Agrekon

VOL. 12 No. 3 JULY 1973

REQUIREMENTS FOR CONTRIBUTIONS

Articles in the field of agricultural economics, suitable for publication in the journal, will be welcomed.

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The Journal is obtainable from the distributors: "AGREKON", Private Bag X144, Pretoria.

The price is 25 cents per copy or R1 per annum, post free.

The dates of publication are January, April, July and October.

"AGREKON" is also published in Afrikaans.

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The influence of the price of water on certain water demand categories

by

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Since water is a scarce resource, just like any other resource, it should be allocated efficiently amongst competing uses and it therefore falls within the realm of economic analysis. The complexity of subjecting water to economic analysis must, however, not be underestimated. This is particularly true in South Africa where the main water sources originate from storage dams which are primarily subject to the variability of rainfall. The yield from a given storage system is subject to the stochastic nature of its inflows. Due to this stochastic nature, the insurance of a certain minimum yield might be enormously expensive. In the design of water supply systems of a trade-off between reliability and cost is therefore involved.[1] This might result in temporary water shortages from time to time.

These are, however, long-term problems, mainly on the supply side, which will not be considered in this analysis. Long-term supply problems can only be solved if it is known that existing water supplies are used efficiently and how the use of water is going to behave in future. Such an analysis would imply some knowledge of the demand functions for water with the associated demand elasticities of water in the different demand categories.

In South Africa the accusation is sometimes leveled against agriculture that a too large proportion of available water supplies is used by this sector. This statement is justified on the basis that the value of the marginal product of water used in agriculture is very low compared with that in industry. This argument therefore implies an inefficient allocation of water amongst competing industries. That inefficiencies exist is no doubt true but the argument above is none the less somewhat partial.

An evaluation of the reasoning above is not intended here. However, reasoning from an economic point of view only, it seems that the use of water for industry and commerce and households will in many cases get priority over agricultural use. In the case of allocating water from the Vaal Dam, for instance, one can reason that the amount of water allocated to agriculture is of a residual nature. That is, during a given period of time calculations are first made of the quantity of water needed by other users before a decision is made on how much water to release to the agricultural sector. This, in turn, will have important effects on the efficiency and income earned by the relatively large numbers of irrigation farmers who use water from the Vaal River.

The decision of how much water is needed for non-agricultural purposes cannot be made without some indication of whether water is used efficiently at present and the price elasticities involved.[2] This article concentrates on the influence of alterations in the price of water for non-agricultural use on the quantity used. Assuming that the existing prices do not allow the efficient allocation of water within this category, would a movement towards some unspecified, efficient pricing system induce a significant change in the total quantity of water demanded for non-agricultural use and thus also the availability of water to agriculture? The price elasticities of demand in different categories of non-agricultural use can provide guidance for this purpose.

The price of water

Before proceeding with the analysis, some background is needed on the role of prices in water allocation for non-agricultural use. In the industrial area dependent on the Vaal Dam, water is made available to the local authorities at a given price. The local authorities in turn must distribute the water and decide on the appropriate price to each demand category. The local authorities should set their prices such that they serve two main functions namely economising and financing. The economising function amounts to the efficient allocation of a given resource amongst competing uses, while the financing function implies the revenue producing aspect. The impression is sometimes created that the financing function receives priority over the economising function. If the water utility operates under conditions of increasing returns to scale, as is usually assumed, the pricing of water runs into theoretical diffi-

1) Scarato, R.F. Time capacity expansion of urban water systems. Water Resources Research. Vol. 5, No. 5, pp. 929 - 936

2) Abstracting from the uncertainty aspects

culties.[3] This is so since the principle, under perfect competition, in the long run, of pricing according to marginal cost thus breaks down. Since the firm cannot cover cost via the marginal cost principle under these conditions, the deficit must be made up through subsidising or some other pricing rule such as average cost pricing. Both subsidising and average cost pricing lead to inefficiency.[4]

Since utilities generally do not like subsidies, rate structures must be devised that cover cost and ideally minimise the distortion in efficiency. The rate structure must therefore be such as not to discriminate amongst users in the same consumption group and allow for the efficient allocation of water amongst different consumption groups. Devising a rate structure subject to these restrictions is not easily accomplished.

Uniform rate structures to different consumption categories do not necessarily serve efficiency. The rational for different rate structures to different consumer categories are due to the difference in peak demands in the different categories. If a water supply system must be designed to meet the peak demand of the different categories, bigger systems are required than would be the case under the average quantity demanded as criterion. Bigger distribution systems imply a shift in average and marginal cost functions. Pricing efficiency would therefore imply a charge equivalent to the users' contribution to peak demands.[5] Enough data are not available to specify rate structures according to the specified restrictions. Even if it was possible, the general applicability of such structures is doubtfull.

Analysis

In order to determine the influence of the price of water on the quantity used, a sample of 27 municipalities in the Witwatersrand area was selected.[6] This area represents more or less homogeneous climatic conditions.

The following information about water consumption in each municipality for the years 1959/60 to 1969/70 was required:

Annual consumption of water and income received for the following categories:

(a) White households

(b) Non-White households

(c) Industries

(d) Commercial concerns

(e) Local authorities

(f) Other

Data were obtained from all municipalities. The degree of disaggregation of total annual water consumption was, however, not uniform. Some municipalities were only able to furnish the total annual consumption, while others could only specify the data for a few categories. In total, however, sufficient detail was obtained to draw meaningful conclusions.

It would have been ideal if more detail was available such as for instance the breakdown of White household water consumption into domestic and sprinkling use. Some idea about the seasonal demand of water as well as peak demand periods would have enhanced the value of the study. Such detail can only be obtained by means of a well designed experiment on a micro basis, over an extended period. This approach was, however, impractical. The use of the average price of water was also necessitated due to the widely differing base and marginal rate structures.

Reasonably accurate data were obtained i.r.o. White households, industries, total water consumption and to some extent commercial concerns for the majority of municipalities. For 1960/61 the water used by White households, industries and commercial concerns accounted for 66 per cent of total annual water consumption. In some cases no time series data extending over the entire period were available. This problem was aggravated by the lack of time series data for some of the independent variables considered. These problems forced a cross-sectional approach for 1960/61, the latest year for which the values of some of the independent variables were available.

The equations considered to determine the influence of the price of water on water consumption were thus simplified to the following four models:

$$q_1 = f(x_1, x_2, x_3, x_4, x_5) \quad (1)$$

$$q_2 = f(x_1^{1}, x_6, x_7) \quad (2)$$

$$q_3 = f(x_1^{11}, x_2, x_3, x_4, x_5, x_6, x_7) \quad (3)$$

$$q_4 = f(x_1^{111}, x_2, x_3, x_4, x_5, x_6, x_8) \quad (4)$$

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3) If decreasing or constant returns to scale prevail then this argument is no longer valid

4) Ruggles, N. Recent developments in the theory of marginal cost pricing. Review of Economic Studies. Vol. 17, 1949/50, pp. 107 - 126

5) Williamson, O.E. Peak-load pricing and optimal capacity under indivisibility constraints. American Economic Review. Vol. 56, 1966, pp. 810-827

6) The municipalities selected were: Alberton, Benoni, Bethal, Boksburg, Brakpan, Carletonville, Delmas, Edenvale, Germiston, Heidelberg, Johannesburg, Kempton Park, Klerksdorp, Krugersdorp, Nigel, Orkney, Potchefstroom, Pretoria, Randburg, Randfontein, Roodepoort, Sasolburg, Springs, Standerton, Vanderbijlpark, Verwoerdburg & Westonaria

TABLE 1 – Regression coefficients estimated for equations (1) to (4)

Equation No.	Intercept	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	Number of observations	R^2
1.1	–42 195,4	–185,33* (–1,58)	15,77 (1,07)	252,50 (1,26)	315,76 (0,91)	2 224,38 (0,95)	–	–	–	19	0,638 6
1.2	22 434,5	–254,30** (–2,63)	–	–	–	–	–	–	–	19	0,537 2
2.1	14 408,42	–162,40 (–1,28)	–	–	–	–	–3,07 (–0,21)	–6 849,11* (–2,02)	–	13	0,797 0
2.2	8 270,52	–189,64 (–1,29)	–	–	–	–	18,99* (1,75)	–	–	13	0,685 5
2.3	13 571,99	–158,00 (–1,33)	–	–	–	–	–	–6 304,25* (–2,98)	–	13	0,795 9
3.1	–2 811,26	–323,51* (–1,50)	4,22 (0,21)	121,46 (0,42)	165,18 (0,24)	3 459,72 (0,68)	23,11* (1,84)	–2 510,49 (0,35)	–	20	0,775 5
3.2	25 345,70	–324,50** (2,10)	–	–	–	–	34,82** (3,21)	–	–	20	0,739 8
4.1	–	19,73 (0,13)	–7,87 (–0,36)	–104,00 (–0,41)	–42,15 (–0,08)	–1 916,56 (–0,52)	20,72 (1,05)	–	124,08 (0,96)	17	0,854 5
4.2	7 045,58	–195,31** (–2,07)	–	–	–	–	–	–	244,77** (2,70)	17	0,661 2
4.3	1 988,31	–42,96 (–0,51)	–	–	–	–	23,36** (3,44)	–	192,31** (2,76)	17	0,840 1

The numbers in brackets indicate the respective t values

* Significant at the 10 per cent level of significance

** Significant at the 5 per cent level of significance where:

q_1 = average annual per capita water consumption for White households (gal./year)

q_2 = average annual per capita water consumption for industries (gal./year)

q_3 = average annual per capita water consumption for White households, industries and commercial concerns (gal./year)

q_4 = average total annual per capita water consumption (gal./year)

x_1 = average price of water per 1 000 gal. for White households

x_1^{1} = average price of water per 1 000 gal. for industries

x_1^{11} = average price of water per 1 000 gal. for White households, industries and commercial concerns

x_1^{111} = average price of water for all users per 1 000 gal.

x_2 = income per capita for White households*)

x_3 = percentage of White population living in private residences*)

x_4 = percentage of economically active population with income below R3 000*)

x_5 = dummy variable with "0" representing municipalities with a White population larger than 10 000, "1" otherwise

x_6 = index of industrialisation

x_7 = dummy variable relating to industrial composition representing "1" for large industrial centers, "0" otherwise

x_8 = percentage White population*)

In these equations the only independent variables with economic content are x_1, x_2 and x_4, representing price of water, income per capita and the distribution of income, respectively. The other independent variables included can be seen as an attempt at stratifying the sample. It is a general problem in cross-sectional analysis that the different observations might not strictly be comparable unless variables accounting for non-comparibility are specifically isolated.

The results obtained with equations (1), (2), (3) and (4) are presented in Table 1.

*) Data obtained from the various reports of the Department of Statistics. Population Census 1960. Government Printer, Pretoria

No significant multicollinearity appeared amongst the independent variables of the different equations except for equation 3 where variables x_6 and x_7 were strongly correlated. A reasonable fit was obtained for the models as indicated by the R^2 which vary from 0,53 to 0,85 and can be considered as acceptable in a cross-sectional analysis.

The regression coefficients associated with the income variable (x_2) are insignificant even at the 10 per cent level of significance, indicating that income is not a major factor in water consumption. For the price variable (x_1) the t values are significant at the 5 per cent or 10 per cent level except for equation 2 where the t value is well above one and thus retained for theoretical reasons.[7)] In equation 4 the regression coefficient for x_1 is not very stable and this equation is thus not applied in the analysis. This instability can be explained by the fact that water consumption by Non-White households, local authorities and other categories such as water used by the railways and mines are included in this category which might not be highly influenced by the price of water. The stratification variables were, with some exceptions, non-significant.

The results are thus not equally satisfactory for all the water consumption categories and the relatively small number of observations contributed to this problem. The "best" equations were 1.2, 2.3 and 3.2 which were considered for the estimation of price elasticities. (No price elasticity was estimated for equation 4).

The price elasticities for the different categories appear in Table 2.

TABLE 2 - Price elasticities of water by categories

Category	Price elasticity at the mean
White households	-0, 694 7
Industries	-0, 623 3
White households, industries and commercial concerns	-0, 628 7
Commercial concerns*)	-0, 835 0

*) Indirectly estimated by the following formula:

$$e = \frac{t^1 e^1 + t^{11} e^{11} + t^{111} e^{111}}{t^1 + t^{11} + t^{111}}$$

$$e^{111} = \frac{e(t^1 + t^{11} + t^{111}) - t^1 e^1 - t^{11} e^{11}}{t^{111}}$$

Where e is the elasticity of White households, industries and commercial concerns and t^1, t^{11}, t^{111} the proportion of water used by White households, industries and commercial concerns, respectively, and e^1, e^{11} and e^{111} the corresponding elasticities

7) Wonnacott, R.J. and Wonnacott, T.H. Econometrics. John Wiley, New York, 1970, pp. 63-67

The elasticities were generally relatively small indicating that a 1 per cent change in the price of water has a less than proportionate effect on water consumption per capita.

Trends in water use and the influence of institutional rationing on water consumption

Although prices should be an efficient allocator of water amongst users under normal conditions, institutional rationing is called for under abnormal conditions. When abnormal shortages begin to appear frequently this might indicate insufficient water supplies, an aspect beyond this analysis.

In an attempt to determine who bears the brunt of water restrictions, a time trend analysis has been performed for the different consumption categories covering the period 1959/60 to 1968/69. Since not all municipalities supplied data for the entire period, the average total consumption per municipality could only be calculated for those who covered the period and disaggregated total consumption in categories. It is therefore not advisable to generalise the results to all municipalities in the sample.

The following time trend equation was used:

$$Z_t = AB^t(D_1D_2D_3)V_t \quad (5)$$

$$B = (1+g)$$

where, Z_t = total consumption per category

t = time

g = growth rate

D_1 = dummy variable being "1" for 1966, representing water restrictions for the period January to June 1965/66

D_2 = dummy variable being "1" for 1966/67, representing water restrictions for July to February 1966/67

D_3 = dummy variable being "1" for 1968/69, representing water restrictions for February to June 1969

V_t = error term

This equation was linearised by a logarithmic transformation, except for the dummy variables which were included in the original form. The results are presented in Table 3.

No definite trend (t) was exhibited for the consumption of water by local authorities, while significant trends were found in all the other categories. The implied growth rates for White households, industries, commercial concerns and Non-White households were 9,7, 7,4, 12,0 and 2,4 per cent, respectively.

The water restrictions did not significantly alter the water consumption for the restriction period 1965/66 represented by D_1. It is further quite interesting to note that the water restrictions did not influence industrial concerns, commercial concerns or local authorities. Water restrictions indicated by D_2 and D_3 did influence the water consumption of White and Non-White households significantly. The available data therefore suggest that water restrictions are biased against household consumption in periods of water shortage. This aspect is understandable because it is more difficult to control the use of water, especially to industry.

Summary of results

It would seem that the price elasticity of water for urban usage is relatively inelastic, indicating that price changes would not influence the quantity of water consumed very much. This result corresponds with estimates in the U.S.A. where Turnovsky[8)] found price elasticities for households of between -0,3 and -0,4. For industries the elasticities ranged between -0,5 and -0,8.

The magnitude of change caused by a 1 per cent increase in the price of water is indicated in Table 4.

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8) Howe, C.W. and Linaweawer, F.P. The impact of price on residential water demand and its relation to system design and price structure. Water Resources Research. Vol. 3, 1967. See: Turnovsky, S.J. The demand for water: Some empirical evidence on consumers' response to a commodity uncertain in supply. Water Recources Research. Vol. 5, April 1969, pp. 350-361

TABLE 3 - Trends in total water consumption in the different water consumption categories for 1959/60 to 1968/69

Consumption category	Intercept	t	D_1	D_2	D_3	R^2
White households	6,180 4	0,040 3** (12,22)	-0,006 5 (-0,26)	-0,102 8** (-3,92)	-0,049 7 (-1,66)	0,988 9
Industrial concerns	5,699 7	0,031 1** (6,44)	-0,008 6 (-0,24)	0,013 1 (0,34)	-0,034 6 (-0,79)	0,966 8
Commercial concerns	5,138 7	0,049 2** (3,45)	0,045 5 (0,50)	-0,044 9 (-0,46)	0,032 5 (0,29)	0,929 3
Non-White households	5,388 3	0,010 6* (1,73)	-0,014 6 (-0,37)	-0,071 9* (-1,73)	-0,087 4 (-1,80)	0,915 1
Local authorities	5,375 1	0,008 4 (0,84)	0,016 7 (0,22)	-0,038 1 (-0,47)	-0,021 7 (-0,24)	0,432 8

The numbers in brackets indicate the respective t values

* Significant at the 10 per cent level of significance ** Significant at the 5 per cent level of significance

TABLE 4 - The influence of a price increase on water consumption

Prediction equation	Estimated per capita consumption at 1960/61 prices (gal.)	Estimated per capita consumption with a 1 per cent increase in price (gal.)	Difference (gal.)
1.2	13 239	13 147	-92
2.3	9 851	9 831	-20
3.2	17 355	17 238	-117

As indicated previously, the approach in this article is based on partial analysis and is subject to criticism on this aspect as well as others. However, the purpose was not to give definitive answers on the allocation problem. Only a small aspect of non-agricultural water use was analysed and even here the analysis is subject to data limitations as well as theoretical problems.

The implications for agriculture

Potentially, the phenomena described above have important consequences for agriculture. As previously stated, a considerable number of irrigation farmers are dependent upon the Vaal River for their irrigation water. Although this was not envisaged in the original planning, these irrigation farmers are mainly residual recipients of water. During those years when relatively little water is available, non-agricultural uses of water constitute a tremendous drain on their supplies. Studies in other irrigation areas in South Africa have proved conclusively that water shortages in irrigation areas give rise to organisational problems, a drop in the efficiency of application of other inputs, and lower incomes on irrigation farms.[9)]

This situation is aggravated by the sharp rise in the non-agricultural consumption of water on the Witwatersrand, to which reference has already been made. If alternative water resources are not found for the non-agricultural consumers, the quantities of water available in the Vaal River for farming purposes will continue to drop. Corollaries of this are that there will be more individual years during which water supplies for farming will be a limiting factor, and that shortages of water for irrigation purposes will continue to grow more acute.

Because of the low price elasticities of demand, price policy is no solution to this problem. Political considerations may also deter the authorities from giving overmuch attention to the matter, particularly in view of the low price elasticities of demand.

The above factors make it impossible for the authorities to give favourable consideration to any extension of irrigation farming in the Vaal River area. In the long run any such extension will only create problems for the farmers taking water from the Vaal and, ultimately, for the authorities themselves. Viewed from a sound planning angle it is important, therefore, that no increased allocations of water to riparian farmers, or to farmers on irrigation schemes along the Vaal, be permitted.

Another factor to which regard should be had is that there are established irrigation farming communities at certain points. In some places, for instance in the Vaalharts irrigation area, comprehensive infrastructural development has taken place. To afford these places a measure of protection, serious consideration will have to be given to the development of alternative water resources for the region through which the Vaal River flows and to the elimination of inefficiencies in water allocations and uses. The question also arises whether the establishment of new industries consuming large quantities of water should be permitted in the Vaal River area.

In view of the rising consumption of water, and having regard to vested interests and the interaction between prosperity in agriculture and general economic progress, the time has arrived for water planning in the Vaal River basin to be tackled on a comprehensive basis. The interests of all groups will have to be taken into account and considered, but they will have to be made subordinate to the national interest.

9) Hancke, H.P. and Groenewald, J.A. The effect of resource availability on optimum organisation in irrigation farming. Agrekon, Vol. II, No. 3, pp. 9-16, 1972. Van Rooyen, C.J. Die gebruik van proefboerderyresultate vir die beplanning van boerderye by die Hartbeespoort-besproeiingskema. M.Sc. (Agric.) thesis, University of Pretoria