An Exercise on the Optimal Use of Groundwater Resources*

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Abstract

According to the EU water framework directive 2000/60, water tariffs should be based on the *full cost recovery principle,* including scarcity and external effects. To disregard these two aspects is not only conceptually misleading, as we try to show, but also leads to determine a wrong, distorted tariff. Our tentative application to the italian case shows, for example, that water tariffs should be up to three times higher than the actual ones, revealing a significant distortion.

JEL classification: D6, Q3, Q58

1 Introduction

As we all know "water" is a necessity for life, it enters into every consumption function and into many industrial processes (as an input and as a waste disposal device); it is largely used in the agricultural sector for irrigation, it affects health and welfare of society and it is increasingly used for recreational purposes. One would expect water to play an important role at various levels including government policy. This is not the case. The following is instead true: 1. water management

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appears to be of little interest both at a theoretical and at a practical level. It suffices to consider how few papers are published, how restricted is the relevance of the subject either as a teaching topic, as a theme of political discussion or as a simple concern by the general public; 2. no use of economic incentives is in general at work to improve water management; on the contrary distortionary subsidies are very often in place. Water-related policies being our general concern, we focus here on groundwater, leaving surface water aside.

A widespread belief among economists is that with no government intervention the groundwater resource is misallocated[1], while getting the right value of water in its alternative uses, namely agricultural, residential and industrial, is crucial for an efficient policy to be designed. The literature on water demand is extensive, although most of the works deal with residential and agricultural water demand[2], leaving the industrial one as the least investigated; several papers also deal with cost functions estimates with respect to various countries[3].

Two aspects seem to be overlooked by the present literature. At a theoretical level, the optimal use of groundwater is in general addressed without considering external effects; at an empirical level, little has been done with respect to Italy. The very limited availability of empirical studies applied to the italian water sector may have several reasons, the lacking of data being the most important. The aim of our paper is therefore twofold. On one hand, we want to investigate the consequences on the rules for an optimal water use, of considering the existence of externalities and, on the other hand, we want to provide empirical estimates concerning the "true" (or shadow) value of water in our country. Such empirical investigation is, in our view, instrumental to the design and implementation of an efficient water sector regulation by public authorities, according to the idea that the State should regulate the services and not provide them.

[1] See for example [6] and the literature that followed it.

[2] To mention just few, for residential demand: [8] and [12]; for agricultural demand: [11] and [17].

[3] Examples may be: [1] and [5].

The building blocks of our simple model are the following. We assume that groundwater is a stock resource which can be considered nonrenewable, as in [7]; in other words we consider that the current withdrawal of groundwater is in fact a reduction in tomorrow supply[4].We then consider two possible scenarios. The first, which is deemed *myopic behaviour*, coincides with the hypothesis of short run net benefits maximization. The second implies instead the maximization of social welfare by a *benevolent social planner*. We first show the theoretical outcomes, which are different in the two cases, as one might expect, and then we draw some lessons for our country.

2 The State of the Art

Optimal rules for the use of natural resources, whether renewable or exhaustible[5], are well established in the economic literature. Take the harvesting rate equal to the rate of reproduction while maximizing the present value of profits from the resource, is the optimal rule for renewable resources and deplete the resource at a rate such that its price grows at the discount rate, is the optimal rule for an exhaustible one. The last rule, known as the Hotelling rule[6], is the common reference for exhaustible resource studies.

The problem of the possible shortage of nonrenewable resources has received intermittent attention by the economists. The "Coal Question" by Jevons (1865) has been one of the remotest contributions, just preceded by Ricardo's lack of fertile land as a constraint to growth. What would have happened to the rate of growth England reached with the industrial revolution as the coal deposits would have become

[4]If one prefers can consider that groundwater is indeed rechargeable although with a recharge rate that is very small relative to the capacity of the groundwater aquifer. Our extreme hypothesis is equivalent to the assumption of an extraction rate greater than the rate of natural recharge, as it is usually the case in reality.

[5]To be precise only renewable resources can be used while the exhaustible ones are depleted.

[6]See the seminal Hotelling 1931 paper, in [9]

exhausted, was the forward looking concern of Jevons[7]. And Ricardo had already warned that the capitalist economy would have stoppd growing when land, due to less and less fertility, would have been exhausted. During the XX century, sort of unconstrained optimism made the problem of natural resource availability forgettable and only around the 70s both the first oil price shock and the publication of a book, namely The Limits to Growth, marked the comeback of NR into the economic theory of growth. The Hotelling rule, demonstrated in 1931, eventually gained momentum.

But it is only in 1987 and thanks to the publication of Brundtland report, that "sustainable development" became the target and the aim, at least in principle, of the economic policies of OECD countries. Attention was called on the possible overexploitation of both types of NR[8] and the problem of "equity" among generations on the use of NR was raised.

At present, controversies are going on about precise definition, content, ways of measuring and pursuing sustainable development, etc., but despite the multiplicity of voices, the debate can reduce to two positions, one optimistic and the other pessimistic . For the first group, thanks to the market incentives to generate "discovery and substitution", there are no limits to growth. No such a threat exists as far as substitution among capital resources (natural or human-made) is possible and as far as technical progress will continue to develop as it did in the past. On the contrary, for the second group, with no government intervention, mismanagement and scarcity will prevail because externalities are present and NR are in general public and/or common goods. That is to say , market signals are quite often wrong and in several cases even missing.

Actually, as standard economics teaches, a growing demand for a good will generate difficulties when its supply is inelastic and/or there

[7]Not a real concern for a modern economic approach based on an unconstrained confidence in a technological progress capable of meeting human being needs.

[8]Declining fish population in the ocean being a straightforward example of mismanagement.

are no substitutes. The starting point of Hotelling investigation into the efficiency of non renewable NR utilization, is in fact the assumption of a "finite" availability of them. Quantities consumed today are no longer available tomorrow: here is an opportunity cost to be considered[9]. Several studies have been produced with the aim of empirically testing Hotelling rule implications and although for the most part they appear not to be consistent with prices and in situ value[10], the reason seems to rely on the existence of several "mitigating factors" (such as new discoveries and technical progress) that have delayed the imminence of nonrenewable resource exhaustion rather than on flaws in the theory. The question is therefore whether, and for how long, the mitigating factors will continue to produce their positive effects in the future, notwithstanding the growing demand of NR by a growing world population. The basic problem remains because NR, which provide life support services, are in general open access and public goods. " *Market interventions are necessary to prevent inefficient use of these resources.* Because of this, *the attention focused on the environmental impacts of non renewable resource use* will continue to increase with increased emphasis on the details of ecological interactions and management of *global public assets.*"[11].

The case of water is probably the most interesting and complicated in the field of NR studies given its importance and peculiarities. First, it may be a renewable resource, although at an unknown rate, when we deal with surface water, or a non renewable one, when dealing with ground water pumped at a rate greater than its rate of recharge. Second , water is a NR which is fundamental to life and has no substitute . Third , its market "signal", i.e. its selling price, is in general wrong in the sense that market does not, of course, capture either all the externalities produced by the water use or the user cost[12] of present

[9]Call it user cost or royalty or in situ value, see footnote 12.

[10]See [10, p. 2066]. This paper is a very interesting review of the main issues on the subject in recent time.

[11][10, p. 2103]. Italics are ours.

[12]'User cost' has the same meaning of 'royalty'. The point is that when an exhaustible resource is used its stock depletes. The price of the resource for the actual

generation use of water. Fourth, the quality of both ground and surface water may be impaired by contamination from several sources; when such contamination is above certain levels water become unsuitable for the sustaining of plant, animal and human life and therefore the available quantity is reduced. Quality and quantity are intertwined as are ground and surface water supplies.

For all these mentioned reasons, economists face the problem of getting the "value" of water right and therefore of using accepted methods to evaluate quality[13] of water, user cost, external effects, etc. We put ourselves in this stream.

3 The Model

We start from a two periods stylized model of a nonrenewable resource depletion, and suppose that social benefits gained in each period t through the use of the natural resource are represented by the following strictly concave function:

$$B_t(R_t) = aR_t - \frac{b}{2}R_t^2$$

where R_t is the amount of resource extracted and consumed in period t, while a and b are positive constants.

Extraction costs are assumed to be linear in the amount of resource extracted in time t: $EC_t(R_t) = cR_t$, where $c > 0$ is a parameter. This is coherent with empirical analysis, as it will be clarified shortly.

We focus on groundwater as a non renewable resource, underlying the scarcity dimension of the water allocation problem[14]. Our

consumer has therefore to include the compensation for the reduction in its stock (that is, the user cost). The value of this compensation, which is in general not considered, has to be calculated.

[13]For a recent and comprehensive study on the water quality valuation see Bergstrom et al. (2001).

[14]The evidence concerning groundwater scarcity is increasing. As it is underlined by [15], "...in certain parts of the world groundwater supplies are being depleted, to the potential detriment of future users." [p. 158]. According to the UNEP's third Global Environmental Outlook [16], parts of India, China, West Asia, the

model also accounts for externalities related to the water pumping from aquifers. The diversion of groundwater causes the soil to subside; we suppose that an increase in the amount of water extracted in the first period ($t = 0$) causes an increase in subsidence in the second period ($t = 1$). External costs related to subsidence are assumed to be an increasing and convex function of the amount of water diverted in $t = 0$: $EX_1(R_0) = \frac{d}{2}R_0^2$. The constant $d > 0$ determines, therefore, the degree of convexity of the external cost function. The structure of the model presented so far implies that net benefits in the first period ($t = 0$) are:

$$B_0 = aR_0 - \frac{b}{2}R_0^2 - cR_0,$$

while those in the second period ($t = 1$) are:

$$B_1 = aR_1 - \frac{b}{2}R_1^2 - cR_1 - \frac{d}{2}R_0^2$$

4 Scarcity Constraints

Scarcity is the central feature of groundwater on which our analysis is focused; this implies that all our maximization problems are subject to two constraints: first, the amount of water extracted by the current generation cannot exceed T, the total amount of resources available at the beginning of the planning horizon:

$$R_0 \leq T; \tag{1}$$

second, we assume that the planner leaves a certain subsistence level of groundwater resources at the end of the planning horizon, call it $\underline{T}$. This implies a constraint on the total amount of water that can be extracted between time 0 and time 1:

former Soviet Union, the western United States and the Arabian Peninsula are experiencing declining water tables. Italy already experienced episodes of water scarcity: for example, on summer 2002 four southern regions - Basilicata, Puglia, Sicilia e Sardegna - were hit by drinking water shortcomings (see [2]).

$$R_0 + R_1 \leq T - \underline{T}. \tag{2}$$

Normalizing the subsistence level to 0 the constraint becomes:

$$R_0 + R_1 \leq T \tag{3}$$

As clearly specified in the introduction we take a rather extreme view concerning scarcity. First of all, we keep out of the analysis the case where some water (above the subsistence level) is left after period one. As a consequence, constraint (3) is expected to be verified as a strict equality, implying $R_1 = T - R_0$. Further, we assume *ex post* that the total amount of available water is equal to the quantity that is extracted by a myopic planner[15]. This implies $T = R_0^m$ and $R_1^m = 0$ for any possible set of parameters' values, where R_0^m and R_1^m are the quantities of water extracted, respectively, in time 0 and in time 1 in a myopic setting.

5 Myopic Behaviour

A *myopic* setting, where the objective is to maximize social welfare in the short run, is in our view a good representation of real life water allocation institutions. Indeed, in many countries groundwater turns out to be a common property resource, where entry is allowed simply through the payment of a "concession" fee and nothing else in terms of water consumption.

The consequences are investigated assuming that a myopic "planner" aims at maximizing current period (time 0) net benefits:

$$\max_{R_0} B_0 = aR_0 - \frac{b}{2}R_0^2 - cR_0 \tag{4}$$

[15]This instrumental assumption made is a useful (or the easiest) way for us to deal with the comparison problem between the two scenarios. In our simplified world, the water extracted by the myopic planner plays the role of a benchmark for the benevolent planner case. Further research will be carried on to ascertain the robusteness of our results.

The first order condition with respect to R_0 is [16]:

$$\frac{\partial B_0}{\partial R_0} = a - bR_0 - c = 0 \tag{5}$$

This implies[17]:

$$R_0^m = \frac{a-c}{b}.$$

6 Benevolent Social Planner

A benevolent social planner maximizes the present value of net benefits from water consumption (we call δ the discount factor) and has, therefore, to solve the following problem:

$$\max_{R_0, R_1} W = B_0 + \delta B_1 =$$

$$= aR_0 - \frac{b}{2}R_0^2 - cR_0 + \delta\left(aR_1 - \frac{b}{2}R_1^2 - cR_1 - \frac{d}{2}R_0^2\right) \tag{6}$$

Given the assumption that, for any possible set of parameter values, all available water is extracted by a myopic planner, we have $T = \frac{a-c}{b}$, and constraint (3) becomes:

$$R_0 + R_1 \leq \frac{a-c}{b} \tag{7}$$

As we assume that no water above the subsistence level (normalized to 0) is left for generations living after the end of our planning horizon, we can solve (7) as an equality for R_1. Substituting in (6), the objective function of the planner becomes:

$$W = aR_0 - \frac{b}{2}R_0^2 - cR_0 + \delta a\left(\frac{a-c}{b} - R_0\right) +$$

$$-\delta\left(\frac{b}{2}\left(\frac{a-c}{b} - R_0\right)^2 + c\left(\frac{a-c}{b} - R_0\right) + \frac{d}{2}R_0^2\right) \tag{8}$$

[16] We limit ourselves to strictly positive solutions for R_0. It it is easy to show that (4) is strictly concave.

[17] In order for our results to have economic sense, we assume that $a > c$.

Assuming strictly positive values for R_0 we get the following first order conditions[18]:

$$a - bR_0 - c - \delta \left(a - b \left(\frac{a-c}{b} - R_0 \right) - c + dR_0 \right) = 0$$

implying that R_0^S,the amount of water extracted in $t = 0$ by the benevolent social planner in our setting, is:

$$R_0^S = \frac{a-c}{b + \delta b + \delta d} \tag{9}$$

7 Comparisons

We can now investigate the consequences and determinants of overexploitation of groundwater in our setting, where extreme assumptions concerning scarcity are made. Indeed, we can calculate excess water extraction in a myopic setting (ΔR_0) as follows:

$$\Delta R_0 = R_0^m - R_0^S = (a-c)\,\delta \frac{b+d}{b\,(b+\delta b+\delta d)}$$

It is clear that, given $a > c$, ΔR_0 is always positive. That is to say, R_0^m is always greater than R_0^S, for any reasonable value of the discount rate (δ) . Notice, further, that

$$\frac{\partial \Delta R_0}{\partial d} = \frac{(a-c)\,\delta}{b\,(b+\delta b+\delta d)} \left(1 - \frac{b+d}{(b+\delta b+\delta d)} \delta \right)$$

which is always positive, as $\frac{\delta b + \delta d}{(b+\delta b+\delta d)} < 1$ always holds.

At the same time, we can investigate how a change in the discount rate affects the degree of overexploitation:

$$\frac{\partial \Delta R_0}{\partial \delta} = (a-c)\,\frac{b+d}{b\,(b+\delta b+\delta d)} \left(1 - \delta \frac{b+d}{(b+\delta b+\delta d)} \right)$$

[18]Again, it is easy to show that (8) is strictly concave in R_0. Indeed, $\frac{\partial^2 W}{\partial R_0^2} = -b - \delta\,(b+d) < 0$.

which, again, is always positive. We can conclude, therefore, that an increase in the discount rate generates a higher degree of myopic overexploitation, as the future grows in relevance in the social planner's objective function. At the same time, a higher relevance of the externality leads to higher myopic overexploitation, as the externality is only accounted for when maximizing the present value of social welfare over the whole planning horizon.

Finally, social welfare implications are straightforward. Indeed, the socially optimal solution is the one obtained under a benevolent social planner, while myopic behaviour leads necessarily to higher short run net benefits but a lower present value of social welfare over the time horizon we are considering.

8 Policy Implications

From our analysis we can conclude that a distortion arises when the water sector planner adopts a myopic view. Nonetheless, a myopic approach seems to be the most prevalent in real life. We therefore investigate the implications of a myopic behaviour in terms of actual water prices, in order to assess the corrections needed to achieve the maximum possible present value for social welfare. In other words, we focus on the increase in prices (i.e. actual, incorrect, market signals) that is needed to account for water scarcity as well as for external costs related to water extraction.

In the myopic case water price in period 0 equals marginal extraction costs; indeed, first order conditions in a myopic setting imply:

$$a - bR_0 - c = 0 \Longrightarrow P_0^m = c$$

Contrary to what happens in the myopic case, under social welfare maximization the water sector planner accounts, in period 0, for the *shadow cost* of extracting water in the current period; such shadow cost is given by the sum of the scarcity rent (or marginal user cost) *plus* the present value of the marginal external cost; under a benevolent social planner the first order conditions may be rewritten as:

$$P_0^S = c + \delta \left(a - b \left(\frac{a-c}{b} - R_0^S \right) - c \right) + \delta d R_0^S$$

From the above expression, it is clear that two "water price corrections" are needed to induce the myopic planner to choose the optimal extraction path:

- $\delta \left(a - b \left(\frac{a-c}{b} - R_0^S \right) - c \right)$ represents the opportunity cost of one unit of water extracted today in terms of the present value of foregone period 1 net benefits.
- $\delta d R_0^S$ is the present value of next period external costs.

The total tariff correction needed, that is, the *shadow cost* of groundwater, is therefore given by the following expression.

$$t = \delta \left(a - b \left(T - R_0^S \right) - c + d R_0^S \right) \tag{10}$$

Substituting $T = R_0^m$ and the value for R_0^S from (9), we get:

$$t = \delta \frac{(a-c)(b+d)}{b + \delta b + \delta d} > 0$$

We can therefore conclude that accounting for scarcity and externalities implies an increase in water prices.

The shadow cost of water increases both with d and with δ. Indeed

$$\frac{\partial t}{\partial d} = \frac{\delta (a-c)}{b + \delta b + \delta d} \left(1 - \frac{b+d}{(b + \delta b + \delta d)} \delta \right) > 0$$

and

$$\frac{\partial t}{\partial \delta} = (a-c) \frac{b+d}{b + \delta b + \delta d} \left(1 - \delta \frac{b+d}{(b + \delta b + \delta d)} \right) > 0$$

As a consequence, an increase in the weight of future welfare, as well as an increase in the relevance of externalities in social welfare, increase the shadow cost of extracting water in the present (time 0) period. The required tariff adjustment to achieve efficiency varies accordingly.

9 An Application Using Italian Data

Our aim is now to use the very simple theoretical model introduced in the preceeding sections in order to provide plausible suggestions concerning the order of magnitude of water tariffs corrections needed to achieve the social optimum in a myopic settin. The myopic setting is, in our view, a good description of what we observe in reality concerning water allocation institutions. To do this, our first concern has been the one of collecting data suitable for our exercise in terms of shadow pricing. On the basis of 1996 data, we have been able to estimate the individual[19] demand for water in Italy, which is the following:

$$P_t = -0,0046 r_t + 1,2501 \tag{11}$$

where r_t is the individual consumption of water. Further we could estimate extraction costs, given by the following function.

$$EC_t = .3098\,1 R_t$$

Finally, approaching the problem of external costs, we had to get to their functional form. As in the theoretical model, we assume it to be quadratic:

$$EX_1(R_0) = \frac{d}{2} R_0^2$$

While in the myopic case water price equals marginal extraction costs, that is:

$$P_0^m = .3098\,1.$$

under social welfare maximization[20] this is no longer true. The social planner accounts for the *shadow cost* of extracting water in the current

[19]Water demand for Italy has been obtained by aggregating individual demands over the 100.000 families of the sample. See Drusiani and Parena [4] for details. All monetary values are in Euros.

[20]In what follows we assume a discount rate $\delta = 0.61027$, corresponding to net benefits from water extraction being discounted at a 2.5% interest rate over 20 years. However, the qualitative features of results do not change with the value of δ.

period, which is given by the sum of the scarcity rent (or marginal user cost) and the present value of the marginal external cost.

To offer the reader an idea of the dimension of the corrections needed, we impose two specific values for the external effect parameter ($d = 0$ and $d = 5.0 \times 10^{-8}$).

When $d = 0$ no external costs emerge and we get $t = 0.356\,36$, which is the value of the scarcity rent in the social optimum. In such a case, the *shadow price* of water should be $P_0^S = 0.666\,17 = 0.30981 + 0.356\,36$. When $d = 5.0 \times 10^{-8}$, that is external costs are accounted for, we get (again, in the social optimum) $t = 0.526\,72$, and the *shadow price* of water is $P_0^S = 0.836\,53 = 0.30981 + 0.52672$, which is the sum of marginal extraction costs *plus* marginal user cost *plus* marginal external cost. In order to correct the market incentives towards an optimal water use, water tariffs should be increased by $0.526\,72$, that is, by 170% of marginal extraction costs.

The behaviour of shadow groundwater cost when the parameters are given by the above values, is shown in figure 1. As it appears, it is positive and increasing with d, in accordance with the theoretical prediction, and it can reach a level of 0.94 or more. This implies that, for relatively high values of the externality parameter, the shadow cost is more than three times greater than marginal extraction costs. Not to account for it is not a minor error.

10 Conclusion

Some clear cut and interesting lessons can be drawn from our very simple setting. First, the distortion due to the fact of not considering future scarcity and subsidence externality is increasing with the discount factor and with the relevance of social subsidence costs. Second, in our tentative application to the italian case we found that a large tariffs' correction would be needed. Under certain circumstances, such correction should be around three times marginal extraction costs. Finally, correcting tariffs in the way we suggest would simply amount to comply with EU water framework 2000/60 which states the *full cost recovery principle* for water services. Not to confuse efficiency with equity is always important.

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Figure 1: Shadow cost of groundwater (*t*)