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# WATER ALLOCATION OF TRANSBOUNDARY RIVER: A MICROECONOMIC OPTIMAL TAX APPLICATION

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**Abtract**: A model is presented that incorporates both water quantity and quality aspects and a market based system is developed to characterize optimum water allocations between two regions or countries. A methodology is developed to compute the optimum tax or subsidy that could support an optimum water quantity and quality allocation in case that the relevant authorities agreed to impose in the marketplace.

**Keywords**: water allocation, optimal tax, externalities

**JEL Classification**: D49, D60, D69, D74, Q25, Q28

## Introduction

To manage effectively freshwater resources requires accounting for an entire river basin, Abbas (1983). This is particularly challenging in cases that a river basin is under the jurisdiction of a number of neighboring countries. There are over 200 river or lake basins all over the world which are shared by two or more countries, Priscoli (1990) and Biswas (1983); which are populated by 40% of the world's human population and covering more than 50% of the Earth's land area. Competition for groundwater allocation across countries is often a reason for international tensions and crisis, for example, in the Middle East, Starr (1991).

The fresh water supplies of Greece are rather limited and its year-round supply of fresh water is unstable due to rainfall distribution patterns, the overwhelmingly rocky structure of its land, uneven regional development, and the international common property identity of some of its surface water bodies.

The Northern part of the country joins four large watersheds around the rivers of Nestos (Mesta), Axios, Strymon (Struma), Evros (Maritza), and Aoos, territorialy shared by Greece, Bulgaria, Yugoslavia, Turkey, and Albania -- countries which are currently undergoing swift socioeconomic changes. Thus, approximately one fourth of Greece's surface waters, which irrigate the cultivated plains of Macedonia and Thrace, originate from international common property water resource systems (OECD 1983). By their very nature these systems are characterized by "free" access to them in both quantitative and qualitative terms, with the countries located near the springs being in a relatively privileged position. Water benefits accrue to the countries in the watersheds and although serious conflicts over the river waters have not occurred as of yet, it is rather inescapable that international co-operation is necessary to resolve conflicts before they even arise.

The Nestos river originates from the Rila mountain within the Bulgarian territory and flows into the Mediterranean through Thrace which is in the 12th water resource region of Greece. In this region 68.6% of the surface water is coming from Turkey and Bulgaria, KEPE (1989, I).

Environmental pollution problems in the region are summarized by Efthimoglou (1988) who states for the Thissavros site crossed by Nestos:

"The sole, at the moment, but serious nevertheless, pollution which was found in the area has its sources in Bulgaria. It concerns the state of the water of Nestos, the changes caused by this state on the flora and animals and on the economic activities related to the river, such as fishing in internal and sea water as well as the irrigated areas of cultivation".

In Bulgaria, Behar (1992), there are more than 240 factories and agricultural cooperative units along Nestos, Strymon, and Evros. Only the 20% of them use some kind of waste water treatment technology. Water pollution problems are of main concern for both countries. However, there are no special centers to monitor the water quality of the river and as a result several environmental damages cannot be avoided, since there is no mechanism to identify them and inform both sides properly and in time. For example, in April 1992, a Bulgarian coal factory discharged into Evros 565,000 $m^3$ of heavily polluted water that poisoned a lot of the fish in the river, since the incident was not monitored in time; Behar (1992).

Thrace is one of the less developed areas in Greece. All indices of regional development for Thrace are relatively low, see KEPE (1989, II). However, it is rich in natural resources and physical attractions, with a good potential for further development which is conditional on the availability of the waters of Nestos river. For example, on August 22, 1995 the Ministry of Agriculture of Greece announced the forthcoming construction of a major irrigation project in the area that will provide 170,000,000 $m^3$ of water from Nestos river to 400,000 stremmas of agricultural land, even though an agreement for the allocation of the waters of the waters of Nestos has not been reached yet.

To avoid conflicts in the future, the allocation of the Nestos waters, as well as the allocation of the waters of other rivers shared by the two countries, is an issue of main concern for Greece and Bulgaria; Giannias and Lekakis (1996). However, this issue remains unsolved for the last 20 years, Naftemporiki (1991). In March 1991, the Greek deputy-Minister of Agriculture announced that a agreement should be reached with the Bulgarian side by the end of May 1991, Express (1991,I). The announcement was followed by meetings in Sofia and Athens, Naftemporiki (1991). At the meetings held in Athens, Express (1991,II), the Bulgarian side proposed a 25% of the water for Greece for 20 years, and a renegotiation between the two countries after the 20 years. The Greek side insisted on a 33% for 35 years. No final agreement was reached during that meeting and as far as we know the problem remains unsolved until today.

The issue of allocating the water between the two countries is very important and it can be seen not only from the recent negotiations between the officials of the two countries but also from Behar (1992), who states that for the 1956-1966 period Greece protested by sending more than 30 diplomatic notes to Bulgaria to complain for the insufficient volume of the water of Nestos and Strymon.

As it concerns the waters of Strymon the Greek and the Bulgarian government agreed recently to cooperate, Express (1995), for protecting the destruction of the ecosystems around the lake Kerkine by the waters of river Strymon that erodes the Bulgarian soil, which is subsequently transfered to Greece in large quantities. The signs of destruction are severe and if the current trends continue it is expected that the Kerkine lake will be destroyed and have Kerkine Falls in its place, and that the waters of Strymon will not be possible to find their way to the sea.

In October 1991, the Greek and the Bulgarian government agreed to cooperate for the settlement of all resource and ecological disputes between the two countries. This agreement declares their "mutual intention to expand the cooperation in this sphere on a long-range basis ... and the particular attention they pay for overcoming any pollution of the Black Sea, the Mediterranean, and the river running through the territories of both countries"; p. 8 of the agreement. In April 1992, the two sides discussed officially issues related to Nestos. Once more the negotiations were unsuccessful since a final agreement was not reached.

The significance of the issue for Greece has resulted in the classification of all relevant information as confindential. Yet, both sides have agreed to exchange information and data to facilitate further negotiations.

In this article a microeconomics model is presented that incorporates both water quantity and quality aspects and a market based system is developed to characterize optimum water allocations between two regions or countries. A methodology is developed to compute the optimum tax or subsidy that could support an optimum water quantity and quality allocation in case that the relevant authorities agreed to impose in the marketplace.

**A Theoretical Framework.**

Our framework assumes that there is no uncertainty, that property rights are exogenous and non-attenuated, and that there is no price for water. The water resource system under consideration is a river shared by two regions, j = 1, 2. The river rises in region 1 and flows through region 2 and into the sea. Its water is used by various activities, industrial, agricultural, recreational, tourism, etc along the watercourse in both regions.

The ith production technology in region j is given by,

$$Y_{ij} = Y_{ij}(X_{ij}; W_{ij}, Q_{ij})$$

where, i assumes two sets of values, i = 1, 2, ..., m for region 1, and i = 1, 2, 3, ..., n for region 2,
$Y_{ij}$ = the level of activity i in region j,
$X_{ij}$ = set of production inputs other than water used by activity i in region j,
$W_{ij}$ = the flow of water in activity i in region j, and
$Q_{ij}$ = the quality of water in activity i in region j.

The ith activity in region 1 generates and disposes into the river $h_{i1}$ units of waste, where $h_{i1} = h_{i1}(Y_{i1})$. Let $h_1 = (h_{i1}, ..., h_{m1})$ be the vector of all wastes disposed into the river in region 1. This vector together with $Q_1 = (Q_{11}, ..., Q_{m1})$ determine $Q_2$, the water quality going to region 2. Therefore, $Q_2$ is a function of the following general form:

$$Q_2 = Q_2(Q_1, Y_1)$$

Following a similar argument, the general functional form of water quality at the point of the river discharge into the sea is given by

$$Q_3 = Q_3(Q_2, Y_2)$$

The decrease in water quality caused by economic activities in regions 1 and 2 is equal to $Q_1 - Q_2$ and $Q_2 - Q_3$, respectively.

$W_1$ and $Q_1$ are exogenous[1]. One of the interesting components of the model would be to determine the optimal allocation of water among activities when the total water volume is exogenous. However, our primary interest is in the inter-regional water allocation. Therefore, the allocation of water within region j is assumed to be exogenous and given by the following function[2]:

$$W_{ij} = W_{ij}(W_j)$$

where $\acute{O}_i W_{i1} = W_1$

Water consumption by the ith activity in region 1 is $W_{i1} - w_{i1} = g(W_{i1}, Y_{i1})$, where $w_{i1}$ is the part of the amount of water diverted to activity i but not consumed by it. Consequently, $W_1$, the flow of water in region 1, and the amount of consumption by economic activities in region 1 determine the flow of water, $W_2$, which is available to region 2, that is,

$$W_2 = W_2(W_1, Y_1)$$

where $W_2 = \acute{O}_i w_{i1} = \acute{O}_i W_{i2}$.

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1 Making $W_1$ and $Q_1$ endogenous would be equivalent to allocating water to more than two countries, when $W_1$ and $Q_1$ would be at the springs.

2 If the exogeneity assumption is relaxed, our model would run into the danger of producing a second best solution, whereas it will certainly generate a first best solution if the optimal allocation rule is given by equation (4).

Following a similar argument, the flow of water at the point of the river discharge into the sea is given by the function,

$$W_3 = W_3(W_2, Y_2)$$

The amounts of water consumed by regions 1 and 2 are given by ($W_1$-$W_2$) and ($W_2$ - $W_3$) respectively. This implies that there is no quota allocation to region 2.

The water quality that is eventually allocated to activity i in region 2 is specified by the following equation:

$$Q_{i2} = Q_{i2}(Q_2, D_1, D_2)$$

where, $D_1$ is the distance of the activity from the point x, $D_2$ is the distance of point x from the springs of the river, and x is the closest to the economic activity i point of the river.

The activities of region 1 disregard their effects on either the volume or the quality of water available to region 2, and the typical profit maximizing firm faces the following problem:

$$\max P_{ij} Y_{ij} - r_{ij} X_{ij}$$

with respect to $X_{ij}$

subject to (1),

where, $P_{ij}$ is the price of product i in region j, and $r_{ij}$ are the prices of the inputs $X_{ij}$ used by economic activity i in region j, and water treated as a free good.

Each firm will employ inputs until:

$$P_{ij} \frac{\partial Y_{ij}}{\partial X_{ij}} = r_{ij} \qquad (8)$$

The absence of measures aiming to correct the externality will lead to an inefficient water allocation. Economic theory suggests that the optimal allocation of water between regions 1 and 2 can be achieved only if the joint profits are maximized, that is,

$$\max \Sigma_j \Sigma_i (P_{ij} Y_{ij} - r_{ij} X_{ij})$$

with respect to $X_{ij}$,

subject to (1), (2), (4), (5), (6), (7)

The first order conditions for this problem are,

$$P_i1 \frac{\partial Y_i1}{\partial X_i1} + \sum_{k=1}^{n} [ P_k2 \frac{\partial Y_k2}{\partial W_k2} \frac{\partial W_k2}{\partial W_2} \frac{\partial W_2}{\partial Y_i1} \frac{\partial Y_i1}{\partial X_i1} + P_k2 \frac{\partial Y_k2}{\partial Q_k2} \frac{\partial Q_k2}{\partial Q_2} \frac{\partial Q_2}{\partial Y_i1} \frac{\partial Y_i1}{\partial X_i1} ] = r_i1 \qquad (9)$$

with respect to the production inputs used in region 1, and

$$P_i2 \frac{\partial Y_i2}{\partial X_i2} = r_i2 \qquad (10)$$

with respect to the production inputs used in region 2.

The solution to the above problem yields an optimum allocation ($Y_{ij}$, $X_{ij}$, $W_{ij}$, $Q_{ij}$, $W_j$, $Q_j$) for all economic activities in both regions which is obtained as follows.

The solutions for $X_{ij}$, are derived from equations (10) and (11) after substituting in them: (2) for $Q_2$, (4) for $W_{ij}$, (5) and (6) for $W_j$, (1) for $Y_{ij}$, and (7) for $Q_{ij}$.

Given the solutions for $X_{ij}$, we subsequently obtain:

a) The allocation of $Q_{ij}$ from (7),
b) The allocation of $W_{ij}$, $W_j$ from (4), (5), and (6), and
c) The allocation of $Y_{ij}$ from (1).

The first order conditions presented in equation (8), and equations (9) and (10) are different, because externalities are present, and, therefore, price taking profit-maximization behavior will not necessarily lead to an efficient allocation of resources.

**An optimum tax policy for efficient water quantity and quality allocation**

Several policies including input controls, output controls, social prices, taxes and subsidies, bilateral water trade, a water market for all water users, and a fixed allocation rule may offer a pareto optimum allocation of water if externalities are present.

An optimal wat`er quantity and quality allocation is possible if an optimum tax is imposed in the market of region 1. The optimum tax of the ith activity in country 1 is given by:

$$\sum_{k=1}^{n}\left( P_k2\,\frac{\partial Y_k2}{\partial W_k2}\,\frac{\partial W_k2}{\partial W_2}\,\frac{\partial W_2}{\partial Y_i1} + P_k2\,\frac{\partial Y_k2}{\partial Q_k2}\,\frac{\partial Q_k2}{\partial Q_2}\,\frac{\partial Q_2}{\partial Y_i1}\right) \qquad (11)$$

When this policy is deployed, the typical profit maximizing firm in region 1 employs the $X_{ij}$ combinations that satisfy (8). Substituting (11) into (8) shows that the conditions for optimality in (9) and (10) are satisfied.

The water of Nestos river is of low quality so that it is suitable only for irrigation. Based on the theoretical premises of the model, it is possible to estimate the optimum tax that can support an efficient allocation.

The allocation supported by the above tax policy is characterized as environmentally optimal because all relevant environmental aspects can be incorporated in water quality which is explicitly introduced in the model and the analysis.

**Estimating the optimum tax.**

The Nestos river originates from the Rila mountain of Bulgaria and flows into the Mediterranean through Thrace of Greece. The waters of Nestos are of low quality and suitable mostly for irrigation. Based on the theoretical premises of the model, it is possible to support an optimum water allocation if we can apply the policy specified above.

To evaluate the social price given in (11), we concentrate on the corn and vegetable production in a sample of 122 communities in Northern Greece. Corn and vegetables are irrigated crops and the majority of the communities in the area of Nestos river grow corn and vegetables in their irrigated land. To estimate (11), we assume that the corn and vegetable production is of the following functional form:

$Y_{pi2} = \min \{á_{pi2}\, LAND_{pi2},\, â_{pi2}\, R_{pi2}(K_{pi2}, L_{pi2}; X_{i2}, Q_{i2})\}$

where, p = c, v (c indicating corn and v vegetables), i is an economic activity in region 2 (Greece),

$Y_{pi2}$ = production of p (corn or vegetables) in community i of Greece,

$LAND_{pi2}$ = land devoted to the production of p in the i community of Greece,

$K_{pi2}$ = capital employed in the production of p in the i community of Greece; it contains the total number of agricultural machines in each rural community related to p crops,
$L_{pi2}$ = the agricultural population in community i of Greece.
$X_{i2}$ = the amount of water available to community i of Greece irrigation purposes,
$Q_{i2}$ = the quality of the water that is available to community i of Greece for irrigation purposes in the area of Nestos of Northern Greece,
$R_{pi2}(K_{pi2}, L_{pi2}; X_{i2}, Q_{i2})$ is a composite input which is a function of $K_{pi2}$, $L_{pi2}$, $X_{i2}$, and $Q_{i2}$, and
$á_{pi2}$, and $â_{pi2}$ are two parameters that are specific to each community.

To be more specific, within the assumed structure the demand for land is given by the following equation:

$$LAND_{pi2} = â_{pi2}\, R_{pi2}(K_{pi2}, L_{pi2}; X_{i2}, Q_{12})/a_{i2}$$

It is assumed that $â_{pi2}/á_{pi2}$ is a constant across all communities (not necessarily the same for the two crops) and that $R_{pi2}(K_{pi2}, L_{pi2}; X_{i2}, Q_{i2})$ is of the following functional form:

$$R_{pi2}(K_{pi2}, L_{pi2}; X_{i2}, Q_{i2}) = B\, K_{pi2}^{b}\, L_{pi2}^{c}\, X_{i2}^{d}\, Q_{i2}^{h}$$

where B, b, c, d, and h are parameters.

Assuming that $Q_{i2} = C\, Q_2^{g/h}\, D_1^{e/h}\, D_2^{f/h}$, the latter implies that the demand for land is of the following functional form:

$$LAND_{pi2} = A\, K_{pi2}^{b}\, L_{pi2}^{c}\, X_{i2}^{d}\, D_1^{e}\, D_2^{f}$$

where $A = B\, C\, â_{i2}\, Q_2^{g} / á_{i2}$, and C, e, f, and g are parameters.

The demand for land devoted to corn and vegetable production, equation (12), is estimated using OLS on cross-section data. For the estimation of the demand for land devoted to corn production a sample of 122 communities in the area is used, while for the estimation of the demand for land devoted to vegetable production a sample of 88 communities is used. The results are given in Tables 1 and 2.

To see if the model makes a significant contribution to explaining the data, the hypothesis that all the coefficients of the demand for land devoted to corn production equation equals zero is tested and rejected at the 1% significance level. A similar test rejects the hypothesis that all the coefficients of demand for land devoted to vegetable production equation equal zero.

The water quality is a latent variable. Without loss of generality we impose the normalisation $Q_2 = 100$ and g = h = 1. This and the estimation results let me obtain that the demand for land devoted to corn and vegetable production are respectively given by the following two equations:

$$LAND_{ci2} = 31.02\ K^{0.18}\ L^{0.004}\ W^{0.89}\ Q\ D_1^{-0.12}\ D_2^{-0.49}$$

$$LAND_{vi2} = 31.02\ K^{0.26}\ L^{0.90}\ W^{0.36}\ Q\ D_1^{-0.10}\ D_2^{-0.96}$$

As seen in Tables 1 and 2, water quantity and labor are the most important factor affecting corn and vegetables production respectively, something that should be anticipated given the nature of the two crops. Moreover, the output and the demand for land are affected by the distance of the activity from the river and the springs of the river. For the case of corn the distance from the river is more significant while for the case of vegetables the distance from the springs.

TABLE 1

Factors affecting the demand for land devoted to corn production

| VARIABLE | COEFFICIENT | STD ERROR | T-STAT |
|---|---|---|---|
| CONSTANT | 3101.8285 | 12493.606 | 0.2482733 |
| K | 0.0181795 | 0.1187890 | 0.1530402 |
| L | 0.0043885 | 0.0965092 | 0.0454726 |
| W | 0.8931758 | 0.1230391 | 7.2592845 |
| $D_1$ | -0.1241152 | 0.0522965 | -2.3732962 |
| $D_2$ | -0.4943910 | 0.3146383 | -1.5712994 |

$R^2 = 66.8$

N = 122

TABLE 2

Factors affecting the demand for land devoted to vegetable production

| VARIABLE | COEFFICIENT | STD ERROR | T-STAT |
|---|---|---|---|
| CONSTANT | 3102.3975 | 21620.609 | 0.1434926 |
| K | 0.2613068 | 0.0689332 | 3.7907247 |
| L | 0.9030617 | 0.1401138 | 6.4452034 |
| W | 0.3651673 | 0.1154803 | 3.1621597 |
| $D_1$ | -0.1032739 | 0.1275100 | -0.8099283 |
| $D_2$ | -0.9641628 | 0.4872928 | -1.9786106 |

$R^2 = 70.6$

$N = 88$

Our structure and the estimation results imply that the quality of the water that is eventually allocated to each activity is affected by its distance from the river and the springs of the river in the following way:

$$Q_{ci2} = Q_2\, D_1^{-0.12}\, D_2^{-0.49}, \text{ and}$$

$$Q_{vi2} = Q_2\, D_1^{-0.10}\, D_2^{-0.96}$$

The estimation results imply that we cannot reject the hypotheses that the effect of the distance from the river and the springs on the water quality that is eventually delivered to each activity is different for the two kinds of crops[3]. That is we cannot reject any of the null hypothesis that follow: $H_0$: $e_c = -0.10$, $H_0$: $f_c = -0.96$, $H_0$: $e_v = -0.12$, $H_0$: $f_v = -0.49$.

Since corn and vegetable yields per stremma are constant for each community, we can obtain corn and vegetables production figures by the product of land devoted to each production times the constant yield factor. This implies that the marginal value of water quantity, MVW, and quality, MVQ, of activity i in region 2 are respectively given by the following equations:

$$MVW_{ci2} = 27.77\, P_c\, y_c\, K^{0.18}\, L^{0.004}\, W^{-0.11}\, Q\, D_1^{-0.12}\, D_2^{-0.49}$$
$$MVW_{vi2} = 11.17\, P_v\, y_v\, K^{0.26}\, L^{0.90}\, W^{-0.64}\, Q\, D_1^{-0.10}\, D_2^{-0.96}$$
$$MVQ_{ci2} = 31.02\, K^{0.18}\, L^{0.004}\, W^{0.89}\, D_1^{-0.12}\, D_2^{-0.49}$$
$$MVQ_{vi2} = 31.02\, K^{0.26}\, L^{0.90}\, W^{0.36}\, D_1^{-0.10}\, D_2^{-0.96}$$

where, P is the product price, and y the yield.

Finally, it is assumed that: $W_{i2} = W_2/n$, $Q_{i2} = Q_2/(D_1\, D_2)$, $W_2 = W_1/Y_1$, and $Q_2 = Q_1/Y_1$. These assumptions, the above marginal product value equations, equations (13) and (14), a \$ 120 per ton price of corn, a \$ 200 price of vegetables, a 1,200 Kgr/stremma yield of corn, a 2,000 Kgr/stremma yield of vegetables, and equation (11) imply that the social price of the product produced on the Bulgarian side of the Greek-Bulgarian borders around Nestos river will be 0.00027 USD less than its market price, that is,

$$\sum_{k=1}^{n}\left( P_k2\, \frac{\partial Y_k2}{\partial W_k2}\, \frac{\partial W_k2}{\partial W_2}\, \frac{\partial W_2}{\partial Y_i1} + P_k2\, \frac{\partial Y_k2}{\partial Q_k2}\, \frac{\partial Q_k2}{\partial Q_2}\, \frac{\partial Q_2}{\partial Y_i1}\right) = -\,0.00027USD$$

[3] A relationship which is determined by the characteristics of the location of each activity, too.

The latter implies that the optimum tax that should be imposed in region 1 must be equal to 0.00027 USD per unit of product. If the two sides agree upon such a tax scheme an optimum water quantity and quality allocation will be supported.

## Conclusions.

A theoretical model is developed to investigate the possibilities of incorporating aspects of water quality in the analysis and specify simultaneously an optimal allocation through a regulatory mechanism that imposes a tax on the product produced in region 1. The analysis shows the procedure needed to obtain computationally this policy. Finally, the available data suitably processed through a standard econometric model provide some first estimates of the tax that will be able to support an optimal allocation in equilibrium.

## References


- B.M. Abbas, "River basin development: Keynote address", in Proceedings of the National Symposium on River Basin Development, Munir Zaman, ed., Tycooly International, Dublin (1983).

- Behar, N. (1992), "Fresh water resources from inland Balkans: International conflicts and regional cooperation", Working Paper, Institute for Social and Political Studies, Bulrgaria.

- Asit K. Biswas, "Some major issues in river basin management for developing countries", in Proceedings of the National Symposium on River Basin Development, Munir Zaman, ed., Tycooly International, Dublin (1983).

- Efthimogloy (1988), "The Thissavros Hydroelectric Project," Public Power Corporation, Athens.

- KEPE (1989, I), Water Resources, Athens.

- KEPE (1989, II), "A Special Program for the Region of East Macedonia and Thrace," Komotini.

- Naftemporiki (1991), issue of 4/16/1991; a major greek economic analysis daily newspaper.

- Express (1991,I), issue of 3/20/91; a major greek economic analysis daily newspaper.

- Express (1991,II), issue of 4/17/91; a major greek economic analysis daily newspaper.

- Express (1995), issue of 11/24/95; a major greek economic analysis daily newspaper.

- D. Giannias and J. Lekakis, "Fresh surface water resource allocation between Bulgaria and Greece", Environmental and Resource Economics (1996).

- Jerome Delli Priscoli, "Epilogue", Water International, Vol. 15, No. 4, International Water Resources Association, Urbana, Illinois (1990).

- Joyce R. Starr, "Water Wars", Foreign Policy, No. 82 (Spring 1991).