		X_{12} = Price of water				
		X_{13} = educational index				
Foster and Beattie (1978, 1979)	Cross-Sectional (U.S.A.)	Aggregate Model:	Price-Exponential			
		Y = water demand per household per year	(1960 data)	-0.47	0.46	0.55
		X_1 = average water price	(1970 data)	-0.53	0.18	0.58
		X_2 = median household income				
		X_3 = precipitation				
		X_4 = average number of residents per meter				
		Regionalized Model:	Price-Exponential			
		Y = water demand per household per year	(1960 data)	-0.30 to -0.69	0.63	0.74
		X_1, X_2, X_3, X_4 are as above				
		X_5 = region dummies (best fit)				
			(1970 data)	-0.33 to -0.68	0.37	0.71
Male et al. (1979)	Cross-Sectional (6 Eastern States, U.S.A., 1965 and 1970)	Y = quantity of water demanded per household (per meter) per year	Linear	-0.200	0.254	0.50
		X_1 = average water price	Double-Log	-0.680	0.459	0.73
		X_2 = median family income per year	Price-Exponential	-0.368	0.545	0.69
		X_3 = persons per meter				
		X_4 = population density				

Table II.1. Summary of Urban Water Demand Studies Based on Cross-Section Data.[1/] (cont'd.)

Investigator	Type of Data and Region Studied	Variables	Type of Model	Price Elasticity	Income Elasticity	R^2
Hughes (1980)	Cross-Sectional (14 water systems in Utah and Colorado, U.S.A.)	Average Demand: Y = average monthly consumption per connection X_1 = average price X_2 = outdoor use index	Log-Linear	-0.29	-----	0.83
		Peak Month Demand: Y = peak monthly demand X_1, X_2 as above	Linear,	-0.33	-----	----
Foster and Beattie (1981)	Cross-Sectional (218 cities, U.S.A.)	Marginal Price Model: Y = per household demand per year X_1 = median household income X_2 = precipitation X_3 = average number of residents per meter X_4 = marginal price X_5 = expenditure differential	Price-Exponential	-----	0.59	0.49
		Average Price Model: Y = as above X_1, X_2, and X_3 are as above X_4 = average price	Price-Exponential	0.47	0.46	0.55
Ford and Ziegler (1981)	Cross-Sectional (Arkansas, U.S.A.)	Y = water consumption X_1 = average price (the only significant variable in all regions, for the other 17 variables, see Ford and Ziegler (1981), p. 25).	Exponential	-0.85 to -1.61	-----	----
Howe (1982)	Cross-Sectional (21 areas, U.S.A.)	Winter (indoor) Demand Y = water demand per day per household in winter X_1 = property value (as income proxy) X_2 = marginal price in winter X_3 = winter difference variable	Linear	-0.06	-----	----
		Summer (sprinkling) Demand: Y = summer water demand per household per day X_1 = property value X_2 = marginal summer price X_3 = summer difference variable	Linear East West	 -0.57 -0.43	 ----- -----	 ---- 0.84

1/ Y is the dependent variable, Xs are the independent (explanatory) variables.

2/ These results were reported by Baine et al. (1966).

3/ These results were reported by Baine et al. (1966)

4/ Income elasticity was calculated using the corresponding mean values of the reported values in Table II.2. in Berry and Bonem (1974).

Table II.2. Summary of Urban Water Demand Studies Based on Time-Series Data.[1]

Investigator	Type of Data and Region Studied	Variables	Type of Model	Price Elasticity	Income Elasticity	R^2
Headley (1963)	Time-Series (14 cities in the Bay Area, California, U.S.A.; 1950-1959)	Y = water consumption per capita per day X_1 = median family income per year	Linear	-----	0.0014 to 0.404	----
Rees (1971)[2]	Time-Series (Malvern, England)	Y = daily demand per capita X_1 = time X_2 = price X_3 = rainfall	Linear	-0.13	-----	0.96
Wong (1972)	Time-Series (Chicago and Suburbs, U.S.A.; 1951-1961)	Y = average per capita demand per year X_1 = price X_2 = average household income X_3 = average summer temperature	Double-Log			
			Chicago	-0.018	0.195	0.90
			Suburbs	-0.283	0.258	0.76
Young (1973)	Time-Series (Tucson, Arizona, U.S.A.; 1946-1971)	Y = annual water production per active service X_1 = average price X_2 = rainfall	Linear:			
			1946-1964	-0.64	-----	0.56
			1965-1971	-0.41	-----	0.64
			Double-Log			
			1946-1964	-0.60	-----	0.47
			1965-1971	-0.41	-----	0.60
Sewell and Roueche (1974)	Time-Series (Victoria, B.C., Canada; 1954-1970)	Y = annual consumption per customer X_1 = average price X_2 = disposable income X_3 = average temperature X_4 = average rainfall	Linear:[3]			
			Annual	-0.457	0.268	0.79
			Peak	-0.114	0.078	0.76
			Off-peak	-0.586	0.467	0.64
			Mid-peak	-0.269	0.347	0.70
			Double-Log:			
			Annual	-0.395	0.191	0.80
			Peak	-0.065	0.049	0.74
			Off-peak	-0.579	0.504	0.63
			Mid-peak	-0.252	0.277	0.67
Morgan (1974)	Time-Series (Santa Barbra, California, U.S.A.; 1967-1972)	Y = quantity consumed each bi-monthly billing period X_1 = account dummy variable (only for equation 1A) X_2 = seasonal binary variable X_3 = linear trend variable X_4 = precipitation X_5 = price binary variable	Linear			
			Equation 1A	-----	-----	0.70
			Equation 1B	-0.49	-----	0.93

Table II.2. Summary of Urban Water Demand Studies Based on Time-Series Data.[1/] (cont'd.)

Investigator	Type of Data and Region Studied	Variables	Type of Model	Price Elasticity	Income Elasticity	R^2
Katzman (1977)	Time-Series (Penang Island, Malaysia; 1970-1975)	Y = average monthly consumption X_1 = price change dummy X_2 = rainfall X_3 = time trend variable	Linear	-0.1 to -0.2	-----	0.03 to 0.99
Colander and Haltiwanger (1979)	Time-Series (Tucson, Arizona, U.S.A.; 1946-1971)	Y = annual water consumption per active service X_1 = average charges adjusted for fixed charges as price data X_2 = rainfall[4/]	Double-Log			
			OLS	-0.06	-----	0.36
			LS-C	0.016	-----	0.83
		Y = annual water consumption per active service X_1 = estimated commodity charges as price data X_2 = rainfall	Double-Log			
			OLS	-0.05	-----	0.37
			LS-C	0.07	-----	0.84
Billings and Agthe (1980)	Time-Series (Tucson, Arizona, U.S.A.; 1974-1977)	Y = monthly water consumption of the average household X_1 = marginal price X_2 = difference variable (= total bill paid - X_1*Y) X_3 = household income per month X_4 = evapotranspiration minus rainfall[5/]	Linear	ϵ_1 = -0.49 ϵ_2 = -0.14	-----	0.82
			Double-Log	.ϵ_1 = -0.267 ϵ_2 = -0.123	1.68	0.83
Agthe and Billings (1980)	Time-Series (Tucson, Arizona, U.S.A.; 1974-1977)	Y = average household's monthly water consumption X_1 = marginal price X_2 = difference X_3 = household income per month X_4 = evapotranspiration minus rainfall X_5 = lagged Y (except in the static model)[6/]	Static:			
			Linear	ϵ_1 = ...; -0.49 ϵ_2 = ...; -0.14	....; 2.39	0.80
			Double-Log	ϵ_1 = ...; -0.33 ϵ_2 = ...; -0.12	....; 1.70	0.81
			Koyck:			
			Linear	ϵ_1 = -0.36; -0.50 ϵ_2 = -0.11; -0.15	2.07; 2.77	0.83
			Double-Log	ϵ_1 = -0.18; -0.27 ϵ_2 = -0.09; -0.13	1.33; 1.97	0.86
			Flow Adjustment			
			Linear	ϵ_1 = -2.23; -0.67 ϵ_2 = -0.41; -0.12	7.83; 2.36	0.87
			Stock Adjustment			
			Linear	ϵ_1 = ...; -0.71 ϵ_2 = ...; -0.12	....; 2.07	0.87

Table II.2. Summary of Urban Water Demand Studies Based on Time-Series Data.[1/] (cont'd.)

Investigator	Type of Oata and Region Studied	Variables	Type of Model	Price Elasticity	Income Elasticity	R^2
Hansen and Narayanan (1981)	Time-Series (Salt Lake City, Utah, U.S.A.; 1961-1977)	Y = average monthly demand per connection (Model No. 5) X_1 = rainfall X_2 = average temperature X_3 = price X_4 = daylight hours X_5 = nongrowing season dummy[7/]	Double-Log OLS C-O	 -0.466 -0.469	 ----- -----	 0.97 0.97
Billings (1982)	Time-Series (Tucson, Arizona, U.S.A.; 1974-1977)	(Same as in Billings and Agthe (1980) above but different way to calculate the difference variable and marginal price.)[8/]	Linear	ϵ_1 = -0.66 ϵ_2 = -0.075	-----	0.82
			Double-Log	ϵ_1 = -0.56 ϵ_2 = -0.087	2.14	0.81

1/ Y is the dependent variable, and the Xs are the independent (explanatory) variables.

2/ These results were reported by Sewell and Roueche (1974).

3/ Income and price elasticities were calculated using the corresponding mean values of Table II.3. in Sewell and Toueche (1974). OLS is ordinary least aquares. LS-C is least squares corrected for first-order autocorrelation.

4/ The figures in column 7 are for the adjusted R^2 (i.e., $\bar{R}^2$).

5/ ϵ_1 and ϵ_2 are marginal and difference demand elasticities estimates, respectively.

6/ ϵ_1 and ϵ_2 defined as above. For each ϵ_1 and ϵ_2 there are two values in column number 5, the first is a short-run estimates, while the second is a long-run estimate. The values reported in column number 7 are adjusted R^2 (i.e., $\bar{R}^2$).

7/ OLS is ordinary least squares; C-O is Cochrane-Orcutt procedure.

8/ ϵ_1 and ϵ_2 defined as above.

Table II.3. Summary of Urban Water Demand Studies Based on Pooled Cross Section-Time Series Data.

Investigator	Type of Data and Region Studied	Variables	Type of Model	Price Elasticity	Income Elasticity	R^2
Danielson (1979)	Pooled (261 residential households, Raleigh, North Carolina, U.S.A.; 1969-1974)	Total Demand: Y_T = average daily consumption per household X_1 = rainfall X_2 = temperature X_3 = appraised value of the dwelling X_4 = real price of water X_5 = household size	Double-Log	-0.272	0.334	----
		Winter Demand: Y_W = average daily consumption per household during November through April X_3, X_4, X_5 (defined as above)	Double-Log	-0.305	0.352	----
		Summer (Sprinkling) Demand: Y = average daily consumption per household in summer (= $Y_T - Y_W$) X_1, X_2, X_3, and X_4 (defined as above)	Double-Log	-1.38	0.363	----
Carver and Boland (1980)	Pooled (13 water utilities in Washington, D.C., U.S.A.; 1969-1974)	Nonseasonal Model: Y = consumption per day per connection from November-April X_1 = lagged consumption X_2 = real household income X_3 = real price X_4 = average number of residents per connection X_5 = average number of employees per connection X_6 = excess charge dummy (Fairfax County only)[2/]	Flow Adjustment Linear: OLS (w/Y_{t-1}) LSDV(CS) LSDV(TS)	 -0.05; -0.70 -0.02; -0.02 -0.04; -0.62	 ----- ----- -----	 0.97 0.98 0.97
		Seasonal Model: Y = consumption per day per connection in excess of winter water use (May-October) X_1, X_2, X_3, X_4, X_5, X_6 (defined as above) X_7 = moisture deficit	Flow Adjustment Linear: OLS (w/o Y_{t-1}) OLS (w/ Y_{t-1})	 -0.11; ---- -0.10; -0.11	 ----- -----	 0.44 0.45

Table II.3. Summary of Urban Water Demand Studies Based on Pooled Cross Section-Time Series Data. (cont'd.)

Investigator	Type of Data and Region Studied	Variables	Type of Model	Price Elasticity	Income Elasticity	R^2
Hanke and de Maré (1982)	Pooled (69 households in Malmö, Sweden; 1971-1978)	Y = household consumption per semi-annual period X_1 = real household gross income X_2 = number of adults per house, per semi-annual period X_3 = number of children per house per semi-annual period X_4 = rainfall per semi-annual period X_5 = dwelling's age dummy variable X_6 = real price per semi-annual period	Linear	-0.15	0.11	0.26

1/ Y is the dependent variable, Xs are the independent (explanatory) variables.

2/ OLS (w/Y_{t-1}) is ordinary least squares with lagged dependent variables on the right-hand side. OLS ($w/o\ Y_{t-1}$) is ordinary least squares without lagged dependent variable on the right-hand side. LSDV(CS) is least squares with dummy variables for cross-sectional units only. LSDV(TS) is least squares with dummy variables for time-series units only. There are two figures in column number 5, the first is a short-run estimate and the second is a long-run estimate. The figures in column number 7 are for the adjusted R^2 (i.e., $\bar{R}^2$). The pooled time series-cross section model (LSDV(All)) was not reported because price and income elasticities were not calculated.

the United States,[1/] he estimated the relationship between average per capita water consumption and average price per 1,000 gallons. However, he did not calculate, or even mention, the price elasticity of demand for water. Nevertheless, an approximate elasticity could be calculated from his data; the figure was found to be -0.65; indicating a price-inelastic demand for water.[2/]

Seidel and Baumann (1957), in analyzing the 1955 data of 480 U.S. cities, plotted a scatter diagram using the data on use per residential unit and monthly water rates which indicated that there was a negative relation between the two variables. Even though there appears a fitted line in the scatter diagram, the authors did not explain how that line was fitted. Nonetheless, they felt their results did not support the notion that water rate changes play a major role in influencing water use. They said that: "...The authors feel that most rate adjustments are moderate enough and that habits of water use are sufficiently stable to consign the rate factor to a distinctly minor role as an influence on fluctuations in water use" [Seidel and Baumann, 1957, p. 1541]. Moreover, they did not mention the word "demand" or the term "elasticity of demand" when they discussed the relation displayed by the fitted line.

Fourt (1958) conducted what might be the first study to estimate the urban residential water demand per se and at the same time calculated the price and income elasticities. Utilizing cross-sectional data for 1955, he estimated these elasticities to be -0.39

1/ Cross-sectional data refer to activities of an individual economic unit (e.g., family, firms, individual, state, etc.) for a given time period [Hu, 1982].

2/ This figure was reported by Bain et al. (1966).

and 0.28, respectively. He was a pioneer in introducing more explanatory variables than average price in the estimation of water demand.

Gottlieb (1963) confirmed the earlier findings of a negative relationship between water consumption and price. Using cross-section data for Kansas, U.S., he estimated the price and income elasticities of demand (aggregate demand) to be in the ranges of -0.65 to -1.28 and 0.28 to 0.58, respectively.

Headley (1963) was the first to use two separate sets of data, time-series and cross-section,[3/] for the same region, the San Francisco-Oakland metropolitan area, to estimate the demand for urban water (residential and commercial, taken collectively). He specified the quantity of water demanded as a function of income only, treating other variables as constant, thus generating Engel relationships. He was also the first to compare two different models, linear and double logarithmic, using the same data, namely, the cross-section data. The income elasticities of demand estimated with the cross-sectional data were 1.49 and 1.24 for 1950 and 1959, respectively using the linear model, and 1.63 and 1.37 for 1950 and 1959, respectively using the double logarithmic model. The time-series linear model yielded an estimated income elasticity of demand in the range of 0.0014 to 0.40, which is smaller than the cross-sectional estimates. However, the author did not offer any explanation for this, i.e., the cross-sectional elasticity estimates being greater than the time-series estimates. Nonetheless, he

3/ Time-series data refer to the data taken at many points of time (weekly, monthly, quarterly, or annually) for the same economic unit [Hu, 1982].

concluded that "water demands to be expected by the addition of a city or subdivision to the system might best be estimated by use of the cross-sectional elasticity . . . (and) increases in demands over time would best be estimated by use of the time series elasticity."

Gardner and Schick (1964) estimated the urban water demand (aggregate) to be affected by average price and per capita lot size (i.e., average land area associated with private residences). Employing cross-sectional data on six northern Utah counties, they estimated the price elasticity of demand to be -0.77 (using a double logarithmic model).

The most comprehensive and most often cited study was carried out by Howe and Linaweaver (1967). Using the massive quantity of data collected by the Department of Environmental Engineering Science at Johns Hopkins University during the period 1961-1966 [Linaweaver, 1966], the study was the first to estimate domestic (indoor, or winter), and sprinkling (outdoor, or summer) demand for residential water, as well as total demand (see the accompanying Table II.1). The researchers showed the domestic demand for residential water to be less price and income elastic than the sprinkling demand, where the estimated price and income elasticities were -0.214 and 0.352 for the domestic demand, and -0.70 to -1.57 and 0.429 to 1.45 for the sprinkling demand, respectively.

The empirical results obtained by Wong (1972), who utilized separate cross-section and time-series data to estimate the municipal demand for water, confirmed the conclusion drawn by Headley (1963) that both the price and income elasticities estimated from cross-section data are greater than those estimated from time-series data.

However, the author did not explain this "phenomenon" other than saying that "the constant price and income elasticities in the cross-sectional analyses were more clear-cut than those results of the time-series analyses." Explaining the low price elasticity for Chicago, calculated from time-series data, as a result of the extremely low price of water in Chicago during the study period (22 cents per 1,000 gallons in 1961), he recommended that "It seems desirable that, if urban water consumption for Chicago is to be reduced, that the flat rate pricing policy of water be reformed" [Wong, 1972, p. 44].

Sewell and Roueche (1974) estimated the demand for urban water in Victoria, British Columbia (Canada) using time-series data. Four demand functions, namely, peak (summer), off-peak, mid-peak, and annual, were estimated using double logarithmic (log-linear) and linear models. The estimated price and income elasticities were -0.065 and 0.049 (peak), -0.579 and 0.504 (off-peak), -0.252 and 0.277 (mid-peak), and -0.395 and 0.191 (annual) using the double logarithmic model. With the linear model, the corresponding estimates were[4/] -0.114 and 0.078, -0.586 and 0.467, -0.269 and 0.347, and -0.457 and 0.208. The researchers were surprised to find out that price had no effect on peak (summer) demand in both models. Another unexpected result was that the estimated off-peak (winter) price elasticities are higher than the peak (summer) price elasticities which the authors interpret to be opposite to the findings of Howe and Linaweaver (1967). The researchers attributed

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4/ The elasticities for the linear model were calculated using the mean values of the corresponding variables from Table III in Sewell and Roueche (1974), p. 394.

this to two factors influencing the peak (summer) demand for water in Victoria. The first is the large tourist trade, and second is the "green lawn syndrome," i.e., the preference of residents in Victoria for green lawns and plants. These two factors were fostered with the declining block water rate scheme that was in effect.

Research by Turnovsky (1969), Wong (1972), Grima (1973), Morgan (1973),[5/] Willsie and Pratt (1974), Batchelor (1975), Darr, et al. (1975), Andrews and Gibbs (1975), Clark and Asce (1976), Morgan and Smolen (1976), Grunewald, et al. (1976), Katzman (1977), Gibbs (1978), Camp (1978), Foster and Beattie (1977, 1979, 1981), and Howe (1982) has been remarkably consistent in their results which, using cross-sectional data and different models and explanatory variables, show the estimated price elasticity of demand for urban water to be less than $|-1.00|$ (except Grima (1973), who found it to be -1.07 for summer demand), and the estimated income elasticity of demand to be less than 0.82. These findings are similar to the earlier Howe and Linaweaver (1967) results.

However, water consumption is affected by, among other things, weather conditions. Even though researchers used weather variables such as temperature and rainfall as early as 1958, it was Morgan and Smolen (1976) who tested three weather variables and found that use of temperature and rainfall as weather variables led to results with fewer statistical difficulties than characterized the model using only potential evapotranspiration minus precipitation, the third tested weather variable.

[5/] Danielson (1979) inadvertently cited this study as a time-series study.

Even though there was only one time-series study cited by Wong (1972), the number increased considerably in the following two decades. This permitted researchers to compare the elasticity estimates computed from models using cross-sectional and time-series data. Studies like those of Rees (1971), Wong (1972), Young (1973), Morgan (1974), Pope, et al. (1975), Dar, et al. (1975), Katzman (1977), Colander and Haltiwanger (1979), Billings and Agthe (1980), Hansen and Narayanan (1981), and Billings (1982) which employed time-series data, when compared to other cross-section studies, confirm the conclusion Headley (1963) drew twenty years ago: that cross-sectional estimates of the income and price elasticity of urban water demand are greater than those obtained using time-series data.

One interesting question pertains to the appropriate measure of the price of water, as water is generally, at least in most of the U.S., sold under a multi-part pricing arrangement, often involving a fixed fee per time period plus charges per unit of water "consumed." Researchers have disagreed on whether the average price or the marginal price is the appropriate price variable to be used in the demand function. Conley (1967) found that "... the coefficients on the marginal prices of water were not only insignificant, but had a positive sign. Thus ... marginal prices are poor predictors. The average indicator is much better" [Conley, 1967, p. 181].

However, Andrews and Gibbs (1975) and Gibbs (1978)[6/] demonstrated the superiority of marginal price over average price on both statistical and theoretical grounds, just the opposite to what Conley (1967) found.

An alternative procedure involving two price-related variables was suggested by Taylor (1975) and modified by Nordin (1976) in the case of estimating the price elasticity of electricity demand with declining block rates. Those two variables were marginal price (P) and a "difference" variable (D) equal to the total bill paid minus marginal price times quantity consumed. This (D) variable, then, represents that portion of "consumer surplus" extracted via the multi-part pricing arrangement.[7/] Nordin [1976, p. 421], says that: "the coefficient on (D) should be equal in magnitude, but opposite in sign, to the coefficient on income."

Utilizing Taylor's (1975) and Nordin's (1976) findings, Billings and Agthe (1980), using time-series data, and Howe (1982), using cross-section data, were able to estimate coefficients on (D) and income variables whose signs were opposite but whose magnitudes were unequal. Foster and Beattie (1981b), on the other hand, could not come up with the opposite sign requirement and argued that, for nonlinear models, the equal magnitude requirement does not apply to the coefficients. Using a model that includes only the average price variable, they concluded that "the empirical results tend to indicate that the average price model provides the best model specification

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6/ The latter's data sources and results were identical to the former but under different title and objective.

7/ Consumer surplus is defined as the area below the demand curve and above price.

of residential demand for urban water supplies given the aggregate nature of this data set" [p. 628]. This conclusion is opposite to that drawn by Andrews and Gibbs (1975) and Gibbs (1978) which employed micro-data[8/] compared to the aggregate data used by Foster and Beattie (1981b). Meanwhile, Howe (1982) was the only researcher who explicitly questioned the "equal magnitude" requirement and cited the results of other researchers who employed this technique but failed to meet the "equal magnitude" requirement.[9/] However, Howe (1982) did not give any explanation for his dissatisfaction with that requirement other than his assertion that "the value of (D) will be positive for decreasing block rate structures and negative for increasing block structures."

Trying to avoid the systematic bias resulting from measurement errors in water consumption (Q) when calculating the values of marginal price (P) and the difference variable (D), and drawing on the work by Taylor, et al. (1981), Billings (1982) calculated P and D as the slope and intercept respectively, of a function resulting from regressing total revenue against the corresponding quantity. However, he was only able to satisfy the "opposite sign" requirement, and did not give any explanation for why he was not able to generate equal coefficients for D and income.

8/ The data consisted of quarterly figures from a sample of 355 households in Dade County, Miami, Florida.

9/ The Foster and Beattie (1981b) argument about the equal magnitude requirement was less explicit and they did not cite, as Howe (1982) did, other work or explain why the equal magnitude requirement does not apply to the coefficients for nonlinear models.

When conducting demand analysis using time-series data, the researcher will most likely have to address the issue of short-run and long-run relationships, especially when calculating elasticity estimates. However, this issue was not addressed extensively in the area of urban water demand estimation. Only two studies, namely Agthe and Billings (1980) and Carver and Boland (1980), estimated the short and long run income and price elasticities. They did so by including the dependent variable lagged one time period as an explanatory variable in the demand function. Both studies reported greater income and price elasticities in the long run than in the short run. In other words, urban water demand is more elastic, with respect to price and income in the long run than in the short run.

Danielson (1979), Carver and Boland (1980), and Hanke and deMaré (1982) pooled cross-section and time-series data to estimate residential water demand (Table II.3). Comparing the cross-section, time-series, and pooled studies to each other indicates, to some extent, that the estimated price and income elasticities obtained from pooled data were smaller than those from cross-section data but somewhat comparable to those from time-series data. However, this comparison is not as clear-cut as that between cross-section and time-series studies due to the small number of studies incorporating pooled data (only three studies were cited). These studies, except Hanke and deMaré (1982), did not explain the advantages and disadvantages of using pooled data. Moreover, they reported their results about the elasticity estimates without explaining whether they were short-run or long-run estimates, a problem associated with the interpretation of the function estimated from pooled data, Koutsoyiannis (1977); since cross-section estimates are long-run whereas time-series estimates are short-run estimates.[10/]

Looking at Tables II.1-II.3, one notices that the number of studies on urban water demand estimation in the United States is apparently much larger than those conducted in any other country. In fact, there were cited only seven studies conducted outside the United States, and only one of them, Katzman (1977), pertained to a developing country, Malaysia; the others were for Canada, Grima (1973) and Sewell and Roueche (1974); the United Kingdom, Rees (1971) and Batchelor (1975); Sweden, Hanke and deMaré (1982); and Israel, Darr, et al. (1975).

As Batchelor (1975) mentioned, when comparisons are made, one should keep in mind "the possibility of inter-country differences in the composition of household water demands." Income and price elasticity estimates in the Canadian studies (except Sewell and Roueche (1974)) compare very well to the United States figures, of Howe and Linaweaver (1967), except that the estimated price elasticity of the annual demand in the Grima (1973) study was double that of the United States demand. In Malvern, U.K., Batchelor (1975) attributed the smaller income elasticity estimates, as compared to the U.S. case, to the higher living standards of the American household samples. Darr, et al. (1975), in Israel, found that the income

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10/ Recall that in a cross-section sample it is assumed that all consumers, in case of water for instance, are homogeneous except for factors appearing in the cross-section function; whereas in a time-series sample it is assumed that the various time periods are homogeneous except for factors appearing in the function [Koutsoyiannis, 1977, p. 405].

elasticity estimate for the total household demand for water (metered) in Tel Aviv and suburbs was smaller than those found in the U.S. In Malmö, Sweden, Hanke and deMaré (1982) found the estimated price and income elasticities were lower than those in the U.S. estimated using the same kind of data they employed, pooled data.

The only study conducted in a developing country, namely, Penang Island, Malaysia, Katzmann (1977) found the income elasticity of demand to be zero for low-income families (per capita annual income less than $300) and 0.2 to 0.4 for higher-income families. Only the latter figures were consistent with the U.S. figures (e.g., Howe and Linaweaver, 1967; Wong, 1972; Morgan, 1973). Price elasticities, on the other hand, estimated using time-series data to be -0.1 to -0.2 were also consistent with U.S. time-series studies' results (e.g., Gottlieb, 1963; Wong, 1972; Young, 1973).

It appears then that there are some consistencies in water demand across countries. The foregoing discussion has focused on estimated income and price elasticities of demand. The studies reviewed have used a variety of functional forms and explanatory variables, however, as revealed by Tables II.1-II.3.

In summary, the area of urban water demand estimation has improved considerably since Metcalf (1926) wrote his paper. Among the variables that have been found to be significant are the price of water (average and marginal), and household income, which have been the focus of this review.[11/] Other variables not discussed here but

11/ Some researchers used property value as a proxy for household income.

found to be important (see Tables II.1-II.3) include: age of the head of the household, education level of the head of the household, number of persons per dwelling, number of rooms per dwelling, number of bathrooms per dwelling, number of washers and/or dishwashers per dwelling, age of the dwelling, irrigable area per dwelling, lot size, precipitation, number of days of rainfall, temperature, and evap-transpiration. Most of the studies utilized cross-sectional data. Several used time-series data and a few used pooled cross-section time-series data. Income elasticity estimates from time-series studies (except Billings and Agthe, 1980; Agthe and Billings, 1980; and Billings, 1982), as well as price elasticities estimates were smaller than those from cross-section studies, but comparable to those from studies using pooled data.

Economists have long distinguished two demands for water: summer (sprinkling or outdoor), and winter (domestic or indoor) demand. In all of these studies summarized in Tables II.1-II.3, the estimated price elasticity of winter demand was less than $|-0.4|$, indicating an inelastic winter (domestic) demand; that is, the percentage quantity demanded changes less than a given percentage change in price. The summer (sprinkling) demand, on the other hand, was found to be more price elastic and sometimes it was estimated to have a price elasticity of greater than $|-1.0|$.

Single equation models were the only models utilized in urban water demand studies cited in Tables II.1-II.3. The functional forms most frequently used were the linear and double logarithmic (log-linear), with the latter being more popular for its simple configuration of the elasticities.[12/]

12/ The use of a single equation to estimate the demand for urban water (or any demand or supply in general) might be susceptible to the identification problem, an issue which was raised by Griffen, et al. (1981) in their comment on the work by Foster and Beattie (1979). However, this problem was nonexistent [Howe and Linaweaver, 1967, p. 21] or, at most, not serious [Foster and Beattie, 1981, p. 260] when estimating the demand for urban water.

CHAPTER III

THEORETICAL FRAMEWORK

Introduction

In empirical demand analysis the economist is interested, first, in estimating a demand equation, then using this equation to calculate elasticities and to make predictions or draw some policy inferences concerning the commodity or service under investigation. Often this part of the analysis involves testing of hypotheses pertaining to the nature of demand (e.g., its price or income elasticities) and/or the impact of alternative policies on prices and consumption.

Economic theory, especially the theory of consumer demand, provides the foundations the economist uses in building and analyzing a demand model. It is useful in formulating hypotheses relating to the model. Economic theory, for example, postulates that the quantity and price of a commodity or service are inversely related, implying that the demand curve for such a commodity is negatively sloping.[1/] This means that, ceteris paribus, as the price of the commodity or service increases, the quantity demanded will decrease, this is known as the Law of Demand in economics.

1/ This discussion holds for normal and inferior goods but not for a Giffen good, where the demand curve would be positively sloping due to the income effect being greater than the substitution effect. For more discussion on the subject see Henderson and Quandt [1980], pp. 25-30.

Economic theory also provides some guidelines for the selection of variables that might affect demand, and in turn should be considered as prime explanatory variables in the demand equation. A demand equation is defined as a functional relationship between the quantity demanded of a commodity or service in question, i.e., the left-hand side, and one or more variables, i.e., right-hand side or explanatory variables. As indicated above, some of these explanatory variables are suggested by economic theory, e.g., price of the commodity in question, price(s) of substitute(s) or complement(s), per capita income, etc.; and some are brought in from empirical work by others or are new variables whose relevance the economist wishes to test. In econometric analysis, where functional forms are specified and parameters estimated, economists add one more variable to the right-hand side: an error (disturbance) term. The inclusion of this variable is aimed at capturing the effects of any variable(s) not explicitly included as well as errors in measuring the dependent variable(s).[2/]

Let's clarify the picture by taking an example of estimating the demand for a hypothetical commodity, call it i.

2/ Note that when there exists errors in measuring the independent variables, then using ordinary least squares estimation (OLS) will yield biased and inconsistent estimates. See Johnston [1972], pp. 281-291.

Theoretically, a specific functional form of the following equation can be estimated as a first approximation of the demand equation:[3/]

$$q_{it} = f_i(P_{it}, Y_{it}, Z_{1t}, Z_{2t}, \ldots, Z_{nt}, U_{it}) \qquad \text{(III.1)}$$

where

q_{it} = per capita consumption of commodity i in time t, $t=1,2,\ldots,T$.

f_i = some function whose exact mathematical form is to be specified.

P_{it} = price of commodity i in time t (usually deflated by some price index).

Y_{it} = per capita income in time t (usually deflated by some index).

$Z_{1t}, Z_{2t}, \ldots, Z_{nt}$ = other factors hypothesized to affect demand in time t.

U_{it} = error (disturbance) term which captures the effect of variables not explicitly included as well as errors in measurement in q_{it}.

Among the explanatory variables, $Z_{1t}, Z_{2t}, \ldots, Z_{nt}$, may be variables suggested by economic theory, such as prices of substitutes or complements, lagged values for P_{it}, Y_t, or q_{it}, a time trend, and other factors postulated to affect the quantity of commodity i demanded.

[3/] A time series example is being explained.

In general, the process through which a demand equation is estimated may be best summarized by Ferber and Verdoorn [1962] who list four distinct steps:

"1. Specification of a set of hypotheses purporting to explain the (one or more) phenomena being studied.
2. Translation of these findings into a form amenable for testing, usually into mathematical equations, and for identification of the individual relations.
3. Estimation of the parameters of the model.
4. Evaluation of the adequacy of the model and of the underlying assumptions and hypotheses, generally by empirical tests." [Ferber and Verdoorn, 1962, p. 403].

The next section will review the different approaches that have been employed in estimating the municipal (urban) demand for water.

Approaches to the Estimation of Municipal Demand for Water

It is important to point out that estimating the demand for water is different than for other commodities in the marketplace. Water is generally sold by a single supplier while other commodities are sold by many suppliers. Water has a different market structure and, thus, different issues in estimating demand for water will be encountered. Another issue contributing to this "uniqueness" is the nature of the water utility (supplier), i.e., its being publicly owned in most cases.

In estimating the municipal demand for water, engineers have long used what is called the "requirements (needs) approach," or what Hanke [1978] called "supply management." However, during the last two or three decades, another approach, called "the demand approach" or "demand management" was advanced by economists. Howe and Linaweaver [1967] were among the pioneers in applying this approach. Each of these approaches is examined next.

The Requirements Approach

In this approach, estimates of future water use (demand) are derived by multiplying the projected population of the service area by the estimated average per capita water use. Thus, if n_t is the expected population figure in time t for the service area in question, and q is the estimated per capita water use; then the expected water "requirements" (use) in time t, Q_t, is given by

$$Q_t = n_t * q \qquad \text{(III.2)}$$

From an engineering perspective, this approach will predict the amount of water needed in time t, given that the expected population figure is correct and all other conditions remain unchanged. However, economists disapprove of this method primarily because the requirements approach ignores the effect of price, income and other variables on the amount of water "required."

The "requirements approach" may yield satisfactory results if one or both of the following assumptions holds (given stable taste and preference):

1. Constant price of water over the projection period.
2. Perfectly inelastic water demand, i.e., the quantity of water demanded is independent of price (i.e., vertical demand curve).

If one talks about the nominal price, it is very difficult to defend the first assumption in these days of double digit inflation rates almost everywhere in the world; however, the real price could be constant or even fall over time. Underlying this assumption is, probably, the additional assumption that, because of institutional rigidities, the supply of water is perfectly price-elastic. This assumption is difficult to defend, however. When water consumption in a specific area increases, the water utility might find it difficult to meet the increase in consumption from existing sources and, therefore, may have to look for other sources of water. This might result in an increase in water costs and, subsequently, prices to consumers. Two examples support this. The first is the pumping of water from the Colorado River to Southern California to meet the increased water demand; the second is the use of desalination plants in the Arabian (Persian) Gulf countries (excluding Iran and Iraq) which was dictated by rapidly increasing water consumption due to rapid development and very limited fresh water sources. In these examples, water prices did increase.[4/] Therefore, the assumption of constant water prices is difficult to accept under the existing circumstances.

4/ However, in the latter case, prices were kept quite low, and sometimes free, through massive government subsidies. In fact in these countries the "real" price of water has been declining in recent years.

The second assumption — that of a perfectly inelastic water demand, has even less chance of being accepted by economists. By showing the existence of a negative relationship between the quantity of water consumed and the price of water, Fourt [1958] and researchers thereafter[5/] were able to refute the perfectly inelastic water demand assumption on empirical grounds. Therefore, the widely used "requirements" approach may yield inaccurate predictions.

Thus the inaccuracy of the "requirements" approach is based on the following factors:

1. It ignores the role of the price of water by assuming its constancy over time, an assumption proven to be invalid. Use of this assumption to make investment decisions may yield an excess capacity or shortage. To see this, consider Figure III.1. Assume the demand for water is given by D_oD_o. Assume also that the water supplying utility uses an average cost pricing scheme, discussed in the next section, and that the utility is facing increasing average costs. Under these circumstances, the initial equilibrium position is given by P_o and Q_o for price and quantity, respectively. Now, suppose the utility forecasts the amount of water needed at time t to be OQ_t, using the requirements approach which assumes that price

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5/ Hanke and Boland [1971] addressed this issue very explicitly.

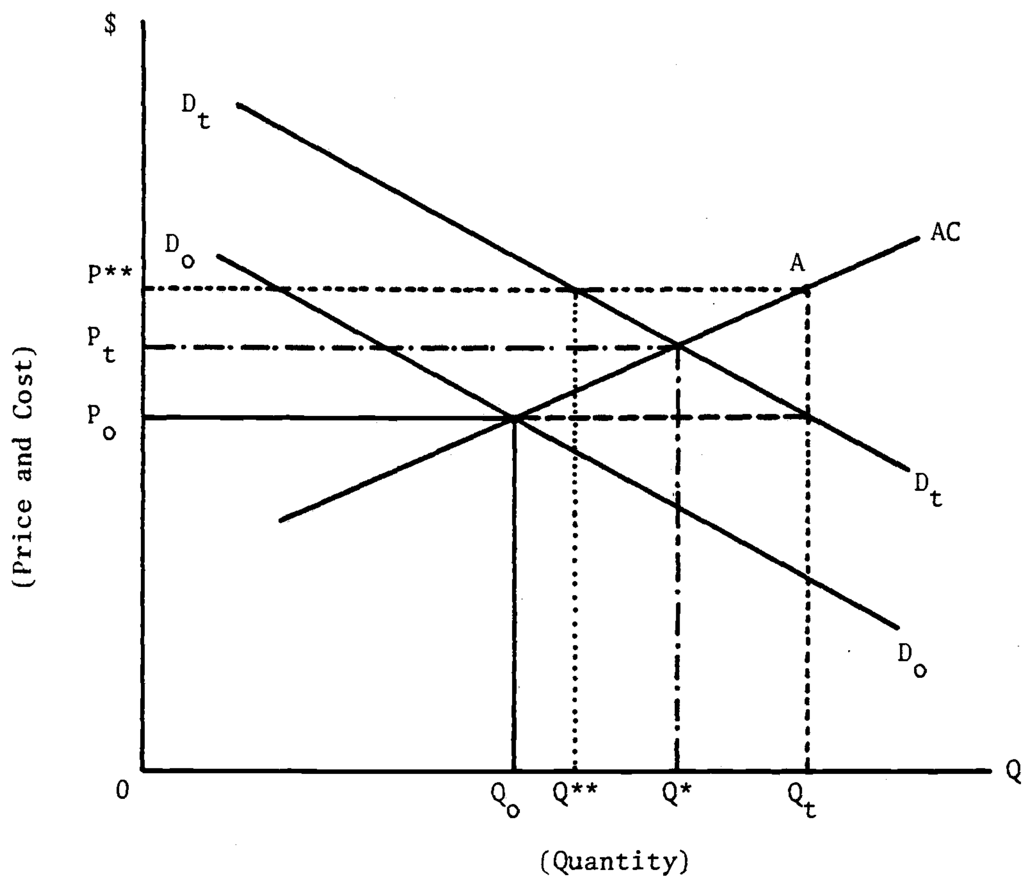

Figure III.1. The Requirements Approach With "Excess Capacity."

P_o will prevail in time t. This would imply a shift in the demand curve from D_oD_o to D_tD_t, which may dictate the need to build additional facilities capable of supplying the amount Q_oQ_t. However, the increase in demand to D_tD_t would result also in an increase in price from P_o to P_t, given the existence of an increasing average cost schedule, and therefore, the quantity demanded at the time t would be OQ*, which is less than the requirements approach figure of OQ_t. Thus, there will exist an excess capacity of the amount supplied equal to Q^*Q_t.[6/] Figure III.2 shows a situation where the requirements approach results in a shortage of the amount Q_tQ^* in the case of a decreasing average cost schedule.

2. The requirements approach also ignores other important variables such as per capita income, weather variables (e.g., temperature, rainfall, evapotranspiration), socio-economic variables (such as education, age, ...) and others which have been shown to be significant in affecting the quantity of water demanded. Possible changes in any of these variables should be considered when estimating or projecting the demand for urban water.

[6/] In fact, consumption may be less (implying even greater excess capacity) and price higher than above. The reason is that by increasing capacity to supply OQ_t, the utility will ask P**, using average cost pricing; however, it realizes that it can sell only OQ** at that price, given demand D_tD_t which is less than OQ_t above. The higher price, P**, is a result of a higher average cost associated with supplying only OQ** due to the under-utilized capacity.

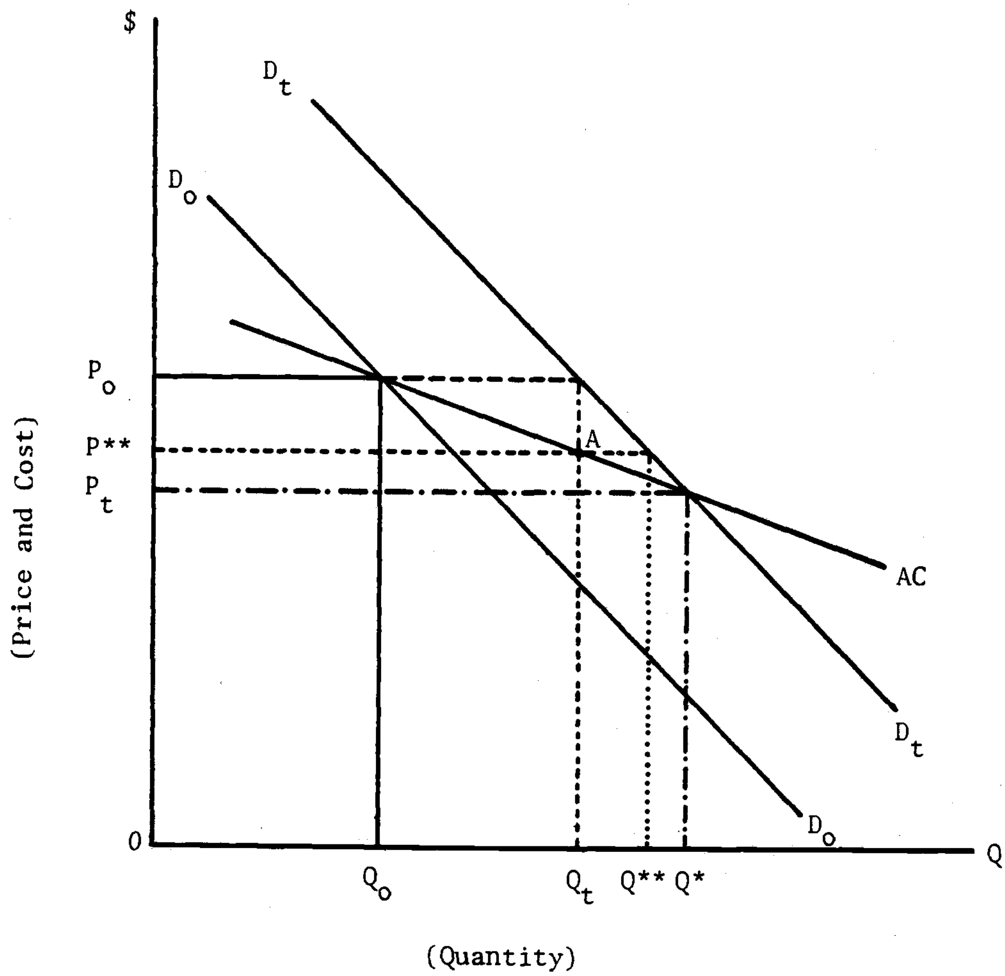

Figure III.2. The Requirements Approach With "Shortage."

The Demand Approach

As stated above, this approach is based on the Law of Demand in economic theory. Since the requirements approach was defended in part by such philosophies as: "water-is-different," "magic-of-water," and "water is cheap at any price,"[7/] economists have first had to challenge these philosophies in order to defend their approach. That is, they have had to show that water is not different from other commodities in the sense that it follows the law of demand.

It is true that water is very essential for living. However, so are food, shelter, and clothing. Therefore, water should not be treated differently than other essential commodities, and in turn, the law of demand should govern its trading in the market place. Hence, price should be a prime factor affecting the quantity of water demanded as should other variables that have been shown empirically to be significant (see Chapter II).

Accordingly, the demand approach does utilize the price of water, which is ignored in the requirements approach, along with other variables when forecasting the amount of water that will be demanded at some date in the future.

Municipal Water Pricing

Public utilities such as water, electricity, and transportation are called "natural monopolies" in economic theory. They are

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7/ These philosophies support the exclusion of price when estimating water needs because water is so essential to life that it should not be treated like other goods. See Milliman [1963], and Warford [1966].

monopolists in the sense that there is only one utility that provides a specific service, but they differ from pure monopolies in the sense that they cannot change rates without the approval of the government. The monopoly status of water utilities is mainly due to technical limitations on rivalry in distribution, Hyle [1971]. It is difficult to imagine how the situation would be if more than one water utility competed for delivering water with each having to set its complete system from storage facilities, filtration and pumping stations to water mains and meters. Reasons for establishing publicly, as opposed to privately, owned water systems include the monopoly status of the service, the importance of water in public health and sanitation, fire protection, and development.

Historically, publicly owned or regulated water utilities have priced water on the basis of the "cost of service" principle. That is, water was priced such that the generated revenues are approximately equal to the cost of providing water. In other words, the price of water is set equal to the average cost of service, i.e., average cost pricing. Economists generally argue that marginal cost pricing is more efficient in allocating scarce water supplies.[8/]

8/ Let AC be average cost; MC, marginal cost; D, demand; and MR, marginal revenue. The perfect competition solution (P = MC) yields quantity Q_M at price P_M; the monopoly solution (MC = MR) yields quantity Q* at price P*; the natural monopoly solution (P = AC) yields quantity Q_A at price P_A. Notice that the

In order to better understand water pricing methods, an understanding of the variables that affect water prices, and the difference between average cost pricing and marginal cost pricing is necessary. First, however, it is helpful to identify those variables which may affect the costs of producing and delivering water, and therefore, water prices.

Variables Affecting Water Prices[9/]

As discussed above, water prices are often based on the costs of producing and delivering water to consumers. Therefore, the factors that may affect the production and/or delivery of water will certainly affect what one pays for water service, i.e., water price. Howe and Linaweaver [1967] estimated that, in the eastern United States, production (source of supply, transmission, treatment, distribution to pumping stations and major feeder mains) and distribution (local distribution mains,

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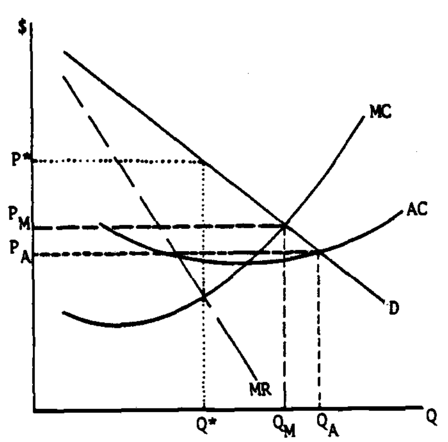
monopolist does not have a supply schedule. It selects a point on the demand curve that will equate its MC with MR and charges the resulting price for the corresponding quantity. For more discussion see Hirshleifer [1980], p. 348



9/ For more discussion on the subject, see Reiter [1977].

connections, and local storage) of water each account for approximately 50 percent of total water system costs.[10/]

The following factors are expected to affect the final figure the consumer pays for water service:

1. Location of supply. The closer the water sources to the public utility the lower the costs of water.
2. Topography. The greater the range in elevation the higher the costs of delivering water due to more pressure being needed.
3. Customer density. The more consumers concentrated in an area the lower the unit cost of water, other factors being the same.
4. Water quality. The higher the quality, in terms of purity and sterility, the higher the cost of water.
5. Quantity. The larger the public utility, the lower the costs of water, assuming increasing returns to scale (i.e., economies of scale) exist.[11/]
6. Inflation and energy costs. The higher the inflation rate and energy (real) prices, the higher the costs of supplying water.

10/ However, the sources of water in these eastern states do not involve any desalination of sea water which, under the existing technologies, would increase the production costs to more than 50 percent of the total water system costs, which is the case in Kuwait.

11/ Increasing returns to scale means that as the utility expands production, the per unit production cost decreases.

7. Source of water supply. Assuming quality is the same, supplying water from surface sources is less costly than from ground sources and this is less costly than desalinating sea water.
8. Weather. The colder the area the more costly it is to supply water due to the need for protecting water from freezing which might destroy water mains and pipes.
9. The existence of storage tanks on the customers' premises reduces the need for constant water pumping by the utility, and therefore, reduces water costs.[12/]

Average Cost and Marginal Cost Pricing: A Comparison[13/]

For simplicity of discussion, assume that the customers of a single, water-supplying utility are homogeneous, i.e., they have identical preferences and budgets. This assumption will make easier the calculation of total costs and total revenue of the service. In Figures III.3-III.5 there are three curves:

12/ In fact, in some countries (e.g., Kuwait, Saudi Arbia) the household must have at least one tank on the top of his home to store enough water for one day since the utility pumps water at low pressure not enough to deliver water through the home's fixtures or pumps water for only a short time during any given day. (In some cities of Saudia Arabia the utility pumps water for few hours once a week; therefore, households are forced to build larger storage tanks, usually two, one underground, the other on top of the dwelling.)

13/ For more discussion on the subject, see Hirshleifer et al., [1969], Ch. 5.

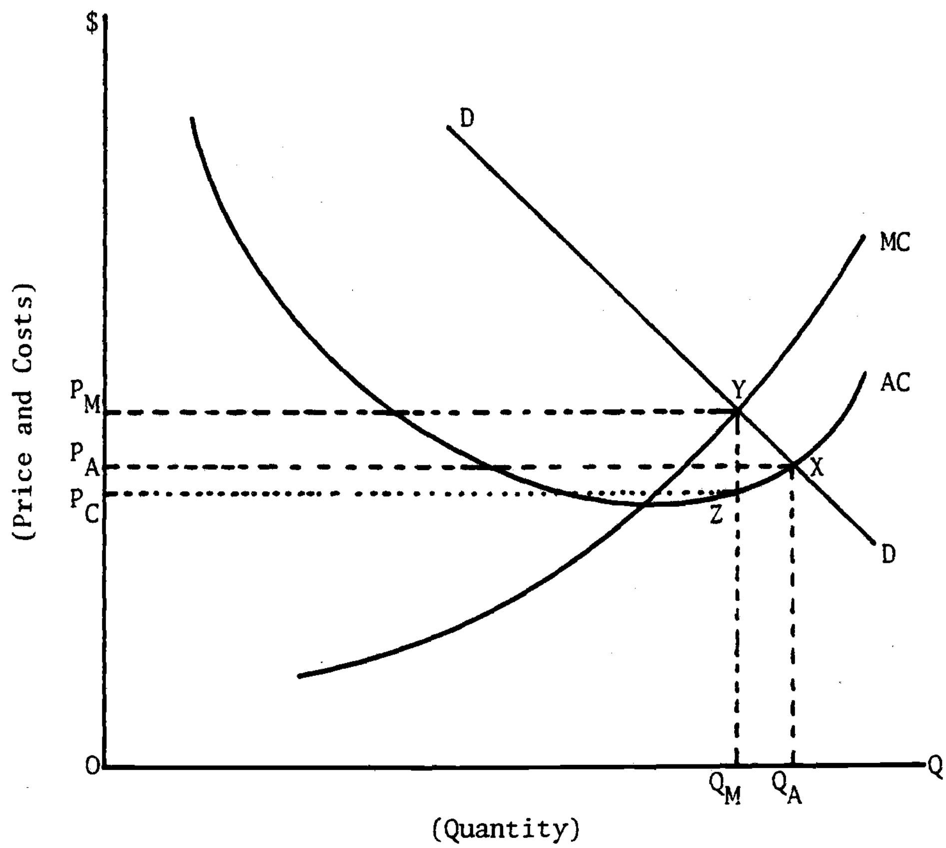


Figure III.3. Average cost vs. marginal cost pricing: increasing average cost.

average cost (AC) and marginal cost (MC) of supplying water, and the demand for water by the customers of the utility under investigation (DD). The three figures represent different assumptions about the relationships of these curves to each other.

Consider the first case, Figure III.3, where the utility faces an increasing average cost schedule. Average cost pricing calls for equating average cost to demand price. This results in the quantity OQ_A being demanded at price $OP_A = Q_AX$, the corresponding average cost.

Economic theory tells us that when price equals average costs, profits will be zero and social efficiency is not achieved (unless AC = MC = P). For social efficiency, i.e., the best use of society's resouces, price should equal marginal cost, not average cost [Layard and Walters, 1978]. Thus, setting marginal cost (MC) equal to demand price will result in quantity OQ_M being demanded at price $OP_M = Q_MY$, the corresponding marginal cost. It is this quantity, OQ_M, and price, OP_M, that will yield a socially efficient solution, i.e., the best use of society's resources, not those which result from using average cost pricing. This is because for each unit between OQ_M and OQ_A the additional cost of supplying each unit, i.e., MC is greater than the amount the consumer is willing to pay for the extra unit (represented by the portion XY of the demand curve DD). This means that there are alternative uses for the resources used in producing this extra quantity, Q_MQ_A, which consumers value more, as reflected by the marginal cost curve MC being higher than (above) the demand curve DD in that range (XY). Thus, in the case of an increasing average cost schedule, marginal cost pricing is superior to average cost pricing since it leads to a socially efficient solution.

It is clear from Figure III.3 that there exists a profit when average cost curve is increasing when it intersects the demand curve. For at output OQ_M the price OP_M is greater than the corresponding average cost Q_MZ, implying that there exists a profit of ZY per unit of output OQ_M. This implies that total profit from selling OQ_M at price OP_M is given by the area P_CP_MYZ.

However, a problem does exist for marginal cost pricing when the utility faces a decreasing average cost schedule, a case common in water utilities. Such a situation is depicted in Figure III.4. Here the intersection of the demand curve DD and the average cost curve AC occurs in the declining portion (range) of the latter. The marginal cost pricing method will result in output OQ_M and price OP_M. At this output level, OQ_M, average cost, Q_MZ, is greater than marginal cost, Q_MY; which implies that by selling OQ_M at price OP_M the utility would experience a loss represented by the area P_CP_MYZ. Average cost pricing, on the other hand, will result in output OQ_A, smaller than OQ_M, and price OP_A, higher than OP_M, which would yield neither social efficiency nor profit but won't yield any losses either.

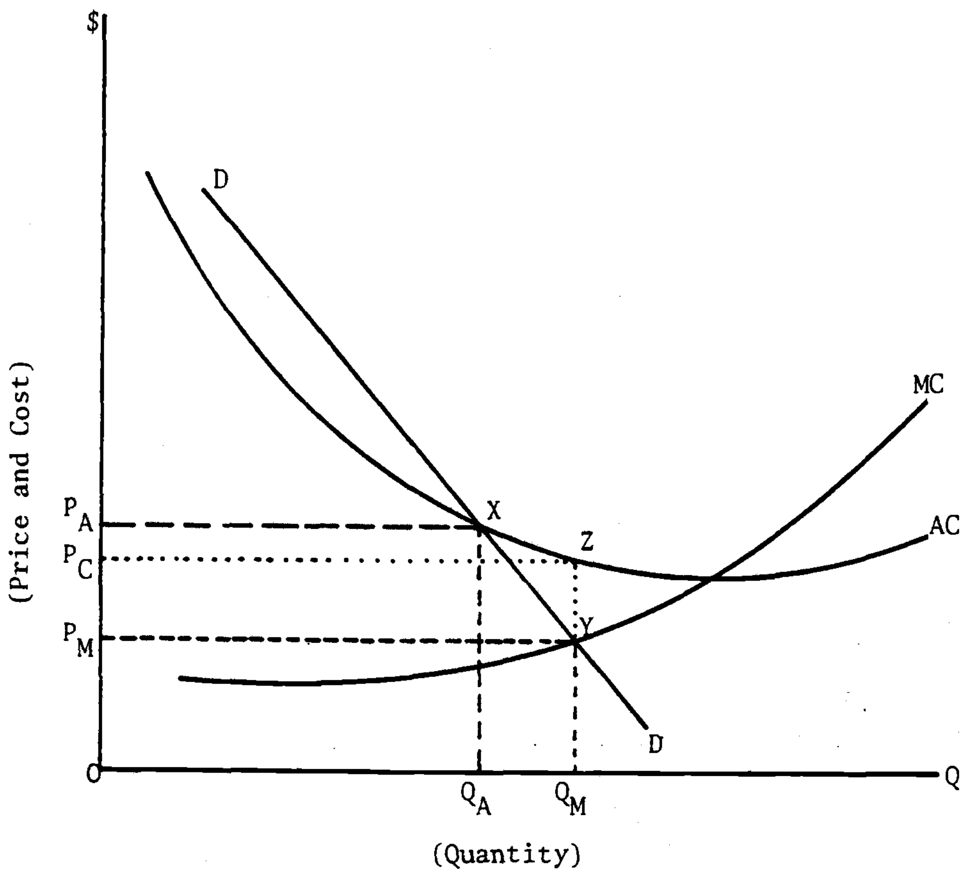


Figure III.4. Average cost vs. marginal cost pricing: decreasing average cost.

One way to resolve this problem, losses due to marginal cost pricing in the presence of decreasing average cost, would be to provide a subsidy to the utility. In the above example, Figure III.4, the subsidy would be the area $P_C P_M YZ$.14/

Another interesting case, depicted in Figure III.5, occurs when the falling average cost curve AC lies entirely to the right of the demand curve DD. In this case, average cost pricing is impossible and marginal cost pricing would yield more losses than in the previous case, Figure III.4, as long as a single price is charged.

Factors Affecting Water Price-Setting

Historically, economic analysis of urban water demand and water pricing was neglected for a long time. Milliman [1963] in describing this neglect wrote:

> "The facts are that urban water policy in general, and urban water economics in particular, have never generated much enthusiasm among students of public policy or among economic theorists. ... All of this is in sharp contrast to the large amount of attention paid to the provision of other urban utility services such as electric power, urban transport, natural gas, and telephone service." [Milliman, 1963, p. 109]

Perhaps, as a result water prices were kept lower than what economists would have considered their "socially optimum" level. Urban water prices (nominal) were either kept constant or

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14/ Since somebody has to pay this subsidy, usually taxpayers, the above solution is not consistent with social efficiency. The reason for mentioning it here is its frequent occurrence in water utilities, i.e., water utilities will have increasing returns to scale in most cases.

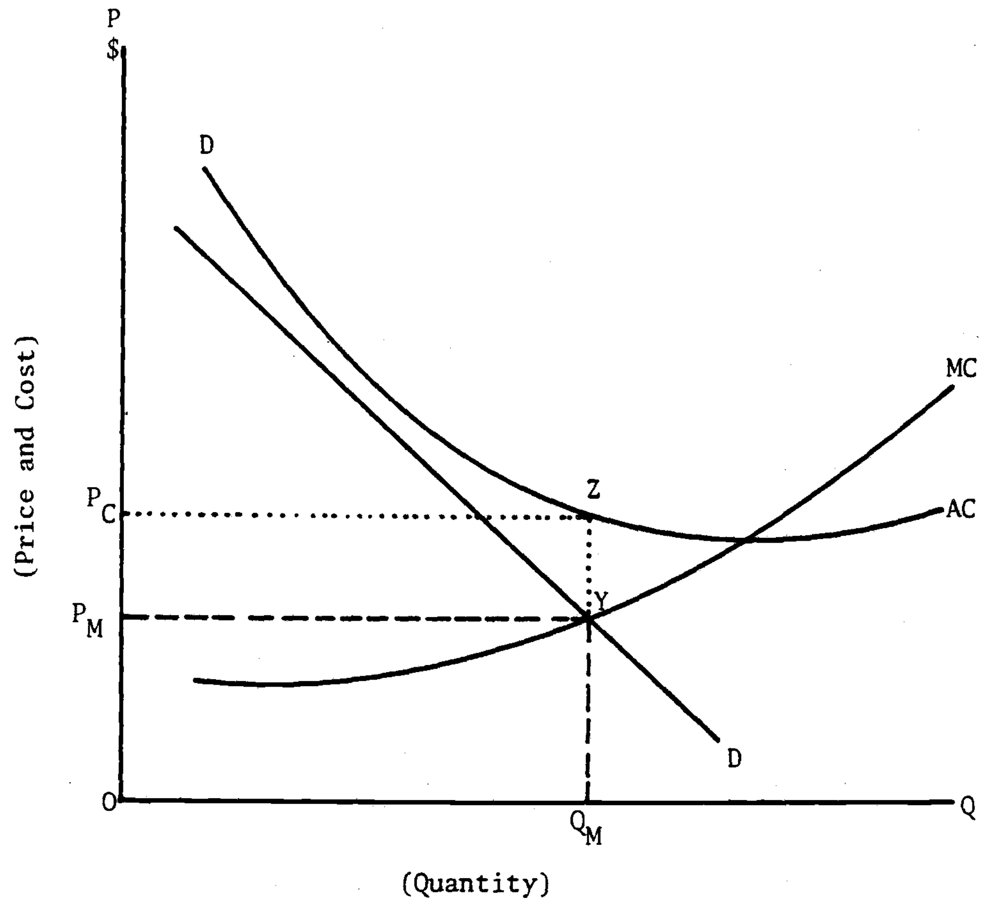

Figure III.5. Average cost vs. marginal cost pricing: decreasing average cost.

increased by less than the rate of inflation.[15/] Mann and LeFrancois [1983] found that the real price of urban water in the United States decreased from 1960 to 1980.[16/]

Reasons for such neglect may include the following:

1. Abundance and accessibility of water; however this condition was changed through excessive use or by pollution.
2. Expenditures on water account for a small fraction of the consumer's budget and most business firms' expenditures.
3. The necessity aspect of water to maintain health, which led to the exemption of water from conventional economic analysis, and in turn made it less susceptible to price changes, as compared to other public utility services, e.g., electricity. This factor is also attributed to the philosophies mentioned earlier that favored the requirements approach, e.g., "water-is-different," and "magic-of-water."
4. Political aspects, where public decision-makers are very sensitive to anything that involves raising prices in general, not to mention those of such a crucial service as water.

15/ The nominal price is the price that the consumer pays without any adjustment for inflation. Real or actual price, on the other hand, is the nominal price deflated by some index to account for inflation. Therefore, the nominal price may increase, but the real price may remain relatively constant or decrease.

16/ A similar result was found by the author in Kuwait from 1972 to 1981.

5. Economic development, which in most cases requires stable supplies of water; thus any increase in water prices might retard development progress.

From the above, it is apparent that water rates are affected by many noncost factors. Mann and LeFrancois [1983] in describing this issue wrote:

> "... Given the many participants (e.g., city administrators, water utility managers, customer groups, special users, bondholders, stockholders, and regulators) who can influence rate setting, it is not difficult to perceive why water rates tend to incorporate noncost elements." [Mann and LeFrancois, 1983, p. 442].

Forms of Water Rates

It is interesting to note that, due to the fact that water expenditures account for only a very small fraction of the consumer's budget, a large body of consumers are not aware of how their water bills are being calculated, i.e., what kind of rate structure is being used; an exception would be flat charges and uniform prices. Regarding this issue, Foster and Beattie [1981] wrote:

> "It is very unlikely that consumers know their detailed pricing schedules, or even their marginal prices. Moreover, if known, it is unlikely that most consumers would find the marginal benefit from applying classical microeconomic analysis to be greater than the marginal opportunity cost given billing complexities and time constraints facing consumers." [Foster and Beattie, 1981, p. 264]

Nevertheless, a discussion of these different rates aids in understanding some of the issues associated with estimating demand relationships. Such a discussion is in order here [Mann, 1977].

1. Flat rates.

   This might be the oldest form of water pricing. The flat rate is a fixed charge per period of time (usually month) independent of consumption. The amount of the charge might be based on such factors as the number of faucets in the house, the number of bathrooms, and the number of people occupying the house. The fixed charge may vary for each class of consumers, e.g., residential, commercial, and industrial.

2. Uniform rates.

   A very common practice, where water is being priced at a constant amount per unit of water, normally, $ per 1000 gallons or 100 cubic feet (ccu).

3. Declining block rates.

   Here the price of water decreases as consumption increases according to certain use blocks.

4. Increasing (inverted) block rates.

   The unit price for each use block, i.e., a specific amount of water, rises for each successive use block. That is, the price of water increases as consumption increases according to specified use blocks.

5. Demand (demand-commodity) rates.

   This form of water pricing involves a two-part rate, a unit charge (could be any of the above rates) and a commodity charge based on the maximum load imposed on the system by the user which is estimated by measuring the peak demand by user class.

6. Value-of-service rates.

   Here water prices are based on the value-of-service for different users; that is on the price elasticity of demand for various user groups. Here consumers with higher price elasticities will pay lower prices than those with lower price elasticities. It is clear here that the utility practices price discrimination.

7. Social pricing.

   This is based on the philosophy that "water is different" and therefore, should be available for everyone. Thus, it might involve providing some group with water at prices below costs. Forms of social pricing include:

   a) Lifeline rates. This involves pricing the amount of water necessary for, say, monthly use at a fixed low charge to low income users.

   b) Lifeline rates coupled with marginal cost pricing. Here the amount of water that is essential for living, i.e., lifeline block (e.g., for drinking, cooking, washing, personal hygiene) is priced at a very low rate and any amount in excess of the lifeline block is priced at the marginal cost. This technique is intended to encourage marginal cost pricing while providing the lifeline amount at low price for poor people.

8. Peak load pricing.

A common practice in telephone, electric, and theater companies. Here the price differs between periods of peak and off-peak consumption with the price during the former period exceeding that in the latter. The reason for the price differential is the increasing unit costs that accrue during the peak period. One should be careful not to confuse this price differential associated with peak load pricing with price discrimination.

In price discrimination, marginal revenue is equated to marginal cost in different markets where the practice takes place, whereas in peak load pricing price is equated to marginal cost.

To see how this procedure works, let's make use of Figure III.6 [Feldman, 1975]. Let D_o and D_p be off-peak and peak demands, respectively. The uniform price P_A equals average cost, and SRMC is the short run marginal cost.[17/] For simplicity assume that the marginal cost pricing is used for all goods in the economy and that there are no externalities. According to Hirshleifer et al. [1969],

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17/ It is implicitly assumed that the utility has a given capacity. This implies that the long-run marginal cost is constant [Hirshleifer et al, 1969], which in turn implies a fixed (horizontal) average cost; because

$$MC = d(TC)/dQ, = AC + (\frac{dAC}{dQ}),$$

where MC is marginal and TC is total cost.

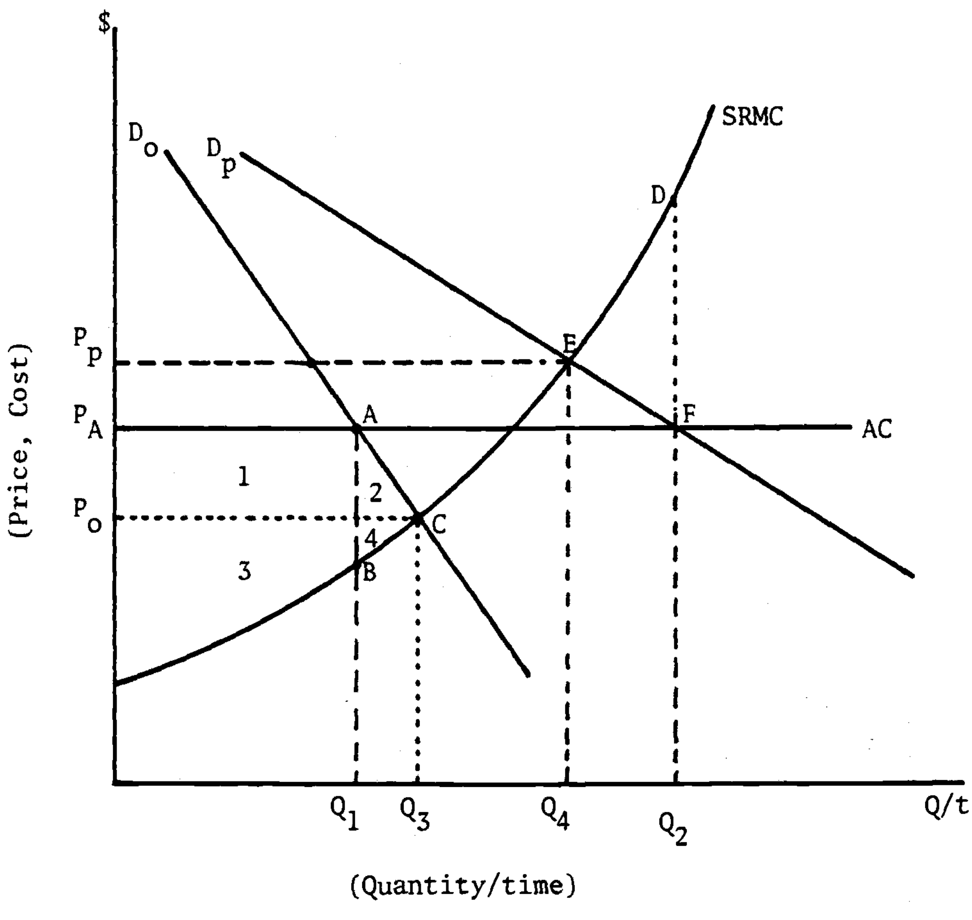

Figure III.6. Peak load pricing.

"... with a given capacity in existence, the long-run marginal cost is a constant; it is the short-run marginal cost of service which varies on-peak and off-peak." Therefore, long-run marginal cost is not needed in Figure III.6 since it is irrelevant for peak-load pricing. Thus, if a uniform average cost pricing is applied, the quantities demanded would be Q_1 and Q_2 at price P_A in the off-peak and peak periods, respectively. However, if peak load pricing is instituted, then quantities demanded would be Q_3 at price P_o in the off-peak period and Q_4 at price P_p in the peak period. Comparing the two pricing schemes' results shows that the quantity demanded in the off-peak period using average cost pricing (Q_1) is smaller than that when using peak-load pricing (Q_3) but price is greater when using the former scheme. As for the peak period the quantity demanded decreases and price increases when using peak-load pricing as opposed to average cost pricing.

Using the approach of comparing welfare triangles to measure changes in "social welfare" Figure III.6 shows that peak-load pricing increases the social gain to consumers and producers by the area ABC in off-peak period and DEF in the peak period.[18/]

18/ The following discussion shows how the area ABC is arrived at as a social gain, which could be extended for the second area, DEF. Let CS be consumer surplus; PS, producer surplus; Δ, change. Thus, changing the pricing scheme from average

It is clear that the effect of peak load pricing will depend on the difference between the two demands, peak and off-peak.

Forms of peak load pricing include:

a) Time-of-day pricing. Here water price varies by the time of day consumption occurs. That is, consumption during the peak time of day, normally between 6 - 8 A.M. and 5 - 8 P.M., would be priced higher than consumption during the off-peak time of day.

b) Seasonal pricing. This is a more practical scheme than the time-of-day pricing, where water prices vary during the different seasons of the year. Normally, summer consumption is priced higher than winter consumption.

9. Any rate combination of the above schemes. The most used scheme is the flat (fixed) rate in conjunction with other schemes. Lippiatt and Weber [1982] cited seven rate schedules that involve some kind of combining two schemes

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cost to peak load pricing will result in

$$\Delta CS = \text{area } (1+2)$$

$$\Delta PS = \text{area } (3+4) - \text{area } (1+3)$$

for a total change of

$$\begin{aligned} \Sigma &= \text{area } (1+2) + \text{area } (4-1) \\ &= \text{area } (2+4) \\ &= \text{area ABC.} \end{aligned}$$

For a good discussion of the use of welfare triangles, see Just et al. [1982], Ch. 4-5.

that are being used in the U.S. They are:

a) fixed charge-uniform rate;

b) fixed charge-decreasing block rate;

c) fixed charge-increasing block rate;

d) fixed charge-seasonal rate;

e) minimum charge-uniform rate;

f) minimum charge-decreasing block rate;

g) minimum charge-increasing block rate.

The above section was a brief discussion about the various forms of water rates. To check the various rate structures in the U.S., a survey was taken by the Valuation and Depreciation Committee, Luthin [1976]. Of the 48 states who responded to the questionnaire sent by the Committee, 33 use the original cost concept of the rate base, eight use the fair value pricing scheme, six use other means of pricing, and one has no cases yet.[19/]

In Kuwait, the area of this study, there exists a uniform charge scheme, namely, 0.8 Kuwaiti dinar (KD) per 1000 Imperial gallons.[20/] Therefore, in the presence of the uniform pricing

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19/ Luthin [1976] did not define either the "original cost concept" or the "fair value" rate base. However, in the literature [e.g., Hanke, 1972] the original cost concept mentioned by Lutin [1976] might be some kind of marginal cost pricing scheme.

20/ 1.0 KD (=1000 fils) equals $3.404 as of January 1984 [International Financial Statistics, March 1984]. 1.0 Imperial gallon = 1.201 U.S. gallons.

scheme in Kuwait, the average price and marginal price of water are equal. This will simplify the task of choosing between average or marginal price of water since they are equal.[21/]

21/ Note that the price of 0.8 KD/1000 Imperial gallons does not reflect the cost of producing 1000 Imperial gallons which is around 3.6 KD/1000 Imperial gallons [personal communication with Deputy Minister of Electricity and Water in Kuwait].

CHAPTER IV

METHODOLOGICAL ISSUES

Introduction

Theoretically, consumer demand functions may be derived from the consumer's utility function. That is, the maximization of a utility function

$$U = U(Q_1, Q_2, \ldots, Q_n) \tag{4.1}$$

subject to the budget constraint

$$\sum_{i}^{n} P_i Q_i = M \tag{4.2}$$

yields demand functions (ordinary or Marshallian) of the form

$$Q_i^* = Q_i(P_1, P_2, \ldots, P_n, M) \tag{4.3}$$

where U stands for utility Q_i, $i = 1, \ldots, n$, are the commodities the individual derives his utility from, P_i, $i = 1, \ldots, n$, are the corresponding prices, and M is total income.

From equation (4.3), the utility-maximizing quantity of commodity Q_i demanded, Q_i^*, is affected by its own price and other prices (for complements and substitutes) as well as total expenditure.

The Hypothesized Equation

Assuming that the individual maximizes his utility function subject to his total income, the individual's demand function for municipal water in Kuwait may be expressed in the following general form:

$$Q_t = f(P_t, Y_t, T_t, S_t, W_t, H_t) \tag{4.4}$$

where:

Q_t = Per capita monthly water consumption, in Imperial gallons (IG)/month.

P = Price of water in Kuwaiti dinar/1000 IG deflated by the cost of living index

Y = Per capita monthly income in Kuwaiti dinar (KD)/ month deflated by the cost of living index

T = Monthly mean temperature (Celsius, C°)

S = Monthly mean number of minutes of sunshine

H = Monthly mean relative humidity (%)

t = Subscript to denote time period, where t=1, ..., 108.

The expected functional form of the above relationship will be discussed below after the variables in the equation are defined more fully.

Dependent Variable in the Equation

The dependent variable (i.e., left-hand side) in the equation is the per capita monthly consumption of municipal (fresh) water measured in IG. This variable was derived by dividing the total monthly water consumption in Kuwait by the corresponding monthly population figure.[1/]

1/ See Appendix A for the calculation of monthly population from mid-year population estimates.

One could question the inclusion of all users (residential, commercial, and industrial) in the calculation of the monthly per capita water consumption. Aside from the main purpose of this study, that is, of explaining the aggregate water use in a municipal (urban) setting and to estimate the corresponding price and income elasticities of demand, the use of the aggregate data may be justified on the following grounds. First, brackish water[2/] is available for most sectors at a nominal fixed charge independent of the amount consumed (see Table IV.1). It is used for irrigating public parks and private gardens, as well as for cooling purposes in the industrial sector.

Table IV.1. Rate Schedule for Brackish Water.

Diameter of the Connection Pipe (Inch)	Price
1/2"	30 Fils/Day
3/4"	50 Fils/Day
1"	80 Fils/Day
More than 1"	100 Fils/1,000 IG
Farms and Dairy farms	20 Fils/1,000 IG

Therefore, the industrial sector consumption of fresh water may be decreased by the substitution of brackish water for fresh water for cooling purposes. Second, the data published by the Ministry of Electricity and Water are in aggregate form rather than by sector

2/ The total dissolved solids (TDS) in brackish water is around 3,985 parts per million, compared to 42,000 in sea water and 1,000 in drinking (fresh) water.

which leaves us with no other choice but to utilize such aggregate data in the study.

Independent Variables in the Model

Price

Following consumer demand theory, the individual when consuming water (or any other commodity) is assumed to maximize his/her utility (or satisfaction) function subject to his/her budget constraint. This maximization process leads one to express the amount of water consumed to be a function of income, the price of water, and the prices of closely related commodities (complements and substitutes). Even though the own price is the most important single factor affecting the quantity of a commodity demanded, it has been suggested that price has very little, if any, effect on water demand (consumption). Nevertheless, researchers (e.g., Howe and Linaweaver, 1967) were able to refute this hypothesis.

Generally, prices of complements and substitutes do affect the demand for a given commodity. However, water has no close substitutes; therefore, there will be no prices of substitutes in the equation. On the other hand, water is complementary to other commodities which are durable items (e.g., appliances) that depreciate over a long period. But, once the household has its supply of these items, their price will not affect the use of water [Foster and Beattie, 1978]. Therefore, all prices of complements are assumed insignificant.

Researchers have debated the issue of "which is better, average or marginal price" to represent the price variable (see Chapter

II and III). However, in Kuwait, the study area, there is only a uniform rate per 1,000 Imperial gallons (IG). This implies that average price equals marginal price, and therefore, no problem arises with respect to the choice of a price variable. In short, only the real price of water is included as the price variable in the model.

Income

Income is the other important factor, besides own price, hypothesized to affect the quantity of almost any commodity demanded. It is well known that the effects of a price change of a commodity on the quantity demanded can be broken into two effects: an income effect and a substitution effect.[3/] It follows that, the larger the proportion of total income (expenditure) devoted to a commodity, the greater will be the income effect of a change in the commodity's price and the greater will be the change in the quantity of the commodity demanded associated with a given price change.

[3/] This is the well known Slutsky equation which is written as (for own-price effect):

$$\frac{\partial X_i}{\partial P_i} = \left(\frac{\partial X_i}{\partial P_i}\right)_{U=\text{constant}} - X_i \frac{\partial X_i}{\partial M}$$

where the left-hand side is the total effect of a price change, the first term on the right-hand side is the substitution effect and the second term is the income effect. In elasticity form, this equation could be written as

$$\varepsilon_{ii} = \varepsilon^*_{ii} - K_i \eta_{im}$$

where ε_{ii} is the own-price elasticity, ε^*_{ii} is the own-price elasticity holding utility constant, K_i is the share of total expenditure (M) spent on commodity X_i, and η_{im} is the income elasticity. For more discussion see Layard and Walters [1978], Chapter 5.

Since a small portion of the total income is spent on water, it has been argued that the income effect of changes in water prices will be small. Nonetheless, researchers have been able to show that the income coefficient is significant in affecting the quantity of water demanded (see Tables II.1-II.3).

Researchers have utilized more than one measure of income in their studies of municipal demand for water. Among those measures were per capita income, median family (or household) income, and property value. The last was used as a "surrogate" for income when it was difficult to come up with a better measure. In the present study, per capita income, deflated by the cost of living index (1972=100) is utilized as a measure of income.[4/]

Weather Factors

In addition to price and income which are commonly included in the demand functions for almost all commodities, researchers have shown that weather and climate conditions do influence the municipal demand for water. Among the variables that have been utilized in previous studies are temperature, rainfall, evapotranspiration, moisture deficit, and percentage of daylight hours. In this study four weather variables are included in the model, namely, temperature, minutes of sunshine, wind speed, and relative humidity.

Temperature. In such a hot and humid area as Kuwait, temperature is expected to have a considerable direct effect on the demand

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4/ See Appendix A for a discussion of the estimation of monthly per capita income from annual data.

for municipal water; that is, the higher the temperature, the higher the water demand and vice versa. Temperature is represented by the monthly mean in degrees Celsius (C°).

Minutes of Sunshine. Even though temperature and minutes of sunshine are highly interrelated, the latter could be thought of as a factor that has a psychological impact on the individual's water consumption of positive nature. In other words, the individual might increase his water consumption on a sunny day more than on a cloudy day with the same temperature on both days. Therefore, a positive relationship is expected. This factor is represented by the monthly mean number of minutes of sunshine.

Wind Speed. In a warm and humid area like Kuwait, air circulation will have a direct effect on human perspiration, evaporation of surface water, and evapotranspiration in plants. Thus, it is expected that wind speed, represented by the monthly mean (miles/hour), will have a positive effect on water consumption.

Relative Humidity. Meteorologically, relative humidity is the amount of water vapor actually in the air compared to the maximum amount of water vapor the air can hold at that particular temperature and pressure [Ahrens, 1982, p. 147]. With a given air temperature, the body will lose more water (mainly through perspiration) when the air is dry than when it is humid. Therefore, it is expected that as relative humidity increases, water consumption decreases. Relative humidity is represented by the monthly mean given as a percentage figure.

Structure of the Model

Linear or Curvilinear

So far, researchers have not agreed on a specific functional form (model) that describes the relationship between residential water use and other explanatory variables. However, among the many models that have been utilized, the linear and the double-log (log-linear or multiplicative or power) models are the most widely employed (see Tables II.1-II.3).

In the literature reviewed in Chapter II some researchers "assumed" that a certain functional relationship(s) exists between the quantity of water consumed and other explanatory variables without explaining the reason for such an assumption, e.g., Gottlieb (1963), Conley (1967), Morgan (1973), Young (1973), Grunewald et al. (1976), and Howe (1982).

Few researchers backed their choice of a specific model. Of those who did, some defended their model selection by "following tradition" in their assumption [Turnovsky, 1969]; some defended their selected model for its simplicity to calculate elasticity estimates [Gardner and Schick, 1964]; and others use two, or more, models (linear and curvilinear) because "theoretical consideration fail to specify a unique functional form" [Howe and Linaweaver, 1967], or to compare their results and choose the one with better results on statistical grounds [Wong, 1972; Agthe and Billings, 1980].

However, two studies were more explicit in their defense of the selected functional relationship. They are Grima (1972) and Foster and Beattie (1979). The latter study defended the selection of the price-exponential model over the double-log model (both are curvilinear) using the argument that the first model "allows the price elasticity to vary directly with price ... and imposes a quantity intercept at a zero price."[5/] The former study, on the other hand, defended the assumption that the demand function for total residential water use is curvilinear, even if the linear form holds for individual water uses. The argument is as follows.

In Figure IV.1(a) there are three linear demand curves. Curve d_1 represents demand for essential water uses (drinking, cooking, washing, ...); it is drawn very steep to reflect the willingness of consumers to pay a high price for water for such purposes. Curve d_2 represents demand for less essential water uses (lawn watering, dishwashing). It is flatter than d_1, reflecting greater sensitivity to price changes. Curve d_3 represents the demand for the least important water uses (leakages, waste); it is flatter than d_2 for the same reason that d_2 is flatter than d_1. Horizontal summation of these three demands yields the total demand curve D, Figure IV.1(b), which must be curvilinear, according to Grima (1972).

Further justification for curvilinearity lies in the fact that some "subsistence" level of water is required for survival. Under the assumption that water is a normal good, throughout at least part of the range of consumption possibilities, the Law of Demand would imply a negatively sloping relationship between quantity consumed

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5/ Foster and Beattie (1979) were the first researchers who adopted such a model.

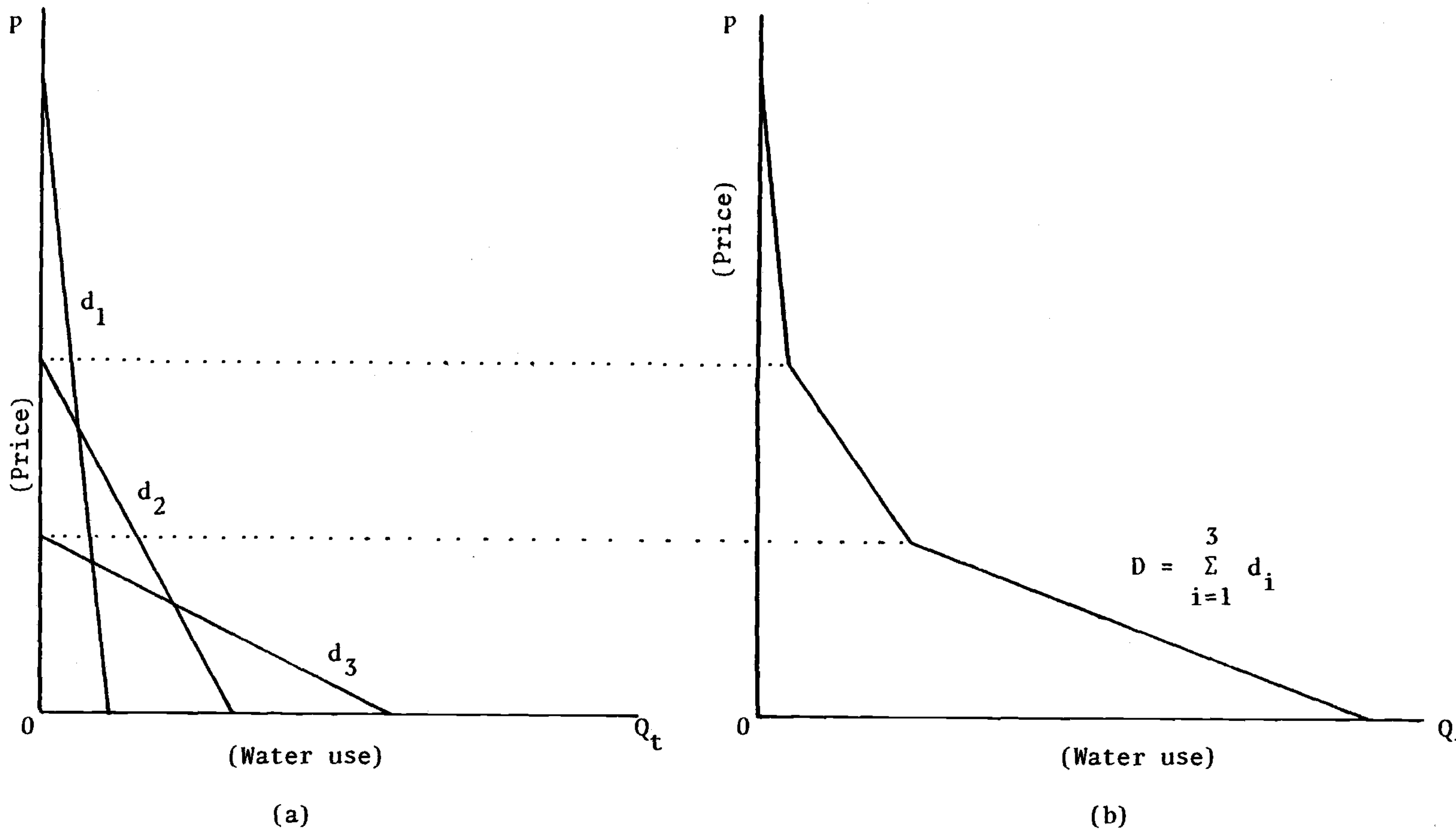


Figure IV.1. Residential Demand for Water.

and price thus excluding the possibility of either horizontal or a vertical relationship. It is difficult to justify other linear relationships for two reasons. First, if a linear relationship does hold, then, given the negative-slope restriction it must satisfy, it will intersect the price (vertical) axis, resulting in zero consumption of water at some price. However, due to the vital need for at least a very small amount of water (to cover drinking and cooking needs) in order to survive, a zero consumption of water is not possible without jeopardizing the life of the consumer. In other words, the demand relationship of water may not intersect the price axis. Second, since the normal good assumption rules out the possibility of a vertical demand relationship, the only shapes of the demand relationship that satisfy both the nonintersection with the price axis and the normal good restrictions are (1) some kind of curvilinear shape, (2) one that is asymptotic to the price axis and may approach the quantity (horizontal) axis, or (3) a relationship — linear or curvilinear — which is "kinked" at the subsistence level.

Therefore, an interesting feature of the demand for urban water is that it will be very steep at high water prices, and very flat at low prices or might intersect the quantity axis. These features are supported by empirical works which showed that the indoor (domestic or winter) water use is less responsive to price changes than outdoor (sprinkling or summer) water use, i.e., the price elasticity of the indoor water use is smaller than that for the outdoor use. In fact, the results reported by Howe and Linaweaver (1967) show the price elasticity of the outdoor (sprinkling or summer) demand to be five times that of the indoor (domestic) demand.

In short, the curvilinear demand function for municipal water is more appealing, on theoretical and empirical grounds, than the linear one.

The Econometric Model

Consumer demand theory tells us that the ordinary (Marshallian) demand functions are derived from maximization of a utility function subject to a budget constraint. These demand functions have four properties, namely, homogeneity, adding-up, symmetry, and negativity [see George and King, 1971].

However, some of the models that have been utilized extensively in the estimation of municipal demand for water, such as the double-log function, are not consistent with utility theory, therefore, do not satisfy some of the above four properties.

In short, researchers in the field of municipal water demand estimation seem to have left a gap between consumer demand theory and consumer demand estimation in the sense that the utility function, from which the ordinary (Marshallian) demand function is derived, has been ignored.

However, there is a utility function which yields a demand function that meets our conditions, namely, curvilinearity and the possibility of a subsistence level of consumption: The Stone-Geary Utility function [Phlips, 1974].

In its general form, the Stone-Geary utility function is

$$U = \sum_i \beta_i \log(Q_i - \gamma_i) \qquad \gamma_i, \beta_i > 0 \qquad (4.5)$$

$$(Q_i - \gamma_i) > 0 \qquad i\text{-}1, \ldots, n$$

which when maximized subject to the budget constraint

$$\sum_i P_i Q_i = M \qquad i=1, \ldots, n \qquad (4.6)$$

yields the following demand functions

$$Q_i = \gamma_i + \frac{\beta_i}{P_i(\sum_j \beta_j)} (M - \sum_j P_j \gamma_j), \ i,j=1, \ldots, n \qquad (4.7)$$

where P_i and Q_i are the price and quantity of the i^{th} commodity, M is total income (expenditure), P_j is the price of the j^{th} commodity, and the γs and βs are parameters to be estimated. Yoshihara (1969) showed that the demand functions (4.7) satisfy all four demand properties.

As discussed by other researchers [Foster and Beattie, 1979] water does not have substitutes and it is complementary to other (durable) commodities in such a way that the interdependence can be assumed to be negligible. Therefore, in the case of municipal water, we have a two-commodity case: municipal water and all other goods (or Hicks-Allen money) where the latter's price is represented by the cost of living index (in which water costs are assumed to play a minor role). Thus, the problem reduces to maximize

$$U = \beta_1 \log(Q_1 - \gamma_1) + \beta_2 \log(Q_2 - \gamma_2) \qquad (4.8)$$

subject to

$$P_1 Q_1 + P_2 Q_2 = M \qquad (4.9)$$

where P_1 and Q_1 are prices and quantity of water, P_2 and Q_2 are price and quantity of all other goods, M is total income (expenditure), and β_1, β_2, γ_1, and γ_2 are parameters to be estimated. Here γ_1 and γ_2 can be interpreted as the "subsistence" levels of demand for Q_1 and Q_2, respectively. The Lagrangian function corresponding to this maximization problem is

$$L = \beta_1 \log(Q_1-\gamma_1)+\beta_2 \log(Q_2-\gamma_2)+\lambda[M-P_1Q_1-P_2Q_2] \tag{4.10}$$

and the first-order conditions are

$$\begin{aligned} \frac{\partial L}{\partial Q_1} &= \frac{\beta_1}{(Q_1-\gamma_1)} - \lambda P_1 = 0 \\ \frac{\partial L}{\partial Q_2} &= \frac{\beta_2}{(Q_2-\gamma_2)} - \lambda P_2 = 0 \\ \frac{\partial L}{\partial \lambda} &= M - P_1Q_1 - P_2Q_2 = 0 \end{aligned} \tag{4.11}$$

Solving (4.11) for Q_1 yields the following utility-maximum demand function for municipal water (Q_1)

$$\begin{aligned} Q_1 &= \gamma_1 + \frac{\beta_1}{(\beta_1+\beta_2)P_1} (M - P_1\gamma_1 - P_2\gamma_2) \qquad (4.12) \\ &= (1 - \frac{\beta_1}{\beta_1+\beta_2}) \gamma_1 + \frac{\beta_1}{\beta_1+\beta_2} \frac{M}{P_1} - \frac{\beta_1\gamma_2}{\beta_1+\beta_2} \frac{P_2}{P_1} \end{aligned}$$

or simply

$$Q_1 = \pi_0 + \pi_1 \frac{M}{P_1} + \pi_2 \frac{P_2}{P_1} \tag{4.12'}$$

where

$$\pi_0 = (1 - \frac{\beta_1}{\beta_1+\beta_2})\gamma_1, \quad \pi_1 = \frac{\beta_1}{\beta_1+\beta_2}, \text{ and } \pi_2 = - \frac{\beta_1\gamma_2}{\beta_1+\beta_2} = - \pi_1\gamma_2.$$

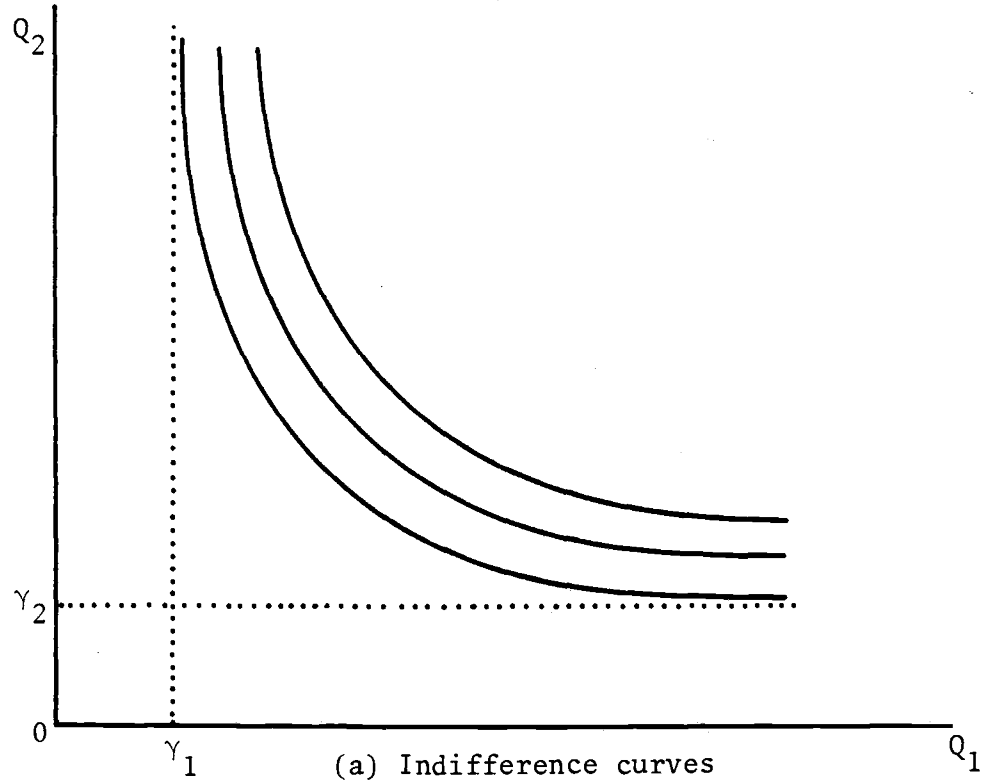
By substituting π_1 into π_0 and solving for γ_1, one finds

$$\gamma_1 = \frac{\pi_0}{(1-\pi_1)} \tag{4.13}$$

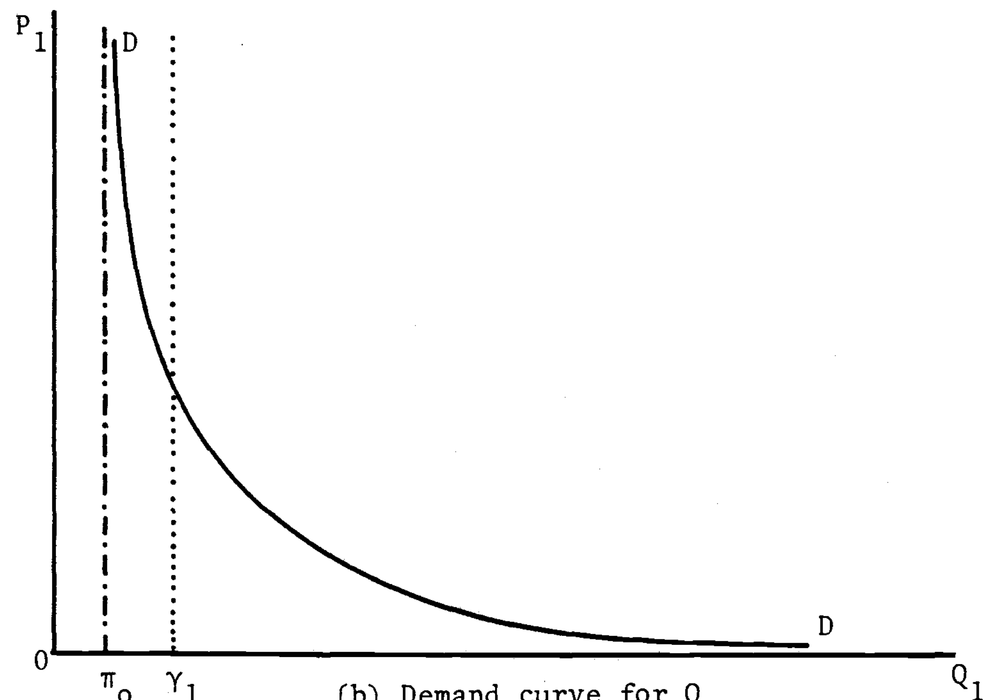
This demand function (4.12') is curvilinear in P_1 and linear in the parameters and, thus, can be estimated using ordinary least squares.

Figure IV.2 illustrates the shape of the indifference curves corresponding to Stone-Geary's utility function (4.8) as well as the corresponding demand curve (4.12') in the simple two-commodity case. It is interesting to note that the demand curve for Q_1 will be asymptotic to a vertical line parallel to the P_1-axis if π_1 and π_2 are positive. Furthermore, if π_1 and π_2 are negative, the demand curve will be positively sloping which is unacceptable under the normal good assumption; on the other hand, the income elasticity of demand will be negative which is also unacceptable for a normal good.

As discussed in the previous section, the municipal demand for water is hypothesized to be affected, besides own price and income, by four weather variables, namely, temperature (T), minutes of sunshine (S), wind speed (W), and relative humidity (H). Thus by including these four variables as shifters in equation (4.13) gives the equation to be estimated



(a) Indifference curves



(b) Demand curve for Q_1

Figure IV.2. Indifference curves corresponding to Stone-Geary's utility function and the resulting demand curve for two-commodity case.

$$Q_t = \pi_0 + \pi_1 \frac{M_t}{P_{1t}} + \pi_2 \frac{P_{2t}}{P_{1t}} + \beta_T T_t + \beta_S S_t + \beta_W W_t + \beta_H H_t + \varepsilon_{1t} \qquad (4.14)$$

where P_{1t} and Q_t are nominal price and per capita quantity of water demanded at time t, respectively, P_{2t} is the cost of living index in time t (1972=100), T, S, W, and H are as defined above, π_0, π_1, π_2, and β's are parameters to be estimated, and ε_{1t} is the error (disturbance) term.

It is appropriate to note that the "adoption" of a single equation (4.1) rather than a simultaneous equations system to estimate the municipal demand for water is defended by the fact that the water rate structure is "exactly defined," therefore, eliminating the need to specify an independent function for supply and to estimate parameters through simultaneous equations techniques [Billings and Agthe, 1981]. In other words, researchers have assumed that water prices are fixed by the utility company, which enabled them to write the demand for municipal water as

$$Q = f(P, Y, X) \qquad (4.15)$$

where Q is the quantity of water demanded, P is the price of water (fixed by the utility company, i.e., the supplier), Y is income (or its surrogate), and X is a vector of variables found to affect the demand for municipal water.[6] Therefore, the problem of identification was avoided.

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[6] An alternative assumption would be to assume that quantities (supplies) of water are fixed by the utility, this will result in the following function describing the demand for water.

$$P = g(Q, Y, X).$$

Studies about the estimation of municipal demand for water were dominated by the use of two models: linear and double-log (see Tables II.1-II.3). The exponential and price-exponential were used to a lesser extent. Therfore, for the sake of comparison, these four models will be utilized to estimate the municipal demand for water in Kuwait and to compare their results to those of the main model (4.14) and another new model, namely the semi-log form, which was employed by Prais and Houthakker (1971) in the estimation of Engel curve in Britian.

The functional forms to be estimated, besides the main model (4.13), are written as:

Linear Model

$$Q_t = \alpha+\beta_P P_t+\beta_Y Y_t+\beta_T T_t+\beta_S S_t+\beta_W W_t+\beta_H H_t+\varepsilon_{2t} \qquad (4.16)$$

Semi-log Model

$$Q_t = \alpha+\beta_P \ell n P_t+\beta_Y \ell n Y_t+\beta_T \ell n T_t+\beta_S \ell n S_t+\beta_W \ell n W_t +\beta_H \ell n H_t+\varepsilon_{3t} \qquad (4.17)$$

Exponential Model

$$Q_t = e^{[\alpha+\beta_P P_t+\beta_Y Y_t+\beta_T T_t+\beta_S S_t+\beta_W W_t+\beta_H H_t+\varepsilon_{4t}} \qquad (4.18)$$

Price-exponential Model

$$Q_t = \alpha\, e^{\beta_P P_t}\, Y_t^{\beta_Y}\, T_t^{\beta_T}\, S_t^{\beta_S}\, W_t^{\beta_W}\, H_t^{\beta_H}\, e^{\varepsilon_{5t}} \qquad (4.19)$$

Double-Log

$$\ell n Q_t = \ell n \alpha + \beta_P \ell n P_t + \beta_Y \ell n Y_t + \beta_T \ell n T_t + \beta_S \ell n S_t$$
$$+ \beta_W \ell n W_t + \beta_H \ell n H_t + \varepsilon_{6t} \qquad (4.20)$$

where α is the intercept (i.e., constant term), the β's are the coefficients of the explanatory variables, P_t is the real price of water, Y_t is the real per capita income, ε_{it} is the error (disturbance) term, and other notations are as defined above.

Figure IV.3 illustrates the possible curvature of the linear, exponential, semi-log, and double-log for a simple case where Q is a function of P only.[7/] Note that whether the curve has a positive or negative slope depends on the sign of the coefficient β_p. When β_p is positive, the slope is positive; when β_p is negative, the slope is negative.

Hypotheses to be Tested

After the analyst specifies the dependent and explanatory variables, he selects the model he thinks will best describe the relationship between the dependent and explanatory variables. Then he specifies the expected relationship between each explanatory variable and the dependent variable, i.e., the expected sign of the explanatory variables' coefficients.

7/ In this simple case (Q=f(P)), the price-exponential model converges to the exponential model, i.e., $Q=\alpha e^{\beta P}$.

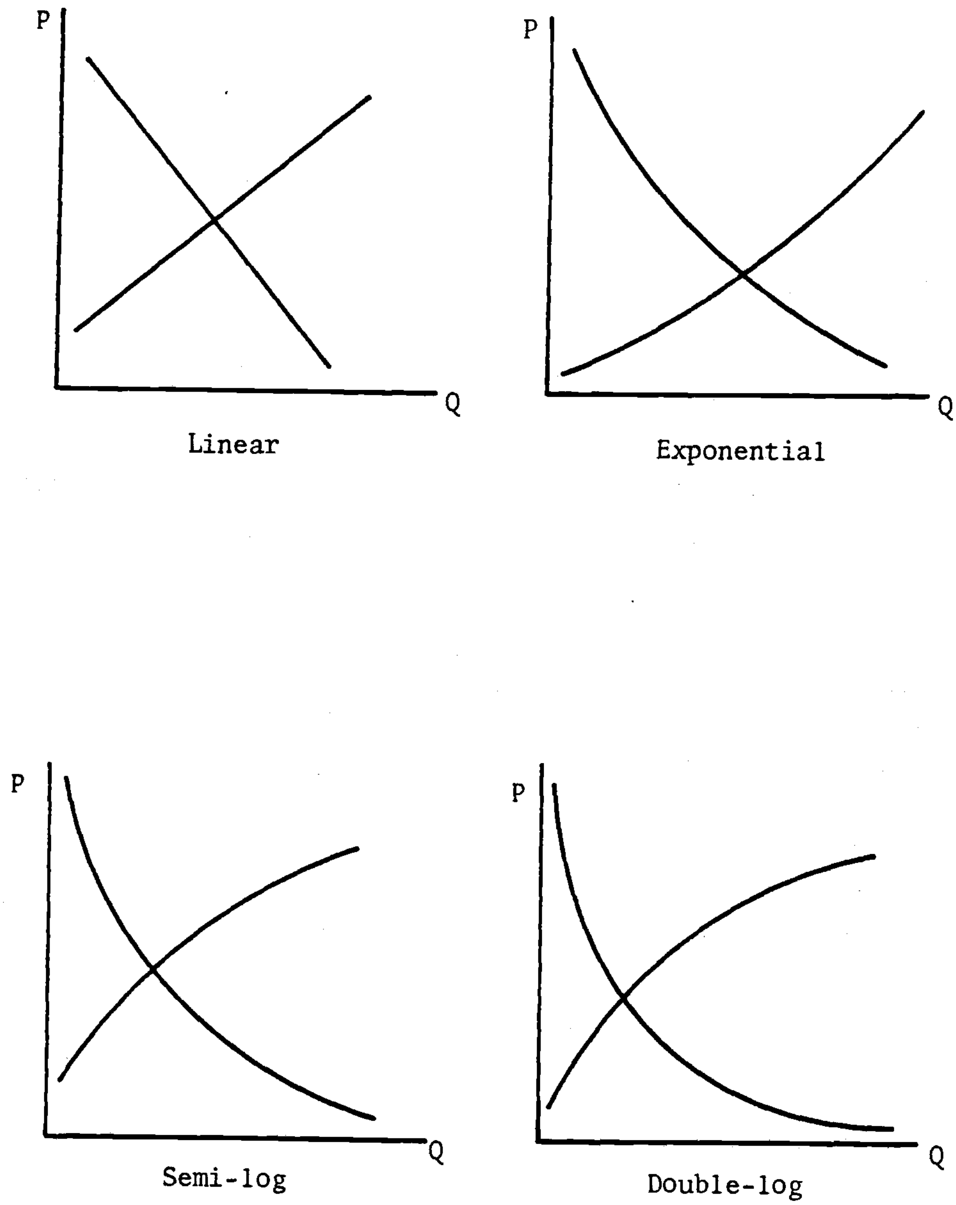

Figure IV.3. Curves Illustrating Four Different Models.

From the above discussion about each of the explanatory variables and their relationship with the independent variable, the expected signs of the parameters in the main model (4.14) are:

1. $\pi_0 > 0$, which along with $1 > \pi_1 > 0$, guarantees a positive γ_1 as given by (4.13), and therefore, a positive "subsistence" level of water which is necessary for life.

2. $1 > \pi_1 > 0$, since a negative value will result in a positive income elasticity of demand which contradicts the normal good assumption, whereas a positive value greater than one will result in a negative γ_1, which also violates the basic assumption of the Stone-Geary utility function as well as our argument that the individual should have some subsistence level of water to sustain life.

3. $\pi_2 > 0$, because a negative value will imply that, given zero income, $\frac{\partial Q_t}{\partial P_1} = - \frac{\pi_2 P_2}{P_1^2}$ will be positive, which means a positively, rather than negatively, sloping demand curve, which is not what we expect for a normal good.

4. $\beta_T > 0$, $\beta_S > 0$, $\beta_W > 0$, and $\beta_H < 0$ as discussed above in the section on weather variables.

The coefficients of the explanatory variables in the other five models (4.15 - 4.20) are expected to have the following signs:

1. $\beta_P < 0$, which is implied by the Law of Demand and the assumption that water is a normal good which means a negatively sloping demand curve.

2. $\beta_Y > 0$, which is implied by the assumption that water is a normal good, which means as income rises, water consumption rises too.

3. $\beta_T > 0$, $\beta_S > 0$, $\beta_W > 0$, and $\beta_H < 0$, as explained above.

Elasticities Formulae

One of the major "by-products" of demand estimation is the calculation of elasticities, especially price and income elasticities. Price elasticity of demand for commodity Q, ε_P, is defined as the proportional change in quantity demanded divided by the proportional change in its price; that is,

$$\text{Price elasticity of demand } (\varepsilon_P) = \frac{\text{\% change in quantity demanded}}{\text{\% change in price}}$$

$$= \frac{\Delta Q/Q}{\Delta P/P} = \frac{\Delta Q}{\Delta P} \cdot \frac{P}{Q}$$

or simply (using partial derivative notation)

$$\varepsilon_P = \frac{dQ}{dP} \cdot \frac{P}{Q} \qquad (4.21)$$

Similarly, for income elasticity of demand (η_Y)

$$\eta_Y = \frac{dQ}{dY} \cdot \frac{Y}{Q} \qquad (4.22)$$

Table IV.2 shows the corresponding price and income elasticity of demand formulae for model (4.14) as well as the other five models (4.16 - 4.20). Since only the double-log model (4.20) has constant price and income elasticities [the price-exponential model (4.19) has a constant income elasticity only], the mean values of M_t, P_{1t}, P_{2t}, Q_t, P_t, and Y_t are employed to calculate a single elasticity estimate for the other models as shown in columns 2 and 3 in Table IV.2.

Table IV.2. Elasticities Formulae for the Models Employed*

Model		Price Elasticity (ε_P)	Income Elasticity (η_Y)
Main model (4.14)	$Q_t = \pi_0 + \pi_1 \frac{M_t}{P_1} + \pi_2 \frac{P_{2t}}{P_{1t}} + \beta_T T_t + \beta_S S_t + \beta_W W_t + \beta_H H_t + \varepsilon_{1t}$	$-(\frac{\pi_1 \bar{M} + \pi_2 \bar{P}_{2t}}{\bar{P}_{1t} \cdot \bar{Q}})$	$(\frac{\pi_1}{\bar{P}_1} \ \frac{\bar{M}}{\bar{Q}})$
Linear (4.16)	$Q_t = \alpha + \beta_P P_t + \beta_Y Y_t + \beta_T T_t + \beta_S S_t + \beta_W W_t + \beta_H H_t + \varepsilon_{2t}$	$(\beta_P \cdot \frac{\bar{P}}{\bar{Q}})$	$(\beta_Y \cdot \frac{\bar{Y}}{\bar{Q}})$
Semi-log (4.17)	$Q_t = \alpha + \beta_P \ln P_t + \beta_Y \ln Y_t + \beta_T \ln T_t + \beta_S \ln S_t + \beta_W \ln W_t + \beta_H \ln H_t + \varepsilon_{3t}$	$(\frac{\beta_P}{\bar{Q}})$	$(\frac{\beta_Y}{\bar{Q}})$
Exponential (4.18)	$Q_t = e^{[\alpha + \beta_P P_t + \beta_Y Y_t + \beta_T T_t + \beta_S S_t + \beta_W W_t + \beta_H H_t + \varepsilon_{4t}]}$	$(\beta_P \bar{P})$	$(\beta_Y \bar{Y})$
Price-exponential (4.19)	$Q_t = \alpha \ e^{(\beta_P P_t)} \ Y_t^{\beta_Y} \ T_t^{\beta_T} \ S_t^{\beta_S} \ W_t^{\beta_W} \ H_t^{\beta_H} \ e^{\varepsilon_{5t}}$	$(\beta_P \bar{P})$	(β_Y)
Dougle-log (4.20)	$\ln Q_t = \ln \alpha + \beta_P \ln P_t + \beta_Y \ln Y_t + \beta_T \ln T_t + \beta_S \ln S_t + \beta_W \ln W_t + \beta_H \ln H_t + \varepsilon_{6t}$	(β_P)	(β_Y)

* $\bar{P}_{1t}$ and $\bar{P}_{2t}$ are the mean value of the nominal price of water and cost of living index (1972=100), respectively. $\bar{M}$ is the mean value of the nominal per capita income. $\bar{P}$, $\bar{Q}$ and $\bar{Y}$ are the mean values of the real price of water, quantity of water demanded, and real per capita income, respectively.

CHAPTER V

EMPIRICAL ANALYSIS

As explained in the preceding chapter, a demand model (4.14) derived from the Stone-Geary utility function (4.5) will be utilized to estimate the municipal demand for water in Kuwait. Its results will then be compared to those from five different models, namely, the linear (4.16), semi-log (4.17), exponential (4.18), price-exponential (4.19), and double-log (4.20), using the same data. In the following section the estimation procedure will be explained.

The Estimation Procedure

The econometric models discussed in Cahpter IV fall into the multiple regression classification where the changes in the dependent variable are explained by changes in several independent (explanatory) variables. In regression analysis, various assumptions are generally made, Maddala (1977):

1. The explanatory variables are nonstochastic with values fixed in repeated samples, and therefore uncorrelated with the error terms.
2. No exact linear relationship exists between two or more explanatory variables.
3. The error (distrubance) terms are normally distributed with zero expected value (i.e., mean) and constant variance (i.e., homoskedastic), that is, $\varepsilon_{it} \sim N(0,\sigma^2)$ for all t.

4. The error terms are independent from each other in different observations (i.e., nonautoregressive errors), that is, $E(\varepsilon_{it}\varepsilon_{it^*})=0$ for $t \neq t^*$.

Under these assumptions and given the suggested model above to be the "true" relationship, the method of least squares gives estimators of the coefficients that are unbiased and have minimum variance, i.e., BLUE (best linear unbiased estimator). Assuming (1) - (4) are postulated to hold for each of the above six equations and thus ordinary least squares (OLS) is used for parameter estimation.

Rather than explaining the consequences of violating one or more of the above assumptions, the regression results will be analyzed and checked for the validity of the four assumptions. Table V.1 displays the means, standard deviations, minimum and maximum values of the dependent and explanatory (independent) variables.

The Results

Preliminary Results

Estimating the per capita municipal demand for water in Kuwait using monthly data for nominal water prices (P_1), nominal per capita income levels (M) and the cost of living index (P_2) (in the main model, equation (4.14)); real water prices (P) and real per capita income levels (Y), (in other models (4.16)-(4.20)); as well as the four weather variables: mean temperature (T), mean minutes of sunshine (S), mean wind speed (W), and mean relative

Table V.1. Means, Standard Deviations, Minimum, and Maximum of the Variables.

Variable	Mean	Standard Deviation	Minimum	Maximum
Q	1215.630	299.006	670.440	1772.130
M	370.296	118.483	110.281	551.961
P_1	0.800	0.000	0.800	0.800
P_2	1.543	0.301	1.037	2.163
Y	234.833	44.726	106.346	302.113
P	0.539	0.108	0.370	0.771
T	25.751	8.899	10.450	38.850
S	537.898	106.612	310.000	741.000
W	8.918	2.202	4.700	16.100
H	40.634	17.944	16.000	78.000
$\hat{H}$	40.273	16.985	16.013	73.990

Notes: Q is the per capita monthly water consumption in Imperial gallons.

M is the nominal per capita monthly income in Kuwaiti dinars (KD).

P_1 is the nominal price of water (KD/1000 IG).

P_2 is the cost of living index (1972=100).

P is the real price of water (KD/1000 IG).

Y is the real per capita monthly income (KD).

T is the monthly mean temperature (° Celsuis).

S is the monthly mean minutes of sunshine.

W is the monthly mean wind speed (miles/hour).

H is the monthly mean relative humidity (%).

$\hat{H}$ is the "estimated" realtive humidity as $H = [\alpha + \beta \ell n\ T + \delta \ell n\ S + \gamma \ell n\ W]$, see equation (5.3) in text.

humidity (H), and using ordinary least squares procedures yields the statistical results presented in Table V.2.

All models show that at least 80 percent of the variation in per capita monthly water consumption (Q) is "explained" by the six explanatory variables (the adjusted multiple correlation coefficient $\bar{R}^2$ is used for comparison rather than R^2, which always increases as more explanatory variables are included). The F-test shows the estimated equations to be statistically significant at the 0.01 level for all six models, implying rejection of the null hypothesis that there is no linear relationship between Q (or $\ell n Q$) and the other variables.

In the main model (4.14) the parameter π_0 is statistically significant at the 0.10 level and positive, as expected, which implies that (using 4.13) the individual must have at least 528.6 Imperial gallons (IG) as the "subsistence" level of water, $\hat{\gamma}_1$, to cover the essential water needs. The coefficients estimated for $(\frac{M}{P_1})$ and $(\frac{P_2}{P_1})$, i.e., $\hat{\pi}_1$ and $\hat{\pi}_2$, respectively, have the expected signs and are statistically significant, at least at the 0.10 level. This suggests that as the nominal price of water (P_1) increases (decreases), ceteris paribus, water consumption, Q, decreases (increases).1/ The reverse

1/ However, note that while real prices varied over the period of analysis, nominal prices did not. Thus, such inferences should be made with caution. Essentially, the variation in per capita consumption attributed to changes in $(\frac{M}{P_1})$ and $(\frac{P_2}{P_1})$ is more accurately associated with changes in M and P_2 alone.

Table V.2. Statistical Results for Municipal Water Demand Models.

Model		$\bar{R}^2$	F	DW
Main Model (4.14)	$\hat{Q} = 383.754 + 0.274\,(\frac{M}{P_1}) + 465.047\,(\frac{P_2}{P_1}) + 17.983\,T - 0.759\,S - 7.501\,W - 4.449\,H$	0.86	114	0.516
	$(1.37)^{*}\quad(1.59)^{*}\quad(6.85)^{**}\quad(4.54)^{**}\quad(-3.27)^{**}\quad(-1.08)\quad(-1.95)^{**}$			
Linear (4.16)	$\hat{Q} = 2563.50 - 2126.75\,P - 0.352\,Y + 17.523\,T - 0.676\,S - 5.096\,W - 3.998\,H$	0.89	147	0.628
	$(11.14)^{**}\quad(-16.86)^{**}\quad(-1.18)\quad(4.92)^{**}\quad(-3.25)^{**}\quad(-0.82)\quad(-1.94)^{**}$			
Semi-Log (4.17)	$\hat{Q} = 1160.17 - 1122.03\,\ell n\,P - 27.056\,\ell n\,Y + 393.814\,\ell n\,T - 269.661\,\ell n\,S - 50.481\,\ell n\,W - 129.785\,\ell n\,H$	0.87	126	0.547
	$(1.71)^{**}\quad(-16.36)^{**}\quad(-0.47)\quad(5.32)^{**}\quad(-2.45)^{**}\quad(-0.77)\quad(-1.72)^{**}$			
Exponential (4.18)	$\hat{Q} = e^{[8.354 - 1.863\,P - 0.0003\,Y + 0.013\,T - 0.0006\,S - 0.008\,W - 0.005\,H]}$	0.90 (0.88)@	174 (132)@	0.688
	$(45.29)^{**}\quad(-18.43)^{**}\quad(-1.24)\quad(4.64)^{**}\quad(-3.29)^{**}\quad(-1.66)^{**}\quad(-2.74)^{**}$			
Price-Exponential (4.19)	$\hat{Q} = 9.297\ e^{-1.928\,P}\ Y^{-0.098}\ T^{0.341}\ S^{-0.196}\ W^{-0.062}\ H^{-0.103}$	0.90 (0.88)@	173 (130)@	0.663
	$(12.78)^{**}\quad(-19.33)^{**}\quad(-2.15)^{**}\quad(6.13)^{**}\quad(-2.37)^{**}\quad(1.26)\quad(-1.81)^{**}$			
Double-Log	$\ell n\,\hat{Q} = 7.361 - 0.973\,\ell n\,P - 0.016\,\ell n\,Y + 0.344\,\ell n\,T - 0.218\,\ell n\,S - 0.068\,\ell n\,W - 0.112\,\ell n\,H$	0.89 (0.86)@	145 (107)@	0.564
	$(9.33)^{**}\quad(-17.40)^{**}\quad(-0.34)\quad(5.70)^{**}\quad(-2.43)^{**}\quad(-1.27)\quad(-1.82)^{**}$			

Notes: For notations see notes to Table V.1. t-values are in parenthesis. The critical values of t(108) are 1.290 and 1.661 at the 0.10 and 0.05 significance level, respectively. * and ** indicates a statistically significant coefficient at the 0.10 and 0.05 level, respectively. The critical value for F(6, 101) = 3.95 at the 0.01 significance level. $\bar{R}^2$ is the adjusted multiple correlation coefficient. DW is the Durbin-Watson statistic, where the critical values for DW(6, 108) are d_L = 1.466 and d_U = 1.656 at the 0.01 significance level. @ indicates the statistic was recalculated using the real values of the independent variable.

holds true for nominal per capita income, M. That is, as M increases, ceteris paribus, Q decreases and vice versa. However, only three of the weather variables, namely T, S, and H are statistically significant at the 0.10 level. Moreover, two of them, S and W, do not have the expected positive sign. The Durbin-Watson statistics, DW, is very low (less than 0.6), indicating the presence of first-order serial correlation (discussed below).

In the other five models (4.16-4.20), S and W continue to have unexpected negative coefficients. The constant term, $\hat{\alpha}$, is statistically significant at the 0.05 level in all models. The estimated coefficient of the real price of water, $\hat{\beta}_p$, is negative, as expected and statistically significant at the 0.05 level in all models. However, the coefficient of real per capita income, $\hat{\beta}_y$, is negative and not statistically significant at the 0.10 level in any of the models. Thus, three of the six explanatory variables have coefficeints whose signs were unexpected. This could be because: (1) there are statistical and/or data problems associated with the estimation process, (2) the models are incorrectly specified, or (3) the models are correctly specified but the prior reasoning underlying the hypotheses is incorrect. The first of these issues is explored next.

Statistical Problems

Because this study uses time-series data, the problem of serial correlation might exist because the assumption that error terms are independent from each other in different observations (assumption 4) often breaks down in time-series studies, Pindyck and Rubinfeld [1981]. Nevertheless, the least-squares estimators are still unbiased but not efficient. The presence of serial correlation results in "inflated" R^2, t and F statistics, Maddala [1977]. One way to check whether or not the error terms are serially correlated is to calculate the Durbin-Watson statistic (DW) to test the null hypothesis of no first-order serial correlation in the error terms. By comparing computed DW values (column 4, Table V.2) to the critical values of DW (d_L = 1.466 and d_u = 1.656 at the 0.01 significance level), one is led to reject the null hypothesis and to confirm the presence of a positive serial correlation (because $0<DW<d_L$) in all six models. Thus, the R^2, t and F statistics tend to be exaggerated.

The solution to this problem, i.e., serial correlation, is to use some procedure that takes account of it. One such procedure is the Maximum Likelihood Iterative technique, Kmenta (1971). The statistical results for the six models, corrected for first-order serial correlation via this procedure, are presented in Table V.3.

In the main model (4.14), the correction for serial correlation resulted in a DW=2.558 indicating that the null hypothesis of no serial correlation cannot be accepted (because $4-d_L<DW<4$) and instead, negative serial correlation is present. Also, the estimated parameter $\hat{\pi}_o$ has become statistically not significant as has the coefficient of mean relative humidity,

Table V.3. Statistical Results for Municipal Water Demand Models Corrected for First-Order Serial Correlation.

Model		$\bar{R}^2$	F	DW	RHO
Main Model (4.14)	$\hat{Q} = 84.875 + 0.50 (\frac{M}{P_1}) + 329.797 (\frac{P_2}{P_1}) + 16.753\ T - 0.22\ S - 1.032\ W - 0.946\ H$ (0.38) (1.38)* (2.43)** (7.29)** (-1.86)** (-0.25) (-0.76)	0.95	323	2.558	0.8198
Linear (4.16)	$\hat{Q} = 1900.70 - 1779.44\ P + 0.105\ Y + 16.57\ T - 0.23\ S - 0.649\ W - 1.095\ H$ (6.53)** (-6.24)** (0.17) (7.10)** (-1.89)** (-0.15) (-0.85)	0.95	330	2.505	0.7772
Semi-Log (4.17)	$\hat{Q} = 423.995 - 954.261 \ln P + 32.801 \ln Y + 314.736 \ln T - 100.98 \ln S - 27.193 \ln W - 84.322 \ln H$ (0.522) (-5.88)** (0.26) (6.74)** (-1.72)** (-0.65) (-1.89)**	0.94	309	2.527	0.7881
Exponential (4.18)	$\hat{Q} = e^{[7.827 - 1.642\ P + 0.00006\ Y + 0.013\ T - 0.0002\ S - 0.003\ W - 0.0019\ H]}$ (34.34)** (-7.69)** (0.14) (6.76)** (-2.28)** (-0.82) (-1.71)**	N/C	N/C	2.552	0.7356
Price-Exponential (4.19)	$\hat{Q} = 8.255\ e^{-1.724\ P}\ Y^{-0.039}\ T^{0.281}\ S^{-0.094}\ W^{-0.039}\ H^{-0.076}$ (11.45)** (-8.05)** (-0.43) (7.18)** (-1.89)** (-0.91) (-2.01)**	N/C	N/C	2.579	0.7239
Double-Log (4.20)	$\ln \hat{Q} = 6.354 - 0.855 \ln P + 0.039 \ln Y + 0.279 \ln T - 0.094 \ln S - 0.033 \ln W - 0.075 \ln H$ (9.66)** (-6.72)** (0.39) (7.21)** (-1.92)** (-0.95) (-2.01)**	N/C	N/C	2.638	0.7705

Notes: For explanation of notations see notes to Table V.1. For the criticial values for t, F, and DW see notes to Table V.2. RHO is the first-order serial correlation coefficient estimated using the Maximum Likelihood Iterative technique. t-values are in parenthesis. * and ** indicates signifiant at the 0.10 and 0.05 level, respectively. N/C indicates not calculated statistics; however, $\bar{R}^2$ and F were greater than 80 and 140, respectively, before correcting for first-order serial correlation.

$\hat{\beta}_H$. However, the estimated coefficients of mean minutes of sunshine, $\hat{\beta}_S$, and mean wind speed, $\hat{\beta}_W$ still have the wrong sign (negative).

The same thing happens to the other models (4.16-4.20). That is, correcting first-order serial correlation using the maximum likelihood procedure resulted in DW>2.5, and therefore, leads to rejecting the null hypothesis of no serial correlation. The estimated coefficient of S and W still have the wrong sign. However, the estimated coefficient of real per capita income ($\hat{\beta}_Y$) did have the expected positive sign in all models except the price-exponential model (4.19) but the coefficients were not statistically significant in any of the models.

It is clear from the above that serial correlation is not the only problem behind these rather unexpected results. Since the estimated coefficients of mean minutes sunshine ($\hat{\beta}_S$) and mean wind speed ($\hat{\beta}_W$) continue to have the unexpected negative signs and the estimated coefficient on real per capita income ($\hat{\beta}_Y$) is not statistically significant, one would suspect the problem of multicollinearity. Multicollinearity increases the standard errors of the estimates, and therefore t-statistics will decrease, which may lead to apparent nonsignificance, Koutsoyiannis [1977].

One way to check whether the explanatory variables are intercorrelated on a pairwise basis is to inspect the simple correlation coefficient between any two explanatory variables, $r^2_{x_i x_j}$.

Table V.4 presents the simple correlation coefficients between all pairs of explanatory (independent) variables. "A high value (about 0.80 or 0.90 in absolute value) of one of these correlation coefficients indicates high correlation between the two explanatory variables to which it refers," Kennedy [1979]. Checking Table V.4, one finds that the simple correlation coefficient between mean relative humidity (H) and mean temperature (T) is high, $r^2_{HT} = -0.945$ as well as that between H and mean minutes of sunshine (S), $r^2_{HS} = -0.877$, and to a lesser extent between H and mean wind speed (W), $r^2_{HW} = -0.659$. Thus, one would suspect that these four variables (H, T, S, and W) are intercorrelated, i.e., that multicollinearity is present.

Although the ordinary least squares (OLS) estimators remain unbiased [i.e., $E(\hat{\beta}_i) = \beta_i$] in the presence of multicollinearity and the R^2 statistic is unaffected, the variances, and in turn, the standard errors of the OLS estimates of the parameters of the collinear variables will be quite large, Kennedy [1979]. These large standard errors will result in small t-values and therefore may result in the rejection of an important explanatory variable which is known to affect the dependent variable (because its coefficient may appear not to be statistically significant).

Treatment of multicollinearity ranges from simply doing nothing to the use of some sophisticated econometric techniques, e.g., ridge regression. One procedure calls for keeping

Table V.4. Simple Correlation Coefficients of the Variables.*

	Q	$(\frac{M}{P_1})$	$(\frac{P_2}{P_1})$	P	Y	T	S	W	H	$\hat{H}$
Q	1.000									
$(\frac{M}{P_1})$	0.721	1.000								
$(\frac{P_2}{P_1})$	0.769	0.903	1.000							
P	-0.790	-0.924	-0.981	1.000						
Y	0.499	0.868	0.595	-0.675	1.000					
T	0.551	0.053	0.050	-0.054	0.043	1.000				
S	0.340	-0.085	-0.081	0.085	-0.060	0.873	1.000			
W	0.214	-0.086	-0.114	0.116	-0.075	0.575	0.488	1.000		
H	-0.506	-0.003	-0.021	0.016	0.033	-0.945	-0.877	-0.659	1.000	
$\hat{H}$	-0.487	-0.001	0.004	-0.003	-0.0001	-0.973	-0.908	-0.687	0.966	1.000

* For explanation of notations see note to Table V.1.

the collinear variables by grouping them together to form a composite index capable of representing this group of variables by itself in such a way that the composite variable has some useful combined economic interpretation, Kennedy [1979].

Since all of the collinear variables (H, T, S, and W) are weather variables, one can group them into one variable to represent the weather factor in the estimated model. Moreover, since relative humidity (H) is known to be negatively affected by temperature (T), and in turn by minutes of sunshine (S), as well as by air movement, i.e., wind speed (W); one can write H as a function of T, S and W; i.e.,

$$H = f(T, S, W). \tag{5.1}$$

A semi-log function is employed to estimate this relation, namely:

$$H_t = \alpha + \beta_T \ln T_t + \beta_S \ln S_t + \beta_W \ln W_t + e_t \tag{5.2}$$

where H, T, S, and W are as defined above, e_t is error term, and α, β's are parameters to be estimated. From the above discussion and from the simple correlation coefficients between H and the other three variables, it is clear that β_T, β_S, and β_W are all expected to be negative, and α to be positive.

Employing OLS procedures to estimate (5.2) and using monthly data for the same period [1973 - 1981] yields the following results

$$\hat{H} = \underset{(14.46)}{296.299} - \underset{(-12.17)}{28.3848} \ln T - \underset{(-5.13)}{21.5005} \ln S - \underset{(-6.78)}{14.3625} \ln W \tag{5.3}$$

$$\bar{R}^2 = 0.93 \qquad DW = 1.5743$$

All coefficients have the expected signs and are statistically significant at the 0.0005 level (t-values are in parenthesis with the critical t being approximately 3.370), $\bar{R}^2$ is very good and Durbin-Watson statistic (DW) is in the inconclusive region ($d_L < DW < d_u$).

Therefore, $\hat{H}$ in (5.3) will be substituted for H, T, S, and W in (4.14) and (4.16 - 4.20) to represent the weather factor in the municipal demand model for water.

The Models Reformulated

In order to treat the multicollinearity problem, H, T, S, and W will be replaced by one variable, $\hat{H}$, in the main model (4.14) and the other five models (4.16 - 4.20). This yields

Main Model

$$Q_t = \pi_o + \pi_1 \left(\frac{M_t}{P_{1t}}\right) + \pi_2 \left(\frac{P_{2t}}{P_{1t}}\right) + \beta_{\hat{H}} \hat{H}_t + u_{1t} \tag{5.4}$$

Linear

$$Q_t = \alpha + \beta_p P_t + \beta_y Y_t + \beta_{\hat{H}} \hat{H} + u_{2t} \tag{5.5}$$

Semi-Log

$$Q_t = \alpha + \beta_p \ln P_t + \beta_y \ln Y_t + \beta_{\hat{H}} \ln \hat{H} + u_{3t} \tag{5.6}$$

Exponential

$$Q_t = e^{[\alpha + \beta_p P_t + \beta_y Y_t + \beta_{\hat{H}} \hat{H} + u_{4t}]} \tag{5.7}$$

Price-Exponential

$$Q_t = \alpha\, e^{\beta_p P_t}\, Y_t^{\beta_y}\, \hat{H}_t^{\beta_{\hat{H}}}\, e^{u_{5t}} \tag{5.8}$$

Double-Log

$$\ln Q_t = \ln\alpha + \beta_p \ln P_t + \beta_y \ln Y_t + \beta_{\hat{H}} \ln \hat{H} + u_{6t} \quad (5.9)$$

where Q_t, M_t, P_{1t}, P_{2t}, P_t, and u_{it} are defined as before, π_o, π_1, π_2, α's and β's are parameters to be estimated, $\hat{H}$ is the "estimated" mean relative humidity using (5.3). The expected signs for π_o, π_1, π_2, α, β_p, and β_y are as before, and $\beta_{\hat{H}}$ is expected to be negative since $\hat{H}$ is still the "estimated" (rather than actual) mean relative humidity, and therefore is expected to affect the individual's water consumption negatively (inversely).

Estimating (5.4 - 5.9) by the OLS procedure and using the same monthly data from 1973-1981 used before yields the statistical results presented in Table V.5. All coefficients (except $\hat{\beta}_y$ in models 5.6 and 5.9) are statistically significant at least at the 0.10 level and some at the 0.05 level. The estimated parameters $\hat{\pi}_o$ and $\hat{\pi}_2$ in the main model are larger than that before grouping (see Table V.3) and significant at the 0.05 level, whereas $\hat{\pi}_1$ is almost identical to the one before. The estimated coefficient of $\hat{H}$, $\hat{\beta}_{\hat{H}}$, has the expected negative sign and is statistically significant at the 0.01 level. Thus by substituting for $\hat{H}$ its value given by (5.3) into models (5.4 - 5.9) in Table V.5, one finds that the coefficients of all weather variables (T, S, W, and H) have the expected signs as hypothesized in Chapter IV. Each of the six models explains over 80 percent of the variation in water consumption (i.e., $\bar{R}^2 > 0.80$). However,

Table V.5. Statistical Results for Municipal Water Demand Models Treated for Multicollinearity.

Model		$\bar{R}^2$	F	DW
Main Model (5.4)	$\hat{Q} = 446.199 + 0.270 (\frac{M}{P_1}) + 514.736 (\frac{P_2}{P_1}) - 8.646 \hat{H}$ (5.62)** (1.45)* (7.02)** (-12.39)**	0.83	177	0.476
Linear (5.5)	$\hat{Q} = 2911.94 - 2308.47 P - 0.441 Y - 8.648 \hat{H}$ (21.08)** (-17.28)** (-1.36)* (-13.79)**	0.86	228	0.599
Semi-Log (5.6)	$\hat{Q} = 1790.99 - 1220.24 \ln P - 38.235 \ln Y - 318.173 \ln \hat{H}$ (5.35)** (-16.37)** (-0.59) (-12.52)**	0.84	191	0.538
Exponential (5.7)	$\hat{Q} = e^{[8.565 - 2.032 P - 0.00041 Y - 0.0075 \hat{H}]}$ (76.81)** (-18.84)** (-1.59)* (-14.78)**	0.88 (0.85)@	267 (208)@	0.668
Price-Exponential (5.8)	$\hat{Q} = 9.80 \; e^{-2.092 P} \; Y^{-0.113} \; \hat{H}^{-0.273}$ (28.71)** (-18.49)** (-2.14)** (-13.69)**	0.87 (0.83)@	239 (180)@	0.655
Double-Log (5.9)	$\ln \hat{Q} = 7.517 - 1.059 \ln P - 0.025 \ln Y - 0.274 \ln \hat{H}$ (26.76)** (-16.93)** (-0.46) (-12.83)**	0.85 (0.81)@	205 (151)@	0.566

Notes: For explanation of notations see notes to Table V.1. t-values are in parenthesis. * and ** indicate a statistically significant coefficient at the 0.10 and 0.05 level, respectively. The critical values for t(108) are 1.290 and 1.661 at the 0.10 and 0.05 significance level, respectively. F(3, 104) = 4.5 at the 0.01 significance level, and DW(3, 108) are d_L = 1.522 and d_U = 1.596 at the 0.01 significance level. @ indicates the statistic has been recalculated using real values of the independent variable.

two problems still exist. First, the DW statistic is still less than 0.7 in all models, which indicates the presence of positive serial correlation (because $0 < DW < d_L$). Second, the estimated coefficient of Y, real per capita income, in models (5.5 - 5.9) still has a negative sign (and is statistically insignificant in models 5.6 and 5.9). Therefore, since the main model (5.4), as well as other models, suffer from serial correlation, it is advisable to correct for serial correlation in all models. The results are presented in Table V.6.

Final Results

After grouping the weather variables (T, S, W, and H) into one variable, $\hat{H}$, given by (5.3), and reestimating the six models (5.4 - 5.9) using the same monthly data (see Table V.5), the problem of serial correlation was encountered as well as a statistically insignificant and negative real income coefficient for models (5.5 - 5.9). Correcting for serial correlation using the maximum likelihood procedure solved these problems as indicated by the DW statistic ($d_u < DW < 4 - d_u$) in all models (see Table V.6). The main model (5.4) explains over 90 percent of the variation in water consumption ($\overline{R}^2 = 0.93$). Except for the estimated coefficient of real per capita income ($\hat{\beta}_y$), all estimated coefficients are statistically significant at the 0.10 level or better and have the expected sign (except that of $\hat{\beta}_y$ in the price-exponential model was negative). The F-statistics are

Table V.6. Statistical Results for Municipal Water Demand Models Treated for Multicollinearity and Corrected for First-Order Serial Correlation.

Model		$\bar{R}^2$	F	RHO	DW	ε_p	η_m
Main Model (5.4)	$\hat{Q} = 553.600 + 0.554 \left(\frac{M}{P_1}\right) + 353.258 \left(\frac{P_2}{P_1}\right) - 6.887 \hat{H}$ (3.19)** (1.43)* (2.42)** (-8.77)**	0.93	493	0.793	2.249	-0.771	0.211
Linear (5.5)	$\hat{Q} = 2519.55 - 1941.37 P + 0.112 Y - 7.036 \hat{H}$ (8.79)** (-6.48)** (0.17) (-9.09)**	0.93	498	0.750	2.229	-0.861	0.022
Semi-Log (5.6)	$\hat{Q} = 1.099.93 - 1.006.26 \ln P + 72.986 \ln Y - 256.88 \ln \hat{H}$ (1.56)* (-5.71)* (0.54) (-8.38)**	0.92	466	0.773	2.078	-0.828	0.060
Exponential (5.7)	$\hat{Q} = e^{[8.266 - 1.776 P + 0.00004 Y - 0.0062 \hat{H}]}$ (36.87)** (-7.69)** (0.08) (-9.58)**	N/C	N/C	0.716	2.264	-0.957	0.010
Price-Exponential (5.8)	$Q = 8.916 \, e^{-1.810 P} \, Y^{-0.012} \, H^{-0.224}$ (12.95)** (-7.27)** (-0.11) (-8.73)**	N/C	N/C	0.720	2.052	-0.976	-0.012
Double-Log (5.9)	$\ln \hat{Q} = 6.880 - 0.898 \ln P + 0.075 \ln Y - 0.220 \ln \hat{H}$ (11.83)** (-6.21)* (0.67) (-8.42)**	N/C	N/C	0.760	2.075	-0.898	0.075

Notes: For explanation of notations see notes to Table V.1. For critical values see notes to Table V.5. t-values are in parenthesis. * and ** indicate statistically significant at the 0.10 and 0.05 level, respectively. N/C not calculated, but before correcting for first-order serial correlation $\bar{R}^2 > 80$ and $F > 150$. RHO is the first-order serial correlation coefficient. ε_p and η_m are price and income elasticity of demand, respectively.

statistically significant at the 0.01 level in all models which implies that the null hypothesis of no linear relationship between per capita water consumption (Q) and the explanatory variables cannot be accepted.

Economic Interpretation of the Results

The municipal demand for water was hypothesized to be a function of per capita nominal income (M) divided by nominal water price (P_1), the cost of living index (P_2) divided by P_1, and four weather variables, namely, mean temperature (T), mean minutes of sunshine (S), mean wind speed (W), and mean relative humidity (H). Grouping the weather variables into one variable $\hat{H}$ (see 5.2) to treat the multicollinearity problem and correcting for serial correlation yielded the following results (see Table V.6) for the main model

$$Q_t = \underset{(3.19)^{**}}{553.6} + \underset{(1.43)^{*}}{0.554} \left(\frac{M_t}{P_{1t}}\right) + \underset{(2.42)^{**}}{353.258} \left(\frac{P_{2t}}{P_{1t}}\right) - \underset{(-8.77)^{**}}{6.887} \hat{H} \qquad (5.10)$$

$$\bar{R}^2 = 0.93 \qquad F = 493 \qquad DW = 2.249 \qquad \text{and}$$

$$\hat{H} = (296.299 - 28.3848 \ln T - 21.5005 \ln S - 14.3625 \ln W) \qquad (5.3')$$

These results imply that, ceteris paribus:

1. A change in the nominal price of water (P_1) will bring about an opposite change in the amount of municipal water demanded by the individual (Q_t) equal to

$$\left(\frac{0.554 * M_t + 353.238 * P_{2t}}{P_{1t}^2}\right)$$ Imperial Gallons (IG),[2/]

since (from 5.4)

$$\frac{\partial Q_t}{\partial P_{1t}} = - \frac{\pi_1 M_t + \pi_2 P_{2t}}{P_{1t}^2}$$

2. A change in the nominal per capita income (M_t) will have a direct change in the amount of municipal water demanded by the individual of the amount ($0.554/P_{1t}$) IG, since

$$\frac{\partial Q_t}{\partial M_t} = \pi_1/P_{1t}.$$

3. A change of one unit of the "estimated" relative humidity ($\hat{H}$) will bring about a change of 6.887 IG in the opposite direction in Q_t, since

$$\frac{\partial Q_t}{\partial \hat{H}} = \pi_3.$$

4. From (5.10) and (5.3') one can infer that, as hypothesized, per capita municipal water consumption (Q) increases as T, S, or W increases, i.e., these three weather variables have a direct (positive) effect on per capita municipal water consumption.

2/ Again the reader is reminded that over the period of analysis P_{1t} did not vary (although $\frac{M_t}{P_{it}}$ and $\frac{P_{2t}}{P_{1t}}$ did). See footnote 1.

The Plausibility of the Subsistence Level (γ_1)[3/]

When the main model (4.14) was derived from the Stone-Geary utility function (4.5), γ_1 was defined as the "subsistence" level of municipal water (Q_t) the individual will require per time period. In the final results (5.10), $\hat{\gamma}_1$ can be calculated by applying (4.13)

$$\hat{\gamma}_1 = \frac{\hat{\pi}_o}{1-\hat{\pi}_1} = \frac{553.6}{1-0.554} = 1241.3 \text{ IGPCM}^{4/} \tag{5.11}$$

The important thing that distinguishes γ_1 in (5.10) from the constant term in other models (5.5 - 5.9) is the fact that, ceteris paribus, if the nominal price of water (P_1) increases indefinitely, the value of γ_1, the "subsistence" level, will not be affected since the terms $\pi_1\ (\frac{M_t}{P_{1t}})$ and $\pi_2\ (\frac{P_{2t}}{P_{1t}})$ will go to zero as P_1 goes to infinity, but the value of π_o (which is used to calculate $\hat{\gamma}_1$) is not affected, whereas the value of $\hat{Q}_t$ in models (5.5 - 5.9) will decrease for <u>any</u> increase in P_1 and might become negative as P_1 increases beyond some level.[5/] Note that as P_1 goes to infinity, the right-hand side of (5.10) reduces to

$$Q_t = 553.6 - 6.887\ \hat{H}, \tag{5.12}$$

3/ See Appendix B for more discussion on the main model and the calculation of γ_1.

4/ Hereafter, IGPCM means Imperial gallons per capita per month, IGPCD means Imperial gallons per capita per day, gpcm means U.S. gallons per capita per month, and gpcd means U.S. gallons per capita per day.

5/ However, the value of the constant term in all models is affected by the value (mean value) of omitted variable(s), if any.

which when estimated using the mean value of $\hat{H}$ (= 40.2727) yields the following subsistence level (adjusted for weather effects) call it γ^*,

$$\gamma^* = \frac{\hat{\pi}_o - \hat{\beta}_{\hat{H}} \bar{\hat{H}}}{1 - \hat{\pi}_1}$$

$$= \frac{553.6 - 6.887\ (40.2727)}{1 - 0.554} \qquad (5.13)$$

$$= 619.4 \text{ IGPCM } (\equiv 744 \text{ gpcm})$$

or

$$\gamma^{**} = 21 \text{ IGPCD } (\equiv 25 \text{ gpcd})$$

Thus, model (5.4) and the empirical results (5.10) demonstrate the plausibility of the subsistence level of municipal water consumption in the individual's demand function.

However, one may argue that the estimated γ^* (619.4 IGPCM) implies that the individual requires, on average, 21 IG (25 U.S. gallons) per day as a subsistence level (γ^{**}), which is far more than the 2 - 2.7 liter (2.1 - 2.9 quarts) per day required to sustain life, Ensminger et al. [1983]. Nevertheless, the 21 IGPCD is not a substantial quantity of water if one considers the factors affecting the individual's daily consumption. One important factor is the "life style" or the standard of living the individuals of Kuwait have developed since the commercial production of oil in 1946, such as plumbed homes, and the use of water closets and household appliances. For the sake of comparison, the daily per capita domestic "baseline" water consumption figures in the U.S. reported by Flack [1982] are presented in Table V.7.

Table V.7. Domestic Baseline Water Use in the U.S.

Water Use Function	Baseline Use (gpcd)
Water Closet	25
Bath/Shower	20
Lavatory Sink	3
Laundry	10
Dishwashing	3
Drinking/Cooking	3
Total	64

Note: gpcd - gallon per capita per day (U.S. gallons).

Table V.7 shows that the subsistence level of water use in Kuwait (γ^{**} = 25 gpcd) is less than half the daily per capita domestic baseline water use in the U.S. This issue merits further discussion.

Since the data employed in this study are of an aggregate nature, one can understand why γ^{**} is larger than the 2 - 2.7 liters per day needed for the body. That is, the per capita monthly water consumption (Q_t) was derived by dividing the total amount of water consumed in month t (call it X_t) by the corresponding population figure. Therefore, X_t includes municipal (residential), commercial, and industrial uses since no separate figures were reported by the Ministry of Electricity and Water's Statistical Year Book. Even though it had been assumed (Chapter IV) that the industrial sector will substitute the inexpensive brackish water for fresh water for cooling purposes whenever possible, X_t still "carries" some aggregate implications because the commercial (business) uses are included and cannot be assumed negligible as in the industrial sectors. A second point is that γ^* is estimated from data that include uses other than the life-sustaining ones (drinking/cooking), and since the former is much greater than the latter (21 times the latter, in the U.S.) it is no surprise that γ^* came closer to the domestic figure in the U.S. than to the life-sustaining level.

As for why γ^{**} was smaller than the domestic baseline water use in the U.S., the major plausible argument is that the nominal price of water in Kuwait is double the average price of water in the U.S. (approximately 90¢ for 100 cubic foot $\equiv$ ¢145/1000 IG, whereas in Kuwait it is roughly ¢275/1000 IG in 1980) as reported by Mann and LeFrancois [1983]. Another point is the scarcity of water in Kuwait that forced people, over the years, to cut back their use of water (e.g., people in Kuwait or Saudi Arabia do not, on average, take a daily shower like people in the U.S.).

From the above discussion it is advisable that the definition of γ_1 should be "relaxed" somewhat from being a subsistence level to a less restrictive one such as "baseline" or "reservation" level of water required by the individual per time period to satisfy domestic (indoor) water needs for drinking, cooking, bathing, personal hygiene, etc. By doing so, one can see that the estimated value of the domestic baseline (γ^*) of 619.4 IGPCM (or γ^{**} = 21 IGPCD) is an estimate of the amount of water the individual would like to have as the minimum amount to meet the monthly needs in such a wealthy society. It appears to be a plausible figure if one compares it to the domestic baseline water use in the U.S. (Table V.7), given the price differential and habits that exist between the two societies.

Elasticities of Municipal Demand for Water in Kuwait

One of the "by-products" of demand estimation is the calculation of elasticities, especially price and income elasticities. The definitions of price and income elasticities, ε_p and η_m, respectively, were given in Chapter IV and the corresponding formulae for the six models were presented in Table IV.2. The estimates of price and income elasticities for the final results (calculated at the mean values of the relevant variables) are presented in Table V.6. The main model (5.4) produces an estimated price elasticity (ε_p) of -0.771 which is slightly smaller than the estimates from the other models (5.5 - 5.9), but an income elasticity of demand estimate (η_m) of 0.211 which is at least double the estimates from the other models. What ε_p means is that for a one percent increase in the nominal price of water (P_1), there will be a 0.771 percent decrease in the individual's water consumption. Similarly, for a one percent increase in the per capita nominal income (M) there will be a 0.221 percent increase in the individual's water consumption. The demand elasticity of the "estimated" relative humidity $(\hat{H})$, call it $\varepsilon_{\hat{H}}$, is estimated to be -0.228, which means that for a one percent increase in $\hat{H}$, there will be a 0.228 percent decrease in the individual's water consumption.

Comparison of Price and Income Elasticity Estimates with Other Studies

The comparison of elasticity estimates among different studies is useful in the sense that it helps the researcher to check the validity of his results by comparing them to those from similar studies in the same area, or if not possible, with those in similar areas. Unfortunately, to the best of the author's knowledge, this is the first study of its kind to be conducted in Kuwait or Saudi Arabia (which has a similar society). Therefore, the only option is to compare the results reported here with those in similar areas or under similar circumstances. Table V.8 is an abridged version of Tables II.1 - II.3 and includes results from studies which have some similarities to the present study. However, when such comparisons are undertaken, one should proceed with caution since there exists "the possibility of intercountry differences in the composition of household water demands," Batchelor [1975].

If one compares this study's elasticity estimates (ε_p and η_m) to those of studies employing similar kinds of data, i.e., time series, he will see that the price elasticity estimated from the main model (5.4, Table V.7), ε_p = -0.771, is larger than those in

Table V.8. Price and Income Elasticity Estimates for Selected Studies.

Investigators	Type of Data and Area Studied	Model	Price Elasticity	Income Elasticity
Howe and Linaweaver (1967)	CS (U.S.A.)	Linear (Domestic Demand)	-0.231	0.319
		Double-Log: Sprinkling	-1.12	0.662
		Total	-0.405	0.474
Grima (1972)	CS (Ontario, Canada)	Double-Log: Summer	-1.07	0.51
		Winter	-0.75	0.48
		Total	-0.93	0.56
Batchelor (1975)	CS (U.K.)	Linear	-0.23 to -0.28	0.38 to 0.93
Male et al. (1979)	CS (Eastern U.S.A.)	Linear	-0.20	0.254
		Double-Log	-0.680	0.459
		Price-Exponential	-0.358	0.545
Sewell and Roueche (1974)	TS (Victoria, B.C., Canada)	Linear: Annual	-0.457	0.268
		Peak	-0.114	0.078
		Off-Peak	-0.586	0.467
		Double-Log: Annual	-0.395	0.191
		Peak	-0.065	0.049
		Off-Peak	-0.579	0.504
Katzman (1977)	TS (Malaysia)	Linear	-0.1 to -0.2	-----
Billings and Agthe (1980)	TS (Az., U.S.A.)	Linear	-0.49	-----
		Double-Log	-0.267	1.68
Danielson (1979)	Pooled (N.C., U.S.A.)	Double-Log: Total Demand	-0.272	0.334
		Winter Demand	-0.305	0.352
		Summer Demand	-1.38	0.363
Hanke and de Maré (1982)	Pooled (Sweden)	Linear	-0.15	0.11

Notes: CS indicates a cross-section study.

TS indicates a time-series study.

Pooled indicates pooled cross section-time series study.

other studies [Sewell and Roueche, 1974; Katzman, 1970; and Billings and Agthe, 1980]. The same thing holds for ε_p from models (5.5 - 5.9). However, the income elasticity estimate (η_m) of 0.211 is smaller than that of the off-peak (i.e., domestic) and annual demands given by Sewell and Roueche and that by Billings and Agthe; this also holds for η_m from models (5.5 - 5.9). In fact, ε_p from (5.4) as well as from (5.5 - 5.9) is higher than ε_p in all studies (see Table V.8) except that for the sprinkling (summer) demand given by Howe and Linaweaver [1967], Grima [1972], and the reverse holds for η_m, i.e., η_m in Kuwait is smaller than those in other studies (except that for the peak demand given in Sewell and Roueche and η_m given by Hanke and deMaré, 1982). The only study that posited similar results was that of Grima [1972]. Although the study is cross-sectional in nature, the ε_p for the relevant demand, the winter (domestic) was -0.75 which is very close to the estimate of -0.771 given by model (5.4) although the η_m was 0.48, more than double those obtained in this study.[6/]

From the above, one can infer two things. First, if one follows the classification of goods according to their income

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[6/] Recall that it had been mentioned in Chapter II that ε_p and η_m from cross-section studies were higher than those from time series studies. However, the ε_p for the winter (domestic) demand in Grima (a cross section analyses) is comparable to that for the off-peak demand in Sewell and Roueche, and η_m was very close in the two studies. Further, the reader is reminded that elasticities for the main model are expressed in terms of nominal prices and income (see footnote 1).

elasticity of demand [luxury if $\eta_m > 1$, normal if $0 < \eta_m < 1$, or inferior if $\eta_m < 0$], the municipal water in Kuwait may be regarded as a normal good by Kuwaiti customers, although responsiveness to income changes appears to be lower than is the case for their counterparts in the U.S. or Canada as reflected by a lower η_m. Second, Kuwaiti consumers are, apparently, more responsive to water price changes than are customers in the U.S. or Canada as reflected by a higher ε_p in Kuwait than in the U.S. or Canada for the relevant demand [domestic (winter or summer)]. This last point has long been dismissed by many or its effects downplayed. To put it more clearly, many (noneconomists) believe that people in the oil-rich countries are ignorant of price changes of almost all goods, and in specific, necessities such as water, food and electricity, in the sense that price of water cannot be effectively used to control water consumption. However, this study demonstrates that, at least in Kuwait, the price of water can be a very effective "tool" in conserving municipal water, a service which is being provided at less than one-fourth of what it costs the government.

The Plausibility of the Model in the Presence of Price Increases

Aside from producing plausible empirical results, the main model (5.4) poses a feature other models (5.5 - 5.9) do not have.

The demand for municipal water presented by model (5.4) does not vanish as the price of water increases indefinitely. Considering reasonable water price increases by 0.10 KD intervals from 0.8 KD to 4.0 KD (just a little more than what it costs to produce water from desalination, namely 3.62 KD/1000 IG in 1980/81) Figures V.1 - V.6 illustrate how the municipal demand for water responds to price changes in each of the six models, keeping other variables constant at their respective mean values (see Table V.7) and Figure V.7 depicts all the demand curves in Figures V.1 - V.6.

It is clear from Figures V.2 and V.3 that both the linear (5.5) and semi-log (5.6) models break down as price increases beyond 1.1 KD for the former and 1.7 KD for the latter. In other words, as price increases beyond 1.1 KD in the linear model and beyond 1.7 KD in the semi-log model, the quantity demanded ($\hat{Q}$) becomes negative, a situation which has been ruled out by the vital need of water for life.

On the other hand, as price approaches the cost of producing water (3.62 KD/1000 IG) two more models break down, namely the exponential (5.7) and the price-exponential (5.8) as depicted by Figures V.3 and V.4. Although $\hat{Q}$ does not turn negative at P = 3.6, it absolutely does not satisfy the amount needed for a healthy body, namely the 2 - 2.7 liters per capita per day.[7/]

[7/] This 2-2.7 liters per person per day is the total amount of water the human "body" needs to function normally. Therefore, a lot more is needed for bathing and cooking, both of which directly and indirectly affect the "health" status of the human body.

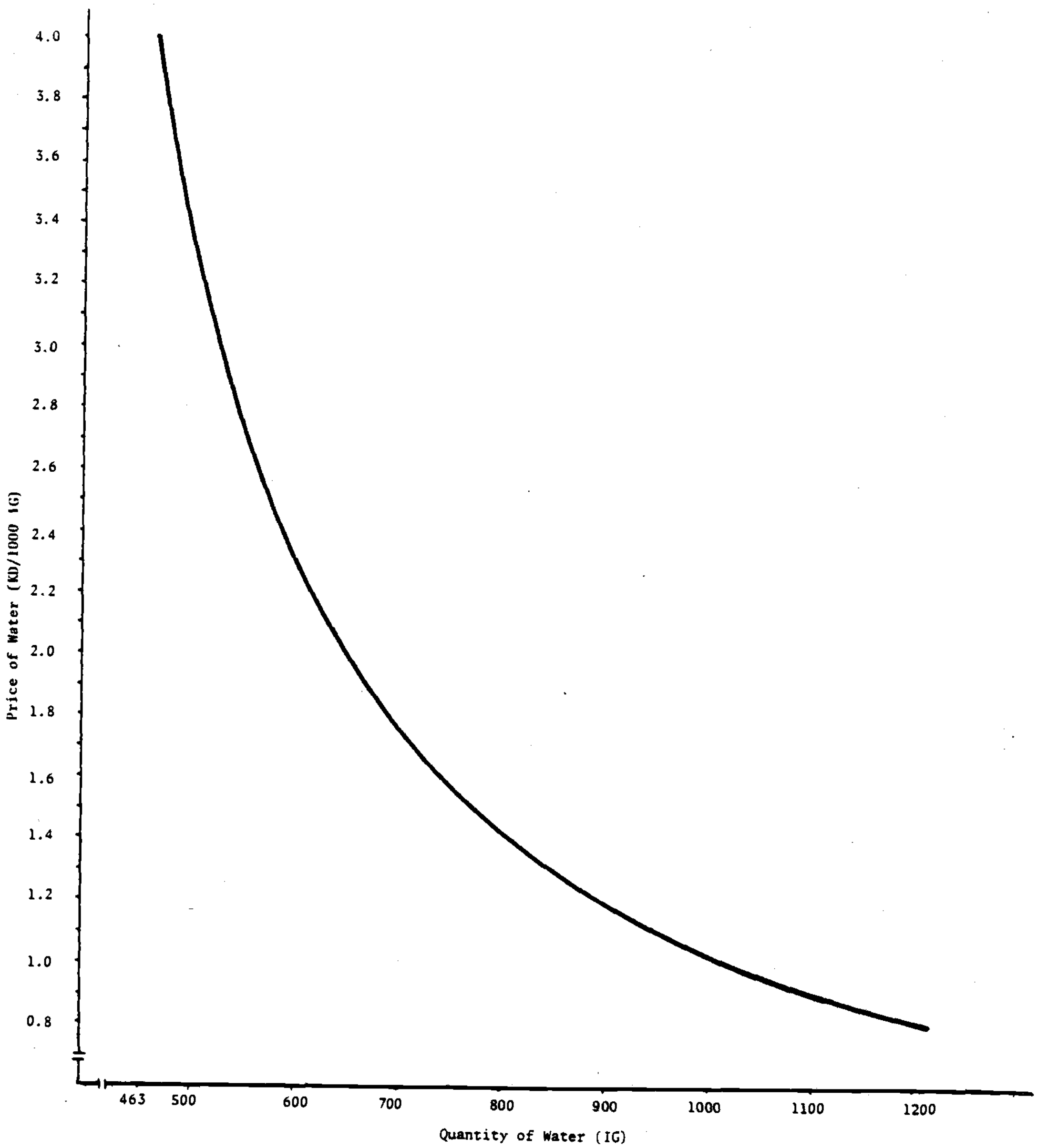

Figure V.1. Estimated Demand Curve for the Main Model (5.4) [where P_2, M and $\hat{H}$ are held constant at their respective mean values].

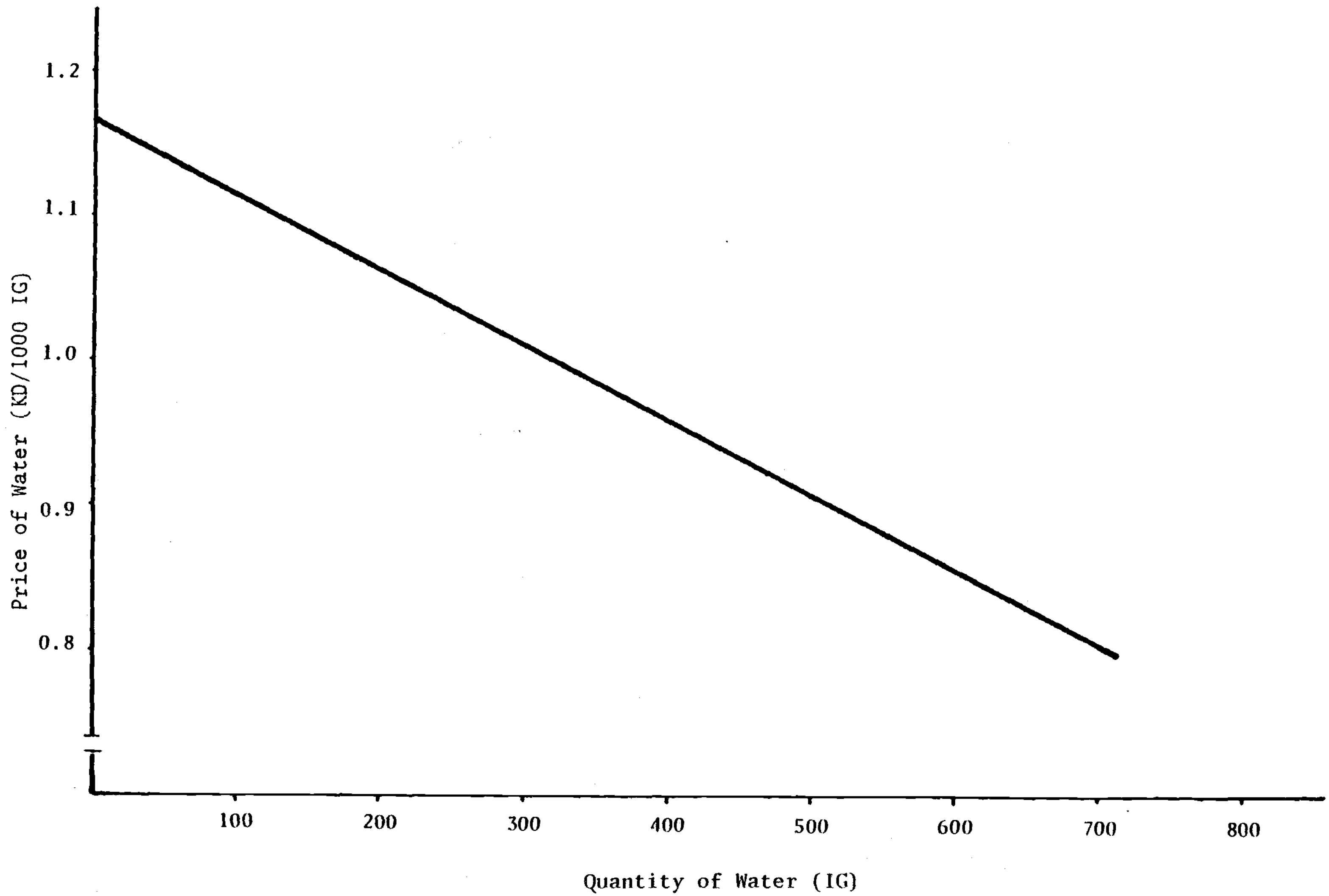

Figure V.2. Estimated Demand Curve for the Linear Model (5.5) [where Y and $\hat{H}$ are held constant at their respective mean values].

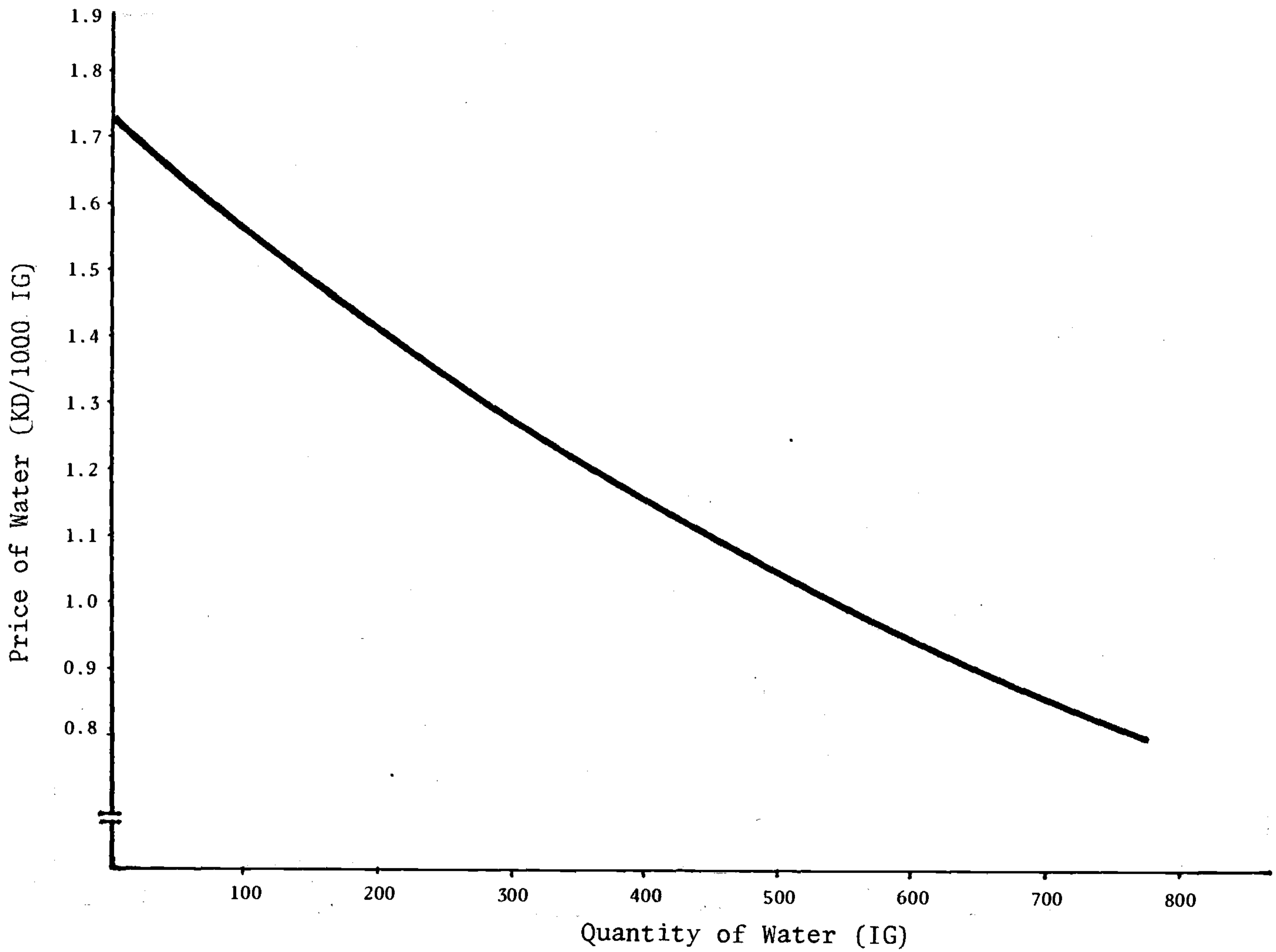

Figure V.3. Estimated Demand Curve for the Semi-Log Model (5.6) [where Y and $\hat{H}$ are held constant at their respective mean values].

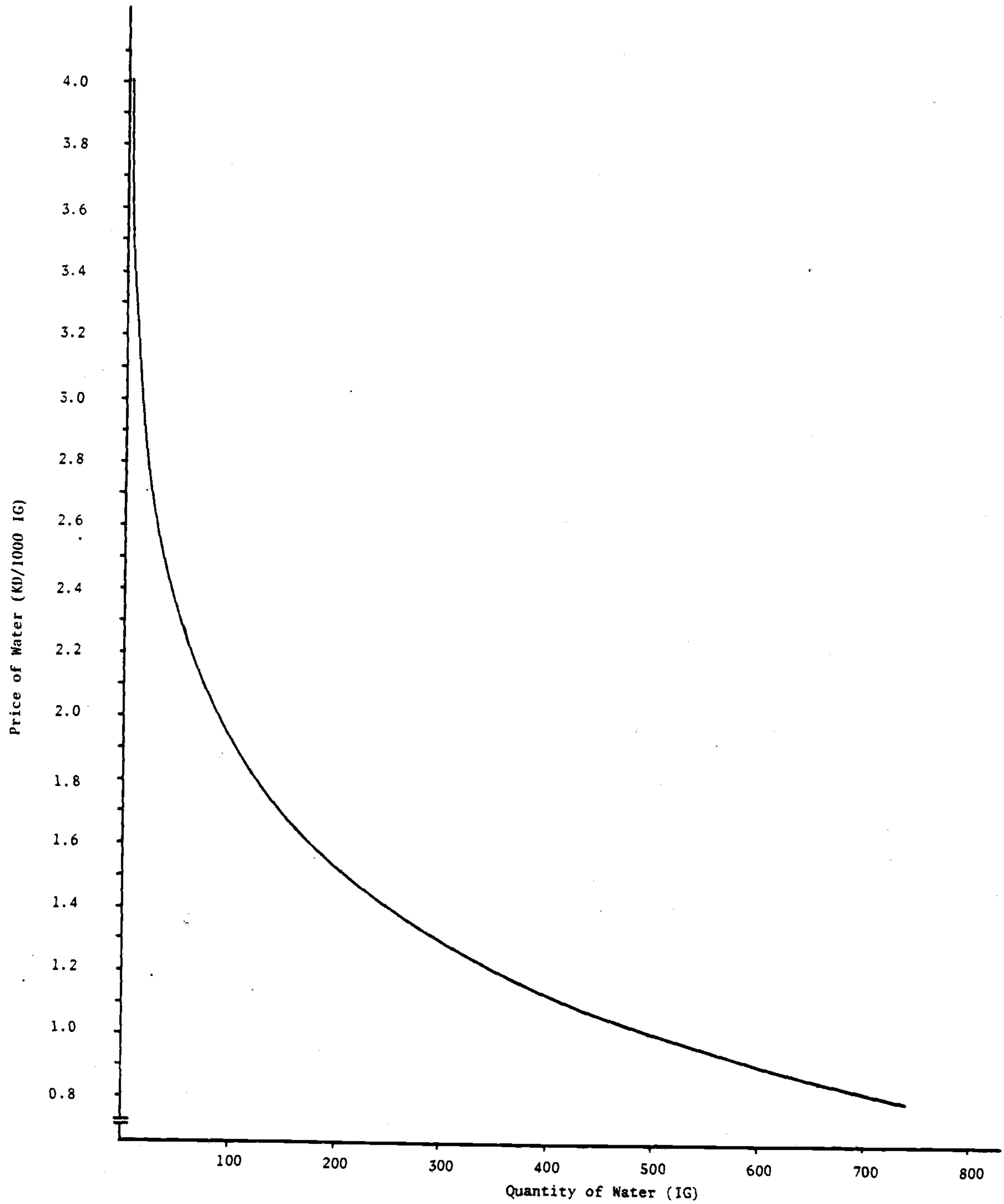

Figure V. 4. Estimated Demand Curve for the Exponential Model (5.7) [where Y and $\hat{H}$ are held constant at their respective mean values].

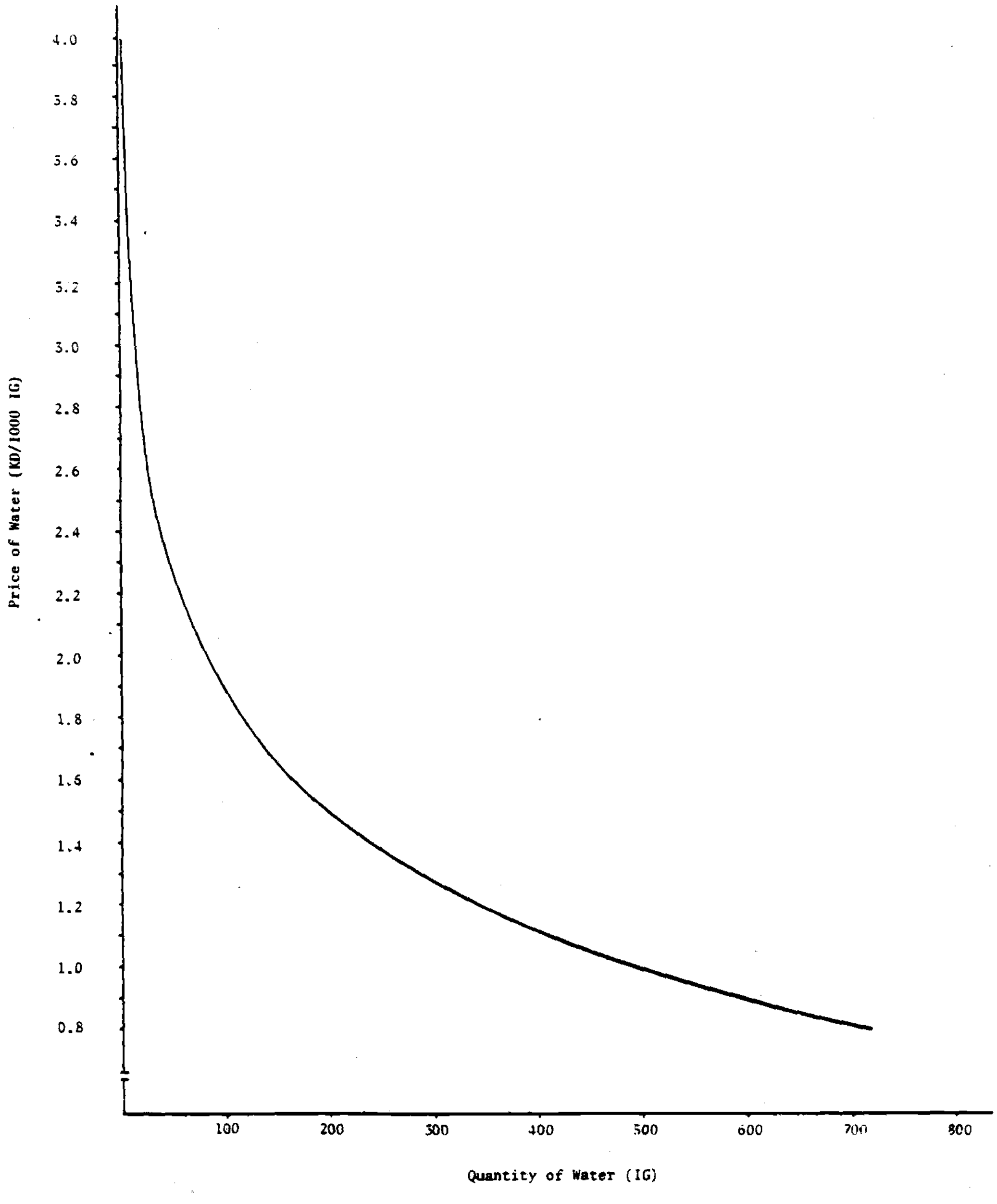

Figure V.5. Estimated Demand Curve for the Price-Exponential Model (5.8) [where Y and H are held constant at their respective mean values].

At P = 3.6 KD, the exponential model yields $\hat{Q}$ = 5.13 IGPCM (0.78 liter per day), whereas the price-exponential model yields $\hat{Q}$ = 5.42 IGPCM (0.8 liter per day).

Therefore, we are left with the double-log model (5.9) to compare with the main model (5.4). Although the double-log model does not break down (i.e., yields $\hat{Q}$ lower than 2 - 2.7 liters per day) until P exceeds 70 KD/1000 IG, a situation unlikely to happen, it is still "inferior" to the main model for the follwoing reasons. First, at P = 3.6 KD, the double-log model yields $\hat{Q}$ = 205 IGPCM (6.8 IGPCD) compared to 485 IGPCM (16.2 IGPCD) in the main model. The latter figure is very close to the one found in studies in Singapore (very similar climate) that "a daily per capita domestic consumption of 90 liters (19.8 IG) of piped water of high quality seemed to be the 'social minimum' for preventing water-borne diseases in this location," United Nations [1976]. Secondly, the double-log models, in general, yield constant elasticities for all levels of variables, a situation that is fairly unrealistic. Finally, the double-log model is inconsistent with utility theory. That is, except in special cases,[8/] the double-log demand function cannot be deduced from maximization of a classical utility function, Hassan and Johnson [1976]. However, the double-log model has been used extensively in empirical work because of its ease of estimation, good fit

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8/ For these cases see Wold and Jureen [1953], p. 105-107.

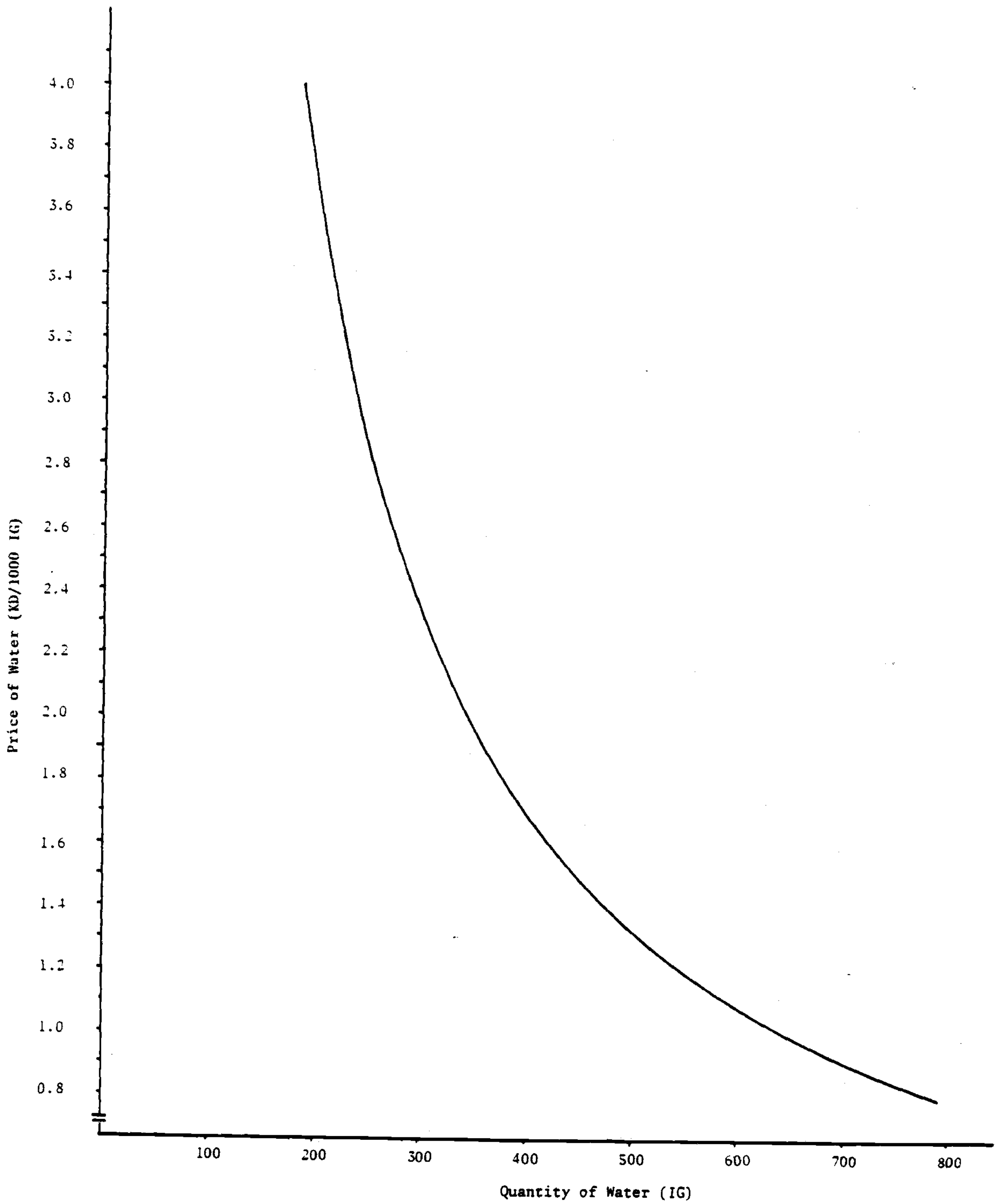

Figure V.6. Estimated Demand Curve for the Double-Log Model (5.9) [where Y and $\hat{H}$ are held constant at their respective mean values].

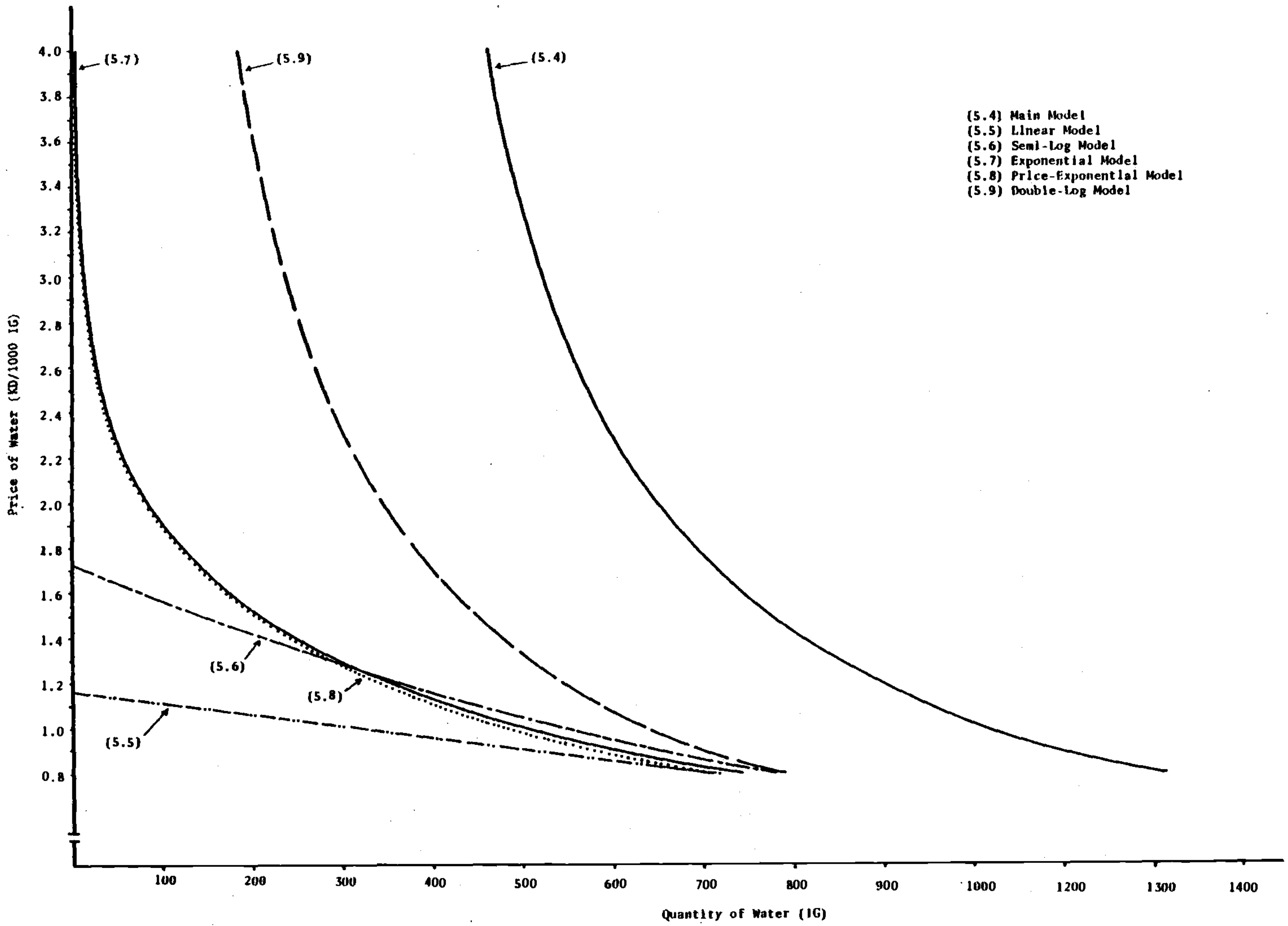

Figure V.7. Estimated Demand Curves for All Models [all explanatory variables, except the nominal price of water, are held constant at their respective mean values].

(i.e., high R^2), and the ease with which elasticity estimates can be calculated by the estimated parameters. Nevertheless, the main model (5.4) produced higher R^2 statistics than the double-log.[9/]

From the above discussion, it is apparent that on theoretical and empirical grounds, the main model which was derived from the Stone-Geary utility function is superior to the linear, semi-log, exponential, price-exponential, or the double-log models.

Implications of the Study for Future Planning Policies

This study resulted in a price elasticity estimate (ε_p) of -0.771 and income elasticity estimate (η_m) of 0.211 (see Table V.6). This relatively high ε_p and low η_m, as compared to those from other studies in Canada, U.K., and U.S. reveals, as discussed above, that people treat water as a necessary commodity but are willing to change their consumption of water more than their counterparts elsewhere for given water price changes. From this one might deduce that municipal water consumers in Kuwait are consuming more than they need when compared to those elsewhere and therefore, they will be more sensitive to water

[9/] Note that the R^2 for the double-log model needs to be recalculated using the real values rather than the log values in order to be comparable to the R^2 of the main model. See Table V.5.

price changes. The following discussion treats the subject of setting a pricing policy under the existing circumstances in the country and drawing on the notion of the domestic baseline water use level discussed above.[10/]

Pricing Policies

As pointed out at the outset of this thesis, the municipal water in Kuwait is sold at a fixed rate per 1000 IG, namely 0.8 KD/1000 IG, a price that is less than one-fourth of the cost to produce fresh water from sea water, not to mention the cost of delivering water into homes. Therefore, there is no incentive for people to conserve water in the presence of this pricing method, particularly when one considers the high per capita income (M) people in Kuwait enjoy, on average. Perhaps then, another pricing policy should be adopted if conservation of water is to be enforced. Such a pricing policy should take the following points into consideration:

1. Provide the minimum domestic baseline water level (defined as γ^*) to all consumers at some price level affordable by all consumers.
2. Pricing the quantities of water beyond the domestic

10/ The suggested pricing policy does not follow from this research rather it is the author's belief that it will aid the government in its effort to provide water to all people and to cut on waste uses.

baseline level at an increasing block rate structure (see Chapter III) to encourage conservation.

However, one might ask what is the domestic baseline water consumption level for the average Kuwaiti consumer? To the best of the author's knowledge, no estimate of this level is available. Therefore, future research has to address this issue and then use the resulting figure(s) in constructing a pricing policy that will provide every individual with the amount of water needed to maintain a healthy society and which discourages any misuse of municipal water and therefore, encourages conservation of municipal water.

Marginal Cost Pricing Revisited

In the discussion of pricing schemes in the water industry (Chapter IV), economists pointed out that the marginal cost of water service (MC) should be used in pricing water. If this is followed, water service in Kuwait will be priced at 3.6 KD/1000 IG, which will result in the individual demanding only 485 IGPCM (16 IGPCD) using the main model (5.4) and keeping other variables at their respective mean values.

Charging this "high" price for water is unlikely, at least in the near future, for the following reasons. The first reason is the political environment that exists in the country. Since the government does not allow individuals to receive oil revenues, the public expects the government to provide all public services free or, at worst, at nominal prices. One example is water (provided at less than 23 percent of the cost of distilling sea water) another is electricity which is being sold for less than 6 percent of production cost. Second, the amount 16 IGPCD (= 73.5 liters) estimated to be demanded when price is set at marginal cost is less than the quantity found as the "social minimum" for preventing water-borne diseases in Singapore (90 liters per capita per day) which may discourage the use of marginal cost pricing for health reasons. Finally, some Moslim scholars believe, based on Islamic teaching, that water should not be sold and, instead, should be provided free for all people.

These three reasons, especially the first, have discouraged any price changes for water services and all other public services in Kuwait and other Emirates and has led some of them to provide some or all of these services free of charge for the public sector.

CHAPTER VI

SUMMARY AND CONCLUSIONS

This study involves the estimation of the municipal demand for water in Kuwait. The quantity of water consumed per time period was hypothesized to be a function of the price of water, per capita income, temperature, minutes of sunshine, wind speed, and relative humidity. It was argued that the municipal demand for water is curvilinear at least in price, therefore, a nonlinear model was applied. The model was derived from the Stone-Geary utility function through a constrained maximization approach. The resulting model is curvilinear in price and income but linear in the parameters which, therefore, was estimated using ordinary least squares procedure. The use of time series data (monthly figures, 1973-1981) resulted in the problem of serial correlation, and the use of four interrelated variables (temperature, sunshine, wind speed, and relative humidity) resulted in the problem of multicollinearity. Grouping the four interrelated variables into one variable ($\hat{H}$) helped to "dampen" the effects of multicollinearity, and correction for serial correlation treated the first problem. The estimated model explains more than 90 percent of the variation in water consumption by the hypothesized variables. The model was shown to guarantee that enough water to sustain a healthy body is demanded even if price of water goes to infinity, a situation which other models fail to satisfy.[1/] This amount was called "the domestic

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[1/] However, the model has the drawback that if price goes to infinity and income goes to zero there might be a positive quantity demanded if $\hat{\pi}_0 > \hat{\beta}_{\hat{H}} * \hat{H}$, a situation that should not happen if income is zero.

baseline water use" in Kuwait.

It was found that, on one hand, the municipal demand for water in Kuwait is price inelastic but less price-inelastic than was found in other studies in the U.S. or Canada ($\varepsilon_p = -0.771$). On the other hand, it was estimated to be more income inelastic than was the case in other studies ($\eta_m = 0.211$). This implies that water is a necessary commodity as perceived by Kuwaiti customers.

Implications for Other Research

Although the results of this study seem plausible, it was difficult to check their validity by comparing them with similar studies in Kuwait or Saudi Arabia (which has a similar economic and physical environment) because no other studies were available. Therefore, additional research on this subject is needed.

As to the data employed, more disaggregated data are desirable in order to describe the demand function efficiently. Cross section data is desirable to explain the municipal water uses across households, and, in turn, broaden the knowledge of how people use municipal water. In such studies, it would be desirable to include such other variables as age and education of households, number of people in household, number of bathrooms in the house, and gardening activities. Also it may be desirable to pool time series and cross section data and compare the resulting estimates to those of other studies.

Although this study is the first to be conducted using Kuwaiti data, it is one of many studies involving the estimation of the municipal demand for water and price and income elasticities for water. However, it is the only one that addresses the "subsistence (baseline)" level of water explicitly in the estimated model. Therefore, it would be of interest to see how the estimated "baseline" level of municipal water consumption in Kuwait compares to that of other countries.

With regard to pricing, it was suggested that the domestic "baseline" level of water consumption be priced at a low level and any quantities thereafter should be priced using an increasing block schedule to encourage water conservation.[2/]

[2/] This conclusion is not deduced from the estimated demand models, rather from discussion in Chapter III about pricing policies and the author's own judgment.

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APPENDICES

APPENDIX A

DATA SOURCES

Data for this study were obtained from different government sources. The data for water consumption were obtained from the Ministry of Electricity and Water. The data for national income, the cost of living index, and population were obtained from the Annual Statistical Abstract, Ministry of Planning. The data for the weather variables were obtained from the Meteorological Department, Climatological Section for the years 1973-1978 and from the Annual Statistical Abstract for the years 1979-1981.

Data Adjustment

The data for all variables except national income and population were available on a monthly basis. Therefore, estimates of monthly income and population figures were generated from the annual data by use of the following simple equation:

$$X_t = X_{t-1}(1+r)^{12} \tag{A.1}$$

where

X_t = annual figure at year t

X_{t-1} = annual figure at year t-1

r = growth rate of X.

Underlying this procedure is the assumption that the growth of X is the same between the months of each year. Solving (A.1) for r enables us to calculate the monthly figures of X for year t using the following equation:

$$X_t^i = X_{t-1}(1+r)^i \tag{A.2}$$

where

X_t^i = the value of the i^{th} month for X_t, $i = 1, \ldots, 12$.

X_{t-1} and r are as above.

In Kuwait, the fiscal year begins in April. Therefore, for national income calculation, X_t^1 will be April's national income of year t, X_t^2 will be May's, and so on. However, each X_t^i should be divided by 12 to get the expected actual monthly national income. Deflating each X_t^i by the corresponding monthly cost of living index with the base year 1972=100 yields the real monthly national income. To generate estimates of the real per capita monthly income, the resulting figures were divided by the corresponding monthly population.

Annual population estimates, on the other hand, were mid-year estimates. Therefore, the procedure outlined above was used, but now X_t^1 is July's population figure in year t.

APPENDIX B

THE DERIVATION OF THE ECONOMETRIC MODEL

The general form of the Stone-Geary utility function is

$$U = \sum_i \beta_i \log (Q_i - \gamma_i) \qquad \beta_i > 0,\ Q_i - \gamma_i \geq 0 \qquad \text{(B.1)}$$
$$i=1, \ldots, n$$

where U is the utility derived from the Q_i commodities, and β_i and γ_i are parameters to be estimated. γ_i has been defined in the literature as the "subsistence" level of commodity Q_i. However, in the case of municipal water, it has been shown that the amount demanded is affected by weather variables (Chapter III). Therefore, to incorporate this finding into the definition of γ, it will be assumed that the subsistence level, γ, of water is affected negatively by a weather variable $\hat{H}$ in the following way:

$$\gamma = \gamma_1 + k\hat{H}, \qquad k \leq 0 \qquad \text{(B.2)}$$

that is, as $\hat{H}$ increases, γ, the subsistence level of municipal water demanded, will decrease, and vice versa.

Thus, substituting (B.2) into (B.1) and taking a two-commodity case (municipal water, Q_1, and all other goods, Q_2), the following utility function emerges:

$$U = \beta_1 \log [Q_1 - (\gamma_1 + k\hat{H})] + \beta_2 \log [Q_2 - \gamma_2]. \qquad \text{(B.3)}$$

Maximizing (B.3) subject to the budget constraint

$$P_1Q_1 + P_2Q_2 = M \qquad \text{(B.4)}$$

where P_1 and Q_1 are price and quantity of municipal water, P_2 and Q_2 are price and quantity of all other goods, and M is income (expenditure), yields the following Lagrangian function:

$$L = \beta_1 \log[Q_1-(\gamma_1+kH)]+\beta_2 \log[Q_2-\gamma_2]+\lambda[M-P_1Q_1- P_2Q_2] \tag{B.5}$$

Solving the first-order conditions (Chapter IV) yields the following demand function for municipal water, Q_1^*,

$$Q_1^* = (1 - \frac{\beta_1}{\beta_1+\beta_2})\gamma_1 + (\frac{\beta_1}{\beta_1+\beta_2}) \frac{M}{P_1} - (\frac{\beta_1\gamma_2}{\beta_1+\beta_2}) \frac{P_2}{P_1} + (1 - \frac{\beta_1}{\beta_1+\beta_2})k\hat{H} \tag{B.6}$$

or simply,

$$Q_1^* = \pi_0 + \pi_1 \frac{M}{P_1} + \pi_2 \frac{P_2}{P_1} + \pi_3 \hat{H} \tag{B.7}$$

where

$\pi_0 = (1 - \frac{\beta_1}{\beta_1+\beta_2})\gamma_1$, $\pi_1 = \frac{\beta_1}{\beta_1+\beta_2}$, $\pi_2 = - \frac{\beta_1\gamma_2}{\beta_1+\beta_2}$, and

$\pi_3 = (1 - \frac{\beta_1}{\beta_1+\beta_2})k$. Thus, the subsistence level, γ, is given by [using (B.2)].

$$\gamma = \gamma_1 + k\hat{H}$$

$$= \left(\frac{\pi_0}{1 - \frac{\beta_1}{\beta_1+\beta_2}}\right) + \left(\frac{\pi_3}{1 - \frac{\beta_1}{\beta_1+\beta_2}}\right) \hat{H}$$

or simply,

$$\gamma = \left(\frac{\pi_0 + \pi_3 \hat{H}}{1 - \pi_1}\right). \tag{B.8}$$

Thus, if $\hat{H} = 0$, then $\gamma = \pi_0/1-\pi_1$.

The Plausibility of the Underlying Utility Function

The Stone-Geary utility function (B.1) is an additive utility function [see Hassan and Johnson, 1976]. When Engel functions are derived from (B.1), rather than demand functions, the general form is given as:

$$P_i Q_i = P_i \gamma_i + \frac{\beta_i}{\sum_j \beta_j} [M - \Sigma P_j \gamma_j] \quad i,j = 1, \ldots, n \qquad (B.9)$$

The system of equation (B.9) is called the Linear Expenditure System (LES) [Stone, 1954].

Although the LES has been employed extensively by researchers following Stone's article, some researchers have raised criticisms of the model. The first criticism is that in the LES every good must be a substitute for every other good and no two goods may be complements. A second criticism is that there is an approximate proportionality between price and income (expenditure) elasticities. This section is not intended to challenge these criticisms of the LES; rather it is intended to show that the demand function (B.7) is plausible and, to a large extent, not affected by the above problems when it is used to estimate the municipal demand for water.

Since we are considering the two-commodity case (B.7) it has been shown that "only substitutability can occur in the present two-commodity case" [Henderson and Quandt, 1980, p. 31]. Therefore, the first criticism is not a problem in this analysis or, at least, has been assumed away.

Deaton (1974) demonstrated the approximate proportionality between own price and income elasticities (ε_{ii} and η_i, respectively) by showing that:

$$\varepsilon_{ii} = \phi\eta_i - \eta_i W_i(1 + \phi\,\eta_i) \tag{B.10}$$

where $1/\phi = \frac{\partial\, \ell n\, \lambda}{\partial\, \ell n\, M}$, and $W_i = P_i Q_i/M$ is the average budget share. Deaton argued that if the number of goods is large, a reasonable degree of approximation of (B.10) would be

$$\varepsilon_{ii} \simeq \phi\eta_i . \tag{B.11}$$

Therefore, the convergence of (B.10) into (B.11) is conditioned on the fact that the number of goods is large which will reduce the value of W_i such that the second term on the right-hand side of (B.10) approaches zero. However, in a two-commodity case, W_i is not likely to be small enough to yield (B.11), and, therefore, the relation (B.11) will not, by and large, be observed under the existing situation. Hence, the second criticism does not pose considerable problems in this case, although W_i in the case of water is, very likely, quite small.

In short, the demand model (B.7) represents a plausible model, i.e., one derived from utility maximization, that recognizes the possibility of a subsistence level of water consumption by including a parameter to represent it; and does not suffer from problems the LES has due to the fact that only a two-commodity case is being considered.

APPENDIX C

DATA EMPLOYED

Table C.1. Data Employed (January 1973 - December 1981).

N	QT	$\hat{Q}$	P_2	P	M	Y	T	S	W	H
1	616.9	712.685	1.037	0.771	110.281	106.346	11.20	511	9.0	56.5
2	624.4	718.692	1.044	0.766	111.151	106.467	17.30	430	9.0	53.5
3	719.2	823.826	1.050	0.762	111.901	106.573	19.25	511	10.0	39.5
4	753.0	858.413	1.057	0.757	112.660	106.584	25.45	523	11.0	32.0
5	750.2	850.085	1.073	0.746	122.409	114.081	31.65	638	10.0	23.0
6	864.0	974.399	1.074	0.745	133.171	123.996	34.60	620	16.0	17.5
7	858.7	964.831	1.092	0.733	145.030	132.811	36.45	632	13.0	19.5
8	858.7	960.407	1.123	0.712	157.805	140.521	37.55	658	7.7	26.0
9	888.0	988.754	1.106	0.723	171.729	155.270	34.30	618	7.6	25.5
10	846.3	938.040	1.113	0.719	186.864	167.892	28.65	613	4.8	39.0
11	738.0	814.210	1.119	0.715	203.314	181.693	18.65	523	8.4	43.0
12	685.1	752.444	1.135	0.705	221.242	194.927	13.30	445	5.2	60.5
13	644.8	704.931	1.183	0.676	240.730	203.491	11.40	313	7.9	74.5
14	616.0	670.440	1.176	0.680	261.968	222.762	13.45	431	9.2	71.0
15	716.1	775.840	1.172	0.683	285.054	243.220	19.35	425	9.1	61.0
16	795.0	857.420	1.195	0.669	310.181	259.566	24.65	551	9.9	44.5
17	930.0	998.390	1.208	0.662	309.952	256.583	30.40	622	8.5	33.5
18	954.0	1019.560	1.231	0.650	309.762	251.635	35.70	741	9.9	18.5
19	985.8	1048.720	1.228	0.651	309.546	252.074	36.60	733	9.4	17.5
20	973.4	1030.160	1.233	0.649	309.140	250.722	36.25	713	10.0	22.5
21	981.0	1032.960	1.247	0.642	308.776	247.615	33.35	616	9.2	29.0
22	923.8	967.634	1.261	0.634	308.355	244.532	26.55	575	6.8	44.0
23	780.0	812.839	1.274	0.628	307.975	241.739	21.45	527	7.3	50.0
24	700.6	726.387	1.272	0.629	307.604	241.827	12.85	359	6.6	71.5
25	725.4	748.221	1.273	0.628	307.210	241.327	11.65	369	7.8	73.5
26	655.2	672.345	1.287	0.622	306.824	238.402	13.95	504	7.7	65.5
27	821.5	838.608	1.279	0.625	306.415	239.574	18.40	549	9.7	44.0
28	921.0	935.310	1.306	0.613	306.015	234.315	24.50	509	6.9	48.5
29	1035.4	1046.180	1.321	0.606	308.128	233.254	31.20	648	9.9	33.0
30	1071.0	1076.490	1.318	0.607	310.201	235.357	35.95	643	13.0	18.5
31	1147.0	1147.000	1.313	0.609	312.327	237.873	37.65	686	11.0	17.5
32	1147.0	1141.410	1.336	0.599	314.539	235.434	36.75	661	11.0	19.5
33	1149.0	1137.850	1.358	0.589	316.774	233.265	34.50	623	6.9	29.5
34	1085.0	1069.280	1.371	0.584	319.033	232.701	26.20	622	8.7	30.0
35	960.0	941.546	1.380	0.580	321.315	232.837	20.15	468	6.7	48.5
36	883.5	862.288	1.370	0.584	323.589	236.196	12.70	310	8.4	66.0
37	874.2	849.068	1.365	0.586	325.887	238.745	12.50	370	6.6	68.0
38	849.7	821.284	1.381	0.579	328.209	237.660	13.75	409	9.4	60.5
39	976.5	939.304	1.378	0.581	330.556	239.881	16.50	472	7.9	58.5
40	1047.0	1002.200	1.360	0.588	332.895	244.775	23.70	475	8.3	52.0

Table C.1. Data Employed (January 1973 - December 1981) (continued).

N	QT	Q	P_2	P	M	Y	T	S	W	H
41	1286.5	1225.590	1.387	0.577	333.056	240.127	29.85	651	9.9	35.0
42	1407.0	1333.780	1.379	0.580	333.162	241.597	35.85	732	12.0	16.5
43	1407.4	1327.740	1.364	0.587	333.308	244.361	36.15	647	13.0	18.0
44	1453.9	1364.270	1.399	0.572	333.273	238.223	36.35	689	9.7	19.5
45	1359.0	1268.430	1.420	0.563	333.249	234.682	33.40	612	8.8	22.5
46	1345.4	1249.090	1.422	0.563	333.233	234.341	28.60	535	6.8	45.0
47	1197.0	1105.470	1.441	0.555	333.227	231.247	20.90	511	6.2	39.5
48	1125.3	1033.710	1.450	0.552	333.200	229.793	16.50	397	6.0	58.5
49	1035.4	946.089	1.506	0.531	333.182	221.236	10.45	398	7.6	66.0
50	1061.2	964.464	1.518	0.527	333.143	219.462	16.85	576	7.8	51.5
51	1249.3	1129.360	1.489	0.537	333.113	223.716	21.60	433	11.0	43.0
52	1332.0	1197.730	1.493	0.536	333.094	223.104	24.75	460	10.0	41.0
53	1550.0	1386.400	1.508	0.531	333.716	221.297	32.20	569	10.0	29.5
54	1614.0	1435.940	1.520	0.526	334.320	219.947	36.10	631	12.0	16.0
55	1664.7	1473.190	1.523	0.525	334.934	219.918	37.10	603	13.0	16.0
56	1705.0	1501.280	1.552	0.515	335.648	216.268	37.25	672	8.6	25.0
57	1689.0	1479.760	1.545	0.518	336.371	217.716	34.75	600	8.5	24.0
58	1630.6	1421.500	1.584	0.505	337.105	212.819	25.85	437	7.5	49.5
59	1416.0	1228.210	1.582	0.506	337.819	213.539	18.85	553	7.6	55.0
60	1370.2	1182.530	1.581	0.506	338.543	214.132	16.00	352	7.2	67.5
61	1370.2	1176.640	1.609	0.497	339.278	210.862	13.40	429	6.2	65.0
62	1276.8	1091.000	1.577	0.507	340.022	215.613	16.00	460	7.8	56.5
63	1515.9	1288.810	1.590	0.503	340.747	214.306	19.90	491	8.6	48.5
64	1647.0	1393.280	1.639	0.488	341.483	208.348	25.60	486	8.8	30.5
65	1813.5	1526.520	1.640	0.488	352.323	214.831	31.50	651	8.8	24.0
66	1929.0	1615.580	1.645	0.486	363.486	220.964	34.60	653	11.0	20.5
67	1928.2	1606.830	1.661	0.482	375.012	225.775	36.80	650	10.0	24.0
68	2011.9	1668.660	1.667	0.480	387.009	232.159	35.35	663	12.0	18.0
69	1887.0	1557.700	1.695	0.472	399.400	235.634	33.50	628	9.6	27.0
70	1980.9	1627.560	1.689	0.474	412.196	244.047	28.15	590	5.6	46.5
71	1668.0	1363.970	1.711	0.468	425.376	248.613	17.00	390	6.1	45.5
72	1670.9	1359.890	1.710	0.468	438.988	256.718	16.95	394	6.1	66.5
73	1559.3	1263.100	1.728	0.463	453.046	262.179	14.45	388	7.1	66.0
74	1464.4	1180.590	1.704	0.469	467.526	274.370	18.05	533	8.1	50.0
75	1686.5	1353.310	1.710	0.468	482.519	282.175	19.80	498	8.1	39.5
76	1860.0	1485.500	1.701	0.470	497.963	292.747	27.20	514	10.0	31.0
77	2067.7	1643.510	1.714	0.467	502.596	293.230	31.35	535	8.7	33.5
78	2148.0	1699.370	1.745	0.458	507.323	290.730	36.50	517	13.0	22.0
79	2250.6	1772.130	1.739	0.460	512.065	294.460	37.15	538	13.0	18.0
80	2182.4	1708.600	1.780	0.449	516.338	290.077	36.10	643	10.0	27.0

Table C.1. Data Employed (January 1973 - December 1981) (continued).

N	QT	Q	P_2	P	M	Y	T	S	W	H
81	2169.0	1688.460	1.788	0.447	520.663	291.198	34.40	581	5.9	38.0
82	2154.5	1667.700	1.802	0.444	525.041	291.366	29.10	500	6.7	44.0
83	1815.0	1396.910	1.809	0.442	529.432	292.665	22.50	488	6.3	46.5
84	1708.1	1307.090	1.786	0.448	533.836	298.900	13.85	420	7.0	63.5
85	1621.3	1233.680	1.876	0.426	538.336	286.959	12.55	457	6.5	62.0
86	1548.6	1171.670	1.845	0.434	542.849	294.227	14.30	427	7.0	62.0
87	1810.4	1361.920	1.831	0.437	547.377	298.950	20.30	389	8.5	53.0
88	2132.8	1595.330	1.827	0.438	551.961	302.113	26.55	446	10.0	33.5
89	2269.2	1687.640	1.855	0.431	548.951	295.930	31.65	605	10.0	23.0
90	2304.0	1703.760	1.881	0.425	545.975	290.258	36.95	687	13.0	16.0
91	2049.1	1506.690	1.887	0.424	543.033	287.776	38.85	690	11.0	18.5
92	2120.4	1549.430	1.875	0.427	539.808	287.898	36.35	687	11.0	20.0
93	2091.0	1518.410	1.917	0.417	536.585	279.908	32.20	628	8.2	28.0
94	1993.3	1438.370	1.938	0.413	533.362	275.213	27.35	543	8.7	31.5
95	1848.0	1325.210	1.945	0.411	530.180	272.586	21.15	406	7.7	56.5
96	1720.5	1226.130	1.945	0.411	527.038	270.971	13.65	428	7.1	63.0
97	1615.1	1143.840	1.926	0.415	523.897	272.013	13.80	407	8.4	69.0
98	1531.6	1077.910	1.894	0.422	520.759	274.952	15.00	411	8.7	64.0
99	1835.2	1283.540	1.916	0.418	517.659	270.177	20.00	450	7.3	52.0
100	1980.0	1376.240	2.024	0.395	514.598	254.248	25.20	522	8.5	32.5
101	2247.5	1552.360	2.016	0.397	503.804	249.903	30.90	507	10.0	25.0
102	2247.0	1542.320	2.004	0.399	493.255	246.135	35.40	707	9.7	20.0
103	2442.8	1666.300	2.031	0.394	482.947	237.788	37.80	637	10.0	19.5
104	2439.7	1655.160	2.049	0.390	473.224	230.954	37.30	646	9.3	19.0
105	2352.0	1586.940	2.107	0.380	463.680	220.066	33.00	635	6.8	33.5
106	2207.2	1481.240	2.115	0.378	454.372	214.833	26.50	538	4.7	40.5
107	2076.0	1385.570	2.142	0.373	445.205	207.846	19.60	478	8.9	47.0
108	1943.7	1290.210	2.163	0.370	436.236	201.681	15.80	418	6.6	64.5

Notes: N=1 corresponds to January 1973.
QT is the total monthly water consumption in Kuwait (million IG).
The nominal price of water (P_1) did not change during the period of study (P_1=0.8 KD).
For other notations see notes to Table V.1.