Chapter 1

INTRODUCTION

Much has been written about economic efficiency and the pricing policies of water supply authorities.[1] Randall (1981) surveyed some of the key issues pertaining to irrigation water pricing in an Australian context. Howe and Linaweaver (1967), Hanke and Davis (1971), Hanke (1975, 1978, 1980), Foster and Beattie (1979) and Gallagher and Robinson (1977) also emphasised the potential efficiency gains to be had by the introduction of a non-zero marginal price for water. Indeed, the economic principles were well established more than twenty years ago when Hirshleifer, de Haven and Milliman (1960) published their seminal book.

The majority of water supply authorities in Australia use a flat rate as the basis for their pricing policies (Gallagher and Robinson 1977). The rating structure is made up of two parts:

(a) a lump-sum charge based on the value of the property to which mains water is connected (this charge gives the consumer the right to a water allowance or quota and normally includes a charge for sewerage); and

(b) a marginal price for water used in excess of the allowance.

To the knowledge of the present writer, only two Australian water supply authorities serving major urban centres have attempted to encourage restraint in water use by introducing non-zero marginal prices for all water consumed by residential consumers. The Perth Metropolitan Water Supply, Sewerage and Drainage Board was the first to introduce such a policy on July 1st, 1978 (Hunter District Water Board 1982<u>a</u>, p. (i)). Four years later the Hunter District Water Board (HDWB), the authority of particular interest in this study, introduced its 'user-pays' tariff for

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[1] For a comprehensive treatment of the general theory and specific applications see Turvey (1968).

residential consumers (Hunter District Water Board 1982a).

The HDWB services with mains water, sewerage and surface drainage, the local government areas of Newcastle, Lake Macquarie, Maitland, Cessnock and Port Stephens. This region, referred to as the Lower Hunter Valley, is approximately 170 kilometres north of Sydney and has a population of some 385 000 people. The main industries are coal mining, electricity generation and steel making.

In a publication explaining its new pricing policy (Hunter District Water Board 1982a), the HDWB outlined both the operational aspects of, and the rationale for, its policy change. Budgetary considerations were of paramount importance. The HDWB faced a backlog of sewerage works and maintenance, as well as the prospect of funding the development of additional storage capacity.

The final two-part tariff upon which the HDWB settled appears to be aimed at achieving three primary objectives:

(a) to raise sufficient revenue to enable the HDWB to cover fixed and variable costs, including maintenance, repairs, depreciation and interest;

(b) to raise revenue for self-funding of some capital works; and

(c) to encourage the conservation of water by residential consumers so that planned extensions to storage capacity can be deferred, thus reducing expected interest payments.

Residential consumers in the Lower Hunter Valley now face the following charges:

(a) a lump-sum charge based on the unimproved land value for each connection (at present this charge is calculated as 0.025 per cent of the New South Wales Valuer General's 1977 Unimproved Capital Value (UCV) if both mains water and sewerage are connected to the property, and as 0.0125 per cent of the 1977 UCV if only water is connected); and

(b) a marginal price for water actually used, as measured by the property's water meter (this charge is currently set at 60 cents per kilolitre if both water and sewerage are connected, and at 40 cents per kilolitre if only water is connected).

Under the 'old' rating system in the Lower Hunter Valley, which corresponded to the generally used pricing system outlined earlier, only a small percentage of households consumed more than their allowance (Hunter District Water Board 1982b, p. 37).[2] In other words, very few consumers faced a non-zero marginal price for water. Hence, the data available to the HDWB cannot be analysed in a way which will yield a 'reasonable' measure of the price responsiveness of the demand for water. Consequently, the HDWB was faced with inadequate knowledge in evaluating the likely effects of the pricing policy change. In the event, all that could be done was to make some guided assumptions. So, based on the Perth experience and consumption trend estimates, the HDWB assumed that residential water consumption would fall by 20 per cent as a result of the introduction of marginal pricing. It was on the basis of this assumption that the HDWB evaluated alternative marginal pricing policies, finally choosing that currently in place.[3]

Motivation for the present study arose from the desire to measure accurately the response by consumers to the HDWB's new pricing policy. This response will be of interest to other water supply authorities throughout Australia in the event that they contemplate changing their pricing policies. The success or otherwise of the new policy, in terms of both revenue and public acceptance considerations, is of great importance.

At the time of the instigation of the new pricing policy it was apparent to the present author that the HDWB was 'feeling its way' with caution. Clearly, the lack of knowledge regarding consumer reaction, in terms of both political and economic behaviour, is a significant factor undermining the confidence with which water authorities can proceed with

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[2] For example, in 1981/82 only 3.5 per cent of households consumed more than their allowance.

[3] It appears that a 20 per cent reduction in consumption was assumed for all policies considered.

policy changes.

1.1 Objectives and Hypotheses

In this study the view is taken that investment and pricing policies appropriate to water supply should desirably be formulated only after consideration is given to the existing levels and responsiveness of the demand for water. The objectives of this study are:

(a) to utilise data available from the HDWB and that obtained by a household questionnaire survey to obtain parameter estimates for annual urban household demand for water in the Lower Hunter Valley region of New South Wales; and

(b) to assess the results so obtained in terms of their implications for the pricing policies of the HDWB and other Australian water supply authorities.

Two testable hypotheses arise from the objectives. These relate to the expectation that residential water demand in the Lower Hunter Valley is both price and income inelastic and the expectation that analysis of available data will yield results which are consistent with those of similar studies completed elsewhere.

The hypotheses to be tested are:

(a) that the price elasticity of demand and the income elasticity of demand for water in the Lower Hunter Valley, for the period of the study and based on the chosen sample, lie between zero and unity; and

(b) that the price elasticity of annual demand for water based on willingness-to-pay (WTP) valuations will not be significantly different from values obtained in selected previous studies.

1.2 Outline of the Dissertation

In Chapter 2 demand theory is examined with a view to providing an analytical framework for the study. The neo-classical theory of demand is presented first and this is followed by a discussion of theoretical considerations relevant to empirical demand estimation and an attempt to apply demand theory to pricing policy analysis.

A review of the literature on empirical studies of residential water demand is provided in Chapter 3. This is presented to serve two purposes: first, to determine the types of analyses used in, and the magnitudes of empirical estimates obtained from, previous studies; and second, to give guidance for model selection in the present study.

A discussion of methods, data and results appears in Chapter 4. This is included to trace the development of the preferred model formulation; to detail the sources of data and methods of data collection; to report and evaluate the empirical results; and to test the stated hypotheses.

Chapter 5 is devoted to a statement of the limitations of the study and a discussion of the implications arising from the results. Finally, Chapter 6 is included to provide a summary of the findings of the study, some recommendations relevant to pricing policy decisions and a brief reference to the need for further research.

Chapter 2

THE THEORY OF DEMAND

Two fundamental goals of economic research are to provide explanation and prediction. Such goals are complementary and can be achieved only through theoretical analysis and empirical investigation. Empirical studies provide tests of the assumptions and conclusions of theories and theories guide empirical analysis by providing an appropriate conceptual framework.

The present study involves an empirical examination of residential demand for water and, as such, requires at the outset the establishment of a general framework for analysis and the choice of a suitable economic model. In particular, the chosen model should (a) provide a plausible explanation of consumer behaviour; and (b) predict accurately the effect of changes in relevant explanatory variables.

It is with these points in mind that the following exposition of demand theory is presented. The purpose of the exposition is to provide the necessary analytical framework and, in addition, expose the tools of analysis which are relevant to a study of residential demand for water. The discussion will begin with an examination of the development of demand theory. This will be followed by a review of the neo-classical theory of demand, a discussion of empirical estimation of market demand and an outline of the restrictions implied by utility theory. A brief note on two recent contributions to demand theory is then presented. The chapter is completed with some water pricing policy analysis utilising the theory of individual consumer demand.

2.1 <u>The Development of Demand Theory</u>

The history of demand analysis is characterised by two distinguishable paths: one which is concerned with the discovery of general laws governing the operation of markets and another which has an empirical base and is concerned with the psychological laws of consumer preference (Brown and Deaton 1972, p. 1146). Developments along each path have been inter-related and the present study utilises results from both.

According to Brown and Deaton (1972), the first publication relating to demand analysis was Davenant (1699) and consisted essentially of a numerical schedule of the demand for wheat. However, it was not until the 1730s that the basis for preference theory was put forward by Bernoulli (1738) who reported that level of wealth and the individual's utility or pleasure were closely related. Almost another four decades were to elapse before Adam Smith (1776) published his classic work An Enquiry into the Nature and Causes of the Wealth of Nations. These authors established that, not only does market price vary directly with quantity demanded and inversely with quantity supplied, but also there is a feedback mechanism whereby quantities demanded and supplied themselves depend upon price (Brown and Deaton 1972, p. 1146).

In the nineteenth century Bernoulli's concept of utility was generalised to include Smith's proposition of downward sloping demand curves. This involved the introduction of the concepts of marginal utility and indifference curves, widely associated with such mathematical economists as Gossen (1854), Walras (1874), Edgeworth (1881) and Jevons (1891). Engel (1857), too, made a significant contribution by formulating the laws governing particular expenditure patterns which relate to income levels.

In the final decade of the nineteenth century Marshall (1890) pioneered the concept of elasticity of demand, thus providing a framework for empirical measurement of consumer behaviour. Following soon after were the publications of Fisher (1892) and Pareto (1906) which showed that utility need only be measured ordinally for the existence of 'well-behaved' indifference curves (Wold and Jureen 1964, p. 61).

Empirical studies which applied the concepts developed thus far included those of Pigou (1910) and Lehfeldt (1914), while further theoretical development is attributed to Slutsky whose rigorous mathematical approach was first published in 1915. Within another fifteen years, Moore (1929) had drawn attention to the problems associated with shifting supply and demand curves and with the existence of short-run and long-run elasticities. This work stimulated many workers, such as Yule (1926), Working (1927), Schultz (1928), Leontief (1929) and Hotelling (1932) to develop further the empirical relationships associated with market demand. Then followed the work of Allen and Hicks (1934) and Allen and Bowley (1935) so that by 1939 the classical approach to demand analysis was well-established. According to Brown and Deaton (1972), this classical approach may be characterised '... as consisting of the application of variations in least-squares single-equation fitting, to both time-series and cross-sectional data, of market models based as far as possible on the theoretical results of Slutsky, Allen and Hicks.' (p. 1148). To the present day, this approach has provided the framework for further development of the theory and for empirical evaluation of consumer behaviour.

It was not until after the Second World War that Samuelson's (1938, 1950) revealed preference theory stimulated the detailed debate which finally established the equivalence of that theory to the classical theory of demand (Houthakker 1950). Of note in this discussion was its attention to '... the observable consequences of demand theory' (Brown and Deaton 1972, p. 1149). Meanwhile, the empirical work of Stone (1954), Nerlove (1960) and Houthakker and Taylor (1966), by the use of more advanced computational and econometric techniques, extended the ambit of demand analysis to a wide range of commodities and to the separation of durables and non-durables.

Since the 1950s, demand analysts have increasingly tackled questions of methodology. It would seem that, with the advent of improved computing facilities and the keeping of more detailed records relating to economic variables, there has been a shift of attention toward the testing of the empirical validity of theoretical models (Brown and Deaton 1972, p. 1149). The literature is vast in this area of demand analysis. However, two notable exceptions to the general trend are worth mentioning. In 1966 Lancaster published 'A New Approach to Consumer

Theory' which viewed commodities in the light of the properties or characteristics they possess, rather than in terms of their physical appearance and/or function. Also, in 1966, Muth examined the proposition that commodities purchased in the market by consumers are inputs into a household production function. These publications would seem to have particular relevance to the present study and attention will subsequently be focused on them. The immediate task is to attempt to outline the theory of demand as it currently stands.

2.2 The Neo-Classical Theory of Demand

As outlined in many micro-economics text books[1], the neo-classical theory of demand is based on the concept of utility. Different quantities of goods yield different quantities of utility to consumers. It is supposed that, given constant tastes, a consumer's preferences may be represented by a utility measure which is a continuous function of the quantities of goods consumed. If this is a cardinal measure, then the consumer will be able to assign to every commodity or group of commodities a number representing the utility associated with it, thus allowing a cardinal ranking of preferences and illustrating rationality in the choice of that bundle of commodities which yields maximum utility. However, in pursuing maximum utility, the consumer is constrained by market prices and his or her income level.

The assumption of cardinal ranking of preferences has been shown to be unnecessarily restrictive as a basis for demand theory and, in practice, lacks empirical foundation (Henderson and Quandt 1980, pp. 8-18; Koutsoyiannis 1981, pp. 17-27; Tisdell 1972, pp. 96-101). The indifference curve approach, popularised by Allen and Hicks (1934), rests on the premise that utility need only be measured ordinally. This implies that individual consumers can distinguish among commodities and/or bundles of commodities so that they can rank their preferences in ascending or descending order, according to the utility gained from

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[1] See, for example, Baumol (1965); Ferguson and Maurice (1974); Henderson and Quandt (1980); Hirshleifer (1980); Intriligator (1971); Koutsoyiannis (1981); Kuenne (1968); Layard and Walters (1978); Lloyd (1967); Samuelson (1970); Tisdell (1972); Watson (1968).

consumption of each. The ordering of preferences is said to be weak, implying transitivity and completeness, but allowing indifference between commodity bundles.

The consumer is assumed to be rational and to have complete knowledge of the market so that for every consumer:

> '... there exists a preference function that is unique up to a monotone transformation (sic), smooth, continuous, globally strictly quasi-concave, and strictly rising as any good or group of goods is increased in quantity consumed, other goods remaining fixed in quantity. Each consumer's preferences are independent of the goods consumed by all other consumers. The domain of this function is the exhaustive set of all goods and services baskets with nonnegative components that it is possible for the consumer to obtain ... The consumer will seek that basket ... which yields the highest preference value for his preference function, subject to ... the restriction that he choose within his attainable set, defined as that subset of baskets whose total cost does not exceed the value of his assets plus income on these assets ...' (Kuenne 1968, p. 319).

2.2.1 The consumer's equilibrium

The individual consumer's indifference map is made up of a family of indifference curves which each trace out a locus of points representing combinations of commodities yielding the same unique level of utility. The optimal position for the consumer will be represented by a point along the indifference curve yielding the highest attainable level of utility.

The attainable region is bounded by the income or budget line which defines the purchasing power of the consumer. The equilibrium position will, therefore, be located where the budget line is tangential to an indifference curve: this position will represent that mix of commodities which yields the highest attainable level of utility. At this point the marginal rate of commodity substitution (MRCS), representing the modulus of the slope of the indifference curve, is equal to the ratio of commodity prices, representing the slope of the budget line.

Mathematical derivation of the indifference curve and the consumer's equilibrium may be used to illustrate the above proposition and, in addition, exposes some of the implications for empirical work arising from the theoretical constructs of the model.

Consider a two-commodity case where utility is a function of the consumed quantities of commodities 1 and 2: that is, $u = f(x_1,x_2)$. An indifference curve may be derived for any particular constant level of utility. The total first-order differential of the utility function equals zero when utility is held constant:

$$
\begin{aligned}
du = (\partial u/\partial x_1)dx_1 + (\partial u/\partial x_2)dx_2 &= 0 \\
f_1.dx_1 + f_2.dx_2 &= 0 \\
-dx_2/dx_1 &= f_1/f_2 \qquad \ldots\ 2.1
\end{aligned}
$$

where dx_2/dx_1 = the slope of the indifference curve and its negative represents the MRCS; and

f_i = the first-order partial derivative of the utility function with respect to x_i.

The rate of change of the indifference curve slope is determined by the second derivative:

$$
\begin{aligned}
d^2x_2/\ dx_1^2 &= d(-f_1/f_2)/dx_1 \\
&= -\ (f_{11}f_2^2 - 2f_{12}f_1f_2 + f_{22}f_1^2)\ /\ f_2^3 \qquad \ldots\ 2.2
\end{aligned}
$$

where f_{ij} = the second-order partial derivatives of the utility function.

Since strict quasi-concavity of the utility function implies that

$$2f_{12}f_1f_2 - f_{11}f_2^2 - f_{22}f_1^2 > 0,$$

the bracketed portion of the numerator of the right-hand-side of equation 2.2 must be negative. Also, since $f_2 > 0$ (marginal utility is positive), $d^2q_2/dq_1^2 < 0$, implying that the slope is decreasing in absolute value as more of commodity 1 is taken, ensuring that the indifference curve is convex to the origin when a strictly quasi-concave utility function is assumed (Henderson and Quandt 1980, p. 11).

The consumer's equilibrium is reached by maximising utility subject to a budget constraint. That is:

$$\max u = f(x_1,x_2)$$
$$\text{subject to } M = p_1x_1 + p_2x_2 \ . \qquad \ldots\ 2.3$$

This position may be illustrated graphically as in Figure 2.1. Alternatively, the Lagrangean expression

$$L = f(x_1,x_2) + h(M - p_1x_1 - p_2x_2) \qquad \ldots\ 2.4$$

may be used. The first order conditions for a maximum are:

$$\partial L/\partial x_1 = 0 \quad \text{or} \quad f_1 = hp_1 \ ;$$

$$\partial L/\partial x_2 = 0 \quad \text{or} \quad f_2 = hp_2 \ ; \text{ and}$$

$$\partial L/\partial h = 0 \quad \text{or} \quad M = p_1x_1 + p_2x_2 \qquad \ldots\ 2.5$$

where h represents the marginal utility of income. Therefore,

$$f_1/p_1 = f_2/p_2 = h,$$

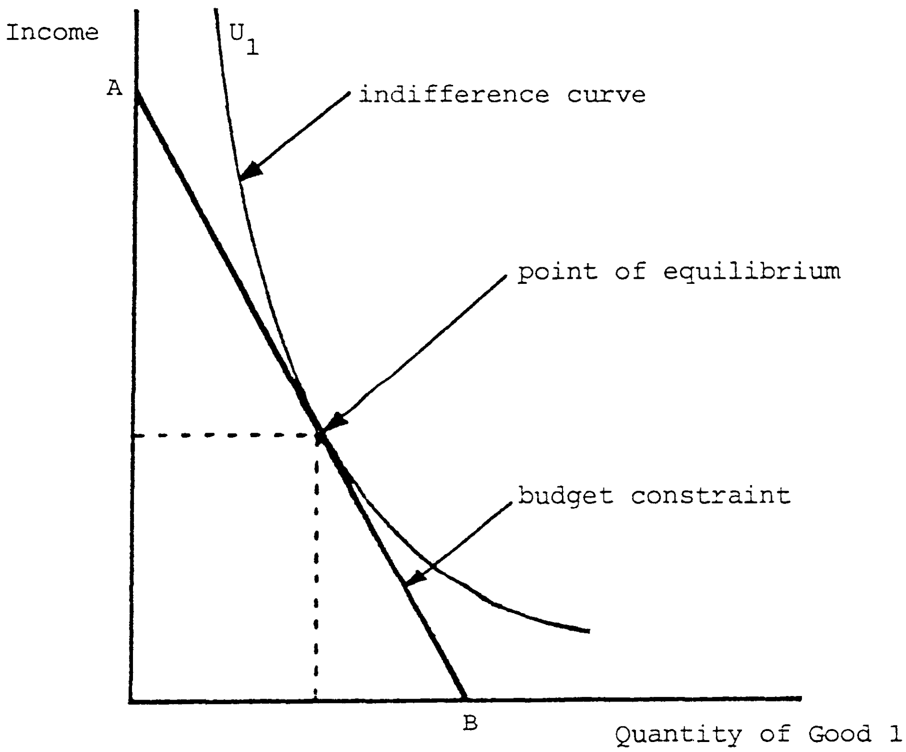
implying that, at equilibrium, marginal utility divided by price is equated with h for all commodities.

The second-order condition is satisfied by the concavity assumption, ensuring that the relevant bordered Hessian determinant, $|H_2|$, is positive for a maximum. That is, for the two-commodity case:

$$|H| = \begin{vmatrix} 0 & p_1 & p_2 \\ p_1 & f_{11} & f_{12} \\ p_2 & f_{21} & f_{22} \end{vmatrix} > 0 \ . \qquad \ldots\ 2.6$$

2.2.2 Deriving the demand function

The demand function for a particular commodity relates the quantity demanded to commodity prices and income. It may be derived by solving the set of simultaneous equations appropriate to the first-order conditions for utility maximisation. This can be readily achieved,



At equilibrium, the budget line, AB, is tangential to the indifference curve, U_1.

Figure 2.1 The Consumer's Equilibrium in Consumption.

provided utility is assumed to take a particular functional form.

Assuming $u = x_1x_2$, ... 2.7a

then $L = x_1x_2 + h(M - p_1x_1 - p_2x_2)$. ... 2.7b

Therefore,

$\partial L/\partial x_1 = 0$ or $x_2 = hp_1$; ... 2.7c

$\partial L/\partial x_2 = 0$ or $x_1 = hp_2$; and ... 2.7d

$\partial L/\partial h = 0$ or $M = p_1x_1 + p_2x_2$ 2.7e

Hence,

$x_2/x_1 = p_1/p_2$

or $x_2 = p_1x_1/p_2$ 2.7f

Substituting for x_2 from equation 2.7f into equation 2.7c, the demand function for commodity 1 is:

$M = p_1x_1 + p_2\,(p_1x_1/p_2)$

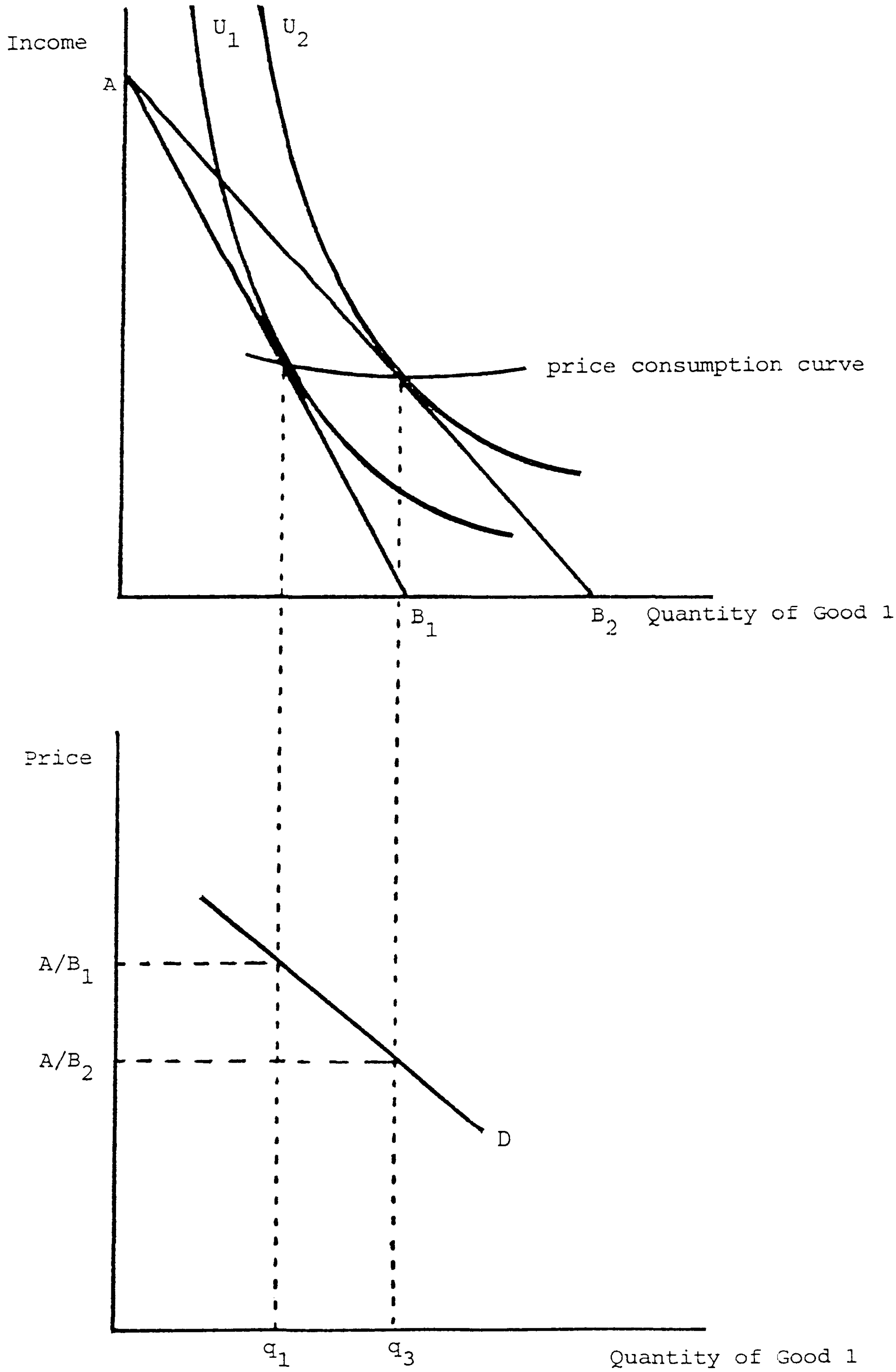
or $x_1 = M/2p_1$ 2.8

Graphically, the demand curve may be derived from the price-consumption curve which is traced along the points of tangency between the stationary indifference curves and the budget line which shifts as a result of relative price changes. This is shown in Figure 2.2.

The demand curve described above (the 'ordinary' demand curve) illustrates the total effect of price changes. However, the effect of a price change may be decomposed into two partial effects. First, there is the substitution effect, which is the change in quantity demanded resulting strictly from a change in relative prices within the consumption bundle; and second, there is the income effect, which is the change in quantity demanded resulting from a change in real income.

The Hicksian decomposition[2] of the effect of a price change separates the income effect from the substitution effect by adjusting the consumer's real income so as to allow the consumer to attain the same level of utility as was the case before the price change. This is shown

[2] The 'Hicksian decomposition' of the effect of a price change is that first put forward by J.R. Hicks. See Hicks (1953, pp. 29-33).



The price consumption curve traces out the points of tangency between the budget line, which shifts as price decreases, from AB_1 to AB_2, and the indifference curves U_1 and U_2. The demand curve is derived by plotting each price against the respective quantity demanded.

Figure 2.2 Derivation of the Demand Curve.

graphically, for a normal good, in Figure 2.3: the substitution effect is given by the distance q_1q_2 and the income effect by the distance q_2q_3, where q_2 corresponds to the point of tangency between the adjusted budget line, $A'B_2'$, and the indifference curve, U_1.

The substitution effect is always negative. Therefore, the slope of the compensated demand curve (that derived after adjusting for real income changes) is always negative. The income effect normally reinforces the substitution effect but for inferior goods, may counteract it (although only for Giffen goods will it more than offset the substitution effect).[3] Consequently, the demand curve is also normally expected to be downward-sloping.

Unfortunately the Hicksian decomposition is not well-suited to econometric study. This is because the tangency point corresponding to q_2 in Figure 2.3 is unobserved in practice. Slutsky's decomposition (Slutsky 1915) is conducive to econometric estimation although, compared to that of Hicks, it over-estimates the substitution effect and under-estimates the income effect. The Slutsky decomposition adjusts income sufficiently for the consumer to be able barely to purchase the same initial bundle of commodities at the new price(s). This is shown graphically, for a normal good, in Figure 2.4. The substitution effect is represented by the distance q_1q_4 which is larger than the corresponding distance in the Hicksian decomposition: q_4 corresponds to the point of tangency between the adjusted budget line, $A^*B_2^*$, and the indifference curve U_1'. The income effect is given by the distance q_4q_3.

The algebraic treatment of the Slutsky decomposition yields the 'Slutsky equation' which provides a useful empirical tool. This is expounded below (in section 2.4.3) as a restriction on demand fuctions.

2.2.3 Elasticities of demand

The elasticity of demand is a measure of the responsiveness of the

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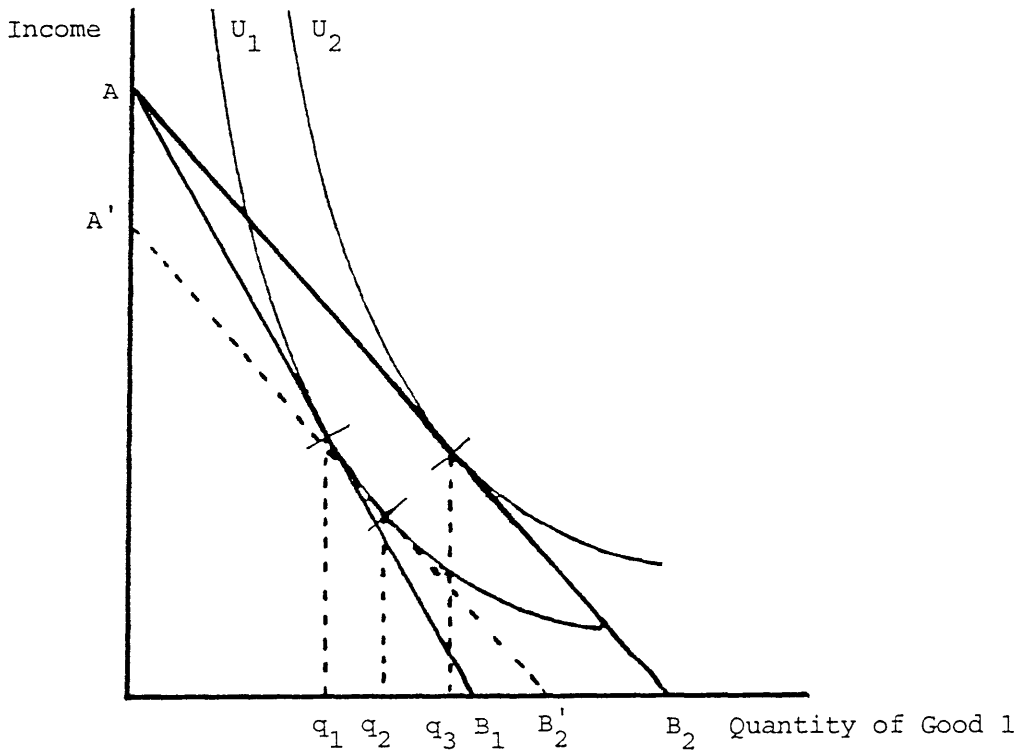
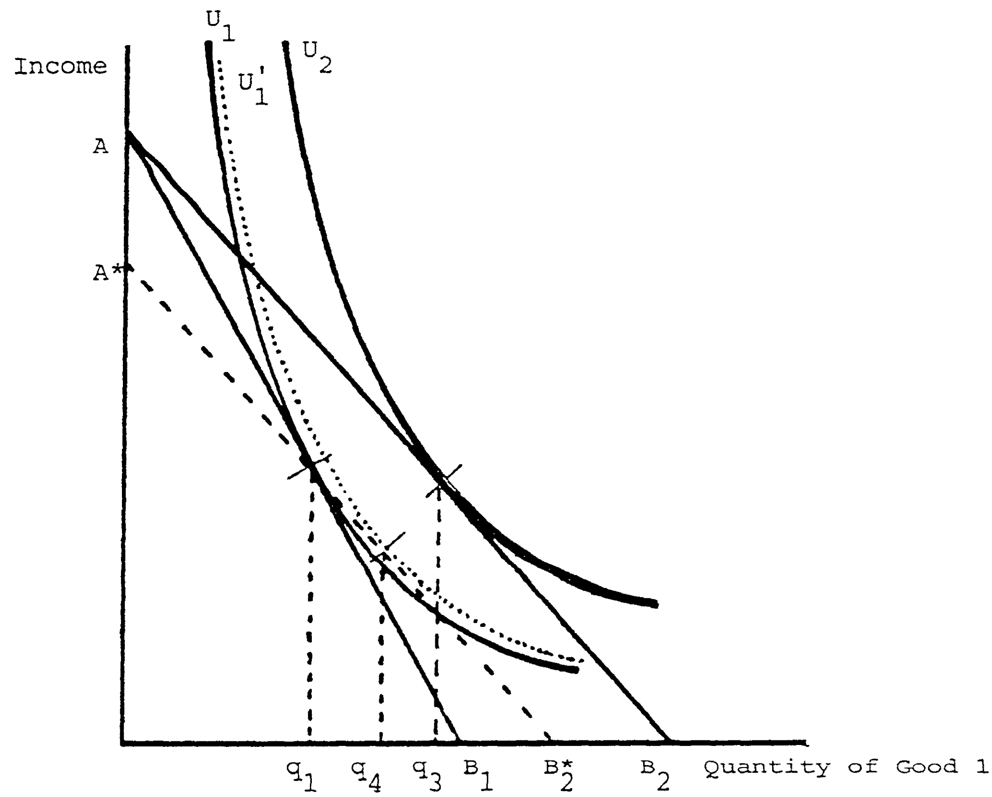
[3] 'Giffen goods' are those for which the ordinary demand curve is positively sloped. Such a good was first observed by Sir Robert Giffen (1837-1910), a British statistician and economist. See Hirshleifer (1980, pp.110-12, 149-50).



As the price of Good 1 decreases the budget line shifts from AB_1 to AB_2. The substitution effect is to increase quantity demanded from q_1 to q_2. The income effect further increases the quantity demanded to q_3.

Figure 2.3 The Hicksian Decomposition of the Effect of a Price Change.



The Slutsky decomposition yields a larger substitution effect (q_1 q_4) and a smaller income effect (q_4 q_3) than that of Hicks.

Figure 2.4 The Slutsky Decomposition of the Effect of a Price Change.

quantity demanded to changes in another (explanatory) variable such as own price, price of another commodity or income. The own-price elasticity of demand for a particular commodity is defined as the proportionate change in the quantity demanded, divided by the proportionate change in its own price, with other prices and income constant; the cross-price elasticity similarly relates proportionate change in the quantity demanded (of one commodity) to the proportionate change in price of another commodity; and the income elasticity of demand relates the proportionate change in quantity demanded to the proportionate change in income.

Mathematically, these measures may be represented by the following definitions (Henderson and Quandt 1980, pp. 22-4):

own-price elasticity of demand $= e_{ii} = \partial(\ln x_i)/\partial(\ln p_i)$
$= (\partial x_i/\partial p_i)(p_i/x_i)$; ... 2.9

cross-price elasticity of demand $= e_{ij} = \partial(\ln x_i)/\partial(\ln p_j)$
$= (\partial x_i/\partial p_j)(p_j/x_i)$; ... 2.10

and

income elasticity of demand $= e_{im} = \partial(\ln x_i)/\partial(\ln m)$
$= (\partial x_i/\partial m)(m/x_i)$. ... 2.11

Determinants of the magnitude of these elasticity measures include the nature of the uses to which the commodity may be put; the availability of substitutes, complements and supplements; the need satisfied by the commodity; the initial levels of incomes, prices and quantities consumed; the proportion of incomes spent on the commodity; and the time period over which the elasticity is measured.

2.2.4 Consumer's surplus

Marshallian consumer's surplus[4] may be measured in monetary units and is equal to the difference between the cost of purchasing a given quantity of a commodity and the amount of money a consumer would be willing to pay for that quantity rather than do without it. This may be

[4] 'Marshallian consumer's surplus' was popularised by Alfred Marshall. See Marshall (1940).

viewed as the area under the ordinary demand curve which is above the price line, as in Figure 2.5a. Alternatively, it may be illustrated graphically using indifference curves, as in Figure 2.5b.

Unfortunately, these measures of consumer's surplus are not equivalent. In addition, there are two other measures of consumer's surplus: compensating variation and equivalent variation. Currie et al. (1971) review the concept of economic surplus and it is evident from their attention to the latter two measures that they believe these best represent consumer's surplus. This observation is supported by a number of more recent publications[5], although it is noted that data limitations may present difficulties for econometric estimation of the compensating variation and the equivalent variation.

> 'The compensating variation (CV) is the amount of money we can take away from an individual after an economic change, while leaving him as well off as he was before it. (For a welfare gain, it is the amount he would be willing to pay for the change. For a welfare loss, it is minus the amount he would need to receive as compensation for the change.)... The equivalent variation (EV) is the amount of money we would need to give an individual, if an economic change did not happen, to make him as well off as if it did. (For a welfare gain, it is the compensation he would need to forego the change. For a welfare loss, it is the amount he would be willing to pay to avert the change.)' (Layard and Walters 1978, p. 151). These measures are illustrated in Figure 2.6.

Clearly the CV and the EV are not equal since they are measured from differing base utility levels. The CV may be represented by the area under the Hicksian compensated demand curve which is above the price line. Such a representation highlights the difference between the Marshallian and Hicksian (CV) surplus measures: only when the income effect is zero are they equal.

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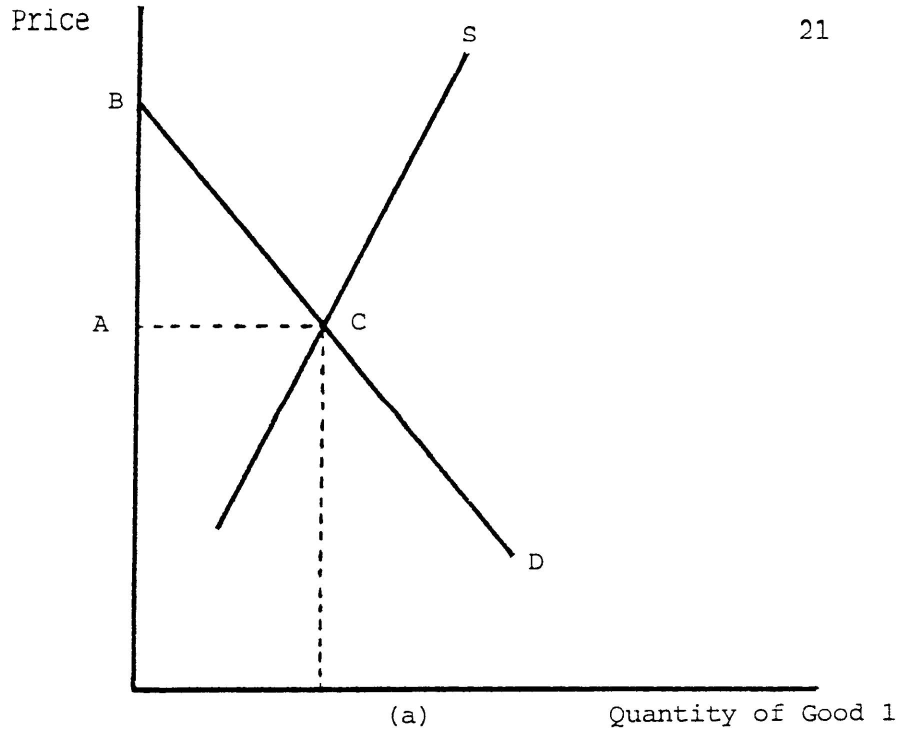
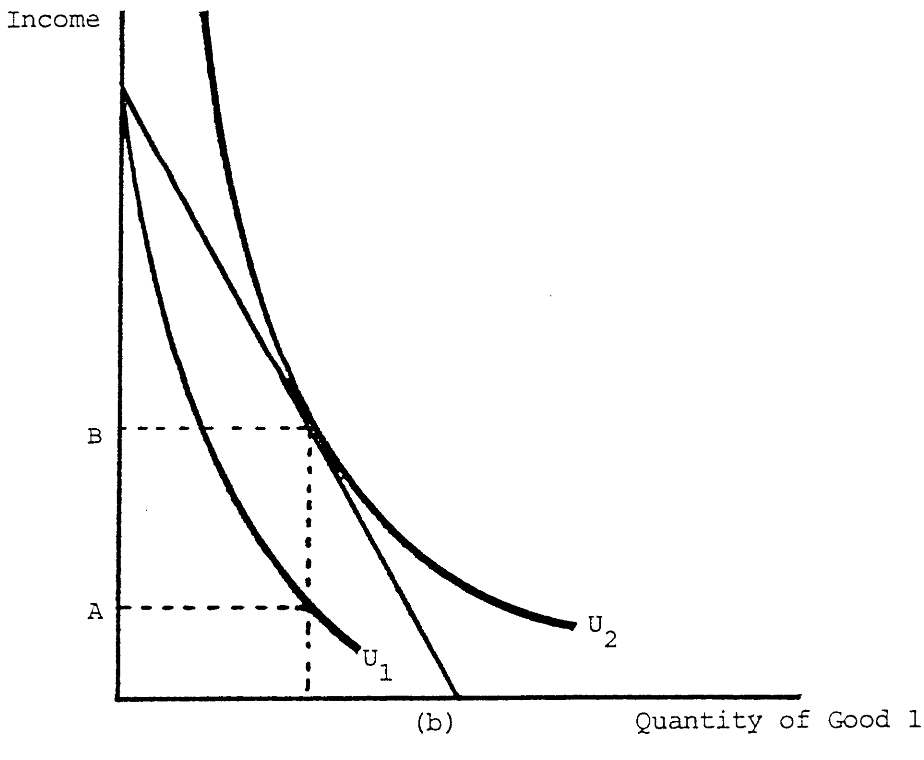
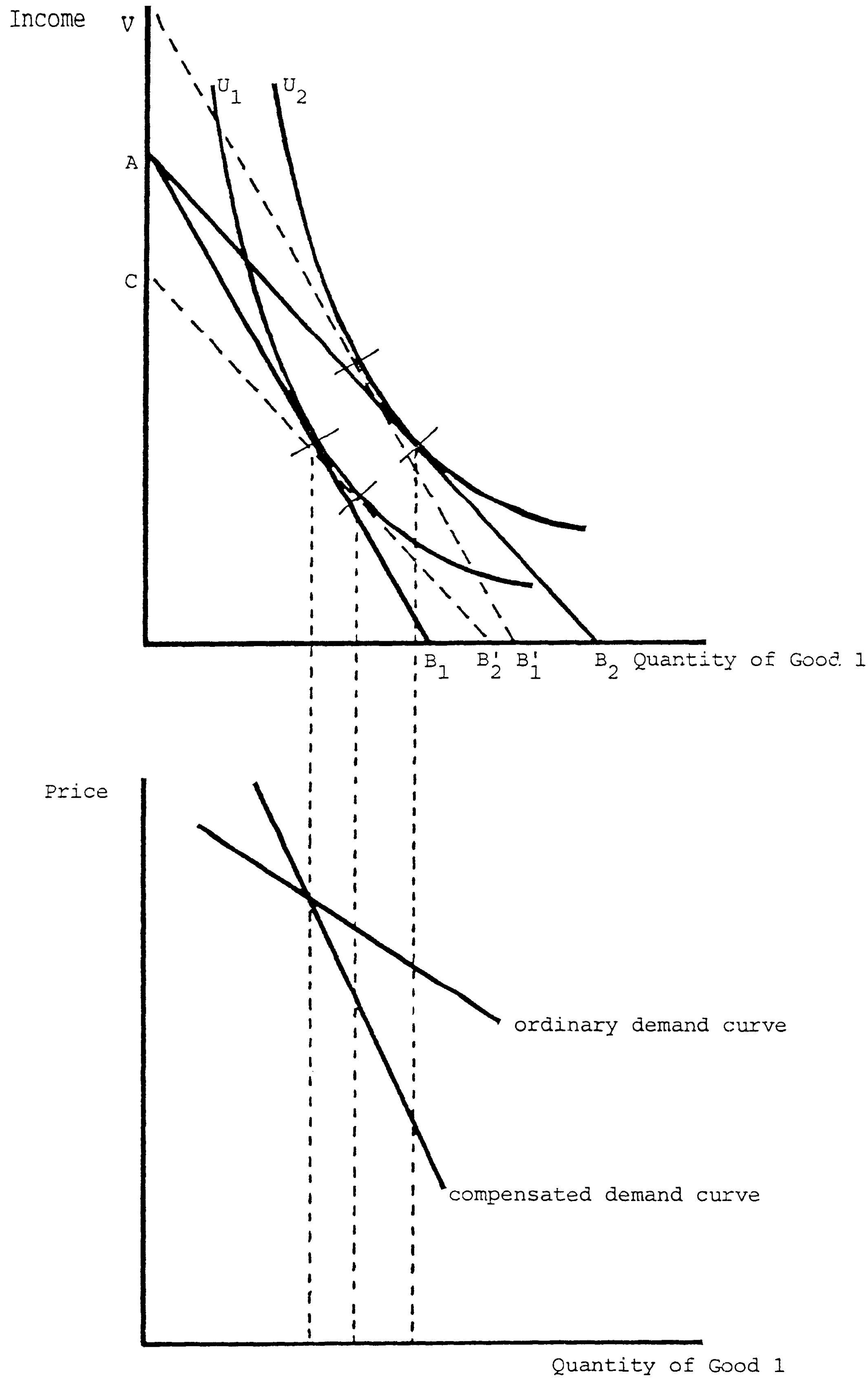
[5] See, for example, Winch (1973); Willig (1976); Dixit and Weller (1979); Chipman and Moore (1980); Cory et al. (1981); and Hausman (1981).





Marshallian consumer surplus may be measured as the area between the demand curve and the price line: area ABC in diagram (a). Alternatively, it may be measured as the difference between the income sacrificed by buying the quantity desired at market prices and the income which the consumer would be prepared to sacrifice in order to avoid losing such a quantity: segment AB in diagram (b).

Figure 2.5 The Two Measures of Marshallian Surplus.



The compensating variation is represented by the segment AC, while equivalent variation is represented by the segment AV. The compensated demand curve is traced out by the points corresponding to the substitution effect of price changes whilst the ordinary demand curve is traced out by the points corresponding to the total effect of price changes.

Figure 2.6 Compensating Variation, Equivalent Variation and the Compensated Demand Curve.

2.3 Market Demand

Utility theory applies to the individual consumer. Constrained maximisation of the utility function yields a complete set of demand equations: one equation for each commodity in the consumption bundle. Such equations describe the individual's consumption behaviour and must hold simultaneously if the effect of consumption of one commodity on the consumption of others is to be captured. Implicitly, it is assumed that factors of a psychological, sociological, cultural or regional nature are fixed at a particular time for each individual and that, as a result, the quantity of a commodity demanded by an individual is adequately explained by price and income variables. It is also assumed that utility is an ordinal measure, so that the theoretically correct way of quantifying market demand is to sum, at each price, the quantities demanded by individual consumers.

In many applied studies, single-equation models have been used to relate the quantity of a commodity demanded by consumers in aggregate to, among other things, its own price, the price of other commodities, consumer tastes and preferences, consumers' past and present income levels, income distribution, population size and composition, consumers' wealth and its distribution, credit availability, and past levels of consumption. This relaxes, to some extent, the assumption of fixity referred to in the previous paragraph. The quantity demanded will change with a change in any of the determinants: movement along the demand curve will result from a change in own price while the curve will shift if other determinants change. At a less aggregated level, empirical demand relationships have been applied to household demand and per capita demand for a variety of durable and non-durable consumer goods (Stone 1954; Wold and Jureen 1964; Houthakker and Taylor 1966). Such applied approaches would seem to be at odds with the 'theoretically valid' demand equations derived from individuals' utility functions. Three major issues are worth raising in this regard.

First, empirical analysis of market demand often proceeds, it seems, from either of two basic premises: there exists an 'aggregate utility function' which has all of the desirable properties necessary to yield demand equations that satisfy the restrictions imposed by utility theory; or demand equations may be specified directly, for their empirical tractability, and the restrictions imposed ex post. Although apparently violating the assumption that individual utilities are ordinal and therefore non-aggregable, these procedures often yield plausible results (Guise 1982, p. 44). For household demand models there is an implicit assumption that either the utility function of the household head accounts for the needs of all household members or there exists a well-defined household utility function.

Second, the introduction of variables, other than those accounting for prices and income, in market demand estimation is justified from the point of view that it is necessary to isolate non-economic elements that influence consumption levels if one is to analyse effectively the effects of prices and income (George and King 1971). This is particularly so when single equation models are used. As well, addition of such variables as age distribution, education and family size may be necessary if all underlying factors causal to quantity demanded are to be modelled adequately.

Third, the validity of the proposition that market demand is the result of simple aggregation of individual's demands at all prices may be brought into question when social influences on demand are considered. The so-called 'snob' and 'bandwagon' effects (Tisdell 1972, p. 118) may invalidate such an assumption, although McShane (1971) suggested that such effects can be incorporated by extending the individual's utility function. He put forward the view that for a wide variety of commodities, price itself may be a determinant of consumer preferences where it signals the quality of the item. In addition, he contended that wealth (or savings) and expected future prices may be important explanatory variables.

The extended utility function presented by McShane (1971, p. 156) appears as:

$$U = U(C_1,\ldots,C_n,S,P_1,\ldots,P_n,P_1^*,\ldots,P_n^*,y^s)$$

where C_i = quantity of the i^{th} commodity consumed;

S = savings and includes that portion of the consumer's previously accumulated net worth that was not used to supplement income, plus that part of income not spent;

P_i = current price of the k^{th} commodity;

y^s = relative income position of the consumer; and

P_i^* = consumer's expected future price of the i^{th} commodity.

Furthermore, the relevant budget constraint is presented as:

$$y_t + W = \sum_{k=1}^{n} C_k P_k + S_t,$$

where y_t = income earned during the period;

W = funds the consumer could obtain if he converted his accumulated net worth to the medium of exchange during the consumption period; and

S_t is defined above (p. 167).

Constrained optimisation of such a utility function, of multiplicative form, will give rise to demand equations which contain explanatory variables additional to prices and income.

The above discussion provides the bridge, well hidden in the literature, between traditional utility theory and the empirical evaluation of demand relationships. Demand equations which model market or household behaviour by including variables such as consumer's age, education level, expectations of prices, wealth and family circumstances, do not conflict with utility theory, provided that they are either arguments in the extended utility function or are necessary in accounting for inter-personal differences. This follows from the relationship

$$u = f(x_1, x_2, \ldots, x_n),$$

where x_i may be a function of a multitude of variables of an economic, psychological, sociological, cultural and/or regional nature. Which of these and/or other variables to include in the utility function and, therefore, in the demand function remains to be answered by advances in the theory. Meanwhile, a priori knowledge and statistical considerations guide the choice of relevant variables, although the theory does imply certain restrictions for estimation of demand relationships.

2.4 Restrictions Imposed on Demand Functions

The traditional theory of consumer behaviour which describes the constrained utility maximisation process implies that valid demand functions must satisfy a set of general restrictions. These restrictions follow from the first-order conditions for utility maximisation. Reynolds (1979) provides an excellent exposition of the derivation of these restrictions. Following George and King (1971) and Intriligator (1978), only the results of such derivations are reported here.

2.4.1 The homogeneity condition

This restriction requires that demand functions are homogeneous of degree zero in prices and income so that if both prices and income are changed by the same proportionate amount, quantity demanded will remain unchanged. That is:

$$\sum_j (\partial x_i/\partial p_j)P_j + (\partial x_i/\partial m)m = 0$$

or, in terms of elasticities,

$$\sum_j e_{ij} + e_{im} = 0 \, . \qquad \ldots\ 2.12$$

2.4.2 The Engel aggregation condition

Also known as the 'adding up' property (Layard and Walters 1978, p. 135), this restriction requires that all additional income is used for consumption (with savings considered to be a form of consumption), so that the budget share weighted average of income elasticities is unity. That is:

$$\sum_i v_i e_{im} = 1 \qquad \ldots\ 2.13$$

where v_i = budget share of the i^{th} commodity, defined as $p_i x_i/m$.

2.4.3 The Slutsky negativity condition

This restriction states that the substitution effect of a price change is always negative. As a result, the Slutsky equation, separating out the substitution and income effects, is:

$$\partial x_i/\partial p_i = (\partial x_i/\partial p_i)\, u_{const} - x_i(\partial x_i/\partial m)$$

or, in terms of elasticities,

$$e_{ii} = \bar{e}_{ii} - v_i e_{im} \qquad \ldots\ 2.14$$

where $\bar{e}_{ii}$ indicates the compensated effect.

2.4.4 The symmetry condition

Derived from the negativity condition, the symmetry condition states that the income compensated cross-substitution effects between commodities should be equal. That is:

$$\partial x_i/\partial p_j + x_j(\partial x_i/\partial m) = \partial x_j/\partial p_i + x_i(\partial x_j/\partial m)$$

or, in terms of elasticities,

$$(1/v_j)e_{ij} + e_{im} = (1/v_i)e_{ji} + e_{jm}\ . \qquad \ldots\ 2.15$$

2.4.5 The Cournot aggregation condition

This restriction requires that re-allocation of purchases resulting from income and/or price changes, must exhaust total income. That is:

$$p_i(\partial x_i/\partial p_i) + p_j(\partial x_j/\partial p_i) + x_i = 0$$

or, in terms of elasticities,

$$e_{ii} + (v_j/v_i)e_{ji} + 1 = 0. \qquad \ldots 2.16$$

2.4.6 Implications of the restrictions for demand estimation

Since the above restrictions are derived from a 'well-behaved' utility function, it follows that a system of demand equations which satisfies them will be consistent with traditional utility theory. However, in the case of estimating a demand function for a single product, only two of the above conditions would normally be tested: the homogeneity condition and the negativity condition (Intriligator 1978, p. 217).

The implications of these theoretical restrictions for empirical estimation are:

(a) that each demand model should be tested to ascertain whether it is consistent with the restrictions and, therefore, utility theory; and

(b) if the relationship is inconsistent with a particular restriction, then it is necessary to examine the demand model with a view to either modifying the model or concluding that the restriction is inappropriate in the case of the product concerned.

2.5 A Brief Note on Two Recent Contributions to Demand Theory

In his 'new approach to consumer theory', Lancaster proposed that consumers demand the characteristics possessed by commodities rather than the commodities themselves. The divergence of this approach from traditional demand theory was summarised by Lancaster (1966) as follows:

'1. The good, per se, does not give utility to the consumer; it possesses characteristics, and these characteristics give rise to utility.

2. In general, a good will possess more than one characteristic, and many characteristics will be shared by more than one good.

3. Goods in combination may possess characteristics different from those pertaining to the goods separately' (p. 134).

The generality of this 'characteristics' approach has considerable appeal in respect of residential demand for water. Householders demand mains water for a variety of purposes, ranging from thirst quenching and cleaning to garden watering and swimming. In addition, water-using appliances play an important role in determining how much utility accrues from (combined) water use. Therefore, evaluation of the demand for water involves a multi-attribute commodity necessarily affected by the stock of water-using appliances, activities and habits within the household, as well as its own price and household income.

An equally attractive approach to the theory of demand is that of Muth (1966). Stimulated by the work of Strotz (1957) and Pearce (1959) who examined the concepts of the 'utility tree' and 'want independence', respectively, Muth put forward the view that consumers purchase commodities as inputs for household production of goods and services. Such production is hypothesised to be characterised by conventional production functions, with the commodities produced being arguments for the household's (or household head's) utility function.

In essence then, Lancaster and Muth recognised the composite nature of demand for many commodities. This, along with the recognition of the importance of household labour in household production, led Muth to the conclusion that such an approach to demand analysis may enable the explanation of apparently inconsistent demand elasticities. In addition, this 'new theory of consumer behaviour' may be useful in explaining why the restrictions on demand equations, imposed by traditional theory, have been frequently rejected in empirical studies.[6]

A concept related to the characteristics and household production approaches to consumer demand is 'derived demand'. This applies to commodities which are inputs into the process of producing the final goods demanded by consumers (Tomek and Robinson 1981, p. 41). For particular types of goods such a concept is of use in reconciling the

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[6] See, for example, Laitinen (1978) and Christensen, Jorgenson and Lau (1975).

traditional utility approach to demand analysis with that credited to Muth (1966) and Lancaster (1966). It may be that a commodity for which there is a derived demand, in the sense that it is used as an input into the household production process, yields a consumer response which is not entirely consistent with utility theory and its implications.

The nature and purpose of the present study prevents the detailed examination of residential demand for water in terms of the characteristics of water and its importance in household production, despite the attraction of such an approach. Time constraints and the need to compare results with other studies have directed this study along the traditional path. However, the characteristics and household production approaches are most valuable in serving to forewarn the researcher of the complex nature of the demand for water and of the likely relationship between it and the demand for water-using activities and appliances.

2.6 The Application of Demand Theory to Pricing Policy Analysis

In a competitive industry, the equilibrium market price is equal to the marginal cost of production. However, in the case of production by public utilities, there has been much debate about the applicability of marginal cost pricing. Ruggles (1949-50) provided a detailed review of the exchanges which followed the recommendation by Hotelling (1938) that the pricing of goods provided by public utilities should be based on marginal cost, with resulting deficits of decreasing average cost enterprises being made up from lump-sum taxes. Farrell (1958) and Williamson (1966) also examined the pricing of publicly produced commodities and Turvey (1971) considered a range of issues regarding the economics of public enterprise. Many of the issues raised by these authors are of obvious relevance to urban water supply, as evidenced by the work of people such as Hirshleifer, de Haven and Milliman (1960) and Warford (1968). However, detailed examination of them is beyond the scope of the present study. This discussion will be confined to an examination, principally from the consumer's viewpoint, of particular types of pricing policies used by water supply utilities.

Gallagher and Robinson (1977) reviewed briefly the role of prices and suggested that a suitable pricing policy would simultaneously:

'1. reflect the marginal social costs of supply to consumers;

2. provide adequate revenues to the supply authority, and encourage optimal capacity adjustments;

3. allow equitable distribution of benefits and costs among investors and consumers as well as among the different classes of consumers; (and)

4. provide an incentive to the authority to locate on the outer-bound of (the) production possibility set at the point of greatest resource use efficiency' (p. 99).

In addition, they discussed seven alternative types of pricing policies (pp. 99-108), three of which are applicable to the present study: water rates policies; constant per unit price policies; and block price policies.

Consider first the rating policy typical of many Australian water supply authorities and used by the HDWB prior to July 1st, 1982. Recall that such a policy involves the imposition of a rate or lump-sum charge based on land value, which entitles the consumer to a quota of water. Only those consumers who use more than their quotas face a non-zero marginal price. Figure 2.7 illustrates the effect of such a rating structure on the equilibrium of consumers. Rates are initially such that retained income is reduced from M_0 to M_1 (Figure 2.7a), leading to the budget line VWW'. Point A, where the budget line becomes tangent to indifference curve, U_0, represents the equilibrium position for consumers who do not use more than their quotas. This point defines the level of demand for water: a demand curve is not apparent since a demand curve can be estimated only in the presence of non-zero marginal prices. In Figure 2.7b q' represents the consumer's quota of water, curve S_1 represents the water authority's 'willingness-to-supply' under the rating

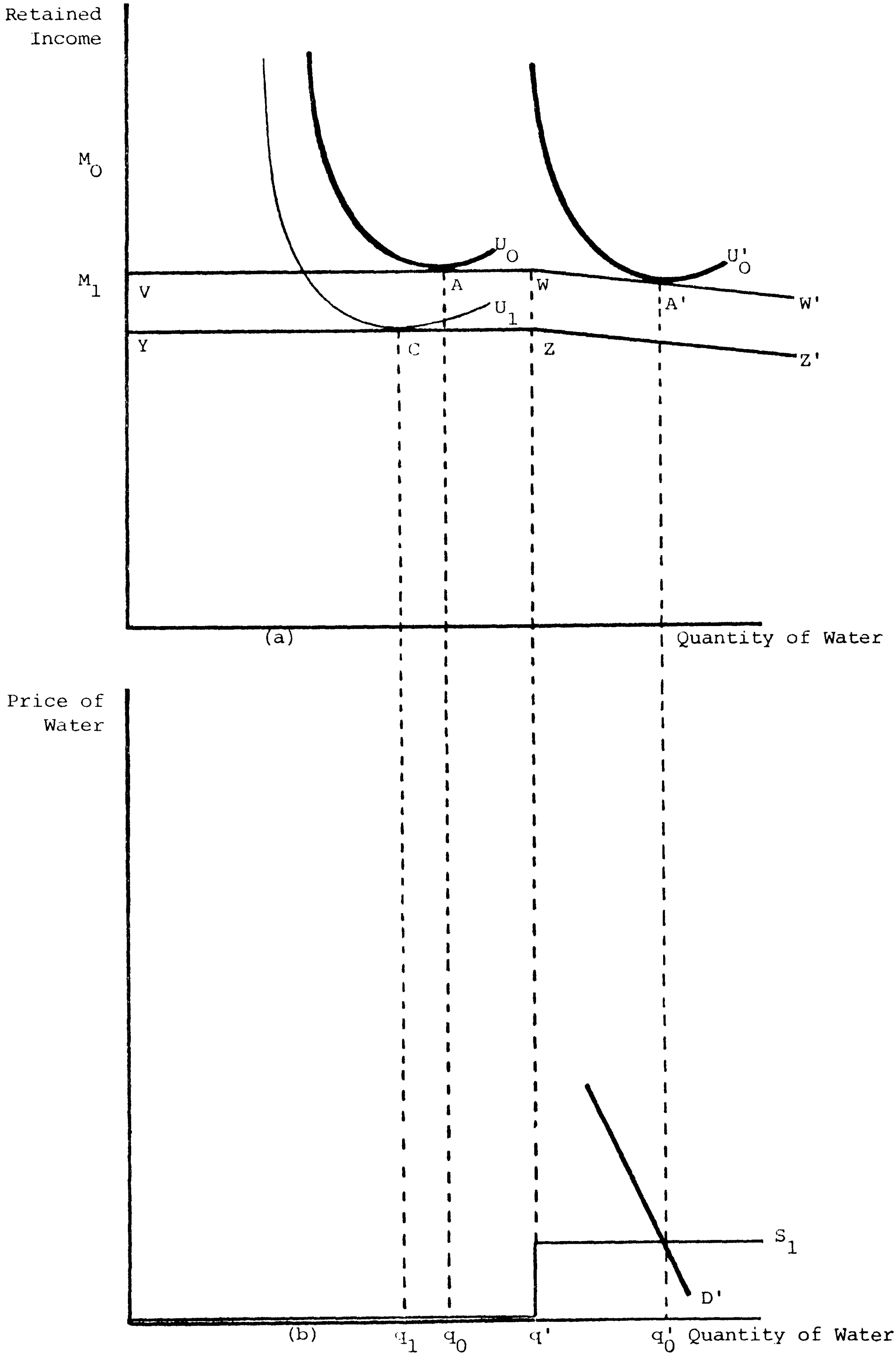

Figure 2.7 Consumer Equilibrium under a Rating Structure.
(Adapted from Billings and Agthe 1980)

system[7] and the quantity demanded is established when the consumer's marginal rate of commodity substitution (between water and other commodities in the consumption bundle) is equated to the (zero) marginal price of water. The indifference curve, U_0', is that for a consumer who uses more than his or her quota. A demand curve (D') can be estimated for such 'excess' users and will be located to the right of q': the quantity demanded will be established when the consumer's marginal rate of commodity substitution is equated to the non-zero marginal price for water.

Although there is no well-defined demand curve for non-excess users, a change in quantity demanded can result from a change in the level of rates. For example, if rates rise so that the budget line shifts from VWW' to YZZ' (Figure 2.7a), then quantity demanded will fall from q_0 to q_1, given that the indifference map truly represents the consumer's preference ranking. The increase in rates has its influence on consumption by decreasing real consumer income, thus further constraining the attainable consumption bundle: points A and C may be interpreted as representing two points on an Engel curve. Therefore, '... ' while households use water efficiently within the price policy adopted by the water authority, water use is not efficient from society's point of view unless the (marginal) cost of water supply is zero, an unlikely event' (Gallagher and Robinson 1977, p. 100).

Consider now a two-part tariff similar to that currently in place in the Lower Hunter Valley. The policy in mind is a constant per unit price policy since it consists of a lump-sum charge and a positive marginal price. As illustrated in Figure 2.8a, the lump-sum charge component reduces disposable income from M_0 to M_1 and the marginal price traces out the budget line VX, with consumer equilibrium at point B. The demand curve of Figure 2.8b is well-defined and is derived from the price expansion path of Figure 2.8a for alternative marginal prices. The willingness-to-supply curve, S_2, is horizontal since the water supply

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[7] The term 'willingness-to-supply' is used here to distinguish between the apparent supply curve resulting from the adoption of a particular pricing or rating policy and the supply curve associated with the marginal costs of production under conditions of pure competition. See Koutsoyiannis (1980, pp. 159-60) for a discussion of supply curves.

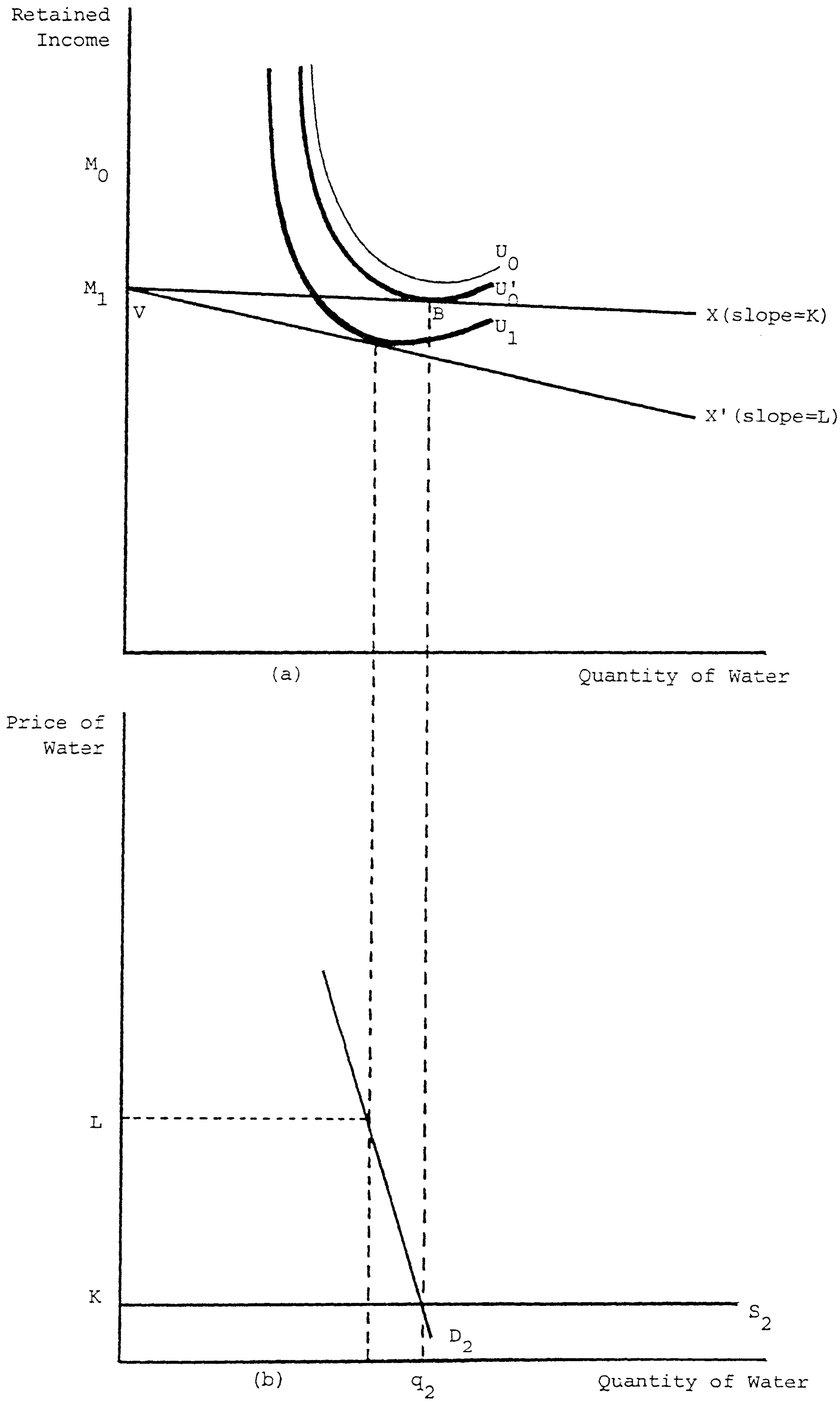

Figure 2.8 Consumer Equilibrium under a Two-Part Tariff.
(Adapted from Billings and Agthe 1980)

authority is apparently willing to supply any quantity of water, provided the marginal price, K, is paid by the consumer.

Turning to Figure 2.9, consider the situation where declining block prices form the basis for the water authority's pricing policy.[8] In this case, the water supply authority behaves like a monopolist in so far as it seeks, through price discrimination, to extract for the authority some of the consumer's surplus. The position of the demand curve will be influenced by the particular marginal price relevant to the consumer: by varying the final block price it is possible to trace out a price expansion path from which the demand curve can be derived; and the initial block prices (or intra-marginal prices) will influence consumption through their effect on the real income level.

Since this is primarily a study of consumer behaviour it follows that a comparison of the above pricing policies should proceed from within the utility framework. Figure 2.10 provides the basis for such a comparison when all pricing policies are formulated so that the consumer is equally well-off under each; while Figure 2.11 allows comparison of the pricing policies under conditions whereby the consumer's total water bill is held constant.

In the case of a pricing policy comparison where all policies yield to the consumer the same level of utility, it is clear that when marginal price is set above zero, there is a reduction in the amount of water consumed. The size of the reduction will depend upon the price elasticity of demand for water, the level at which marginal price is set and the effect on consumer income of intra-marginal prices and/or fixed charges. These types of pricing policies are illustrated in Figure 2.10. The water rates policy yields the budget line VWW' and the point of consumer equilibrium A. The consumption level for the 'non-excess' consumer is q_0: this compares with the water quota of q' which corresponds to the point W.

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[8] This is only one of a multitude of possible block pricing structures. See Taylor (1975) for a comprehensive treatment of the effects of varying intra-marginal and marginal prices when decreasing block prices apply. See Billings and Agthe (1980) for an examination of policies involving increasing block prices.

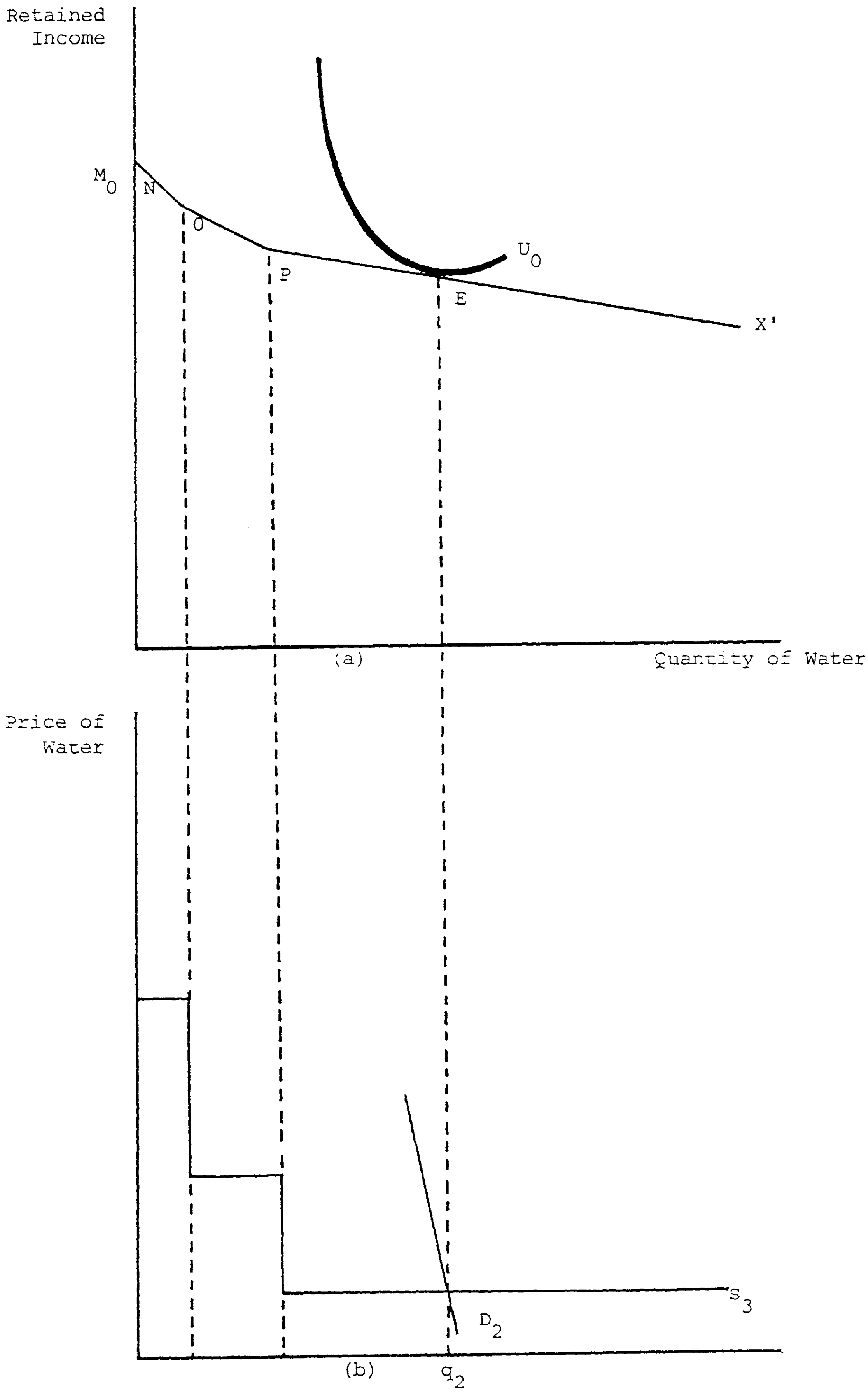

Figure 2.9 Consumer Equilibrium with Declining Block Prices. (Adapted from Billings and Agthe 1980 and Gallagher and Robinson 1977)

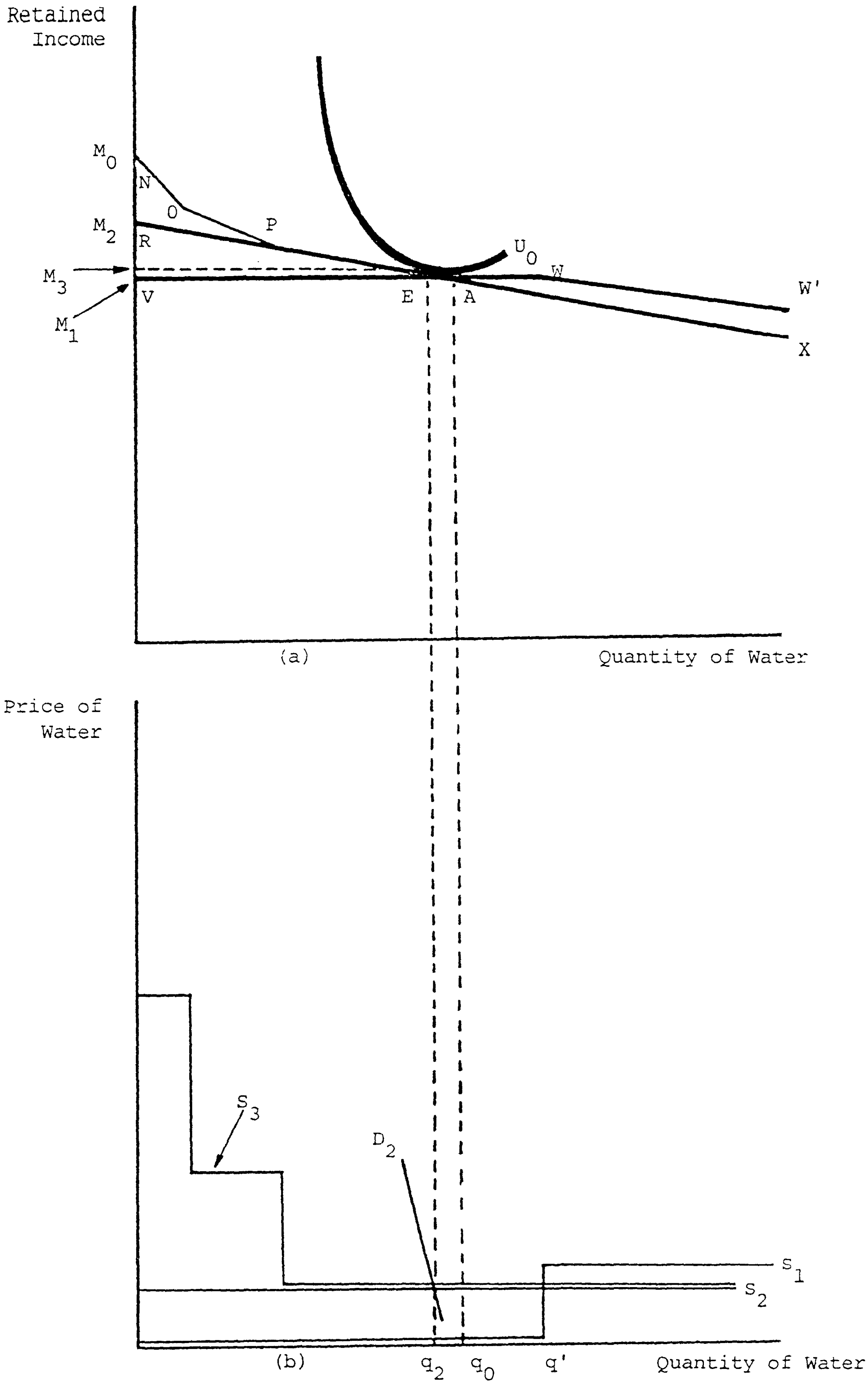

Figure 2.10 Alternative Pricing Policies Yielding Constant Utility.

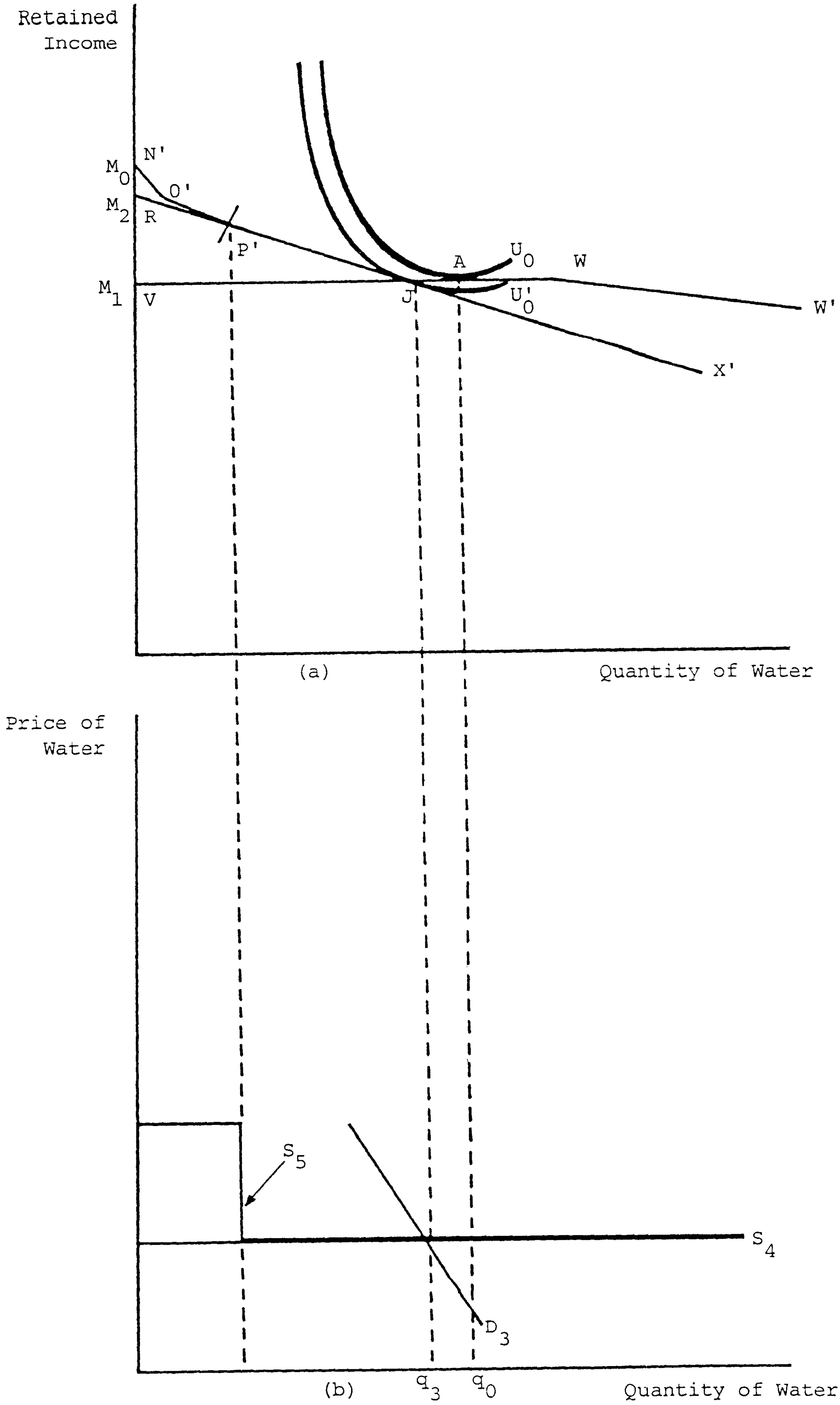

Figure 2.11 Alternative Pricing Policies Yielding Constant Expenditure.

The budget line RX follows from the two-part tariff which is made up of a lump-sum charge and a constant per unit price. The consumer's equilibrium lies at point E and the corresponding level of consumption is q_2. Finally, the declining block pricing policy, which incorporates a final block price equal to the marginal price of the two-part tariff, yields the budget line NOPX, the equilibrium point E and the consumption level q_2.

In each of these pricing policies, average price and marginal price are unequal. Therefore, as noted by Gallagher (1980, p. 68), the quantity demanded depends not on marginal price alone but on the whole market offer. As a result, any comparison of pricing policies must acknowledge that marginal price changes have both income and substitution effects and that intra-marginal price changes and changes in fixed charges generally have only income effects.[9]

All three policies represented in Figure 2.10 yield the same level of utility to the consumer. However, expenditure on water falls as one diverges from the rating policy. The expenditure on water under the rating structure is given by the distance M_0M_1 while expenditure under the alternative policies is given by the distance M_0M_3. This is of importance to the water supply authority since it implies that total revenue will fall if non-zero marginal prices are adopted whilst, at the same time, consumer utility is held constant. This may or may not be a problem for the water authority, depending on the relative sizes of the revenue losses and the cost savings which follow from reduced consumption. From the long-run economic efficiency point in view, it is likely that a net social gain will follow from a reduction of the diversion of resources into the water supply services, provided the implemented marginal price represents the marginal cost of production (Hirshleifer 1980, p. 349).

Consider now a comparison of alternative pricing policies which each motivate the consumer to spend the same total amount on water. Figure

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[9] Intra-marginal price changes may have substitution effects when such changes are sufficiently large as to shift the consumer's equilibrium from a position involving one block price to a position involving another block price (Taylor 1975, p. 99).

2.11 provides the basis for such a comparison: the rating system yields the budget line VWW′, with corresponding equilibrium point A and consumption level q_0; the two-part tariff yields the budget line RX′, with corresponding equilibrium point J and consumption level q_3; and the declining block pricing policy yields the budget line N′O′P′X′, with equilibrium point J and consumption level q_3. Clearly, when expenditure on water is held constant at the level given by the distance M_0M_1, the introduction of a positive marginal price results in a reduction in water consumption and a loss of consumer utility. At the same time, the water authority enjoys a more favoured position because it is able to supply less water but with no adverse effect on revenue. Unfortunately, society's position is unclear: there will be an efficiency gain if marginal price is equated with marginal cost and a net social gain only if the improvement in efficiency (more than) compensates for consumers' loss of utility.

2.7 Conclusions

The theory of demand has been surveyed in an effort to establish a sound framework for empirical estimation of residential demand for water. This has exposed a number of conflicts between classical utility theory and the practice of estimating market demand relationships. Fortunately these conflicts are not severe: data limitations would seem to present more serious problems. In addition, the theory has been applied in a brief analysis of alternative pricing policies relevant to water supply. This has revealed that the introduction of a non-zero marginal price for water may not only improve the efficiency of urban water supply but may also maintain levels of revenue for water supply authorities.

Chapter 3 contains a review of the empirical studies of residential demand for water. This, it is hoped, will further guide model formulation and provide a basis for data collection, empirical analysis and the reporting of results.

Chapter 3

EMPIRICAL ESTIMATION OF RESIDENTIAL DEMAND FOR WATER

This chapter is devoted mainly to a review of empirical studies of residential demand for water. The review is presented to provide guidance for model formulation in the present study. Some implications of the results of previous research are also addressed.

Previous researchers have applied the least-squares regression technique to both cross-sectional and time-series data in analysing the residential demand for water. These data have been collected from water supply authorities and individual households. Early studies were plagued with the problem of data inadequacy which led to the appearance of conflicting parameter estimates. Wong (1971) provided a useful outline of the results of these investigations and highlighted the effect of data deficiencies on demand equation estimation. The elasticity estimates of more recent studies appear in Table 3.1.

The classic work relating to residential demand for water was that of Howe and Linaweaver (1967). Theirs was a cross-sectional study involving data from 39 areas spread across the Eastern and Western U.S.A. For each area in the study, the data consisted of average per household values of the following variables:

(a) hourly and daily indoor use in gallons (q_d) determined from winter use patterns;

(b) hourly and daily sprinkling use in gallons (q_s) determined by subtracting winter use from summer use;

(c) market value of dwelling unit in thousands of dollars (v);

(d) number of residents per dwelling unit (d_p);

Table 3.1

Residential Water Demand Elasticity Estimates

Data	Investigator	Price elasticity	Income elasticity
Cross-sectional	Howe and Linaweaver (1967)	-0.703 to -1.57	0.43 to 1.45
	Turnovsky (1969)	-0.05 to -0.40	
	Wong (1972)	-0.26 to -0.82	0.84 to 1.03
	Grima (1972)	-0.93	0.56
	Morgan (1973)		0.33 to 0.61
	Batchelor (1975)	-0.23 to -0.90	0.38 to 0.93
	Darr et al. (1976)	-0.14	0.728
	Gibbs (1978)	-0.51 to -0.62	0.57 to 0.80
	Pullinger (1978)		0.15
	Foster and Beattie (1979)	-0.27 to -0.76	0.42
	Billings and Agthe (1980)	-0.27 to -0.61	
Time-series			
	Wong (1972)	-0.28	0.20 to 0.26
	Young (1973)	-0.41 to -0.63	
Pooled time-series, cross-sectional			
	Hogarty and MacKay (1975)	-0.56 to -0.86	
	Danielson (1979)	-0.27	0.33
	Gallagher (1980)	-0.26 to -0.75	
	Gallagher and Robinson (1977)	-0.24	
	Hanke and de Mare (1982)	-0.15	0.11

Adapted from Wong (1972)

(e) age of dwelling unit in years (a);

(f) average water pressure in pounds per square inch (k);

(g) sum of water and sewer charges which vary with water use, evaluated at the block rate applicable to domestic use in each study area (p_w) and average summer rates of use (p_s);

(h) number of billing periods each year (n_p);

(i) regional price index (r_{pi});

(j) irrigable area per dwelling unit (b);

(k) summer potential evapo-transpiration in inches (w_s);

(l) maximum day potential evapo-transpiration in inches (w_{max}); and

(m) summer rainfall in inches (r_s), of which 60 per cent was assumed to be effective.

The preferred equation for daily in-house demand in areas connected to both mains water and sewerage, and facing a positive marginal price, was:

$$q_d = 206 + 3.47v - 1.30\, p_w \qquad (R^2 = 0.717),$$
$$(\text{S.E.}) \qquad (0.59) \quad (0.34)$$

with a price elasticity of demand (at the point of means) of -0.23 and an income elasticity of demand (at the point of means), as calculated from the dwelling value parameter, of 0.35.

The preferred equations for daily summer sprinkling demand were the multiplicative (base ten) forms:

$$q_s = 1130\, p_s^{-0.703}\, v^{0.429} \qquad (R^2 = 0.729); \text{ and}$$
$$(\text{S.E.}) \qquad (0.32) \quad (0.23)$$

$$q_s = 0.164b^{-0.793}(w_s - 0.6r_s)^{2.93}\ p_s^{-1.57}\ v^{1.45}$$
$$(S.E.) \quad (0.22) \qquad\qquad (0.43) \quad (0.19) \quad (0.31)$$
$$(R^2 = 0.674),$$

for the West and the East, respectively. These indicate price elasticities of -0.703 and -1.57 and income (surrogate) elasticities of 0.429 and 1.45.

Turnovsky (1969) contributed to the quality of empirical water demand studies by introducing a variable to account for uncertainty of supply of mains water. Using a linear model he estimated price elasticities of demand (at the point of means) ranging from -0.05 to -0.40 and found that water price, housing space and supply variance were significant in explaining household water use patterns. Then Hanke (1970) used a time-series of data for Boulder, Colorado, to analyse the dynamics of residential demand for water. Hanke's results indicated that significant savings in both in-house and garden water uses can be had by the simultaneous installation of domestic water meters and the imposition of a positive marginal price for water. In addition, evidence advanced supports the proposition that such action also decreases the rate at which water consumption grows over time.

Wong (1972) reported the findings from his analyses of time-series data for Chicago for the period 1951 - 1961 and cross-sectional data for 103 community groups across Illinois. For the time-series analysis, per capita water demand (q_{it}) was postulated to be a function of price (p_{it}), average household income (y_{it}) and average summer temperature (s_{it}), while for the cross-sectional study, the temperature variable was omitted. The preferred relationship was of the multiplicative form:

$$q_{it} = a_i\ p_{it}^{b_i}\ y_{it}^{c_i}\ s_{it}^{d_i}\ u_{it}$$

where a_i, b_i, c_i and d_i are parameters; and
u_{it} is a disturbance term.

Wong's time-series analysis showed that, in areas where price was low (22c/1000 gallons), the price elasticity (b_i) was not significantly different from zero while, in areas where price was high (up to

\$1.25/1000 gallons), significant elasticity measures of around -0.28 were recorded. Income elasticities were consistently significant, ranging from 0.20 to 0.26.

The analysis of cross-sectional data yielded values for price elasticities which were mainly larger in absolute value than those for the time-series study, ranging from -0.26 to -0.82. Values for income elasticities of 0.84 to 1.03 were significantly different from zero only for the larger community groups of the sample. Carver and Boland (1980) have since suggested that the elasticity estimates derived from time series analyses are indicative of short-run elasticities, while long-run elasticities are approximated by cross-sectional analyses. It is, therefore, uncontentious that Wong produced differing elasticity measures for time-series and cross-sectional data sets.

Grima (1972) was among the first to recognise explicitly the importance to household water use of appliances such as taps, toilets, garden-watering equipment, cars, swimming pools, air conditioning units, dishwashers and garbage disposal units. Grima recognised that the consumer's ability to use and willingness to buy such items directly affects household water use. He further recognised that, because of the composite and complementary nature of water demand, patterns of water use will change gradually over time only as water-using appliances and habits are replaced or changed. Such change is strongly influenced by the pattern of change of real income.

Grima's hypothesised demand relationship was:

$$WU = b_0 + b_1V + b_2L + b_3L_i + b_4N_p + b_5P + b_6N_b + b_7A + b_8F + u$$

where WU = average water use in gallons per day per dwelling unit;

P = water price in cents per 1000 gallons (this is the marginal price to which the rational consumer is sensitive);

V = assessed property value in hundreds of dollars, a surrogate for income level;

L = residential lot size in hundreds of square feet;

L_i = land not covered by buildings in hundreds of square feet (this, along with L, was postulated to reflect both the general standard of living and sprinkling demand);

N_p = number of persons per dwelling (Grima argued that over the major part of the year the greatest use of water is for bathroom purposes, which is a linear function of the number of residents: a useful refinement, suggested for future work, is to separate out the number of adults and children; those who spend most of the day away from home; and the number of days the family is away for holidays);

N_b = number of billing periods per annum (the number of billing periods was thought to affect the household's awareness of the cost of water which may in turn influence water use);

A = amount of water allowed with the minimum bill, usually implying an average water charge above the marginal price;

F = fixed charge for the household (the interpretation of F is unclear); and

u = error term, assumed to have the usual statistical properties.

Both linear and multiplicative (base ten) functional forms were estimated for the sample of one in 3000 metered households in the Toronto region of Canada. The preferred equation was:

$$\log_{10}WU_a = 2.78 + \underset{\substack{(0.13)\\ [4.43]}}{0.56 \log_{10}V} + \underset{\substack{(0.08)\\ [7.26]}}{0.5 \log_{10}N_p} - \underset{\substack{(0.22)\\ [-4.14]}}{0.93 \log_{10}P} - \underset{\substack{(0.14)\\ [-2.26]}}{0.311 \log_{10}F}$$

(S.E.)
[t]

(R^2 = 0.56).

Thus, Grima's results were consistent with those of Howe and Linaweaver (1967), Turnovsky (1969) and Wong (1972).

Using a time-series of average annual consumption per water connection and average price during the period 1946-1971, Young (1973) estimated the price elasticity of demand for water in Tucson, Arizona. For the period 1946-1964, the price elasticity was estimated to be -0.63 and for the period 1965-1971 it was -0.41. The preferred functional form was the logarithmic and an income variable was found to have virtually no explanatory power.

Also reported in 1973 were Morgan's results of a study of 92 individual households in Santa Barbara County, California. Morgan argued that the use of area averages reduces the variance of variables, which is a shortcoming in the context of econometric estimation. Hence, he used an opinion survey of individual households to supplement data available from the local water authority. With data on number of residents per dwelling, annual water usage and assessed property value (a surrogate for income), it was possible to obtain estimates of income elasticities (ranging from 0.33 to 0.61) and 'people' elasticities (0.25 to 0.57). Unfortunately, the marginal price was constant for all households and, hence, was omitted from the analysis.

During the following year Berry and Bonem (1974) reported the results of a pooled time-series, cross-sectional study of 16 New Mexico urban centres. This work added little to the state of the art but confirmed the importance of income as an explanatory variable. Soon to follow was the work of Hogarty and MacKay (1975) and Batchelor (1975), whose findings supported Hanke's contention that significant increases in the marginal price of water will induce immediate and quasi-permanent reductions in household water use. Hogarty and MacKay (1975) reported a short-run price elasticity estimate of -0.86 and a longer-term price elasticity estimate of -0.56, indicating that, although there are few substitutes for mains water, householders can make substantial changes in their water using habits by adjusting the household production process.

Batchelor's work also assisted in explaining the sudden drop in consumption and longer-term dampening of consumption growth which accompanies changes in marginal price. His study built on the framework established by Lancaster (1966), focusing attention on household water-using technology. He estimated the price elasticity of residential demand for water in Britain to be within the range -0.23 to -0.90 and the wealth elasticity to be within the range 0.38 to 0.93. These findings support the contention that marginal price changes, which affect real income levels, can alter water-using activities which rely on accumulated household technology (or wealth).

The Israeli study to follow, by Darr, Feldman and Kamen (1976), was not only useful in its application to an extremely arid country, but also demonstrated that socio-economic surveys can be of value when data limitations are severe. The study began with the use of average water price[1] and motorisation rate (assumed to be equal to the number of vehicles per household and used as a proxy for income), in a cross-sectional analysis of urban areas across Israel. The price and income elasticities were estimated to be -0.138 and 0.729, respectively.

Severe data limitations, including possible multicollinearity, led Darr et al. (1976) to the use of a survey of 1892 households. The purpose of the survey was to gather more detailed information, including consumers' willingness-to-pay for improved water supply services, so that a more reliable analysis of water-using behaviour could be undertaken. Although price was not introduced as an explanatory variable, regression analysis showed that per capita water consumption was negatively related to household size and positively related to respondent age and per capita income. An important field of enquiry in the study was '... the relative willingness of respondents to pay more in order to receive better quality water, to receive an uninterrupted supply or to avoid self-limitation on their home uses' (Darr et al. 1976, p. 69). The approach involved asking respondents a series of questions related to their willingness to pay for improved water quality and for avoiding a reduction in the standard of services provided by the water supply authority. Unfortunately, because of the manner in which these questions were asked, responses obtained were unsuitable for meaningful inclusion in regression analyses.

Despite its shortcomings, the data collection technique employed by

[1] Average water price is calculated by dividing the total charge for water by the total amount of water consumed during the billing period.

Darr et al. (1976) appears to be suitable for providing information about consumer response to changes in the marginal price of water, especially when available historical data are inadequate for this purpose. Furthermore, it seems likely that, provided questions are framed correctly, the data so obtained can be used effectively in least-squares estimation of demand equations prior to the introduction of new water prices.

Gibbs (1978) was the next to make a notable contribution to residential water demand analysis. He compared the results of empirical estimation using average price with that using marginal price as the relevant price variable. Using a sample of 355 households in Miami, Florida, an additive functional form was used to relate the log of quarterly household consumption (Q) to:

(a) price (P_m or P_a);

(b) a dummy variable (Z) taking the value one for households facing zero marginal price, in the case of the regression using marginal price;

(c) annual household income (I);

(d) number of residents per household (R_s);

(e) a dummy variable (HWH) taking the value one for households having hot-water heating; and

(f) three seasonal dummy variables (D_1, D_2 and D_3).

The preferred equations were:

$$
\begin{array}{llllllll}
\ln Q = 3.12 & - 1.85P_m & - 1.93 & + (4\times10^{-5})I & + 0.14R_s & + 7.79HWH & + 0.06D_1 \\
\text{(S.E.)} & (0.17) & (0.07) & (3\times10^{-6}) & (0.02) & (1.26) & (0.03) \\
 & - 0.03D_2 & - 0.03D_3 & & & & \\
 & (0.03) & (0.03) & & & &
\end{array}
$$

(R^2 = 0.60); and

$$\ln Q = 2.02 - 1.07P_a + (6.4\text{x}10^{-5})I + 0.29R_s + 3.92HWH + 0.08D_1 - 0.02D_2$$
$$\text{(S.E.)} \quad (0.03) \quad (4\text{x}10^{-6}) \quad (0.02) \quad (1.44) \quad (0.04) \quad (0.04)$$
$$- 0.02D_3$$
$$(0.04)$$
$(R^2 = 0.46)$.

For the first equation, using marginal price, the price elasticity (at the point of means) was estimated at -0.51, while the income elasticity (at the point of means) was 0.57. These results compare with, for the second equation (using average price), -0.62 for the price elasticity and 0.80 for the income elasticity. Therefore, Gibbs rightly concludes that the average price model over-estimates the response to price (by 22 per cent) and to income (by 57 per cent), thus supporting the theory-based view that marginal price is the appropriate measure of the price variable: '... the proper concept of price is defined by answering the question "what charges can be avoided or changed in magnitude by the (water consumption) decision now being made by the decision unit ...?"' (Howe and Linaweaver 1967, p. 14).

In what may be described as an ambitious project, Foster and Beattie (1979) attempted to establish a general cross-sectional model for the entire U.S.A. They avoided what they termed 'the pernicious effects of multicollinearity' (p. 47) evident in many previous studies, by excluding variables such as house value, lawn area, number of bathrooms and ownership of swimming pools, each of which is related to income. This was done despite the apparently universal belief that wealth has an influence on consumption levels. The effects of weather and climatic differences between regions were accounted for by the inclusion of a precipitation variable. Of interest is the use of a multiplicative functional form but with price represented as an exponential (allowing for variable price elasticity), so that the estimated relationship was:

$$Q = 0.2492e^{-0.1278P}\, Y^{0.419}\, R^{-0.1619}\, N^{0.4345}$$
$$(t) \quad (10.71) \quad (4.69) \quad (0.79) \quad (3.69)$$
$(R^2 = 0.545)$

where Q = annual average quantity of water demanded per household for the region (in 1000s of cubic feet);

P = average water price for the region ($/1000 cubic feet);

Y = median annual household income for the region;

R = rainfall during the growing season; and

N = average number of residents per household for the region.

Although the authors reverted to the use of a set of average regional prices, the elasticity estimates obtained are in broad agreement with those of other studies.

Arguing that reliance on cross-sectional analyses for water demand forecasts requires the heroic assumption that the spatial effect of the explanatory variables is the same as their temporal effect, Danielson (1979) chose to evaluate a pooled time-series, cross-sectional data set involving 261 households for a 68 month period. The demand relationship for total residential water use in Raleigh, North Carolina, was postulated to be:

$$Y_{it} = \sum_{k=1}^{6} b_k X_{it,k} + e_{it}$$

where Y_{it} = average daily water consumption for the i^{th} household in the t^{th} period;

$X_{it,1}$ = intercept term;

$X_{it,2}$ = average daily rainfall for the period;

$X_{it,3}$ = average temperature for the period;

$X_{it,4}$ = property value (surrogate for income);

$X_{it,5}$ = real marginal water price (cents per 1000 gallons); and

$X_{it,6}$ = household size (number of residents).

The multiplicative form of this relationship yielded a price elasticity of -0.27, a household size elasticity of 0.74, a rainfall elasticity of -0.018, a temperature elasticity of 0.316 and an income (surrogate) elasticity of 0.334.

In the period since 1979, Billings and Agthe (1980; 1981), Griffin and Martin (1981) and Terza and Welch (1982) contributed to the literature by attempting to identify the relevant marginal price variable for best linear unbiased regression analysis when block rates are part of the pricing structure for water. However, since householders in the present study area do not face such a price structure, the details of their analyses are not reported here. It is sufficient to say that the empirical results of Billings and Agthe (1980) are consistent with those of previous studies.

Following the example of Danielson (1979), Hanke and de Mare (1982) used a pooled time-series, cross-sectional data base for Malmo, Sweden, to estimate the residential demand relationship for water. Their preferred equation was:

$$Q = 64.7 + 0.00017\ Inc + 4.76\ Ad + 3.92\ Ch - 0.406R + 29.03\ Age - 6.42P$$
$$(t) \qquad (3.26) \qquad (2.98) \qquad (3.09) \qquad (3.12) \qquad (11.54) \qquad (1.99)$$
$$(R^2 = 0.259).$$

The resulting estimates of elasticities were: for income (Inc), 0.11; for number of adults per household (Ad), 0.13; for number of children per household (Ch), 0.05; for rainfall (R), -0.21; and for marginal price of water (P), -0.15.

Meanwhile, Australian researchers (Gallagher and Robinson 1977; Pullinger 1978; Gallagher 1980; Gallagher et al. 1981; and Robinson 1981) applied the approaches thus far developed to Australian conditions. Of significance was their contribution toward overcoming data inadequacy arising from the nature of Australian water supply authorities' pricing and data collection policies. Gallagher and Robinson (1977) and Robinson (1981) pointed out that the usual price or rating structure applied by

Australian water supply authorities was conducive to neither water conservation nor empirical research. Apart from making recommendations to water authorities concerning data collection and demand oriented pricing policies, and Robinson's preference for a household production process - time allocation approach to the problem, their main offering was to report the results of a consumer demand survey conducted in New South Wales. The objectives of the survey were to identify attitudes to, and explanatory variables for, residential water use and to generate data suitable for estimation of demand parameters.

A random sample of 20 households was selected in the township of Nowra. For this sample a survey questionnaire was used to obtain information related to: household budget patterns; water expenditure; household size; attitudes to, and awareness of, water and its use; and the types of water using appliances operated in the dwelling. Surprisingly, none of the respondents were aware of their water allowance and, therefore, they had no knowledge of average expenditure per kilolitre of water used.

As well as their involvement in the questionnaire survey, volunteer households participated in a price experiment. Participating households were divided into two groups. The control group members simply had their water meters read twice daily, while members of the trial group were given information on water price, including a marginal price for water for the following week, and also had their water meters read twice daily. The experiment lasted for six weeks during winter and regression equations were fitted to the data. The preferred equation (for winter use) was:

$$
\begin{array}{llllll}
\ln q_d = & 7.906 & + 4.131\,A & + 0.283\ln N & - 0.334\ln T & + 0.206\ln U \\
(S.E.) & (0.566) & (1.264) & (0.150) & (0.138) & (0.099) \\
& -0.242\ln P & + 0.133\ln L & - 0.200\ln G & - 0.712\ln PB & \\
& (0.119) & (0.069) & (0.041) & (0.123) &
\end{array}
$$

$(R^2 = 0.646)$

where q_d = quantity of water demanded per week (gallons);

T = income-wealth proxy of water using facilities such as taps, washing machines and toilets (number of taps was used directly in the regression);

A = 0-1 variable for washing machines;

U = number of unit facilities (baths, showers, toilets);

PB = hours per week of personal bathing (showering equivalent);

G = time in the garden/lawn in hours per week;

L = laundry patterns (number of washing machine cycles per week);

P = marginal water price in cents per 100 gallons; and

N = number of residents per household.

A similar summer experiment of twelve weeks duration was run using 19 households in the city of Wollongong. Only one of the respondents stated an awareness of both water rate and quota, confirming that water consumers appear to have little knowledge of water as a marketable commodity.

The preferred equation for in-house use was:

$$\ln q = \underset{(S.E.)(0.279)}{-0.547 \ln Y} + \underset{(0.054)}{0.1201 \ln P} + \underset{(0.105)}{0.609\ NA} + \underset{(0.138)}{0.683\ NC} + \underset{(0.239)}{0.809 \ln WA}$$

$$\underset{(0.202)}{-0.575 \ln L} + \underset{(1.43)}{2.721 \ln T} + \underset{(0.029)}{0.049 \ln Q_{t-1}}$$

(R^2 = 0.428)

where q = quantity of water used in-house per week;

Y = consumer income;

P = change in price;

NA = number of adults in household;

NC = number of children in household;

WA = adults' bathing habits;

L = laundry habits; and

T = number of inside taps.

In the case of garden use, the preferred equation was:

$$\ln q^{*} = 0.974 \ln Y + 3.384 \ln Temp - 0.663 \ln Rain$$
$$(S.E.)(0.446) \quad (1.203) \quad (0.091)$$
$$(R^2 = 0.538)$$

where q^{*} = weekly water use for garden purposes;

Temp = weekly sum of maximum temperature readings (°C); and

Rain = sum of total rainfall per week.

These results are consistent with those of studies carried out overseas.

Pullinger (1978), too, relied on cross-sectional survey data for his analysis of residential demand for water in Geelong, Victoria. Again there was no variation in water price so a price variable was not included in the regression equations. Household income and household size were found to be significant explanatory variables, with their respective elasticities estimated at 0.15 and 0.08 for the preferred linear functional form.

In providing a useful framework within which to analyse the income and substitution effects of alternative pricing policies, Gallagher (1980) analysed the demand relationship in a pooled time-series, cross-sectional study of 123 households in Toowoomba, Queensland for the period 1972/73 through 1976/77. The analytical approach follows from Houthakker and Taylor (1966) and is based on the premise that water consumption is subject to the holding of a stock of water-consuming durable goods and a psychological stock of water-use habits.

The preferred equation was:

$$q_t = 425.2 + 0.5804\, q_{t-1} - 4.7587\, Dp_t - 5.6949\, P_{t-1} - 337.303\, Z_t$$
(S.E.)(39.51)(0.033) (3.119) (2.483) (35.481)
(R^2 = 0.707)

where q_t = demand for water in year t;

$Dp_t = P_t - P_{t-1}$;

P_t = price of water per kl in year t; and

Z_t = dummy variable having the value zero for households using up to their water allowance and one for excess users.

The estimated short-run price elasticity for excess use was -0.263 and the estimated long-run elasticity was -0.749. These results fall within the range of those of other studies. However, less than fifteen per cent of water users consumed more than their quota (and thus faced a positive marginal price) for all but the first year of the period examined. In addition, multicollinearity and autocorrelation were problematical.

Finally, Gallagher et al. (1981) summarised a general approach to forecasting water demand which is consistent with economic theory. In outlining their approach, mention was made of the data inadequacies which can be overcome by water authorities. Procedures for analysing urban sector demands (residential, commercial, industrial and public) were put forward and the problem of aggregation for supply planning purposes was addressed.

In summary, empirical estimation of residential demand for water has produced a number of elasticity estimates, ranging from 0.11 to 1.03 for income and from -0.05 to -1.57 for price. The analytical technique common to all is least-squares regression, although model specification and locational characteristics vary from study to study.

In the present study, the author needs to identify the explantory variables associated with residential demand for water and so obtain reliable estimates of income and price elasticities for the Lower Hunter Valley region of New South Wales. The above discussion serves not only to guide the choice of variables and models, but also to demonstrate likely problems and possible means of solving them.[2]

However, consideration of the theoretical issues, outlined in Chapter 2, brings forward some words of warning concerning the extent to which previous empirical water demand studies should influence the present project. Clearly, there is evidence of ad hoc variable and functional form selection in these studies: whether or not this is a major problem is difficult to ascertain since, in most of the publications cited above, there is little discussion of why particular variables are chosen, implying that the theory and/or a priori reasoning may have played only a minor role in the selection process. In addition, statistical results may be questionable in some studies. All have resulted from least-squares regression analyses but the testing of models against theoretical and statistical assumptions receives scant treatment. This leaves the reader with little information from which to judge the efficacy of parameter estimation and the validity of conclusions put forward by the researchers.

Despite these shortcomings, five generalisations arise from the studies outlined above. First, it is clear that in-house and garden uses of water are readily distinguishable consumption activities. Relevant parameters may be estimated separately for each: this is particularly useful when researchers seek to understand the details of household water consumption behaviour. Second, it may be appropriate to distinguish between hourly, daily, seasonal and annual water use patterns: a task particularly pertinent to the planning of extensions to storage and distribution facilities. Third, the variables found to be statistically significant in explaining household water demand include water price, consumer income, season, household size, property value, property size, length of billing period and number and type of water using appliances

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[2]Some empirical studies of energy demand are also relevant in this regard. See, for example, Barnes et al. (1981), Beierlien et al. (1981), Cargill and Meyer (1971), Halvorsen (1975), Kasulis et al. (1981), Lillard and Acton (1981), Parti and Parti (1980), Pitts et al. (1981), Ritchie et al. (1981),Taylor (1975) and Wills (1981).

used in the household. Fourth, multicollinearity may present difficulties in analyses of both cross-sectional and time-series data, heteroscedasticity may be apparent with cross-sectional data, and autocorrelation may be a problem with time-series data. Fifth, data limitations might be ameliorated by the use of household surveys.

In specifying the model outlined in the next chapter, the author builds on the above review of empirical studies of residential demand for water and the review of demand theory in Chapter 2. The methods and data used in the present study are examined and the results of econometric estimation are presented.