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ASSESSING WATER PRICING POLICIES TO ENHANCE WATER EFFICIENCY IN AGRICULTURE

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Abstract

The improvement of water use efficiency is one of the priorities of the Water Framework Directive 2000/60/EC. In order to pursue this objective, the European Union suggests member countries adopt a direct pricing method, in which each user is charged proportionally to water consumption. However, since the implementation cost and the operational costs of the volumetric pricing method are usually higher than those related to other methods the present paper is aimed at verifying whether the volumetric pricing is capable of achieving a higher efficiency. Two aspects of the efficiency are considered and evaluated with a two-step Data Envelopment Analysis (DEA): the technical efficiency, depending on the profitability of the crops, and the ecological efficiency, affected by environmental externalities of the irrigation practice. The results prove that the gain of efficiency due to direct pricing method is rather limited, compared to other methods.

Keywords: European Water Directive, Water pricing, Eco-efficiency, Data Envelopment Analysis, Irrigation

1. INTRODUCTION

The enhancement of water use efficiency is one of the priorities of the Water Framework Directive 2000/60/EC (WFD), and the most relevant effects of its implementation are expected on the agricultural sector, which is the main responsible of water use with its share ranging from 50-60% of fresh water bodies in the Mediterranean regions (Dworak et al., 2007). There are several economic measures suitable for the achievement of this objective, such as environmental taxes, tariffs, subsidies (e.g. guaranteed prices and compensations), creation of water markets (e.g. auctions), regulatory regimes (e.g. penalties), restrictions on water consumption (quotas), extension services for promoting best practices (OECD, 2006). Among these measures, the WFD has highlighted the importance of water pricing, suggesting member countries the adoption of a volumetric pricing method, in which each user is charged proportionally to water consumption.

The economic concept underlying this approach is that perfect competitive markets of goods and resources are capable of achieving the most efficient allocation of resources, since the price works as an indicator of scarcity. The drawback of this approach is that in the real world there are several market failures hindering the perfect allocation of water resources. Among the most relevant causes of market failures, it is worth mentioning the fact that water resources are public goods (with ill-defined property rights), and water services are often managed under natural monopoly conditions (Dosi and Easter, 1994). In addition, water uses cause negative externalities (e.g. pollution of water bodies, salinization and depletion of groundwater). Consequently, the analysis of the technical efficiency may provide a valuable source of information in the process of water policy design.

Contrarily to the analysis of the economic efficiency, which measures the irrigator and water distributor losses caused by any disturbance of the competitive market, the technical efficiency evaluates how different decision making units (e.g. firms, departments, sellers) are able to allocate inputs to generate one or more outputs and, therefore, how far they are from the production frontier. In the case of a single output and a single input, the technical efficiency consists on the ratio between the two, while in the case of multiple outputs and inputs a more sophisticated method is required. To this purpose, the Data Envelopment Analysis (DEA) is a flexible technique which has been developed to calculate the ratio between the weighted sums of multiple outputs and multiple inputs (the ratio between the so-called virtual output and virtual input) (Charnes et al. 1978; Cooper et al. 2000). Further development of this technique is proposed by Korhonen and Luptacik (Korhonen and Luptacik, 2004), in which the DEA is used to measure the ecological efficiency of decision making units that is, the ratio between multiple outputs and multiple externalities caused by the production process. In other words, the ecological efficiency represents an indicator of the pressure of the firm on the environment.

From the methodological point of view, a full assessment of policy effects is usually performed with traditional policy evaluation analysis (e.g. Cost-Effectiveness Analysis, Cost-Benefit Analysis). However, in the specific context of the WFD, Messner (2006) argues for the homogeneity assumption regarding measurement effects and their costs and for the existence of multiple water-related benefits and objectives as limitations for the CEA. In particular, two main limitations of the CEA approach have been pointed out in this respect: i) the need for all outcomes to be expressed in monetary units (water management typically involves many non-market factors that are not easy to assess); and ii) the difficulty of achieving a fair distribution of resources among stakeholders (Hajkowicz and Higgins, 2008). Furthermore, CEA and CBA provide useful information on the profitability of the policy, but do not take into account of the efficiency which, in the case of water management, is one of the most relevant objectives of the policy (as stated by the EU Water Framework Directive).

Therefore, the DEA represents an alternative and complementary policy assessment tool, since it is an objective and rigorous method, which does not require prior assumptions on input and output prices (Coelli et al., 1998; Sengupta, 1999)[1]. This is an advantage, since administrative tariffs are applied to public goods (e.g. water). In fact, monetary methods require weights to evaluate the relative social value of inputs and outputs of the policy (criteria), which are difficult to be evaluated (Tyteca, 1996).

Therefore, this paper proposes a methodology in which the effects of different water pricing schemes are simulated on a group of farms, and the DEA is applied to measure the different performances of firms operating under different water policy regimes. Analysis on simulated policy scenarios have been proposed by Bono and Matranga (2005) and Musolino and Rindone (2009). In our case, the efficiency depends on the capacity of producing output from input (technical efficiency) and also the production of output and externalities (ecological efficiency). The paper deals with two aspects of the efficiency. The first, the technical efficiency, depends on the optimal allocation of the resource to the most profitable crops (ceteris paribus). The second, the ecological efficiency, considers the externalities caused by the irrigated crops on the environment, and particularly groundwater depletion and pollution. In both cases, the water pricing scheme will be preferred if it induces an increase of output, or the reduction of the externality, by consuming the same volume of water. Alternatively, the policy is preferred if the same output or externality is produced, with less water.

The analysis may be applied in order to follow two different perspectives: public and private approaches. In the first, the public decision maker may be interested in evaluating whether the policy produces some social benefit from an efficient allocation of resources (including water), with maximum production of output (e.g. economic growth or externality reduction) and minimum cost or external effects. Input and output are referred to the public domain. In the second, the representative of the stakeholders of the agricultural sector (farmers' associations), which are the main players affected by the policy reform, may be more interested to economic gains deriving from efficient resources allocation. In this case, input and output are referred to the private domain. The information to public decision maker and to stakeholders is intended to facilitate the public debate and negotiation process, based on scientific evidence.

In the specific context of this paper, a two-step DEA has been applied to evaluate the technical efficiency to a group of farms operating under different water pricing schemes. In particular, the objective is to verify whether, as stated by the economic theory, volumetric water pricing schemes are always the most efficient, compared to indirect pricing schemes (e.g. input, output, area). The hypothesis we challenge in this paper is that, the unavoidable market failures affecting the allocation of water resources in agriculture already mentioned above, may flatten the differences between volumetric and indirect pricing schemes. In fact, according to our findings, we found that the gain of efficiency due to the introduction of the volumetric pricing does exist, but they are rather limited or absent, if compared to indirect pricing schemes.

The study is based on the simulation of the effects of the water pricing reform on farms located in the watershed of the Candelaro river located in the province of Foggia (Italy), by a territorial linear programming model. In order to estimate the efficiency of the policy, a comparison of the direct pricing scheme with indirect pricing schemes (input, output, and area) is performed. Public and private perspectives of the efficiency are compared, in order to consider the point of view of regulators and farmers, which are involved in the negotiation process of the water pricing reform.

In the next paragraph, an overview of pricing policy concepts and the characteristics of the most diffused water pricing methods are described. In paragraph 3, the methodology for measuring the relative efficiency of alternative water pricing policy based on a two step DEA is proposed. Paragraph 4 deals with the empirical case of study, that is based on the comparison of the efficiency of volumetric pricing methods, with indirect pricing methods (input, output, and area), and a quota system, in the province of Foggia (Italy). In paragraph 5, the results are shown, while paragraph 6 closes with some concluding remarks and discussions.

2. WATER PRICING POLICY OPTIONS

The idea of managing water resources through water pricing dates back several decades, but in 1992 the Dublin International Conference on Water and the Environment proposed that the management of the water source as an economic good may lead to an efficient and equitable use and effective to encourage the conservation and protection of water resources. In addition, the Rio Declaration on the Environment and the Development of the United Nations in 1992 mentions the legitimacy of an economic analysis and economic tools to support the implementation of regulatory measures (Molle and Berkoff, 2007a).

Water pricing is seen in the WFD as an efficient system for natural resources management in general and specifically for water management. It is seen as a way to 'internalize' costs and it reflects scarcity in resources that lack of a proper market. The directive obliges Member States to take into account the principle of recovery of the costs of water services (abstraction, impoundment, storage, treatment and distribution of surface water or groundwater, waste water collection and treatment facilities) and specifically include environmental and resource costs. This implies that water pricing has to be seen and used within the frame of the environmental objectives of the WFD.

The economic theory suggests coherently with the WFD approach, that the most suitable water pricing scheme is represented by direct pricing methods, based on volumetric methods. In this way, users will pay proportionally to their consumption, and a certain degree of fairness among users is also pursued. The drawback of this approach is that the externalities (either positive or negative) of irrigation are not always taken into account. In fact, crops may lead to different environmental impacts that are not always related with water use. In a similar manner environmental benefits occur with irrigation (Goméz-Limón, 2006), and generally the return of water flow downstream is related to water use.

In addition, it is claimed that by direct water charging, the signal of the scarcity of the water resource is directly and effectively conveyed to farmers, who are supposed to promptly react by adopting a water saving technology (Tsur and Dinar, 1995, p.21). Empirical evidence, however, shows that technology choice is hardly driven by water price. It is mainly determined by structural factors, agronomic conditions and financial constraints (see Molle and Berkoff, 2007b), as well as crop choice (Varela-Ortega et al. 1998).

Numerous obstacles hinder progress in implementing volumetric rates. Among them, the fact that it may not be efficient to do so under a broad range of realistic situations. A relevant obstacle for its application in many European irrigation districts is the lack of appropriate water metering devices. Yet, volumetric systems are costly and not suitable for monitoring natural water sources (e.g. groundwater, streams, natural reservoirs, etc.). Work done by Tsur and Dinar (1997) illustrates how the efficiency gains may not justify the costs of restructuring tariffs.

Therefore, in order to comply with these aspects, some other alternative pricing methods may offer some advantages, such as requiring lower management costs, being easily monitored, or suitable for pricing diffused natural water sources. The comparison of pricing methods adopted in different countries in terms of efficiency, equity and water quality management is already documented in the literature (Tsur and Dinar, 1995; Dinar and Subramanian, 1997; Johansson et al., 2002). In general, it is pointed out that the implementation of volumetric pricing is complicated (Burt, 2007) while per area pricing is easier. Other pricing schemes, such as output or input and tiered schemes are relatively complicated (Dinar and Subramanian, 1997).Irrigation water charges in several European countries are shown in Berbel et al. (2007). They review the irrigation pricing policies that were in place in a selection of European countries before the WFD was adopted in 2000. A variety of legislative and institutional arrangements across European members emerge. Agricultural water tariffs are quite heterogeneous across countries, regions and even within regions. Tariff structures apply almost exclusively to surface water and they rarely reflect relative water scarcity, which depends on complex geographical, technical and institutional factors. Fixed per hectare tariffs are predominant in Southern European countries, mostly in districts supplied with surface water from publicly developed infrastructure, while volumetric charges prevail in northern countries. Most of the water pricing policies are related to surface water under public schemes, but the use of groundwater may account locally for 100% of irrigation. The majority of countries do not consider any form of 'eco-tax' for groundwater, or any kind of economic instrument in areas with local aquifers at risk of over-exploitation.

After it came into force a decade ago, progress in the implementation of the WFD is reported in a working document elaborated by the European Commission (CEC, 2007)[2]. The conclusion of the document highlights both positive and negatives results, and as a whole progress "…has been made 'Towards Sustainable Water Management in the European Union'. However, there is still a long and challenging road ahead" (CEC, 2007).

Based on the literature, the pricing scheme alternatives to volumetric pricing, considered in this research are as follows:

a) per area pricing: water fees are proportional to the irrigated farmland, regardless of the actual demand of water. This method can be easily implemented, and could be managed and monitored through GIS systems. However, it shows some shortcomings, in terms of fairness, as water consuming crops are considered similarly to water saving crops, and also farmers do not have any incentive to adopt water-saving technologies;

b) input pricing: water charges are estimated as a proportion of the cost of the specific input of irrigated crop (e.g. seeds, plants, mulching materials, etc.). To a certain extent, this method is coherent with the principle that in most cases intensive crops are also responsible for externalities and, therefore, it is coherent with the polluter pays principle;

c) output pricing: in this case the cost of water consumption is calculated from the output of irrigated crops. It is relatively fair, but may not induce farmers to choose the most profitable use of water;

d) quota: in addition, the pricing schemes are compared with the quota method, since it is more popular among policy makers. According to this method, farmers have the right to use an amount of water which depends on historical records (the so-called prior-appropriation water rights). These amounts could be modified by the ruling authority, but since in most of cases it does not require the payment of any relevant fees, it enjoys a wider consensus among farmers. In some other cases, farmers are allowed to make the best use of a limited amount of water resource, for which they pay a discounted tariff. The drawback of this method is that by applying tariffs that are lower than the marginal productivity, it usually induces farmers to an inefficient use of the water resource.

In this paper it is assumed that the farmers detain full information and decision making is rational, in the sense of maximizing the value function, under a set of technical and economic constraints. The application of different water pricing schemes are supposed to affect farmers' behaviour in terms of resource availability (technical constraints), or resource price (economic signal for scarcity), and in both cases farmers will pursue the optimal allocation of the resource. Finally, it is assumed that the transaction costs of the policy option implementation are negligible.

In this context, it is expected that different pricing schemes induce different technical and ecological efficiencies of irrigated farms.

3. METHODOLOGY

The first attempt to compare the multiple performance of firms in terms of desirable and undesirable outputs is reported in Fare et al. (1989), in which a data set of 30 US paper mills using pulp and three other inputs in order to produce paper and four pollutants. In their research they assumed weak disposability of undesirable outputs. Their results showed that the performance rankings of DMUs turned out to be very sensitive, whether or not undesirable outputs were included.

However, the emphasis on the ecological issue has occurred later, and generally externalities have been treated as undesirable outputs of the production process. Tyteca (1996) presents an exhaustive literature review, and found that the DEA is frequently used to measure the efficiency of decision units, such as firms, industrial plants, governmental departments (Glass et al., 2006; Bono and Matranga, 2005; Korhonen e Luptacik, 2004).

In this paper, we adopt the modified two steps DEA, as first proposed by Korhonen and Luptacik (Korhonen and Luptacik, 2004, 437-446), in order to measure the technical and ecological efficiency of different water pricing policies. This methodology allows the calculation of relative efficiency and, consequently, the ranking of the most efficient policies, considering the technical and the ecological aspects. Korhonen and Luptacik (2004) propose to measure the eco-efficiency of 24 power plants in Europe in two different ways. In the first approach, they measure the eco-efficiency in two steps. First, technical efficiency and the so-called ecological efficiency are estimated separately. Then, the results of both models are taken as the output variables for the new DEA model (with the inputs equal to 1), which provides the indicator for eco-efficiency. In the second approach, they attempt to build up a ratio that simultaneously takes into account the desirable and undesirable outputs. The authors found that both approaches (i.e., separate and simultaneous) achieve almost the same result in terms of finding the most efficient plants, although the ranking for all power plants is slightly different.

In this research the first approach is adopted, where the comparison of the eco-efficiency is made among the performances of the local irrigated farms, under different water pricing hypotheses. Both efficiency measures reveal the actual contribution of the water pricing reform to the enhancement of water use efficiency, as stated by the Water Framework Directive.

In order to compare the relative efficiency of n water pricing schemes, the analysis is performed on data derived from the simulation of the effects of the policy. There are two reasons justifying this approach. Firstly, by working on simulated data, the interferences on the efficiency due to other factors than the water policy are avoided, and therefore the measure of the relative efficiency is truly referred to the policy reform. Secondly, it is hard to finding reliable data of similar irrigated agricultural systems. National and regional regulations will often affect farming cropping schemes, and farming cropping systems or local constraints may exert a strong impact, regardless of the water pricing scheme.

The simulation of the effects of different water pricing policy is made through a multi-agent regional linear programming model (Tisdell, 2001; Berbel and Gutierrez, 2005; Giannoccaro et al., 2008; 2009). This sort of mathematical programming model is applied in order to simulate farmers' decision making, in terms of cropping patterns and the allocation of irrigation water. The decision variables of the model are the crops' activity levels (i.e. crop areas), which determine the utilization of production inputs including water. In addition, environmental data on pollutants emitted by the agricultural practices are also estimated.We estimate a number of parameters that can be fed into the mathematical model, in order to evaluate the impact on agricultural system according to the different pricing policy scenarios.

On the basis of existing studies, paying special attention to the OECD report (OECD, 2001), and Berbel and Gutierrez (2005, pp. 52-55), a series of indicators has been selected. Indicators express the impact per hectare of used farmland, and according to the simulated cropping pattern (different crops exert different impacts), they result in the impact on the agricultural system.

The most obvious indicators are those pertaining to the consumption of water and indicators of the economics of farming. For latter concept, it should be considered the firm perspective (that is, farm revenue), as well as the public perspective, taking into account the value added of agricultural system. Further indicators are related to the environmental issues. In particular, we select the fertilizer and pesticide impacts of cropping patterns (non-point pollution caused by nitrogen fertilization and pest control). Water conservation (i.e. water saved) is seen as a positive environmental externality[3].

The values of these variables are the outcomes of the agricultural system and will be used later in the DEA.

The model is based on the assumption of the maximization of the regional agricultural net revenue (NR), in accordance with the following equation:

$$\text{Max } NR = \Sigma_j \lambda_j \{\Sigma_i x_{i,j} [q_i p_i - \Sigma_z (c_{i,z} v_{i,z}) - mls_{i,j}] - WC_j - Fix_j + SFP_j\} \qquad (1)$$

s.t.

$\Sigma_i (x_{i,j} \ t_{s,i}) \le T_{s,j}$: seasonal occupation of the land use necessary to the cultivation of the x_i cropped area, constrained by the overall farmland availability T in each season s, for the j farm type;

$\Sigma_i \, (x_{i,j} \quad \Sigma_b \, a_{i,b}) \leq W_{b,j}$: water specific consumption a (cubic metres per hectare) for the crop i, constrained by the water availability W for the b water source type and the j farm type;

$\Sigma_i \, (x_{j,i} \; l_{c,i}) \leq L_{c,s,j}$: labour type c (hours of labour) required by the i crop during season s, constrained by the farm endowment L (hour of labour per year),

where:

λ_j : weight of the j farm type (number of farms);

$x_{i,j}$: cropped area (hectares) devoted to the cultivation of the i crop by the j farm type;

$t_{s,i}$: seasonal farmland use (hectares per season) required to cultivate the i crop, during the season s;

$T_{s,j}$: total farmland availability (hectares), referred to the s season and the j farm type;

q_i , p_i : yield (tons) and market price (EUR), of the produce of the i crop;

$mls_{i,j}$: differential competitive margin, due to the different technology (yields and input) and market prices of the i crop for the j farm type (EUR/hectare);

$c_{i,z}$, $v_{i,z}$: amount of the z variable technical input (kg per cropped area), and its related market price (EUR);

Fix_j : fixed running costs of the j farm (EUR/farm), including insurance, maintenance and depreciation of equipment and building, tax

SFP_j : the single farm payment under the CAP regime (EUR/farm);

WC_j : cost for irrigation water, faced by the j farm (EUR)

The above economic model has been adapted in order to simulate different water pricing schemes, according to different specification of the water cost (WC) faced by each farm type.

In particular, the volumetric pricing is modelled considering a water charge that is proportional to the water consumption: $WC^V = \Sigma_i \, \Sigma_b \, (x^I_i \; a_{i,b} \, w_{i,b})$, where $a_{i,b}$ and $w_{i,b}$ are the technical coefficients referring to the specific water consumption (cubic metre per hectare of the irrigated area x^I_i) from the b source type (e.g. different block, in the increasing block tariff method applied by the CBC, or ground water), subject to w tariff or extraction cost (EUR/ cubic metre). The superscript I denotes the irrigated crops included in the set of all the possible crops i.

In the case of input pricing, the water cost is proportional to the sum of all variable costs that are specific for irrigation crops: $WC^I = \alpha^I_i \, \Sigma_z \, (x^I_{i,j} \; c^I_{i,z} \; v^I_{i,z})$, where α is an empirical parameter[4], while c^I and v^I refer to technical coefficients and related prices of input that are specifically related to irrigate crops (e.g. material propagation, such as seeds or bulbs, disposable irrigators, fertirrigation, pesticides and herbicides).

Similarly, output pricing considers the water cost as the proportion of the total value of product obtained by the irrigated crops: $WC^O = \Sigma_i \, \alpha^O_i \; (x^I_i \; q_i \, p_i)$

Area pricing is calculated by applying a tariff to the area devoted to irrigated crops: $WC^A = \alpha^A \, \Sigma_i \; x^I_i$

Finally, the quota system is modelled by reducing quota allotments per hectares according to the water rights of each farm type. This is included in the model by reducing the parameter $W_{b,j}$ in the constraint: $\Sigma_i \, (x_{i,j} \, a_{i,b}) \leq (W_{b,j})$

Simulations are performed by changing the water pricing scheme, affecting the level of pricing and the water availability allocated to each farm type. From the data simulation of each policy, the agricultural system variables are selected and categorised as inputs, desirable outputs, and undesirable outputs.

The two steps DEA are performed on the pay-off matrix obtained. The first step for calculating the relative technical efficiency is performed by the traditional DEA, where the technical efficiency of the policy '0' (h_0). This model is also named "Frontier Economics", and consists of a linear programming model through which the (positive) weights to be applied to outputs (μ_r) and inputs (v_i) are estimated, in order to find a ratio of output on inputs that ranges from 0 to 1:

$$\text{Max } h_0 = \left(\sum_{r=1}^{k} \mu_r y_{r_0}\right) / \left(\sum_{i=1}^{m} v_i y_{i_0}\right) \quad (2)$$

s.t.

$$\left(\sum_{r=1}^{k} \mu_r y_{r_j}\right) / \left(\sum_{i=1}^{m} v_i y_{i_j}\right) <= 1,\ j = 1,2,\ldots,n$$

$$\mu_r,\ v_i => \varepsilon,\ r=1,2,\ldots,k \ ;\ i=1,2,\ldots,m$$

$\varepsilon > 0$ (Non-Archimedean)

The second step consists of the measurement of the ecological efficiency (g_0), through the calculation of the weights to be applied to the desirable outputs (μ_r) and the undesirable outputs (μ_s). This model is also denominated "Deep Ecology" (Korhonen and Luptacik, 2004):

$$\text{Max } g_0 = \left(\sum_{r=1}^{k} \mu_r y_{r_0}\right) / \left(\sum_{s=k+1}^{p} \mu_s y_{s_0}\right) \quad (3)$$

s.t.

$$\left(\sum_{r=1}^{k} \mu_r y_{rj}\right) / \left(\sum_{s=k+1}^{p} \mu_s y_{sj}\right) <= 1,\ j = 1,2,\ldots,n$$

$$\mu_r => \varepsilon,\ r=1,2,\ldots,p$$

$\varepsilon > 0$ (Non-Archimedean)

Then it is possible to combine the results of both models as the output variables for the new DEA model (with the inputs equal to 1), in order to find an indicator for eco-efficiency.

4. CASE STUDY

4.1 Area description

The Candelaro river is located in southern Italy within the Capitanata Board (CBC) system that covers a surface of 442,000 ha and a population of less than 500 thousand people living in 39 municipalities (ISTAT, 2001). The irrigation board is located within the Apulia region, a semi-arid area with fluctuating precipitation and increasing man-made pressures. The yearly average of rainfall is 500-700 mm, mostly concentrated in autumn and winter, but there are also recurrent periods of drought. In addition, water management issues include, water allocation among sectors (i.e. agriculture, industry and urban) water quality, and, in many areas, groundwater overdraft.

Water supply for irrigation campaigns lasts from April to November, and every year the system conveys about 106 million of m^3 accumulated in autumn and winter in the catchment systems. Apart from the water conveyed by the CBC, groundwater is the other source serving the agriculture, estimated to cover about 60% of the overall irrigation water (INEA, 2005).

The infrastructure managed by the irrigation board consists of a network of underground pipelines, through which high-pressure water is conveyed to final distribution points, from which farmers may directly attach their devices (e.g. sprinklers, drip irrigation systems). The water supply is available on demand.

At present, water is allocated through a system of water rights. In most cases, water rights are based on the historical use of the resource by the farmers. Farmers are not allowed to exchange their water use rights, although the use of water is indirectly transferred through the lease of farmland. In the case of water shortages, water is diverted from irrigation to industry and municipal uses, with no compensation given for farmers' loss in revenue.

The types of agricultural systems found in the area are mainly, rain fed cereals, basically durum wheat amounting to 61% of UAA (CCIAA, 2007). A single crop system based on durum wheat is farmed in most of area where water is unavailable. Depending on water availability, vegetable and orchard crops (which are irrigated crops) are highly profitable, compared to wheat. Among them, processed tomato (4%) and vineyard (7%) are the major profitable crops. In addition, irrigated agriculture consists of the fresh vegetable crops, representing important cash crops for the region, covering 9% of area. Finally, the olive grove systems for olive oil production cover almost 12% of the area. Olive grove is a Mediterranean crop with a strong capacity to adapt to water scarcity and is a partially irrigated crop, according to water availability. Some descriptive data are reported on Table 1.

Table 1: Main crops data of the case study

Cropping patterns (ha)	
Durum wheat	176,000
Sugar beet	13,400
Tomato crop	29,000
Broccoli	2,400
Olive trees	21,000
Grape wine	9,800
Grapes fruit	3,700
Peach	1,700
Others	9,000

Source: Elaboration on national statistical data (ISTAT) and Capitanata Irrigation Board (Consorzio per la Bonifica della Capitanata, CBC), referred to year 2006.

4.2. Data modelling

Farms were classified into three main groups according to farm size and cropping patterns.

According to the ISTAT (2001) data, farms are conducted by elderly farmers (40% of whom are over 65 years old), and labour is provided by the farming family (in 95% of cases). The major difference between farms types concerns labour. In small farms, the labour is provided by the farmer's family members, while in the case of large farms, it is provided by hired workers. The three types of farms also differ in terms of the "single farm payment" under the current CAP regulation. In addition, there are some relevant differences among the crops (such as yields, prices, and input uses), which have been included in the model. Although irrigation technology varies across crops, it is almost the same across the farms operating in the area. Drip irrigation is the dominant technique, for irrigated crops, while durum what is always rain fed. The technical coefficients consider the agronomic rotations typically adopted by the farmers in the area. Input and output prices are based on the average (2004-2007) local market prices (Bulletin of the Chamber of Commerce). The size of each farm is fixed. Demand and supply constraints (agronomic operations, input availability, permanent crop area, and CAP framework) reflect the current farms' features. The resource constraint for water is specified to accommodate the water delivery schedule from the CBC, which distributes some 106,000,000 m^3 between April and November. In the case of the non-CBC water source, there are constraints with regard to delivery, and availability is estimated at 89,000,000 m^3 at the most. The latter is particularly fragile and it is currently monitored and controlled very little by water authorities. In fact, a reform to control the excessive exploitation of natural resources leading to irreversible environmental degradation started in 2008[5].

Table 2: Variables for measuring input, output and externalities

Conventional Resources						
	Input				Output	
	Land	Labor	Capital	Water	Farmer's Revenue	Value added
Unit of measurement	10^3 hectares	10^3 hours	10^6 euro	$10^6\ m^3$	10^6 euro	10^6 euro
Environmental Externalities						
	Desirable outputs	Undesirable outputs				
	Water saving	Pesticides risk	Nitrate surplus			
Unit of measurement	$10^6\ m^3$	10^3 Kg	10^6 t			

The variables of input, output and externalities derived from the optimal solution representing the current situation (baseline) is shown on (Table 2).

Pesticides and fertilisers impacts represent the environmental undesirable outputs. Pesticide risk is estimated by combining information about a pesticide's toxicity and exposure to that pesticide, with information about pesticides use (OECD, 2001, pg. 149). Nitrate surplus is the physical difference between nitrogen inputs and outputs from an agricultural system, per hectare of agricultural land (OECD, 2001, pg. 20). All nitrogen put into cultivated soil is considered to be input, while that embedded into the harvested production is considered as output.

For the purposes of this research, data on pesticides risk and nitrate surplus are from Giannoccaro et al. (2009). For the case study, values are referred to each crop (per hectare of farmland) on the basis of technical and agronomical farming practices typically adopted by farmers in the area.

Finally, as pointed out by Korhonen and Luptacik (2004), positive externalities can also be included as desirable environmental outputs.

Taking into account the most sensitive water problem for the area study on groundwater depletion, water saving is referring to the amount of groundwater saved from agriculture system under different pricing options.

4.3 Water policy scenarios

Simulations are made to consider both the effects of the pricing scheme and the level of the price charge, in order to consider the effects of the enforcement of the WFD. The scenarios considered in the analysis are presented on Table 3.

Table 3: Structure of the water pricing policy simulations

Pricing scheme	Price charge		
	Current	Moderate increase	Significant increase
Baseline	1a.Baseline	1b.Baseline +	-

Tot_Vol	2a.Tot_Vol	2b.Tot_Vol+	2c.Tot_Vol++
Area	3a.Area	3b.Area+	-
Input	4a.Input	4b.Input+	-
Output	5a.Output	5b.Output+	-
Quota	6a.Quota	6b.Quota+	6c.Quota++

As follows, a brief description of the main features of each scenario is provided.

1a.Baseline: the current situation refers to a situation in which the pressure water distributed by the water irrigation board is charged according to increasing block tariffs, while the water from other sources (non-CBC) is free of charge, although farmers have to face the burden for pumping the water and pressuring into their irrigation systems. Water pricing currently consists of a fixed annual fee per hectare (around 15 EUR/ha), and Increasing Block Tariffs. Two tariffs, respectively 0.09 EUR/m^3 for consumption up to 2,050 m^3/ha, and 0.18 EUR/m^3 from 950 m^3/ha, and 0.24 EUR/m^3 are applied. A third tariff, 0.24 EUR/m^3, is applied in the case of exceeding 3,000 m^3/ha. In the case of non-CBC water, farmers are assumed to carry only the private cost (0.09 EUR/m^3) of lifting, accumulating, and pressuring water. In this case a high technical efficiency is expected, but with a low eco-efficiency, since farmers tend to overuse natural water sources;

1b.Baseline+: it is assumed a moderate increase of water tariffs on the pressure water distributed by the irrigation board, consequently to the full cost recovery principle of the WFD. According to the economic theory, the rise of the input price leads to an increase in the technical efficiency on the pressure water, while the pressure on natural water sources is unchanged. However, farmers try to substitute pressured water with groundwater;

2a.Tot_Vol: similarly to the baseline, the pressure water is charged with increasing block tariffs, while a volume tariff is also applied to groundwater. In this case, the rise of the eco-efficiency is expected;

2b.Tot_Vol+: a moderate increase in water tariffs is assumed for both pressure and natural source water. Consequently, farmers are expected to make a more efficient use of both water sources, leading to an increase in the technical and the eco-efficiency;

2c.Tot_Vol++: a significant increase in water tariffs is applied, closer to its marginal product value. According to the WFD, this will lead to a higher efficiency. However, from the farmers' point of view, this implies an excess of burden and, therefore, a reduction in terms of technical efficiency;

3a.Area: volume pricing is substituted by a fixed charge per hectare of irrigated land, regardless of the consumption of water. This scheme is easier to be implemented, but is supposed to negatively affect the technical efficiency. Eco-efficiency may increase, as there is a loss of incentive among farmers to overuse water from natural sources;

3b.Area+: similar to the above, but by applying a higher tariff. No further effects are expected on the efficiency, in respect to the above pricing scheme;

4a.Input: the water tariff is proportional to the specific costs for the inputs of irrigated crops. Since the input for intensive irrigated crops are also responsible for environmental pollution, this pricing scheme is expected to raise the eco-efficiency;

4b.Input+: similarly to the above scenario, a further increase of the water tariff is supposed to pursue a higher eco-efficiency;

5a.Output: the water tariff is proportional to the value for agricultural sale of irrigated crops.

Although this method seems more equitable, it is supposed to lead to a lower technical efficiency;

5b.Output+: similar to the above scenario, an increase in the water tariff is supposed to lead to a higher efficiency. However, an excess of water charges may produce the opposite effect;

6a.Quota: the tool to control the water consumption is not relying on water price, but relies on the enforcement of rigid constraints on the water availability to each farm. A relatively lower water charge is applied and, farmers are still expected to achieve a higher technical efficiency. The rigid control also on natural sources is expected to lead to a higher eco-efficiency;

6b.Quota+: similar to the above, but with a moderate reduction in terms of water availability to each farm. The reduction of water availability is expected to increase the technical efficiency;

6c.Quota++: similar to the pricing scheme 5.a, but with a significant reduction of the water availability. The higher efficiency due to the lower availability may be offset by the lower profitability of farming.

5. RESULTS AND DISCUSSION

The starting point for the DEA is the pay-off matrix resulting from the optimal solutions of the simulations found by the linear programming model (see the appendix). The outcome of each water pricing policy is represented by the basic production inputs (land, labour, capital, and water use), the most relevant economic indicators (farmers' revenue and value added), the desirable environmental output (groundwater saving), and the undesirable environmental output (pesticides risk, nitrates surplus).

The analysis of the efficiency consists of the ranking of the relative efficiency of the performance of the regional agricultural system under different water pricing policy. In the case of efficient policy, the score is equal to 1, while on the contrary, in presence of inefficiency, this score is lower than 1. In order to disclose the cause of the inefficiency, the DEA provides the assessment of the residual slack, in terms of input excess or output shortage. This concept is related to DEA, and refers to the problem arising because of the section of the DEA frontier which runs parallel to the axes.[6] In other words, the values of each slack are the explanation of the reason for policy inefficiency.

First, we analyse technical efficiency accounting for farmers and sector perspectives separately. In Tables 4 and 5, the results of the DEA are shown.

Table 4: Score of the technical efficiency and DEA slack (private perspective)

Water policy		Input excess				Output shortage
	Score	Land	Labour	Capital	Water	Farm revenue
1a.Baseline	0.98885	6.00000	4.00000	34.00000	-	-
1b.Baseline+	0.98043	11.30368	0.49173	14.25177	-	-
2a.Tot_Vol	0.98070	9.24547	4.18122	37.44152	1.60626	-
2b.Tot_Vol+	1.00000	-	-	-	-	-
2c.Tot_Vol++	1.00000	-	-	-	-	-
3a.Area	0.97415	15.92127	0.91065	23.87629	-	-
3b.Area+	0.89007	81.55848	2.66063	80.11862	2.44646	-

4a.Input	1.00000	-	-	-	-	-
4b.Input+	0.99671	58.69852	0.05931	6.28995	10.98023	-
5a.Output	0.99176	3.24547	2.18122	14.44152	1.60626	-
5b.Output+	0.88979	75.29489	2.20428	76.44316	33.26524	-
6a.Quota	0.98885	6.00000	4.00000	34.00000	-	-
6b.Quota+	0.98949	4.43420	4.01062	30.56915	-	-
6c.Quota+	1.00000	-	-	-	-	-

The first step of the DEA (Frontier Economics) shows differences in the policy efficiency. This proves that changes in water pricing policies induce farmers to adopt different farm strategies and thus different farm performances.

At farm level analysis, total of 4 options out of the 14 simulated are the relatively most efficient. Average efficiency value is 0.97648, and minimum value is 0.88979 for 5b.Output+ policy option. This means that, in order to be efficient, policy 5b.Output+, should induce a lower consumption of all inputs by 11.026%.

A similar result is found taking into account overall agricultural system (Table 5). In this case 8 policy scenarios are efficient, showing that the current pricing policy is already efficient. The 2a.Tot_vol scheme is efficient, but it shows a slack for the capital value amounts to EUR 2 million. Lowest efficiency score is found for the area pricing (3b), while sample reaches 0.97641, average efficiency.

Through analysis of the slacks, results show also that in all cases, the area pricing is less efficient, as it induces an excess use of all inputs.

In the case of output pricing, the efficiency loss occurs only in the case of a higher pricing level, due to an overuse of capital and water. In this case, the efficiency seems related with finding the most suitable pricing level. This concept may be extended to the Quota schemes.

As a whole, technical efficiency under both approaches reaches a good score, showing on average 97.6% of efficiency.

From a comparative analysis between the two different perspectives, emerges that only 4 options are the most efficient under both approaches (2b, 2c, 4a, 6c). The efficiency score for the overall agricultural system marks more policy options as best efficient. Anyway, similar average efficiency value is reached, even if the lowest value is found for the sector perspective analysis.

Spearman rank correlation coefficient (R), which is adopted to determine the measure of association between ranks obtained by two different approaches, is used in the present study (Gibbons, 1971). When the Spearman R values assumes values, respectively, of1, 0 and -1,

Table 5: Score of the technical efficiency and DEA slack (public perspective)

Water policy		Input excess				Output shortage
	Score	Land	Labour	Capital	Water	Value Added
1a.Baseline	1.00000	-	-	-	-	-
1b.Baseline+	0.99907	0.67157	-	8.29872	-	-
2a.Tot_Vol	1.00000*	-	-	2.00000	-	-
2b.Tot_Vol+	1.00000	-	-	-	-	-
2c.Tot_Vol++	1.00000	-	-	-	-	-
3a.Area	0.97670	13.53024	-	14.89516	8.33871	-
3b.Area+	0.84152	92.48726	1.85350	69.63694	27.78344	-
4a.Input	1.00000	-	-	-	-	-
4b.Input+	1.00000	-	-	-	-	-
5a.Output	1.00000	-	-	-	-	-
5b.Output+	0.85261	87.26115	1.50318	66.94268	58.43949	-
6a.Quota	1.00000	-	-	-	-	-
6b.Quota+	0.99981	-	0.29679	-	0.19898	-
6c.Quota++	1.00000	-	-	-	-	-

*Weak efficiency, according to the slack value

it means perfect association, no association and perfect disagreement respectively between the approaches. The result of non parametric test was 0.786, indicating high association value, but not at all in all cases.

According to the results of this analysis, it is not proved that the implementation of the volumetric pricing will necessarily lead to a higher efficiency, in comparison to other methods. The application of quota to a direct water allocation to farmers as well as indirect pricing method on the irrigation inputs also represents a valid alternative to direct water pricing.

In addition, the enforcement of higher pricing does not increase the efficiency, but it rather induces a substitution of the water source with other inputs (land, labour, and capital).

The second step of DEA is reported in the Table 6 and 7. Following the previous analysis on the technical efficiency, the eco-efficiency from the farmer's point of view, reaches the highest value only for 3 policy options (2b.Vol_tot+, 2c.Vol_tot++, 4a.Input). Average efficiency value is 0.93736, and minimum value is 0.84890 for Output+ policy option. Current pricing policy (1a.Baseline) is not best efficient, meaning that there is opportunity to improve environmental efficiency through a water pricing reform.

The findings for the agricultural system stress that eco-efficiency reaches the best value for 4 out of the 14 options analysed. According to the Table 7 direct water pricing (2b.Vol_tot+, 2c.Vol_tot++), as well as indirect pricing options (4a.Input, 5a.Output), are relatively more efficient. Lowest efficiency score is found for the area pricing (3b.Area+) that covers 0.795257 efficiency value. The average value for all sample accounts for 0.95257 efficiency level.

Table 6: Score of the ecological efficiency and DEA slack (private perspective)

Water policy	Undesirable Output excess	Desirable Output shortage

	Score	Nitrate surplus	Pesticide Risk	Water Saving revenue	Farm
1a.Baseline	0.93103	-	30.91193	38.46831	-
1b.Baseline+	0.87392	-	26.50041	71.42305	-
2a.Tot_Vol	0.92337	-	32.80082	42.74609	-
2b.Tot_Vol+	1.00000	-	-	-	-
2c.Tot_Vol++	1.00000	-	-	-	-
3a.Area	0.93410	-	104.15638	36.75720	-
3b.Area+	0.85338	1.57447	146.08511	45.36170	-
4a.Input	1.00000	-	-	-	-
4b.Input+	0.96559	-	80.94321	13.11975	-
5a.Output	0.99176	-	111.88889	4.27778	-
5b.Output+	0.84890	0.35783	83.92843	68.12766	-
6a.Quota	0.93103	-	30.91193	38.46831	-
6b.Quota+	0.92797	-	28.66749	40.17942	-
6c.Quota++	0.94205	-	23.74486	31.21193	-

Table 7: Score of the ecological efficiency and DEA slack (public perspective)

		Undesirable Output excess		**Desirable Output shortage**	
Water policy	**Score**	Nitrate surplus	Pesticide Risk	Water Saving Added	Value
1a.Baseline	0.98875	-	16.37509	9.92469	-
1b.Baseline+	0.92747	-	16.79870	88.48443	-
2a.Tot_Vol	0.98875	-	16.37509	9.92469	-
2b.Tot_Vol+	1.00000	-	-	-	-
2c.Tot_Vol++	1.00000	-	-	-	-
3a.Area	0.92893	-	103.68646	63.86604	-
3b.Area+	0.79891	-	98.61538	65.84615	83.76923
4a.Input	1.00000	-	-	-	-
4b.Input+	0.93986	-	81.04852	43.63505	-
5a.Output	1.00000	-	-	-	-
5b.Output+	0.81170	-	65.00000	84.00000	59.00000
6a.Quota	0.98875	-	16.37509	9.92469	-
6b.Quota+	0.98329	-	15.09269	16.88487	-
6c.Quota++	0.97954	-	15.05214	20.62274	-

Comparative analysis between the two different perspectives, points out that only 3 options are best efficient under both approaches (2b, 2c, 4a). Average efficiency value is higher for the agriculture sector, reaching 95.2% efficiency level, even if the lowest value is found at agricultural system level. Spearman rank correlation coefficient (R), is 0.783, indicating similar association to technical efficiency in the case of environmental efficiency.

As a whole, it is confirmed that the volumetric pricing applied to the pressure water and to the natural sources will lead to the highest eco-efficiency, though input and output pricing may also lead to similar results. In addition, it is clear that a careful analysis on the effects of the pricing levels is also required.

Area pricing is the least efficient policy, regardless of the pricing level. The input pricing, at the current pricing level is among the most efficient, but contrarily to initial expectations, higher levels may have a lower efficiency due to an excess of environmental externality (pesticide risk).

Lastly, the overall efficiency index is reported on Table 8 and 9.

It is evident that the current situation is not efficient, but the magnitude of improvement in efficiency is at least less than 2% (at farm level). It is confirmed that the full volumetric pricing is the most efficient, as well as the input pricing (to a certain extent). However it is important to evaluate the impact of the pricing level.

In the case of the quota method, it emerges as an interesting alternative, since its efficiency levels are rather high, relatively to other methods. Area scheme is always the less efficient.

Table 8: Rank of water pricing policy options: eco-efficiency score (private perspective)

Pricing scheme	**Price charge**		
	Current	Moderate increase	Significant increase
Baseline	0.98885	0.98043	-
Tot_Vol	0.98070	1.00000	1.00000
Area	0.97415	0.89007	-
Input	1.00000	0.99671	-
Output	0.99176	0.88979	-
Quota	0.98885	0.98949	1.00000*

*Weakly efficient according to the slack value

Table 9: Rank of water pricing policy options: eco-efficiency score (public perspective)

Pricing scheme	**Price charge**		
	Current	Moderate increase	Significant increase
Baseline	1.00000*	0.99907	-
Tot_Vol	1.00000*	1.00000	1.00000
Area	0.97670	0.84152	-
Input	1.00000	1.00000*	-
Output	1.00000	0.85261	-
Quota	1.00000*	0.99981	1.00000*

*Weakly efficient according to the slack value

6. CONCLUDING REMARKS

The reform of water pricing methods is one of the mandatory policy instruments in the WFD for the enhancement of water efficiency and the improvement of its quality status, as well as the protection of natural sources depletion. Policy makers require a clear overview of the different outcomes deriving from alternative water management policies, and tools aimed at decision support are needed in order to select of the most suitable option. This research is committed to providing knowledge either, to public decision maker and to farm representatives in order to allowing or facilitating a participatory process based on scientific evidence.

In the present paper we propose a methodology based on DEA, specifically developed to assess the relative technical and ecological efficiency of an agricultural system subject to alternative water pricing policies. These measures of the efficiency may be convenient for ranking policy options in case of scarce information on social preferences towards some outcomes, as well as in presence of some externalities.

According to our findings, some differences emerge among alternative pricing schemes, in terms of technical and ecological efficiency. It is confirmed that the full volumetric pricing is efficient, but also some indirect pricing (e.g. input pricing) show very close levels of efficiency. In addition, the efficiency seems affected also by the pricing level. Therefore, in order to enhance water efficiency, it is important to focus either, on the pricing scheme and also on the pricing level.

The enforcement of tariffs does not result in technical or environmental efficiency improvements. As a consequence, this policy implication may be important given that water policy reforms are addressed to increase water price according to the WFD 'cost recovery' concept. However, it is worth mentioning that the study is based on a short-term horizon, with a fixed coefficient linear programming model. Therefore, further research is still needed aimed at exploring technological change that farmers may decide to introduce, in the long run.

Finally, it should be kept in mind that volumetric allocation and charging do imply an inherent additional cost, given by higher investment for water measurement technology and its management (public and private). There are also some additional administrative and hardware costs associated with volumetric charging because of the need of keeping good records and to have accurate flow rate measurement devices. As a consequence, since indirect methods are claimed to be easily implemented (Tsur and Dinar, 1995), they might be preferable, without significant losses in terms of efficiency.

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Appendix

Pay-off matrix

	Input				Output		Externalities		
Pricing	Land	Labor	Capital	Water	Farm Revenue	Value Added	Water Saving*	Pesticide Risk	Nitrate Surplus
1a.Baseline	400	26	209	195	607	657	0	711	29
1b.Baseline+	399	21	195	148	546	589	0	668	28
2a.Tot_Vol	400	26	211	195	602	657	0	711	29
2b.Tot_Vol+	394	20	190	118	517	562	77	615	27
2c.Tot_Vol++	394	19	189	106	492	543	89	603	26
3a.Area	412	23	200	195	609	626	0	785	29
3b.Area+	410	21	226	165	506	501	30	748	28
4a.Input	394	22	175	195	607	617	0	649	27
4b.Input+	380	18	149	170	495	509	25	641	24
5a.Output	394	24	188	195	602	631	0	759	27
5b.Output+	394	20	218	191	491	484	5	668	26
6a.Quota	400	26	209	195	607	657	0	711	29
6b.Quota+	400	26	207	192	605	653	0	708	29
6c.Quota++	398	24	196	172	593	628	0	683	28

*Water saving refers only to the groundwater source

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[1] Coelli proposes a multi-stage DEA version, where a sequence of radial PL's to identify the efficient point are conducted. By contrast earlier versions (i.e. one-stage and two-stage) are not invariant to units of measurement.

[2] This document gives a snapshot of the situation of implementation in the Member States, based on reports due to be submitted in 2004 (for transposition and article 3) or 2005 (for article 5). According to the Directive's timetable, implementation of water pricing policy is due to by 2010 (Art. 9). It is not envisaged to update this report before 2012 when the first comprehensive implementation report is required in accordance with Article 18 (1).

[3] Following the directive framework, we preferred to take into account only the relating fertilizers and pesticides pollution, as well depletion of water resources. The general model it could hold more variables.

[4] The value of this parameter is empirically found, through a "trial and error" process, when the overall water consumption calculated by the simulation model is equal to the current water consumption.

[5] Reform has been introduced by the Regional Law No 9 of May 2008 (PUGLIA, L.R. n. 9/2008).

[6] See Coelli (1996) for more details.