Water Resource as a Factor of Production: Water Use and Economic Growth

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Abstract

Water is one of the most important natural resources that is necessary for the rise and development of any biological and human activity. The paper sets out a logical scheme for the analysis of productive uses of water, with the purpose of understanding both the functioning of an economy in the presence of a technical constraint to the exploitation of water resources, and the possible policy instruments available to the public authority. A complementarity hypothesis between the two forms of capital considered (physical and water capital) arises, with the first coming from private investment and the second being defined as the amount of public investment in services and infrastructures for water resource exploitation. As public investment in water capital crowds out private saving eventually available for private physical capital accumulation, an allocation criterion is needed to maximize total production of the system, never falling behind the optimal physical capital-water capital ratio. Developing the model, equilibrium conditions in a "water economy" are described and a parametrical device is set in order to identify optimal taxation policies to finance public water infrastructures investment.

key-words: water, economic growth, Solow-model.

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1 Introduction

Results of researches and assessments have shown that water resources worldwide are experiencing large-scale changes in water withdrawals and availability [7]. Using current terminology these can be termed as "global changes" due to their universal measure and to their link with global processes. Both the geopolitical and economic implications of increasing water scarcity call for a great engagement in analyzing and examining the theoretical, institutional and empirical aspects related to the different dimensions of a possible "water crisis".

The nature of problems involving water is typically one of conflict among alternatives stemming from both economic and physical shortages; the conflicts may be of various types, examples of which include competition among different uses, competition between geographic locations of use or between current and futures uses. The global water crisis is a highly complex problem; it is characterized by its multidimensionality encompassing a wide variety of problems such as water shortage, water pollution, public health and food security, all of which have social, ecological, cultural and economic dimensions [12]. According to various scenarios, water scarcity is expected to grow dramatically in some regions as competition for water increases between agricultural, urban and industrial sectors [1]. From an economic point of view the contribution that economic theory can make to the current hydrological debate over the future 'water crisis' must be to examine the terms of 'economic' water scarcity as a consequence of structural and physical water shortages, to analyze the implied economic and social costs and to envisage possible political and institutional solutions to the problem identified. We will first set out the problem that has to be analyzed, concentrating on the kind of water provision that is directly related to productive uses. Starting from the existence of a complementarity mechanism that characterizes the use of physical capital and water productive resource, we will examine the condition of water scarcity and the implied water constraint to the economic system.

Our starting point is that the increasing degree of competitiveness between economic sectors for the use of a scarce resource like water, brings with it the need to analyze and identify a set of conditions which leads to an efficient use of the resource; the conditions identified are restricted to productive uses of water, including industrial and agricultural water withdrawals, in a way that gives to productive water utilization the meaning of that amount of resource flow that is needed to make the stock of physical capital productive.

The main idea is that there is a predetermined optimal ratio between physical capital and water resource, acting like a technological parameter, that is fixed for a given technology and which represents a constraint to be satisfied for a system to act in an efficient way and to not incur in economic and social costs. The above costs are associated with conditions of either under-use of the amount of water that would be necessary, or over-use of it. In both cases the generation of costs is linked to the economic and social consequences of under-provision of water, which could lead to either unproductive economic processes or to low quality products, or to the implications related to an over-provision of the resource which may compromise future uses of water or its availability for alternative uses.
The identification of those conditions which guarantee an efficient allocation of water to productive uses is then a way to ensure a sustainable and "optimal" use of the resource.

After having formulated the logical and technical assumptions, we set up the model starting from the neoclassical growth theory assumptions and including the resource flow among the factors of production. Following Barbier [3], we assume that the flow of water used in productive sectors is directly related to the stock of public investment in water infrastructure; this assumption implies a trade-off between private investment in physical capital and public investment in "water capital", originating form a mechanism that, through fiscal policy, imposes a limit on the possibility of increasing private physical capital without increasing the water productive flow.
Public authority is finally responsible for the maintenance of the stability of the system, being able to influence, through fiscal policy, the behaviour of economic agents, regulating the system provision of water relative to physical capital.

An empirical exercise is curried out which is not directly related to the theoretical model specified above, but which represents a way to describe empirically the relationship between water use and a measure of a system economic performance. The analysis is run on a longitudinal data set along a temporal horizon of five decades (1960-2000) and a cross-section dimension of 38 observations comprising both developed and less developed countries.

2 Water Use and Economic Growth: A neo-classical revisited approach

The analysis of the relationship between the growth performance of an economic system and its natural resources availability has been tackled both from the point of view of economic growth literature [11], [2] and from a resource economics perspective [14], [8]. For what concerns the relationship between water resource use and the qualitative characteristics of a system growth path, Barbier [3] develops a growth model in which water supply is treated as a government-provided non-excludable good subject to congestion. Following the approach of Barro [4] and [5], and partially taking the distance from them, the Barbier growth model is based on a set of assumptions that relate private production to the collective use of water, through a mechanism of costs generation caused by a congestion effect that reduces the amount of water available to each producer. The author presumes the existence of diminishing marginal product of water resources originating from both their structural scarcity features, and so the congestion effect, and from the nature of the assumed government intervention in water provision. Public authority is finally responsible for the provision of water through appropriating and purchasing a greater share of aggregate economic output in terms of dams, pumping stations, supply infrastructure, etc. as water becomes increasingly scarce [3]. The contribution of water use to private production is therefore modeled as:

$$y_i = Ak_i f\left(\frac{r}{y}\right) \tag{1}$$

where the standard sign conditions are satisfied: $f' > 0, f'' < 0$. Then part of private production depends on constant returns to the per capita capital stock, k_i, on the level of technology, A, and to some degree, on a composite variable which captures the intensity of water use in the whole economy,$\frac{r}{y}$. The variable r measures per capita fresh water utilization by a country and y is generally defined as Ny_i, implicitly assuming a same level of production along each producer. [1]

Government intervention in the provision of water is captured by this identity $r = zy$, which assumes that the public authority assigns an amount z of total production, to water provision measures; it is also assumed that z is an increasing function of the rate of water utilization (r) relative to per capita freshwater availability (w), denoted by $\rho = \frac{r}{w}$,where the water constraint is represented as $r \leq w$.

Model formulation follows the classical analytical steps with the derivation of standard solution to the welfare maximization problem and the description of the system dynamics in the presence of a water constraint as defined above. The conclusions of the model suggest the existence of a socially efficient rate of water use that is able to maximize growth, and the identification of a concave type relationship between growth and the rate of water use.

A necessary condition for a theoretical model to be representative of real world is its capacity to interpret and explain the functioning of real systems; the aggregate growth model as the one presented above, can be a useful instrument to understand functional relationships between variables, but it does not deeply analyze water use features in relation to the nature of inter-sectors conflicts. A better representation of the effects of a water constraint on the economic performance of a system has to take into account the increasing competition in water use levels between the resource multiple and alternative uses.

Given these considerations, in this study we make several basic assumptions about both the kind of water uses we want to model and the nature of a water constraint; this latter is defined after having introduced a complementarity mechanism which regulates the use of private physical capital in

[1]It would be more precise to better define total aggregate output in a way that allows for the assumption of diverse production levels, such as their summation along each producer.

relation to public water flow in a productive context. The analysis is concentrated on the definition of "productive water use" as including the amount of water flow that is necessary to make the stock of physical capital productive. This assumption is clearly valid if one thinks about the effects of a condition of water scarcity or water abundance on agricultural output: if one of these critique conditions occurs, the productive capacity of physical capital used in the agricultural production process, may be seriously hampered. We also assume that a necessary condition for water resource flows to be used, distributed and stored is the presence of an efficient system of water infrastructure that may counteract negative effects caused by conditions of water scarcity or water abundance.

The general and technological features of the analyzed economic system are described by a generic constant returns to scale production function $Y = Af(K, W)$, where K and W measure respectively the amount of physical capital and fresh water used in the production process. Water resources is then valued as a private good, even if it is publicly provided, being rival in consumption and excludable in its access due to the presence of increasing costs of access. The nature of increasing costs is linked to the existence of an efficient way in which physical capital and water flow can be combined together; if this "optimal" ratio cannot be maintained, either because of an excessive water use compared to physical capital or because of its insufficient provision, substantial costs may be generated in terms of reduced water availability for alternative uses (domestic and civil uses) or in terms of reduced guarantee of products quality. The model analyzed is a Solow-type growth model in which standard assumptions implied by Inada conditions apply and in which the functioning of the system is represented by a Cobb-Douglas production function of this form:

$$y = Ak^{\alpha}w^{1-\alpha} \tag{2}$$

where α is a constant parameter that takes value between 0 and 1, A is the standard technological parameter, and the following conditions are satisfied:

$$\partial y/\partial k > 0 \qquad \partial^2 y/\partial k^2 < 0 \qquad \lim_{k\to 0}(Y_k) = \lim_{w\to 0}(Y_w) = \infty$$

$$\partial y/\partial w > 0 \qquad \partial^2 y/\partial w^2 < 0 \qquad \lim_{k\to\infty}(Y_k) = \lim_{w\to\infty}(Y_w) = 0 \tag{3}$$

Dividing (3) by W, we obtain a "water intensive" production function:

$$\frac{Y}{W} = A\left(\frac{K}{W}\right)^{\alpha} \tag{4}$$

where the dependent variable measures the inverse of product water intensity, similar to a water average product, while the right hand side of the equation measures the inverse of capital water intensity as being a technological parameter that is fixed along a given technology. We tried to model the dynamics of the productive water stock as being proportional to the growth rate of "water capital" that is necessary to have access to public available water stock; the water growth rate is then expressed as a function of both an infrastructural investment component and a stochastic component which captures all those elements that affect water availability in a non-deterministic way. The productive water resource stock then changes following this expression[2]

$$\left(\frac{\dot{w}}{w}\right) = \left(\frac{\dot{k_w}}{k_w}\right) + \Omega \tag{5}$$

where the left hand side shows productive water growth rate as being determined by respectively the effect of water capital investment and the effect of the stochastic component Ω (climate change, technological shocks).
We now define investment functions describing the patterns of water capital and physical capital accumulation; the former can be expressed as:

$$\dot{K_w} = f(Y) = \tau Y - \gamma K_w \tag{6}$$

Water capital changes proportionally to a coefficient τ which measures the amount of national income that is explicitly assigned to water infrastructures

[2]The dot on variables stands for a time derivative; where the term is a ratio of two variables, the time derivative of the ratio is indicated through the use of parenthesis.

through a system of fiscal policy applied to income capital. A tax is then levied on income capital along each producer in order to redirect private investment towards the efficient combination of physical and water capital. We then introduce a standard depreciation component,γK_w. The stock of physical capital is determined by the standard investment function:

$$\dot{K_w} = (s - \tau) Y - \delta K_t \tag{7}$$

Dividing both sides of (7) by W, the stock of productive water, we obtain this expression:

$$\frac{\dot{K_t}}{W} = (s - \tau) \frac{Y}{W} - \delta \frac{K_t}{W} = (s - \tau) f(k_t) - \delta k_t \tag{8}$$

We can rearrange (8) as a function of $\frac{K_t}{W}$ using the following condition:

$$\left(\frac{\dot{K_t}}{W}\right) = \frac{dK/W}{dt} = \frac{\dot{K}}{W} - \frac{\dot{W}}{W} \cdot \frac{K}{W} \tag{9}$$

which can be expressed as:

$$\frac{\dot{K}}{W} = \left(\frac{\dot{K}}{W}\right) + \frac{\dot{W}}{W} \cdot \frac{K}{W} \tag{10}$$

Substituting the expression for $\frac{\dot{K}}{W}$ given in (10), into (8) and changing variables notation so that $\chi = \frac{K}{W}$, we obtain an expression for $\left(\frac{\dot{K}}{W}\right)$:

$$\dot{\chi} = (s - \tau) f(\chi) - \left(\frac{\dot{W}}{W} + \delta\right) \chi \tag{11}$$

Equation (11) is then the "water intensive" version of the fundamental differential equation of the Solow-Swan growth model, in which the term $\frac{K}{W}$ captures the nature of a water constraint as defined above in the text, so that the second term on the right hand side of the equation measures the functioning of this constraint: if $\tau = 0$ capital-water ratio changes as a function of both the propensity to save and the physical capital depreciation rate; as the control variable τ increases the capital-water ratio evolves following the effect of this change on the water flow available to production, $\frac{\dot{W}}{W}$.

If we define a condition of steady-state as the system efficiency condition, in which the capital-water ratio stays constant due to the fact that the two variables are changing in a proportional way, then equation (11) must equal zero, that is:

$$(s-\tau)\, f(\chi) = \left(\frac{\dot{W}}{W} + \delta\right) \chi \tag{12}$$

If this condition is satisfied the amount devoted to the accumulation of physical capital equals the amount of $\frac{K}{W}$ that must be provided in order to maintain efficiency. Given that χ is constant at the steady-state, also y and c are both constant at the levels $y* = f(\chi*)$ and $c* = (1-s)f(\chi*)$ respectively.

Therefore in conformity with traditional neoclassical models, the intensive variables χ, y and c do not grow, so that the same variables measured in aggregate terms will grow, once they reach a condition of steady-state, at the rate $\frac{\dot{W}}{W}$, representing the rate at which technical efficiency, as defined above, can be obtained.[3]

The figure below describes graphically equation (11):

As shown in the diagram, the $f(\chi)$ curve represents the system production function as described in the text; each point along the curve illustrates the quantity of output per unit of water, $\frac{Y}{W}$, associated with any given level of capital per unit of productive water. A fraction s of any level of intensive output is saved and the curve $(s-\tau)f(\chi)$ plots the level of net savings associated with any level of capital-water ratio. The line $(\frac{\dot{W}}{W}+\delta)\chi$ is drawn with its slope reflecting the rate of growth of productive water flow and physical capital depreciation rate. The equilibrium condition as defined above in the text, is then indicated by the amount $\frac{K}{W}^*$, corresponding to which the two terms on the right hand of (11) are equal. The economy is therefore in equilibrium if it reaches the efficiency capital-water ratio; it will not automatically converge toward this equilibrium level unless public authority, through the use of fiscal policy, does regulate the use of the two production factors.

How the economy behaves before reaching the equilibrium condition? Divid-

[3]From the expression for intensive variables, $\chi = \frac{K}{W}$, we have an expression for the aggregate variable, i.e. $K = W\chi$, so that the rate of growth of K is given by the sum of the rate of growth of χ,that equals zero at the steady-state, and the rate of growth of W

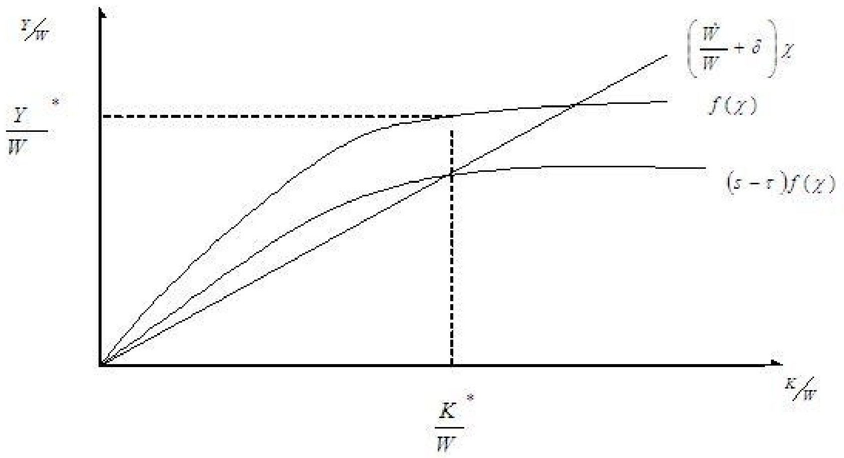

Figure 1: Water constrained Solow diagram

ing both terms of (11) by χ we obtain an expression for the growth rate of capital-water ratio:

$$\frac{\dot{\chi}}{\chi} = (s - \tau)f(\chi)/\chi - \left(\frac{\dot{W}}{W} + \delta\right) \tag{13}$$

Equation (13) shows the capital-water ratio growth rate is given by the difference between the right hand side terms of the equation. The first term can be represented by a negative slope curve, which tends to infinity as χ tends to zero, that is, as water is overused with respect to capital; the second term is represented as a horizontal line for simplicity. As shown in the diagram below, the equilibrium condition is a function of the "water constraint":

Given the existence of an exogenous efficient level of capital-water ratio, the system is in equilibrium whenever the two curves intersect each other at the technical efficient capital-water ratio (the level $\chi*$ in the diagram).
If we think about a departure from this equilibrium condition, that can originate from inefficient patterns of water use with respect to capital use, as illustrated in the diagram at the intersection of the curves labeled with 1,

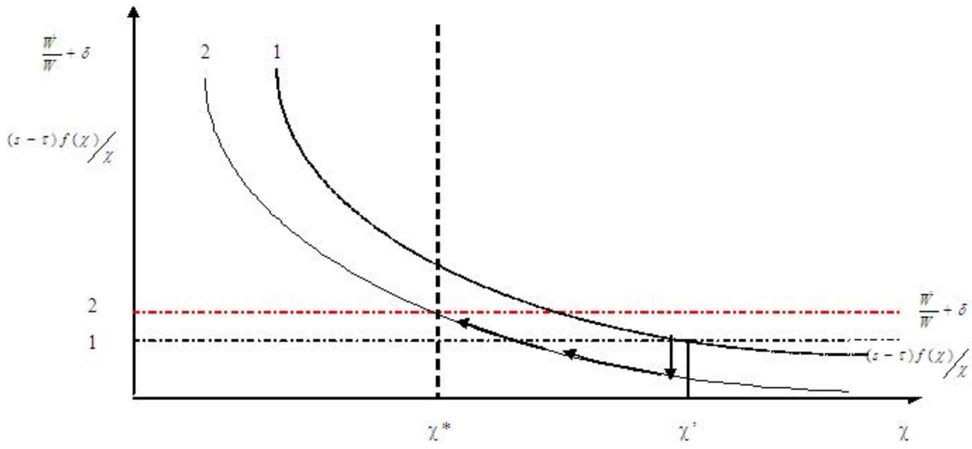

Figure 2: The dynamics of a water constrained system

then the public authority has to increase or decrease the tax rate in order to make the system reaching the efficiency condition.
The final effect of changing the tax rate will be the result of an adjustment process that acts on the system variables, mainly s and $\frac{\dot{W}}{W}$, reestablishing the equilibrium condition.

What can be said about the optimal level of the tax rate? First of all we have to define optimality and then we can look for a parametric solution that satisfies this condition.
The optimal tax rate is that level which enables the system to reach the equilibrium condition as defined above; therefore it can be expressed as the solution to equation (13) when we solve it for τ; this result will be the same as the one that can be obtained after the imposition of the efficiency condition as defined below:

$$\frac{dK/dt}{dW/dt} = 1 \tag{14}$$

Equation (14) describes the equilibrium condition in which the two quantities change proportionally, as implied by the technical efficiency condition defined above in the text. If we substitute in equation (14) for the expressions of dK/dt and dW/dt that we derived above, we obtain the following identity:

$$\frac{(s-\tau)Y-\delta K}{\tau Y-\gamma K_w}=1 \tag{15}$$

Solving (15) for τ we obtain an expression for the optimal tax rate level, as given by:

$$\tau=\frac{s}{2}+\frac{\gamma K_w-\delta K}{2Y}=\frac{1}{2}\left(s+\frac{\gamma K_w-\delta K}{Y}\right) \tag{16}$$

According to equation (16), for given depreciation rates of the two forms of capital considered, there will be a unique tax rate which can guarantee the efficient functioning of economic system along the optimal growth path; it will be function of the saving rate, in a way that if the propensity to save increases it means that investment in physical capital is increasing, which, for a given water supply, has to be followed by a proportional increase in water sector public investment. The optimal level of τ will also be a function of the term $\frac{\gamma K_w-\delta K}{Y}$.

Given these considerations an efficient criterion in productive water use is envisioned, which is analyzed in relation to the use of physical capital and to its accumulation; reasoning in terms of the best allocation of water to its competitive uses, the model described above enables us to identify a way to treat water as a productive resource and to allow for the implicit consideration of its alternative uses; if productive water instead of being wasted is used efficiently, then the demand for domestic and civil water, or water demand for ecological services, can be satisfied.

3 Some empirical evidence on water use and economic growth

In this section we want to test the existence of some empirical evidence in favour of a direct role of water use in aggregate income production. The empirical model cannot represent a test of the above theoretical model, as the latter implied the use of water data not easily available at a regional or local scale.

The following empirical analysis must then be considered an empirical exercise to analyze the relationship between water use and aggregate economic output at a regional scale. Drawing from the literature on growth empirics [16], we make use of longitudinal data and though panel data techniques, to construct the model. The advantages of panel data analysis compared to cross-country or time-series analysis, have been clearly explained in the econometric literature (see for example [9, 17]), and are mainly related to estimate results in terms of their improved efficiency; moreover panel data analysis can be used, under certain assumptions, to obtain consistent estimators in the presence of omitted variables [17]. Depending on the research question, the use of panel data analysis is a tool to capture the effect on the dependent variable of *"unobserved effects"*; when t represents different time periods for the same individual, the unobserved effect is often interpreted as capturing, depending on the nature of the unit of observation, features of the observed unit which can be of particular interest if the object of the analysis is to account for those characteristics that are fixed and specific to that unit. If the unit of observation is a country, as in the following analysis, these "fixed effects" contain all those features that are fixed and specific to a country, such as climatic and morphological conditions or geographic conditions in general.

3.1 *Model Description and Data*

Taking the above considerations into account, the following basic empirical specification can be used to test the hypothesis that there is a statistical significant relationship between patterns of water use and income production. We start from the hypothesis that economic system can be described by a Cobb-Douglas production technology as follows:

$$Y = AK^{\alpha}L^{\beta}W^{\gamma}, \qquad 0 < \alpha < 1, \quad 0 < \beta < 1, \quad 0 < \gamma < 1 \tag{17}$$

where Y measures real GDP, K is physical capital stock, L is a measure of labour force and W shows withdrawn water resource; A is a technological scale parameter.

After dividing (17) by L and with some simple algebric manipulation, we obtain the labour intensive version:

$$\frac{Y}{L} = A\left(\frac{K}{L}\right)^{\alpha} L^{\alpha+\gamma+\beta-1}\left(\frac{W}{L}\right)^{\gamma} \tag{18}$$

or equivalently:

$$y = Ak^{\alpha}w^{\gamma}L^{\alpha+\gamma+\beta-1} \tag{19}$$

After a linear transformation of equation (19) we have:

$$\ln y = \ln A + \alpha \ln k + \gamma \ln w + (\alpha + \gamma + \beta - 1) \ln L \tag{20}$$

The way the data set has been constructed reflects the poor availability of complete water variable time-series, so that the analysis is run using five temporal observations comprising the beginning of each decade from 1960 to 2000 for 38 countries; the total number of observations is then 190. GDP data are from Summers and Heston time-series (2002),[4] while data on labour force are from World Development Indicators (2002).[5]

The capital stock time-series has been constructed using [10] estimates from 1960 to 1988 and then integrated with data generated through the "perpetual inventory method" [6] according to the following identity:

$$K_t + 10 = (1 - \delta)K_t + I_t \tag{21}$$

where physical capital stock at time t+1 is a function of capital stock at time t net of a depreciation rate and gross investment at time t.[6] Data on water withdrawals are from [13].

The estimated model is as following, where λ_t and μ_i capture the time and individual effects respectively:

$$\ln y_{it} = \mu_i + \lambda_t + \alpha \ln k_{it} + \gamma \ln w_{it} + (\alpha + \gamma + \beta - 1) \ln L_{it} + \epsilon_{it} \tag{22}$$

3.2 *Estimation Results*

Tables 1 and 2 summarize the regression results for equation (22).

From a pure statistical point of view the empirical model seems to confirm the existence of a significant relationship between income produced and freshwater withdrawals; single coefficients are highly significant along the three sample specification, the overall significant of the estimate is confirmed

[4]The Penn World Tables, 6.1: Real GDP per worker, 1996 constant international prices.
[5]World Development Indicators, CD-Rom, The World Bank.
[6]Following King and Levine (1994)we assume a constant depreciation rate of 0.07.

Table 1

Panel-Data Regression of Water Use and GDP

Two-way LSDV Estimation with fixed-effects two-way error component: Dependent variable is $\ln(y_{it})$

Sample: N **of obs.**	TOTAL 190	TROPICAL 100	TEMPERATE 90
$\ln(k)$	0.62* (0.02)	0.06*** (0.03)	0.12* (0.02)
$\ln(L)$	-0.4* (0.1)	-0.7** (0.3)	0.42* (0.07)
$\ln(w)$	-0.16* (0.05)	-0.2** (0.09)	0.073° (0.05)
$Adjusted R^2$	0.93	0.86	0.91
F-test	63.20*	26.13*	48.73*
LM test	194.44*	72.04*	82.01*
Hausman test	103.14*	26.73*	45.56

Note: Figures in parenthesis are White Standard Errors
*Significant at 1%
**Significant at 2%
***Significant at 5%
∘ Not Significant

by the value of the F-test and by both the LM and Hausman test on panel data model specification. For what concerns the interpretation of the labor-force coefficient, it is necessary to look at the original empirical specification in which the coefficient on L is assumed to be equal to $(\alpha + \gamma + \beta - 1)$; from this value it is possible to derive the real estimated value of the L coefficient.[7]

In analyzing the signs of single coefficients we can confirm the logical and economic interpretation of single partial effects on the income dependent variable, except from the sign of the water coefficient; the negative sign observed on this coefficient in the aggregate model, reflects the effect of

[7] The estimated coefficient on L is 0.7 in the first model(total), equal to 0.36 in the second model (tropical) and equal to 1.23 in the third model (temperate).

the negative sign of the coefficient estimated in the tropical countries subset. The reason for this negative sign can be traced back to the functioning of a mechanism that took place in less developed agricultural economies, characterized by intensive water use patterns, in their early stages of development; this mechanism can be think as originating from the "technological transition" experimented by these countries in the period of the "green revolution", which favoured the transition from extensive agricultural techniques to more intensive ones, causing significant water reduction per unit of output produced. Given the above considerations we can think about an inverse relationship between output and water used as a factor of production.

Table 2

Panel-Data Regression of Water Use and GDP

Two-way LSDV Estimation with fixed-effects two-way error component:
Dependent variable is $\ln(y_{it})$

Sample: N **of obs.**	TOTAL 190	AGRICULTURAL 110	INDUSTRIAL 80
$\ln(k)$	0.62* (0.02)	0.05° (0.03)	0.13* (0.02)
$\ln(L)$	-0.4* (0.1)	-0.88* (0.2)	0.32* (0.06)
$\ln(w)$	-0.16* (0.05)	-0.26* (0.08)	0.16** (0.08)
$Adjusted R^2$	0.93	0.85	0.88
F-test	63.20*	23.72*	34.76*
LM test	194.44*	67.04*	84.90*
Hausman test	103.14*	31.95*	18.75

Note: Figures in parenthesis are White Standard Errors
*Significant at 1%
**Significant at 2%
***Significant at 5%
∘ Not Significant

In Table 2 are reported estimation results, using the same estimation techniques, for a different countries classification on the basis of single country economic structure; the reason for the above sample split is linked to the possibility of accounting for a "structural effect" on the performance of output-water use relationship.

The estimated coefficients on the water withdrawal variable for both agricultural and industrial countries are statistically significant; the difference in their magnitude does not seem to be enough to argue in favour of the structural effect as mentioned above and the sign of the water coefficient for agricultural countries reflects the functioning of the "technological" effect as previously explained. Considering the original empirical specification the coefficient on the labour force is equal to 0.33 for the agricultural sub-set and 1.03 for the industrial aggregate.

Overall the above regression model confirms the existence of a significant relationship between a measure of a country economic development and its water use levels; the validity of the panel model specification suggests the hypothesis of a significant effect of those elements that account for fixed countries characteristics which can in general be related to a country climatic and morphological features and which affect each country initial conditions.

4 Conclusion

This paper has sought to shed light on recent concerns expressed over the global "water crisis" by examining the possible linkages between water scarcity and growth through both a theoretical and, though not linked, empirical analysis.The approach taken was to examine the influence of the rate of "productive" water utilization on an economy in a neoclassical growth model that includes a measure of a system water use in relation to physical capital stock. The basic hypothesis was the existence of a complementarity relationship between the two forms of capital, as measured by "water infrastructures" and physical capital.

Through this model specification a condition of water scarcity is derived, which captures the effects, on the overall economy, of an inefficient way in which water and capital can be combined to generate output. The efficient level of the water-capital ratio is specific and fixed to each technology and

is related to that level which does not generate either water waste or water under-provision.
We looked at the potential effects of this kind of water constraint on the performance of an economy, analyzing the potential role of public policy in terms of a fiscal intervention that indirectly affects, through the effects on private investment capacity, water use patterns.

Throughout the paper, a neoclassical solow-type model is revisited in order to take into account the effect of the water constraint as mentioned above; technical conditions are derived and parametrical solution to the system efficient tax-level is provided.

The empirical analysis has not been formulated to test the theoretical model but instead it represents a way to provide an empirical test to the delicate relationship between water use and a measure of a system economic performance. The use of panel data estimation techniques allows for the consideration of the contribution of those effects that can be generally classified as fixed effects and that relate to countries specific features.
The paper has focused mainly on the availability of fresh water supply to provide economic uses of water; the wider ecological services provided by water has been ignored, and there is inevitably a trade-off between maintenance and protection of these services and the increasing allocation of water for use in the economy. As pointed out by [15], any resulting decline in the hydrological functions of ecosystems may in turn reduce future water availability.

Given these consideration this paper attempts to provide possible theoretical and analytical tools to formulate technical and practical rules for water use efficiency which can translate in policy recommendations for an optimal resource allocation between its competitive uses. Efficiency in economic and productive water use patterns, could be a guarantee of its availability for other uses, such as the provision of environmental services or domestic and civil uses.

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