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Abstract

The present study attempts to estimate the shadow price of unextracted groundwater in the Vozvozi aquifer. In the context of this study, we model the production function of vertically integrated agricultural firms in terms of an input-oriented distance function with multiple inputs. Duality theory is employed in order to extract information regarding the *in situ* shadow price of groundwater. This shadow price is of vital importance to the implementation of the EU Water Framework Directive and EU groundwater Directive, because it allows per farm estimation of the value of groundwater. It also allows the investigation of the level of cost recovery when resource's environmental and resource costs are also considered. In this context, groundwater dependent ecosystems are of great relevance. In our case study, groundwater level decline induces recharge from Vosvozis River and Ismarida Lake, diminishing thus an important source for the life of the wetland ecosystem. Another threat due to groundwater level decline is the intrusion of seawater in the wetland area, causing thus a serious alteration in the initial character of this protected ecosystem. This study offers the opportunity to reveal individual farmer's valuation of the marginal unit of groundwater in the aquifer and provide policy recommendations for water pricing that provides adequate incentives for users to use groundwater resource efficiently considering groundwater dependent ecosystems.

Keywords: Distance function, *In situ* shadow price, Groundwater dependent ecosystems.

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1. Introduction

The objective of this work is to derive the *in situ* shadow price of unextracted groundwater in the Vosvozi aquifer, through modelling and empirically analyzing the technology of vertically integrated agricultural firms that both extract and use groundwater as an input in their production. This shadow price, also referred to as the resource's scarcity rent or royalty, represents the marginal valuation of the individual agricultural producer for the resource left *in situ* and is not directly observable. In the model developed, the non-observability of the *in situ* shadow price of groundwater is caused by the fact that market transactions in vertically integrated agricultural firms occur only after groundwater has been extracted and used in the production of agricultural products; that is there is no market for groundwater.

This research uses duality theory in order to derive information on the *in situ* shadow price of the resource and the effects of cumulative extraction on the marginal cost of extraction. Firstly, we solve the "restricted" version of the dual cost minimization problem of the vertically integrated agricultural firm. The solution of this problem establishes the relationship between the current (unobserved) *in situ* shadow price of groundwater in the unrestricted solution of the problem, with the derivatives of the observable and estimable restricted cost function. This exact same method has been employed in theoretical and applied work, for the derivation of the time path of *in situ* shadow prices of unextracted ore, to be used as a production input in the vertically integrated Canadian metal mining industry (Halvorsen and Smith, 1984, 1991).

Secondly, another method that allows derivation of the unobservable shadow price of *in situ* resources through the use of an input distance function is proposed. The relationship between the derivatives of the estimable input distance function with the unobserved shadow price of *in situ* groundwater is established. The derivation of this lemma is possible by the use of the duality between Shephard's input distance function and the cost function.

The key extension of our work on the existing literature is that it establishes that when cost, profit or revenue function representations are precluded (i.e. profit maximization or cost minimization are violated, resulting in distortions in the shadow prices of resources that are both produced and used as inputs in the production processes of vertically integrated firms), the restricted distance function provides an excellent analytical tool for estimating unobservable shadow prices of in situ natural resources produced and used as inputs in production processes of vertically integrated firms. We also review alternative methods of estimating distance function frontiers and argue for the superiority of the stochastic frontier model, adopted in the empirical analysis to follow. The stochastic frontier model exhibits two major advantages over alternative estimation methods: (a) it acknowledges that observed costs may deviate from an efficient cost frontier due to events that are both within and outside a firm's control, and (b) it allows firm-specific derivation of shadow prices, whereas other methods allow derivation of shadow prices for efficient firms only.

With regards to the empirical application of the Vosvozi case study it involves the use of micro (at farm level) dataset in order to estimate a restricted input distance function stochastic frontier and provide an estimate of the individual producer's valuation of the marginal unit of groundwater in the aquifer. This shadow price is central to the implementation of the EU Water Framework Directive and EU groundwater Directive, because it allows per farm estimation of the value of groundwater. It also allows the calculation of the difference between the current priced charged for groundwater, i.e. the current level of cost recovery. This in turn allows suggestions of policy instruments (economic and social tools) for the achievement of full cost-recovery, as indicated by the WFD. Finally, a brief discussion on estimated farm-specific technical inefficiencies/efficiencies is provided, which indicates whether agricultural production can be made more efficient. If such potential exists then the relevant policy instruments can be identified.

The rest of the chapter is organized as follows. Section 2 provides a description of the case study area and the relevant dataset, while Section 3 outlines the empirical model. Results are presented in Section 4, while in Section 5 policy implications are commented. The chapter closes with conclusions offered in Section 6.

2. <u>Description of the Case Study Area and Data Set</u>

2.1 Case Study[1]

Vosvozis catchment area covers an area of 340 km². The river's length is 40 km. Vosvozis River discharges into Ismarida Lake. In the coastal part of the study area a system of coastal lagoons is formed, where surface, groundwater and seawater interact. All the area of Ismarida Lake and the coastal lagoons forms an extremely important ecosystem (Figure 1). Land uses in the Vosvozis River basin are mainly agricultural (cotton, corn, tobacco, sugar beets, barley and clover cultivations), cattle breeding, industrial (mainly in the form of cotton industry, dairy product industry and meat processing plants) and urban/residential. The area has 70,000 inhabitants, while the main urban center is Komotini town. Point sources of pollution are formed from industrial activities which discharge their wastewaters in Vosvozis River or in its tributaries in an uncontrollable manner and by private septic tanks (half of the population is served by such systems) which are point sources of pollution for groundwater. It should also be noted herein that Komotini's wastewater treatment plant discharges

[1] Kupfersberger (2010)

treated wastewaters in Vosvozis River. Special attention should be focused on the Komotini's industrial area which is not located within Vosvozis river basin but adjacent to it. This industrial area comprises plastic, paper, wood, food processing plants, as well as a thermo-electric power producing plant. Industrial waste waters are disposed in Filiouris River (Figure 1) which discharges in the coastal lagoon ecosystem, thus forming a serious threat to it. Particularly, the main threat to the wetland ecosystem is eutrophication, diminishing its aerial and seawater intrusion which seriously affects the fragile wetland ecosystem. Agriculture is the disperse source of pollution for the study aquifer system, merely through the application of fertilizers and pesticides. The existing hydrochemical data from 25 irrigation boreholes within the study aquifer showed that groundwaters are seriously affected by nitrate pollution, with nitrates ranging from 30 to 100 mg/l. Besides the quality problems of the aquifer system, piezometric data for the last 10 years indicate that there is a constant groundwater level drawdown which ranges from 10 to 50 meters in the examined boreholes.

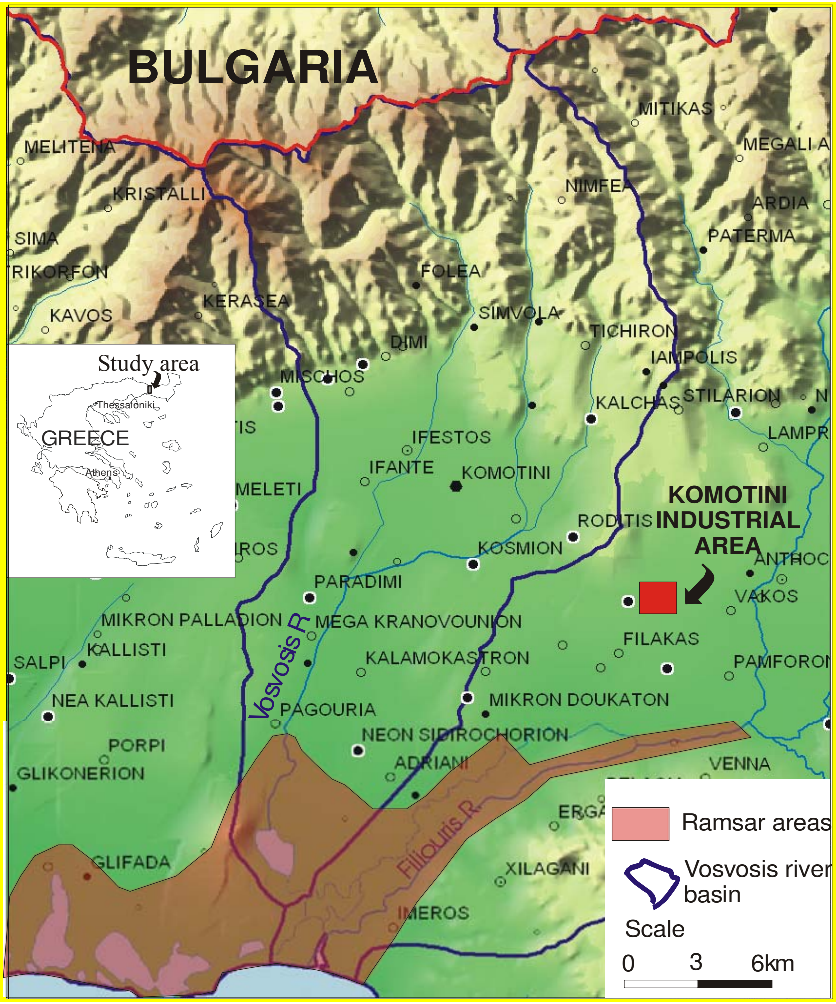

Figure 1. *Location map of the study area*

Water for human consumption is provided by the Komotini wellfield and by direct abstraction from Vosvozis River. The total daily discharge pumped from the Komotini wellfield reaches 23,000 m^3/d, providing domestic water to almost 70,000 inhabitants of the Komotini city and the surrounding settlements. The wellfield consists of 21 boreholes drilled in the study area, 15 of which are productive while the remaining 6 are currently used as observational ones. The average discharge of the productive well ranges from 45 to 90 m^3/h. Groundwater pumping is taking place mainly during summertime, whereas during the rest of the year Vosvozis river is used directly for domestic consumption, and when its water is of appropriate quality (because storm surges usually carry large amounts of sediments, thus making river water unsuitable for domestic use). The origin of the water extracted from the aquifer in the Komotini wellfield is the nearby river, i.e., Vosvozis River, rain infiltrated directly into the aquifer, and lateral inflows from the northern mountains (Moutsopoulos et al., 2008). Particularly, regarding groundwater dynamics Sidirohori aquifer, the second major aquifer system located on the southern part of the study area, shows serious groundwater level decline. Groundwater drawdown from May (beginning of pumping period) to September (end of pumping period) in certain location reaches 20m, leading to the obvious conclusion that the aquifer system is overexploited. Moreover, groundwater level decline induces recharge from Vosvozis River and Ismarida Lake, diminishing thus an important source for the life of the wetland ecosystem. Finally, another threat due to groundwater level decline is the intrusion of seawater in the wetland area, causing thus a serious alteration in the initial character of this protected ecosystem.

2.2 Data Set

The micro (at farm level) dataset was drawn from a Production Survey conducted during 2010 in the agricultural region of Vozvozi aquifer, located in the region of Thrace, Greece. Parcel-specific data includes: area of holding, land use and tenure, area planted, production of temporary and permanent crops, production inputs (including extracted ground- water), administrative costs, hydro geological characteristics (i.e., head of the underlying aquifer), personal characteristics of buyers and sellers, employment of holders and family members, labor costs and other investment and indirect costs. In particular, the data-set is an unbalanced panel of the same 100 cross sections over the year 2010.

An important consideration in the estimation of production functions is the selection of the proper output and input variables. Following the relevant literature output is defined as the firm-specific total value from production of agricultural crops measured in Euros and is denoted as y. It should be noted that output variable has been deflated using the agricultural price index for Greece provided by Eurostat. Regarding model inputs as in Koundouri and Xepapadeas (2004) we have employed the following: farm-specific total area of non irrigated land (variable x_1), farm-specific annual labour costs in Euros (variable x_2), farm-specific total value of input costs (variable x_3) deflated using the agricultural price index, farm-specific yearly groundwater extraction (m^3) (variable x_4) and farm-specific water table head (dummy variable, variable x_5). With respect to variable water table head we have constructed a dummy variable that differentiates the location of the farm in terms of water quality based on hydro geological information. In particular variable x_5 takes the values 1, 2 and 3 based on water quality (low, medium and good respectively).

3. Methodology

The distance function representation of a production technology, proposed by Shephard (1953, 1970), provides a multi-output primal alternative, which requires no aggregation, no prices and no behavioral assumption. A distance function may have either an input orientation or an output orientation. In empirical applications, distance functions have a number of advantages: (1) they do not necessarily require price data to compute the relevant parameters, only quantity data is needed; (2) they do not impose any behavioral hypothesis and (3) they allow the estimation of firm-specific inefficiencies.

In the context of the present study we opt for a translog stochastic input distance function (Aigner et al., 1977) for the case of K inputs and M = 1 output. To obtain the frontier surface (i.e., the transformation function) we set D_i = 1. Model estimation was performed employing STATA. Necessary restrictions for (1) homogeneity of inputs of degree +1, (2) symmetry and (3) separability between inputs and outputs have been imposed.

$$\ln(D_i / X_{Ki}) = \alpha_0 + \alpha_1 \ln y_i + \frac{1}{2}\alpha_2 (\ln y_i)^2 + \sum_{k=1}^{K-1} \beta_K \ln x^*_{ki} + \frac{1}{2}\sum_{k=1}^{K-1}\sum_{l=1}^{K-1} \beta_K \ln x^*_{ki} \ln x^*_{li} + \sum_{k=1}^{K-1} \delta_k \ln x_{ki} * \ln y_i$$

$$for \;\; \mathrm{i} = 1,2,....\mathrm{N} \;\; \text{and} \;\; \mathrm{x}_k^* = \frac{\mathrm{x}_k}{\mathrm{x}_K} \qquad (1)$$

where i stands for the i-th firm within the sample.

The frontier function has an error term with two components that are independent. The first component is a symmetric error term (V_i) that accounts for noise, which is assumed identically and independently distributed with zero mean and constant variance (N (0, σ^2_V)). The second component is an asymmetric error term (U_i) that accounts for technical inefficiency, which is assumed to follow an *iid* distribution truncated at zero (N (v, σ^2_u)). It should be noted that the two error components are independent.

Estimated values of $D_i = \exp(U_i)$ are obtained employing the conditional expectation $D_i = E(\exp(U_i / \Omega_i))$, where Ω_i equals V_i - U_i. If we alter notation $ln(D_i)$ to U_i equation (1) is as follows:

$$-\ln(x_{Ki}) = TL(y_i, \frac{x_i}{x_{Ki}}, \alpha, \beta) + V_i - U_i \quad i = 1, 2 \ldots N \qquad (2)$$

4. Results

The dependent variable of Equation (2) is irrigated land and the model was estimated by maximum likelihood. Results are presented in Table 1. Variable x_1 that stands for farm-specific total area of no irrigated land was dropped from the estimation due to a large amount of missing values. Gross products and squared coefficients are not reported because they were excluded from the empirical model after a preliminary estimation which indicated that their estimated effects were not significantly different from zero.

Estimated coefficients have the anticipated signs (positive for inputs and negative for outputs). Coelli (1995) has derived a one-sided test for the presence of the inefficiency term and according to this we fail to reject the null hypothesis of no inefficiency component. Moreover, the reported value of gamma (γ) that is close to zero indicates that the deviations from the frontier are entirely due to noise.

Table 1. *Estimated parameters for the input distance function*[a]

Variable	Parameter	ML Estimates	t-ratios[b]
Constant	α_0	-1.37	-0.73
Output	α_1	-0.18	-1.67
Labor	β_2	0.08	1.6
Costs	β_3	0.17	1.59
Water Extraction	β_4	0.013	0.18
Head	β_5	0.68	5.72
	log (likelihood)	-7.8002	
	γ	0.004	0.000
	σ^2	0.1	
	σ^2_u	0.0004	
	σ^2_v	0.104	

[a] The dependent variable is irrigated land. Number of cross sections is 27.

[b] Hypothesis tests are carried out at 95% confidence level.

Firm-specific technical efficiencies are reported in Table 2. A firm is said to operate in an efficient manner if it is impossible to produce larger amount of output with the given inputs or the same output with less of one or more inputs without increasing the amount of other inputs. Our results reveal a significant level of operational efficiency for the firms/farms in our sample. The mean efficiency level is 0.99. Technical inefficiency results from employing a larger amount of inputs than required in order to achieve a certain output level and is explicitly related to the lack of incentives faced by the owners of the firm. Technical inefficiency measures could help regulators to implement the designated policy regarding taxes and subsidies granted to each farm relying on the costs of a similar (in terms of input mix) but more efficient firm. This process is widely known as competitive benchmarking (''yardstick competition''). Such a regulatory framework can (1) raise the managers' of the farms incentives toward efficiency and (2) alleviate the informational asymmetry between the managers of the farms (agent) and the regulators or consumers of agricultural products (the principal).

Table 2. *Estimated firm efficiency levels*

Firm	**Efficiency**
1	0.99014
2	0.99026
3	0.99009
4	0.99003
5	0.99000
6	0.98957
7	0.99048
8	0.99025
9	0.99006
10	0.99033
11	0.99001
12	0.99004
13	0.98981
14	0.99044
15	0.99045
16	0.98997
17	0.98973
18	0.98988
19	0.98987
20	0.99008
21	0.99017
22	0.99001
23	0.99014
24	0.98985
25	0.98971
26	0.99034
27	0.99014
Mean	0.99007

In Table 3, we calculate the estimated *in situ* price i.e. value for farmers (use value) per cubic meter, of unextracted groundwater in the Vosvozi aquifer as in Koundouri & Xepapadeas (2004). The mean annual per farm minimum restricted cost function $\hat{C}_i^R$ is approximated by the mean annual per farm revenue. The change in the restricted distance function per unit change in groundwater extraction $\frac{\theta \ln D_i^R}{\theta \ln W_i}$ measured in € per cubic meter is the estimated parameter of the quantity of groundwater extraction from the stochastic distance function estimation, the results of which are presented in Table 1 and W_i is the mean groundwater extraction per farm, measured in m^3.

Table 3. *Estimated in situ price of unextracted groundwater*

Year	$\hat{C}_i^R$	$\frac{\theta \ln D_i^R}{\theta \ln W_i}$	W_i	μ_i
2010	€4083.61	€ 0.01/m^3	18686.33 m^3	0.009 m^3

5. <u>Policy Implications</u>

The economic value of groundwater in a specific aquifer is derived from the use it can be put to, and therefore it originates from the benefits that it generates or the services that it provides. Local availability and quality compared to surface water are also determinants of its economic value. These are determined by factors such as population growth, economic development, pollution and climatic variability. Figure 2 offers an overview of the total economic value of groundwater according to which its services can be divided into two basic categories: extractive services and *in situ* services. The more familiar of these two components are the extractive values, while the *in situ* services include, for example, the capacity of ground water to: (1) buffer against periodic shortages in surface water supplies; (2) prevent or minimize subsidence of the land surface from ground water withdrawals; (3) protect against sea water intrusion; (4) protect water quality by maintaining the capacity to dilute and assimilate ground water contaminants; (5) facilitate habitat and ecological diversity; and (6) provide discharge to support recreational activities (Committee on Valuing Ground Water, National Research Council, 1997). Discharge to ecosystems, rivers and lakes can be seen as a groundwater service of indirect (ecosystem) value (Kemper et al., 2002-2006).

Physical State Terminology	Economic Terminology	Accounting Terminology: Stocks	Accounting Terminology: Flows
A. Extractive values			
1. Municipal use values			*
2. Industrial use values			*
3. Agricultural use values			*
4. Other extractive use values			*
B. *In situ* values	▶ Use Values		
1. Ecological values		*	*
2. Buffer values		*	*
3. Subsidence avoidance values		*	*
4. Recreational values			*
5. Sea water intrusion values		*	*
6. Existence values	▶ Nonuse Values		*
7. Bequest values			*

Figure 2. *Taxonomy of groundwater valuation terminology* (Source: Committee on Valuing Ground Water, National Research Council, 1997)

However, in many cases the human health focus ignores other functions of ground water that humans might value such as the role of ground water in ecological functions and in particular in providing an important contribution to unique terrestrial and aquatic ecosystems. As Kløve et al. (2011) note (p.779) "these systems are typically of high value as they support high biodiversity and provide the habitat for several endangered species. Some of these ecosystems and related water bodies have been protected to a certain extent by international conventions such as the Ramsar convention and, in Europe, by several laws such as the Habitat and Water Framework Directive". This is the case of our case study area in which groundwater dynamics interact with important ecosystems such as these of the area of Ismarida Lake and the coastal lagoons. The exclusion of these services and values may be due to the lack of knowledge regarding status of groundwater and impacts of land and water use, pollution and climate change.

Few studies have attempted to measure the value that people place on the ecological services that ground water supplies, while few are also the studies that estimate non-use values related to quality (Hasler et al., 2005; Press and Söderqvist, 1998; Rozan et al., 1997; Jensen et al., 1995) or quantity (Koundouri et al., 2012) of groundwater. In particular, in Rozan et al., (1997) the estimated 52€ per household/year in 1995 of non-user households to protect the Alsatian aquifer (France) is considered as a proxy of its existence value and is used to assess the economic non-use value of the aquifer. Similarly, Press and Söderqvist (1998) employed Contingent Valuation (CV) method to estimate the benefits of groundwater protection in the Milan area (Italy) in order to also consider non-use values directly. The study elicited a high value of ITL 640 000 per household/year showing the broad values at stake in the preservation of groundwater. In addition, Jensen et al. (1995) by using CV method estimated the Willingness to Pay (WTP) for groundwater protection from pollution at DKK 1000 household/year elicited by an open-ended payment format, and at DKK 2100 using the close-ended format. Regarding the Choice Experiment (CE) method the applications are even less. Hasler's et al. (2005) national CE study assessed the non-marketed benefits associated with increased protection of the groundwater resource and revealed an estimated WTP of 253 €/year for protected and naturally clean groundwater, not in the need for purification, a WTP for good conditions for flora and fauna in waterways and lakes of 161 €/year, and a WTP for purified water of 122 €/year (all in 2005 prices). Finally, in Koundouri et al., (2012) the case study of interest is Rokua in Northern Finland, a groundwater dependent ecosystem very sensitive to climate change and natural variability that faces disturbance of the water dynamics and in particular of water quantity. Results of a CE survey indicate that an average household is willing to pay €22 - €23 (one-off payment) in order to ensure that water management will not allow the decline of total quantity of water available in groundwater aquifer, lakes and spring. As a result, the above prices in contrast with the *in situ* derived value from Vosvozi case study reveal the important role of non-use values which are of considerable magnitude when seen from residents' perspective.

Furthermore, the reported in Table 3 *in situ* value of unextracted groundwater is much lower than the established *in situ* per cubic meter groundwater's total economic value. This total economic value is equal to the relevant backstop technology for water, which is for example the per cubic cost of desalination (at €0.05, see Koundouri 2000). This divergence points to the significant non-use values of groundwater, such as option value and ecosystem resilience value, as well as alternative use values of economic sectors other than agriculture. Another point is raised after comparing our estimate of the individual farmer's valuation of the marginal unit of groundwater in the aquifer with the socially optimal shadow price of *in situ* groundwater derived for the Kiti aquifer in Cyprus in 1999 by Koundouri and Christou (2000). The *in situ* value (in Cyprus pounds) of the resource was determined to be £0.2017 per m^3 of water. As it has been also noted in Koundouri and Xepapadeas (2004) where results were similar to this study, such a divergence can be rationalized in the presence of no cooperative behavior and common pool externalities, as current users of the resource are willing to pay only the private cost and not the full social cost of their resource extraction.

In this context, it becomes apparent that the notion of total economic value can be used to inform decision-makers regarding the use of water resources allowing determining the net benefits of policies and management actions, since what is commonly observed is that groundwater tends to be undervalued, especially where its exploitation is uncontrolled. In this situation the exploiter of the resource receives all the benefits of groundwater use but pays only part of the costs (Figure 3)—usually the recurrent cost of pumping and the capital cost of well construction, but rarely the external and opportunity costs (Kemper et al., 2002-2006). The fact that ground water is priced well below its value, has as a consequence its misallocation in two ways: (1) the ground water resource is not efficiently allocated relative to alternative current and future uses; and (2) authorities responsible for resource management and protection devote inadequate attention and funding to maintaining ground water quality (Committee on Valuing Ground Water, National Research Council, 1997). This is also the case of Vosvozi where no charge is imposed for water withdrawn, and the consumer, whether a public water supply entity, an individual, or a firm regards the cost as being confined to the energy used for pumping and the amortization of well construction and the costs of the treatment and distribution system. As a result, depletion and pollution continue as it is not recognized that ground water has a high or long-term value. This is apparent by the difference between the estimated *in situ* shadow price of the stock of groundwater in Vosvozi (use value) and total economic value that explains the inefficiency of agriculture using water and paying only for its use value. That is agriculture uses water efficiently as far as groundwater agricultural use value is concerned but seriously overexploits/overextracts groundwater as far as its total economic value is concerned.

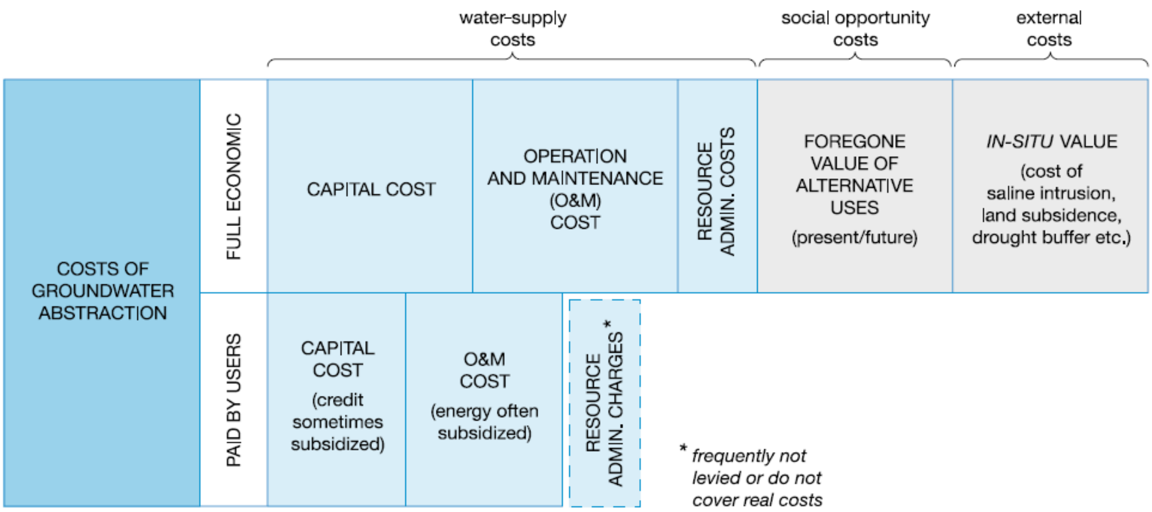

Figure 3. *The costs of groundwater use* (Source: Kemper et al., 2002-2006)

In Greece it has been noticed to charge water use by farm-specific total area and not by type of crop, to subsidize irrigation, to have illegal private wells or when they are legal not to have metering to monitor the volumetric use of the resource. As a result, these practices have eroded the same farmers' resource availability in the longer term because of excessive groundwater abstraction.

Economic instruments can provide incentives to allocate and/or use groundwater more efficiently. There are two categories relevant to groundwater, namely those that focus upon (Kemper et al., 2002-2006):

- changing groundwater abstraction costs by (a) direct pricing through resource abstraction fees, (b) indirect pricing through increasing energy tariffs and (c) the introduction of water markets

● positive economic incentives for certain activities by (a) modifications to agriculture and food trade policies and (b) subsidies to encourage the use of more efficient irrigation technologies to achieve real water savings.

Therefore, appropriate institutional foundations are required to provide farmers with the incentive to pay today for conserving *in situ* groundwater for future extraction and avoid myopic behavior which resides from the absence of properly defined property rights for groundwater. Efficient pricing of the resource should incorporate marginal cost of extraction and scarcity rents. Regarding the later the establishment of interactions between groundwater resources and ecosystem goods and services is of paramount importance in order to estimate resource's full total cost incorporating its scarcity value. Supplementary to this approach is the use of lump-sum payments to poor farmers at the beginning of the year to cover their estimated energy bill, in order to give them an incentive to use water more efficiently and consume less, maybe through a shift to higher-value crops (Kemper et al., 2002-2006) and herbal, medicinal and aromatic plants. Hence, since they receive lump sum payments to offset their increased energy bills, they can actually gain twice by being more efficient. It is important therefore for our region under investigation to identify an avenue that combines promising production and efficient water use through the prism of sustainability.

Finally, the relatively new approach of payments for environmental services has often focused on supporting watershed protection and water quality enhancements that target the provision of surface water and groundwater (Wunder et al., 2008). It has been suggested recently that farmers should receive payments or 'green water credits' from downstream water users for good management practices that enhance green water (rainfall stored in soil moisture) retention as well as surface water and groundwater conservation (ISRIC, 2007).

6. Conclusions

This study replicates the distance function methodology for estimating scarcity rents that has been applied to the irrigated agricultural sector of the Kiti region of Cyprus employing data for a sample of farms situated in Vozvozi River, Thrace. In order to estimate the *in situ* shadow prices in a framework irrespectively of cost minimization restrictions, we opt for a methodology based on the input distance function, which does not require any behavioral assumptions. Documented failure of farmers to minimize costs, provides support for the use of the distance function and proves the potential for estimation inaccuracy should one wrongly choose to use the restricted distance function methodology. The suggested methodology could be useful in estimating shadow prices for renewable resources as well such as groundwater, forest and fisheries. As it has been mentioned, this shadow price is of vital importance to the implementation of the EU Water Framework Directive and EU groundwater

Directive, because it allows per farm estimation of the value of groundwater. It also allows the calculation of the difference between the current priced charged for groundwater, i.e. the actual level of cost recovery.

In addition to the potential of this methodology as a demand management tool via pricing, technical inefficiency measures can be employed by the regulator for competitive benchmarking (‘‘yardstick competition’’) in which taxes or subsidies granted to each farm are based on the costs of a similar (in terms of input mix) but more efficient firm. As indicated in the previous section of the paper, such a regulatory framework can spur managers toward efficiency, an admittedly difficult task when regulation of common-pool resources is at stake. Moreover, introducing competitive benchmarking could probably help to alleviate informational imbalance between the farmers and the regulators, an issue that calls for regulators’ attention when it comes for the implementation of agricultural policies.

Results show that groundwater in our case study area is undervalued and economic instruments should provide incentives to use it more efficiently by agricultural sector incorporating the notion of total economic value and therefore groundwater’s indirect (ecosystem) value and non-use values in water management. However, in order to achieve that, as Kløve et al. (2011) note integrated multidisciplinary knowledge on hydrology, geochemistry and biology from individual systems as well as on the scale of regional catchments and aquifers is needed. Therefore, it is important to clarify connections among ground water processes, ecosystems and base stream flow and better define the extent to which changes in ground water quality or quantity contribute to changes in ecologic values. Finally, other parameters of importance when designing policy are the finite nature of the resource needing a long-term view and the fact that any actions should consider avoidance of irreversible situation regarding groundwater.

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