# CONSUMPTION OF GROUNDWATER AS A PRIVATE OR A PUBLIC GOOD

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## ABSTRACT

Groundwater constitutes a resource asset that generates economic benefits. These benefits are at the same time subject to externalities of one kind or another. This article examines the trade-off involved in using depletive or non-depletive extraction policies in groundwater exploitation.

A perfect system of recharge in non-depletive use of groundwater means that the total amount of water available for use is unaffected. Rivalry between consumers would not exist. Therefore, groundwater could be considered to be a public good, as described by Samuelson in 1954. On the other hand, where extraction is depletive, it must then be considered a private good.

The problem then lies in the optimisation of the resources allocation to be exploited using either one of these two alternatives and to determine the optimum number of consumers for each option. Once the problem has been analysed from a Paretian point of view, no interior solution exists. Maximum social welfare must necessarily be derived from using either one or the other of the two solutions possible.

## 1 INTRODUCTION

From an economic point of view, groundwater constitutes an asset whose benefits -tangible and intangible- are closely related to, and influenced by, consumer and production activities. Groundwater is also the cause of, and the result of, external economies and diseconomies.

When exploiting an aquifer, not only should economic agents determine the type and size of capital investment required as well as the amount of water to be withdrawn. The influence of externalities should also be determined in terms of social welfare if these figures are to be optimised.

The results will be influenced by existing legislation - in particular, property rights over groundwater resources. Moreover, in our case, it is possible to decide whether groundwater is a private or a public good using the definition given by Samuelson (1954).

Although the simplest way of defining groundwater is as a pure private good, the fact that property rights are not clearly defined means that problems may arise similar to those that exist in the case of public goods. Where two or more users have the right to exploit the same aquifer, negative and reciprocal externalities appear ipso facto. This situation is typical of "common ownership of natural resources", and, as Aguilera points out (1987), in the absence of policies to correct the situation, withdrawal is uneconomical because the amounts of groundwater withdrawn are excessive.

Whether adequate legislation does or does not exist, even supposing an ideal situation did exist, groundwater exploitation is always subject to the influence of externalities. The contamination of aquifers and the relationship between health and water consumption are examples of positive and negative externalities affecting groundwater exploitation.

According to Bird (1987), a proper analysis of the problem must involve differentiating between transferible and non-transferible externalities. A distinction should also be made between depletable externalities -acting as pure private good- and non-depletable externalities characteristic of a pure public good (Baumol and Oates, 1975).

On the other hand, an aquifer may be exploited where fixed costs are low and variable costs high, or, where fixed costs are high and variable costs low. Where fixed costs are high, groundwater may be considered a public good (Mueller 1979, and Baumol; Panzar and Willing 1982). It is, therefore, possible to convert a private good into a public good at any one time.

Similarly, the withdrawal of a particular quantity of water by one consumer may reduce the total amount of water available for the use of other consumers (depletive extractions). Rivalry between consumers would then exist -a characteristisic of a private good. Alternatively, withdrawals may be made so that the total amount of water available is not affected (e.g. using perfect recharge methods or non-depletive extraction policies)- a situation which would be characteristic of a pure public good. Again, the possibility of deciding whether to use groundwater as a private or a public good arises. Groundwater is therefore a "transformable natural resource" (private $\rightleftarrows$ public).

The situation, then, is a complex one which can best be understood by breaking it down into more simplified forms, each of which deals with one relevant aspect of the whole. In this way, the situation can be better defined as a result of more detailed analysis.

The following article is a study of groundwater as a transformable natural resource which may be used wholly or partially as a pure private good or a pure public good without legislative restrictions of any kind. The aim is to find the optimum allocation of available resources for depletive or non-depletive extractions within the framework of a general Paretian model. Similarly, an effort will be made to optimise the number of consumers for each alternative.

## 2. THE MODEL

Taking H as identical individuals having definite preferences for the consumption of a transformable good X -groundwater- as a public good, $X_n$, as well as for the consumption of the same groundwater X as a private good, $X_m$. Individuals have also established preferences over the consumption of a non-transformable pure private good, L. These preferences can be represented by the utility function,

$$U^h(X_n^h,\ X_m^h,\ L^h);\ h=1,\ \ldots,\ H$$

which we suppose strictly concave and twice continually differentiable. Two types of individuals are considered. On the one hand, one that consumes X only as a private good, m, whose utility function will be,

$$U^m(X_m,\ L),\ m\varepsilon M,\ 0\leqslant M\leqslant H$$

and another that consumes X as a collective good, n, whose utility function will be,

$$U^n(X_n, L_n);\ n\varepsilon(H-M),\ H>1.$$

The problem consists of determining which is the optimun size of each of these groups -choosing M- and allocating the initial resources of the transformable good between consumption as a private and as a collective good -choosing $X_m$ and $X_n$. Being w the initial resources of groundwater, the feasibility constraint will be,

$$w-MX_m-X_n=0.$$

This equation reflects that each of the M consumers consumes a quantity $X_m$ of X as a private good, while $X_n$ represents that part consumed as a collective good by the rest of consumers (H-M).

With respect to the non-transformable private good, there exist initial resources, T. The individual consumptions $L_m$ and $L_n$ are additional decision variables. The associated feasibility constraint is,

$$T-ML_m-(H-M)L_n=0$$

The welfare in this society will be evaluated by using Bergson's social welfare function,

$$W=MU^m(X_m,L_m)+(H-M)U^n(X_n,L_n).$$

Firstly, we will consider the problem of attaining a first best optimum within a planned economy where decision-makers have at their disposal all the variables in the problem as decision variables. Secondly various problems of second-best optimum will be examined when some of the control variables are predetermined.

## 3. THE FIRST-BEST PROBLEM

### 3.1 General Case

The problem to be solved in its singlest version is as follows:

$\max\ W=MU^m(X_m,L_m)+(H-M)U^n(X_n,L_n)$ (1)

s.t. : $w-MX_m-X_n \underset{(\geqslant)}{=} 0 \quad r_1$ (2)

$T-ML_m-(H-M)L_n \underset{(\geqslant)}{=} 0 \quad r_2$ (3)

where $X_m$, $X_n$, $L_m$, $L_n$ are the decision variables and, H, w, T are parameters.

This is a problem of conditioned non-linear programming in which we know that if the objective function as well as the constraints (in the form $\geqslant$ ) are concave, the problem has a maximum (interior).

Since the utility functions are strictly concave, by hypothesis it is easy to prove that the objective function W (.) is also concave. The feasibility constraint for the non-transformable private good (3), is concave as well. Conversely, the constraint corresponding to the transformable good (2) is convex on ($X_m$, $X_n$, M).

*Thus, there is no interior maximum, hence the choice is* limited to the study of two candidate points, the two corners. These points are $W_0$ and $W_1$,

$W_0(M=0,X_m=0,L_m=0,(H-M)=H,X_n=w,L_n=T/H)$ (4)

$W_1(M=H,X_m=w/H,L_m=T/H,(H-M)=0,X_n=0,L_n=0)$ (5)

$W_0$ measures the social welfare when all the resources w of the transformable good are consumed by all the individuals as a pure collective good. The expression $W_1$ measures the social welfare when all the resources of the transformable good are consumed by all the individuals as a pure private good.

As all the individuals are identical, we can do without the consumption of the non-transformable good, L, to evaluate the candidate points. The decision depends exclusively upon the sign of D:

$D \overset{\det}{=} U^m(w/H)-U^n(w)$ (6)

Consequently, a sufficiency condition to ensure that it is not socially preferred in any case to consume as a private good a good that can be consumed as a collective one, is,

$$U^m(X_m) \leqslant U^n(X_n),\ \text{for every}\ X_m \leqslant X_n$$

given that $w/H<w$ because $H>1$ by hypothesis. That is,

$D \leqslant 0 \Leftarrow U^m(X_m) \leqslant U^n(X_n)$, for every $X_m \leqslant X_n$ (7)

The reverse is not true. If the preferences are such that:

$U^m(X_m) \geqslant U^n(X_n)$ for every $X_m \geqslant X_n$ (8)

then nothing can be said about the sign of D without knowing exactly those preferences. In order to observe the result of different preferences over the consumption of X either as a private good or as a collective good, a simulation was effected, as shown below.

## 3.2 Simulation

Let

$$U^m(.)=(1/a)X_m^a+L_m;\quad 0<a<1$$

$$U^n(.)=(1/b)X_n^b+L_n;\quad 0<b<1$$

be the preferences of the consumers.

The problem can be simplified in this case, by (1):

$$\max\ W=M\ (1/a)X_m^a+(H-M)(1/b)X_n^b$$
$$\text{s.t.: } w-MX_m-X_n \underset{(\geqslant)}{=} 0$$
$$X_m\geqslant 0,\ X_n\geqslant 0,\ M\geqslant 0.$$

This problem, for the same reasons as those explained earlier for the general case, does not have an interior maximum.

In Table I, the values taken for the social welfare function for each corner solution are shown for various values of a and diverse relations between a and b. We will suppose that the value of the parameters of the initial resources of the transformable good w and the population H is w=200 H=100.

As follows from the observation of Table I, whether or not the option of consuming X as a pure collective good will dominate the option of consuming it as a pure private good will depend upon the relative strength of the preferences between both types of consumption.

The goodness of each alternative cannot be established "a priori" but it should be computed for each case, since it depends on individual preferences.

## 4. SECOND BEST PROBLEMS

As we have seen in the above section, the first-best problem has a maximum, which is unique but it is a corner solution. There are no interior solutions. It is for this reason that it is worth looking at some second best cases that are closer to more realistic situations. Let us take some variables of the general case as predetermined values which means that they should be considered as a parameter.

We will study two cases in particular. Firstly, when the number of individuals, M, consuming the good as a pure private good is institutionally fixed, and secondly, we will suppose that some other variables are predetermined.

In the first case, the constraint (2), which was convex (in the form $\geqslant$ ) in the general case, will be transformed into a straight line and consequently, there will be an interior solution. If the quantity $X_m$ consumed as a pure private good were predetermined, the lack of concavity of the constraint (2) would persist. Moreover, a corner solution (M=0) is not feasible since it not possible to fulfil the constraint (2) for this value. Furthermore, if given $X_n$, the necessary concavity of the objective function fails, the study will be limited to Case 1.

<u>Case 1. M given</u>

It would be to solve:

$$\max.W=MU^m(X_m,L_m)+(H-M)U_n(X_n,L_n) \qquad (9)$$

TABLE 1

Measure of welfare for options $W_1$ (water consumption as a private good) and $W_0$ (consumption as a public good) as a function of the preferences (a,b), being w=200 and H=100

| a | $W_1$ \ $W_0$ | b=(4/3)a | b=(2/2)a | b=2a | b=(5/2)a | b=(11/4)a | b=(14/5)a | b=(29/10)a |
|---|---|---|---|---|---|---|---|---|
| 1/100 | 10.069 | 8.049 | 7.218 | 5.559 | 4.567 | 4.207 | 4.142 | 4.021 |
| 1/50 | 5.069 | 4.319 | 3.908 | 3.090 | 2.606 | 2.433 | 2.403 | 2.344 |
| 1/20 | 2.070 | 2.135 | 1.983 | 1.699 | 1.551 | 1.507 | 1.500 | 1.487 |
| 1/15 | 1.571 | 1.802 | 1.698 | 1.520 | 1.451 | 1.440 | 1.440 | 1.441 |
| 1/10 | 1.072 | 1.520 | 1.476 | 1.442 | 1.504 | 1.561 | 1.574 | 1.603 |
| 1/7 | 772,9 | 1.440 | 1.452 | 1.590 | 1.858 | 2.040 | 2.081 | 2.168 |
| 1/5 | 574,4 | 1.540 | 1.633 | 2.081 | 2.828 | 3.351 | 3.470 | 3.725 |
| 1/4 | 475,7 | 1.754 | 1.944 | 2.828 | 4.388 | 5.555 | 5.829 | 6.426 |
| 1/3 | 378,1 | 2.371 | 2.828 | 5.129 | 9.924 | 14.030 | 15.052 | 17.340 |
| 5/12 | 320,2 | 3.417 | 4.387 | 9.924 | 23.942 | 37.779 | 41.456 | |

s.t.: $w-MX_m-X_n=0 \quad r_1$ (10)

$T-ML_m-(H-M)L_n=0 \quad r_2$ (11)

where $X_m$, $X_n$, $L_m$ and $L_n$ are control variables and M. H, w and T are parameters.

The first-order conditions of this programme are necessary and sufficient for an overall maximum and they are:

$$M(U^m_{Xm}-r_1) = 0 \tag{12}$$
$$M(U^m_{Lm}-r_2) = 0 \tag{13}$$
$$(H-M)U^n_{Xn}-r_1 = 0 \tag{14}$$
$$(H-M)(U^n_{Ln}-r_2) = 0 \tag{15}$$

That is, from (12) and 1=(13), and from (14) and (15):

$$r_1/r_2=U^m_{Xm}/U^m_{Lm} \tag{16}$$
$$r_1/r_2=(H-M)(U^n_{Xn}/U^n_{Ln}) \tag{17}$$

which coincide with the optimality conditions for a pure private good (16) for M consumers and for a pure collective good (17) for (H-M) consumers, respectively.

From (13) and (15) results, $U^m_{Lm}=U^n_{Ln}$, so as that from (16) and (17) it can be written,

$$U^m_{Xm}/U^n_{Xn}=(H-M)$$

That is, the utility at the optimum of an individual due to a marginal increase in the consumption of the good $X_m$ has to be (H-M) times higher than that corresponding to an individual n due to marginal consumption of $X_n$.

## 5. CONCLUSIONS

Groundwater may be considered to be an asset influenced by a multitude of factors, each in itself of sufficient importance and complexity to justify a separate analysis. This article has examined the social desirability of depletive extraction policies (as a private good) as opposed to non-depletive extraction (as a public good) independent of other relevant aspects.

If it is considered that groundwater may be used wholly or partially as a private good or as public good, then independent of the social welfare function, a two-good solution can never be an optimum solution.

That is to say that, depending upon individual preferences for one or other system, it will either be socially beneficial to use the total amount of water available without depleting resources or it will be socially beneficial to carry out depletive extraction. Any in-between solution would not be as socially beneficial. This conclusion is valid for nations, as well as any society organised in nations even though differing individual preferences may exit.

The analysis has been made from a Paretian point of view in an institutional vacuum.

The conclusions reached are independent of any property rights that may be established. The concession of property rights must however be in consonance with whatever system is chosen. If not, rivalries will develop between private and social interests (Turvey 1963) which could give rise to inefficient allocation.

## 6. REFERENCES

Aguilera Klink (1987). "Los recursos naturales de propiedad común:una introducción". Revista de Estudios Regionales. En imprenta.

Baumol, W.J., and Oates, W.E., 1975. "The theory of Environmental Policy: Externalities, Public Outlays and The Quality of Life". Prentice-Hall, Englewood Cliffs, N.J.

Baumol, W.J., Panzar, J.C. and Willig, A.D., 1982. "Contestable Markets and the Theory of Industry Structure". Harcourt Bran Jovanovichs, Inch. N.Y.

Bird, P.J.W.N., 1987, "The Transferability and Depletability of Externalities". Journal of Environmental Economics and Management 14, 54-57

Kindleberger, C.P.; 1986. "International Public Goods without International Government", The American Economic Review, 76, 1: 1-13

King D., 1984. Fiscal Tiers: "The Economics of Multilevel Government". George Allen and Unwin (Publishers) Ltd. London.

McCormick, E. et al., 1981. "Politicians, Legislation, and the Economy: an Inquiry into the Interest-Group Theory of Government". Martinus-Nijhoff, Boston.

Milleron, J.C., 1972. "Theory of Value with Public Goods: A Survey Article", Journal of Economic Theory, 5: 419-447.

Mueller, D.C., 1979. "Public Choice, v.c." Alianza Editorial. Madrid,1984.

Samuelson, P.A., 1954. "The Pure Theory of Public Expenditure", Review of Economics and Statistics, 36: 387-389.

Turvey, R., 1963. "On Divergences between Social Cost and Private Cost", Economica, NS 30: 309-313.

Zodrow, G.R., 1983. "Local Provison of Public Services: The Tiebout Model after Twenty - Five Years". Academic Press Inc. New York. 778772.