# DEA APPLICATION TO EVALUATE THE TECHNICAL AND ECOLOGICAL EFFICIENCY OF WATER PRICING POLICIES

**Giannoccaro G., Prosperi M., Zanni G.**

**University of Foggia**
**Contact: m.prosperi@unifg.it**
**Via Napoli, 25 – 71100 Foggia - Italy**

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# DEA APPLICATION TO EVALUATE THE TECHNICAL AND ECOLOGICAL EFFICIENCY OF WATER PRICING POLICIES[§]

Giannoccaro G., Prosperi M., Zanni G.

*Dept. PrIME, University of Foggia, Via Napoli, 25 - 71100 Foggia - Italy*
*Contact: m.prosperi@unifg.it*

## Abstract

*With the enforcement of the Water Framework Directive 2000/60/EC (WFD), policy makers are required to pursue the improvement of the use efficiency of the water resources in the agricultural sector. For this purpose, we suggest a methodology to perform an ex-ante analysis of the efficiency of water pricing policies, based on a two stage DEA technique, by which it is possible to disaggregate the technical and the ecological efficiency of the policy. According to our results, we found that, coherently with the WFD principles, the direct pricing methods show the highest levels of efficiency. However, we have also found that some indirect pricing methods show relatively high levels of efficiency. Therefore, since the high cost for the management and implementation of water measurement devices required to apply the volumetric methods, indirect pricing methods might still be preferable.*

**Key words: Data Envelopment Analysis, efficiency, water pricing, water framework directive**

## 1. Introduction

With the enactment of the Water Framework Directive 2000/60/EC (WFD), member states are expected to revise significantly water pricing policies, according to a river basin management approach. The WFD emphasizes the need to fully consider the "polluter pays principle", as well as the the full recovery cost for water use, including distribution, environmental and opportunity costs. In most of cases this new approach implies a dramatic reform of water pricing policies.

Since the largest water consumer is represented by the agricultural sector, the analysis of water policy reform impacts is a relevant issue, for which several aspects deserve to be investigated. Furthermore, in different climatic areas (e.g. Mediterranean basin), the water resource cannot be substituted with other production factors, therefore an eventual water policy change is expected to affect the efficiency of the whole agricultural sector. For this purpose, the present study is focused on the analysis of the efficiency of the agricultural sector, under different water pricing policies. The measure of the efficiency may be useful to support policy makers while choosing among alternative water pricing schemes.

In particular, this paper challenges a methodology to perform an *ex ante* analysis of alternative water pricing policies, consisting firstly on a simulation of alternative water policy application, through a regional multi-agent linear programming model, and secondly on the analysis of the results with a modified Data Envelopment Analysis, as proposed by Korhonen and Luptacik (2004), allowing to

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decompose the efficiency into technological and ecological efficiency. The technical efficiency is calculated as the ratio between the weighted sum of multiple outputs and inputs. The ecological efficiency emphasizes the concept that, in order to achieve a certain output, the production process necessarily produces also some undesirable outputs (pollutants, or emissions). Therefore, the ecological efficiency is calculated as the ratio between the weighted sum of multiple desirable outputs and undesirable outputs.

This methodology is useful whenever there are no informations about the relative importance among outputs or inputs. In fact, the DEA deals with variables regardless to their unit measure, and does not require assumptions *a priori.*

The paper shows an application of the methodology on a case study referred to the application of alternative water pricing policies on an irrigated area of the South of Italy. The volumetric pricing scheme, considered to be the most efficient, has been compared with indirect water pricing schemes (pricing referred to area, inputs, outputs) and the application of quota. In fact, we found that volumetric pricing methods are the most efficient. However, also some of the indirect pricing methods have also shown a relatively high efficiency. Furthermore, the change of the Common Agricultural Policy (CAP) has also taken into account, and we found that it may significantly affect the efficiency of the water use, therefore water tariffs may require periodical adjustments.

The structure of the paper is the following. In the next paragraph, we introduce the basic principles of the WFD and the characteristics of the most diffused water pricing methods. In paragraph 3 we propose the methodology for the *ex-ante* analysis of alternative water pricing policy, based on a two step DEA methodology, by which it is possible to discriminate between the technical and ecological efficiency. In paragraph 4, we present a case of study, referred to an area in the South of Italy, in which we compare the efficiency of volumetric pricing methods, with indirect pricing methods (input, output, and area based), and a quota system. In paragraph 5 the results are discussed, while in paragraph 6 some concluding remarks are discusses.

## 2. Pricing policy

The WFD is aimed at the pursuing of a good water quality status before 2015 all over EU member states. Within this period, EU member states are expected to reform their water regulatory framework, and the adoption of the full recovery cost and the polluter pays principles is recommended.

The enforcement of the WFD will likely affects remarkably the agricultural sector, for two main reasons. Firstly, the agricultural sector is the largest water consumers, with share ranging 60-70% of fresh water bodies. Secondly, the water resource in some environmental conditions, represents an indispensable input for intensive cropping systems, that are very relevant either for producing foodstuffs, as well as a source of agricultural revenues.

In accordance with the WFD perspective, the economic theory suggests that the most suitable water pricing scheme is represented by direct pricing methods, based on volumetric systems. In this way, users will pay proportionally to their consumption, and a certain degree of fairness among users is also pursued. However, the pricing methods are not always able to take account of the externalities consequent to the water use. Crops differ in terms of environmental impact, that is not always related with the water consumption. Moreover, volumetric systems are costly and not suitable for monitoring of natural water sources (e.g. underground water, wells, etc.).

Consequently, there are several examples of alternative water pricing methods that, though less efficient, may be offer several advantages, such as lower management costs, easier to be monitored, suitable for pricing diffused natural water sources. In this research we compare the volumetric methods with the following indirect pricing methods:

a) fixed *per area* pricing method: farmers have to pay an amount that is proportional to the irrigated farmland, but is not related with the demand of water. This method might be relatively easy to be managed and monitored through GIS systems. It is not fair and it does not represent an incentive for farmers to adopt water-saving cropping methods;

b) value of inputs specific to irrigated crops: the cost for water consumption is calculated according to the inputs necessary to the cultivation of irrigated crops (e.g. seeds, plants, mulching materials, etc.). In many cases intensive crops are also responsible for externalities, therefore this method, to a certain extent, is coherent with the polluter pays principle;

c) value of outputs from irrigated crops: in this case the most profitable crops will lead to a higher cost for water consumption. It is relatively fair, but may not induce farmers to choose the most profitable use of water.

Besides these methods, we also consider the quota method, in which farmers are allowed to make the best use of a limited amount of water resource, for which they pay a discounted tariff. The application of tariffs lower than the marginal productivity leads usually to an inefficient use of the resource.

Alternative water pricing policies will likely induce farmers to different firm strategies, and therefore to a different performance. However, policy makers require a clear overview of the different outcomes deriving from alternative water pricing policies, and therefore a further analysis in required, through which the most suitable policy to the specific situation will be preferred (Tyteca, 1996).

It is necessary, therefore, to define a set of criteria, according to which the effects of the policy are measured. Inputs, outputs, and externalities can be measured in physical or value terms, but the most difficult task relies on the comparison of different performances.

In the case the relative importance of each criteria is already known, it is possible to proceed to a multi-criteria analysis, in order to obtain the ordered rank of the most preferred scenario. This sort of methodologies are generally referred with the term *parametric* analysis.

However, there are many cases in which the relative weights between the criteria are hard to be specified. Therefore, non-parametric methods, such as the DEA, are suitable, since they do not require a priori assumptions, while the emphasis is put on the efficiency of the production process, that is generally defined as the ratio between outputs and inputs.

The first non-parametric analysis to compare multiple desirable and undesirable outputs is reported in Fare et al. (1989), in which a 1976 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 for undesirable outputs. Their results showed that the performance rankings of DMUs turned out to be very sensitive to whether or not undesirable outputs were included. The emphasis to the ecological issue has occurred later, and generally externalities has been treated as undesirable outputs of the production process. Tyteca (1996) presents an exhaustive literature review. 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 firstly proposed by Korhonen and Luptacik (2004), in order to measure the technical and the ecological efficiency of different water pricing policies. This methodology allows the calculation of the relative efficiency and, consequently, the ranking of most efficient policies, either considering the technical and the ecological aspects.

## 3. Methodology

The evaluation *ex ante* of the efficiency of the policy requires figures of the expected outcomes in terms of inputs, desirable outputs and undesirable outputs. For this purpose, econometric models or mathematical programming models are suitable to simulate the effects of the water pricing policy. In our case, we adopted a multi-agent regional linear programming model (Tisdell 2001; Berbel e Gutierrez 2005, Chinnici et al. 2006), mostly because we did not have time series referred to the case of study, or referred to similar areas. Furthermore, mathematical programming models provide technically optimal strategies adopted by farmers, therefore the comparison between different policies would reveal the inefficiency related to the implementation of the policy for the specific case of study, and nothing else.

The objective of the optimization model is the maximization of the regional agricultural gross revenue (*GR*) of the region, as follows:

$$Max\ GR = \Sigma_j\ \lambda_j \left[\Sigma_i\Big((\ x_{i,j}\ \ q_i\ \ p_i\ -\ mls_{i,j}) - \Sigma_z (x_{i,j}\ \ c_{i,z}\ v_{i,z}) - \Sigma_b\ \Sigma_z (x_{i,j}\ \ a_{i,b,r}\ w_{i,b,r})\Big) - Fix_j + \ SFP_j\right] \quad (1)$$

s.t.:

$\Sigma_i\ (x_{i,j}\ \ t_{s,i}) \leq T_{s,j}$ (farmland availability, for the *j* farm type and the *s* season)

$\Sigma_i\ (x_{i,j}\ \ a_{b,r,z}) \leq W_{b,r,j}$ (water availability, for the *j* farm type, and the *b* water source typology)

$\Sigma_i\ (x_{j,i}\ \ l_{c,i}) + lr_{c,s,i}\ \leq L_{c,s,j}$ (labour availability, for the *j* farm, and the *c* labour type, for the *s* season)

where:

$\lambda_j$ : weight of the *j* farm typology;

$x_{i,j}$ : activation level of the *i* production process, by the *j* farm typology;

$q_i$, $p_i$, $mls_{i,j}$ : yield, market price, and parameter for model calibration, related to the *i* process;

$c_{i,z}$, $v_{i,z}$ : technical coefficient of the *z* input, and its market price;

$a_{b,r,i}$, $w_{b,r,i}$ : specific water consumption for the *i* production process, of the *b* source type, subject to the *r* tariffication scheme;

$Fix_j$, $SFP_j$ : fixed running costs of the j farm, and the single farm payment, under the CAP regime.

The simulation of the policy is performed by modifying water tariffs and the quota allocated to each farm type. From the simulation of each policy, the most significant variables are selected, referred to critical inputs, desirable outputs, and undesirable outputs. These variables, that will be analyzed by the DEA technique, can be classified into three typologies: economic outcomes (e.g. added value, profit), technical indicator of performance, and environmental impact indicators (e.g. pollutant loads).

The DEA (Charnes *et al.* 1978) is a technique based on the application of a linear programming algorithm, aimed to find the most suitable weights for each variable such that the ratio of outputs on inputs of several data set, is made as closer as possible to 1. Once the most suitable weights are found, from each data pattern (performance of a decision making unit, or outcomes of each policy) the relative efficiency index is calculated (the most efficient equal to 1, while other have a lower index).

In this research a modified DEA technique, proposed by Korhonen and Luptacik (2004) is applied, in order to separate the technical and the ecological efficiency of different water pricing policies. In case of the comparison of *n* water pricing policies, we simulate their effects through the above discussed linear programming model, and we find the amount of *m* production inputs, and the *k* outputs.In particular, for *k=1,2,..,r*, we identify the subscript for desirable outputs, while for *k=r+1, r*

+2,.., $p$, we specify the undesirable outputs. Therefore, in the case of the implementation of the $j$ policy, we have the vector $x_{ij}$ of the inputs and the vector of outputs $y_{rj}$.

The DEA technique consists of the two following steps:

a) measurement of the technical efficiency of the policy '0' ($h_0$), according to the basic traditional model of DEA. The model is also named "*Frontier Economics*", and consists of a linear programming model through which the (positive) weights to be applied to outputs ($\mu_r$) and inputs ($v_i$) are estimated, in order to find a ratio of output on inputs that is lower or equal to *1*:

$$Max \quad h_0 = \frac{\sum_{r=1}^{k} \mu_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \tag{2}$$

$$s.t. \quad \frac{\sum_{r=1}^{k} \mu_r y_{rj}}{\sum_{i=1}^{m} v_j x_{ij}} \leqslant 1 \quad , \quad j=1,\ 2,\ldots,n$$

$$\mu_r, v_j \geqslant \epsilon,\ r=1,\ 2,\ldots,k \quad ; \quad i=1,\ 2,\ldots,m$$

$$\epsilon > 0 \quad (\text{Non-Archimedean})$$

b) measurement of the ecological efficiency ($g_0$), through the calculation of the weights to be applied to the desirable outputs ($\mu_r$) and the undesirable outputs ($\mu_s$). This model is also denominated "*Deep Ecology*":

$$max \quad g_0 = \frac{\sum_{r=1}^{k} \mu_r y_{r0}}{\sum_{s=k+1}^{p} \mu_s y_{s0}} \tag{3}$$

$$s.t. \quad \frac{\sum_{r=1}^{k} \mu_r y_{rj}}{\sum_{s=k+1}^{p} \mu_s y_{sj}} \leqslant 1 \quad , \quad j=1,\ 2,\ldots,n$$

$$\mu_r \geqslant \epsilon,\ r=1,\ 2,\ldots,\ p$$

$$\epsilon > 0 \quad (\text{Non-Archimedean})$$

Finally, Korhonen and Luptacik suggest a third optional step, in which the inputs are equal to *1*, while the outputs are those obtained with the above models ($h_0$ and $g_0$), in order to find an overall index of efficiency.

## 4. Case of study

### 4.1. The study area

The case study is referred to the area of Foggia province, located in the South of Italy, characterized by a Mediterranean climate, whit mild winter (temperature ranging 4-12 degrees), and summer hot and dry (temperature ranging 20-42 degrees). The yearly average of rainfall is 500-700 mm, mostly concentrated in autumn and winter, but there are also recurrent periods of drought. The potential evapo-transpiration reaches 5-6 mm/day during the third decade of July, corresponding to the period in which most of irrigated crops are in the vegetative stage (e.g. tomato, grapevine).

The irrigation system 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 network is extended on the area of 442,000 ha, of which almost 32% can be potentially irrigated. The area is under the administration of 39 municipalities, although the management of the system is under the control of the land reclamation consortium of land owners, named *Consorzio per la Bonifica della Capitanata* (CBC). The irrigation campaign lasts from April to November, and every years the system conveys about 106 Million of $m^3$ of freshwater most of which is accumulated in autumn and winter in artificial lakes and reservoirs.

Apart from the water conveyed by the CBC, the usage of water from other natural sources (most of which underground water) is also very diffused and it is estimated to cover about 60% of the overall irrigation water (INEA, 2001).

At present, the CBC applies a volumetric pricing method, with increasing tariff system, aimed at a fair allocation of water volumes among landowners whose fields are served by the conveyance system. Farmers are not allowed to exchange the water use rights, although the use of water is indirectly transferred through the lease of the farmland. On the contrary, other water sources are almost out of control, and there is still difficult to delineate the precise state of depletion of natural sources, and in particular for underground water.

4.2. Data collection and modelling

The basic source of data is the 2000 Agricultural Census (ISTAT, 2000), in which farms are classified into three main groups, according to the hectares of cropped area:

a) less than 5 ha (18,199 farms), in which the owner manages directly his farm, but often is employed also in an off-farm job. The most important crops are represented by orchards (grapevine and olive), with almost 50% of the farmland, wheat, about 40%, and vegetable crops;

b) 5-20 ha (13,063 farms), managed directly by the owner, for which the farm is the main source of revenue. Most of the labour is provided by the farmer and his family, while other workers are hired during the pick season. The cropping pattern is strongly characterized by wheat (68% of the land), tomato (3%), sugarbeet (2%), vegetables (2%). Vineyard and olive occupy about 20% of the land;

c) larger than 20 ha (4,720 farms), managed directly by the farmer, but most of the labour is hired. Most of the land is occupied by extensive wheat cultivation (75% of the land), while the remaining is dedicated to intensive crops, such as tomato and vegetables. Tree crops are cultivated on 9% of the land.

In any farm typology we assume the objective of maximizing the agricultural gross revenue, since in most of the farms the land, the labour, and the capital are provided by the farmer and his family. The detail of the calculation of the gross revenue is coherent with the equation (1) discussed in paragraph 3 in this paper. In regards to the CAP, we considered two groups of scenario, one referred to the year 2006, in which the single farm payment (SFP) system is applied only to arable crops and olives, and another referred to the year 2013, in which the SFP includes also the decoupled payments of the sugar sector, and processed vegetables (e.g. tomato).

The technical coefficients included in the linear programming matrix, have been monitored through *ad hoc* interviews to local experts and representative farms. We considered the agronomic rotations usually adopted by the farmers in the area. Input and output prices are based on the average local market prices (Bulletin of the Chamber of Commerce), but also taking into account of the farmers' expectations. We assume that the farm size is constant.

The water resource availability is represented by two types of constraints. The first, referred to the amount of water allocated by the CBC, proportionally to the farmland served by the conveyance structure. The second, referred to other water sources, the availability is estimated by dividing the overall amount estimated by INEA (2001), for the overall farmland.

4.3. Water pricing policies scenarios

The scenarios we have considered, in order to evaluate the effect of the water pricing policy, are compared with the baseline, that is referred to the actual situation (CAP 2006), in which arable crops and olive oil are under a free market regime, while farmers receive the single farm payment (SFP). However, since it is expected a further enforcement of the decoupled payments system of the CAP to the sugar and the processed vegetables sectors, we assumed a second group of scenarios (CAP 2013), in which sugarbeet and tomato are supposed to be sold to a free market, while the SFP is increased accordingly.

The scenarios simulating the enforcement of alternative water pricing policies are build by following two criteria. Firstly, we assumed the substitution of the actual pricing policy with an alternative policy, but considering to charge farmers with almost the same amount for the water. Secondly, we assumed the adaptation of the water policy to the WFD principles. Our interpretation of the WFD is that the water pricing should be able to divert some of the water from the agricultural sector, to other sectors, or to make it available to the environment.

*1a.Baseline*: referred to the actual situation, in which the water allocated by the CBC is charged according to increasing block tariffs (0.09 Eur/$m^3$ up to 2050 $m^3$/ha suitable of irrigation, 0.18 Eur/$m^3$ from additional 950 $m^3$/ha, and 0.24 Eur/$m^3$ in case of further consumption). The water from other sources (non-CBC) is free of charge, although farmers have to face the burden for pumping the water up to their irrigation systems. In average we estimate a private cost of 0.09 Eur/$m^3$;

*1b.Baseline+*: we assumed a significant increase of water tariffs applied by the CBC (respectively 0.68 Eur/$m^3$ , 1.35 Eur/$m^3$, 1.80 Eur/$m^3$), in order to save some of the water conveyed by the CBC. On the contrary, the non-CBC water is still free of charge;

*2a.Vol_tot*: similar to the baseline, in which the CBC water is charged by increasing block tariffs, but with the difference that also the non-CBC water is charged by 0.03 Eur/$m^3$;

*2b.Vol_tot+*: we assumed an increase of water tariffs either for the CBC tariffs (respectively, 0.45 Eur/$m^3$, 0.90 Eur/$m^3$, 1.20 Eur/$m^3$) and for the non-CBC (0.15 Eur/$m^3$);

*2c.Vol_tot++*: we assumed an additional increase for CBC tariffs (respectively, 0.68 Eur/$m^3$, 1.35 Eur/$m^3$, 1.80 Eur/$m^3$) and non-CBC tariffs (0.23 Eur/$m^3$), in order to divert more water from the agricultural sector to other uses.

*3a.Input*: we applied an average tariff equivalent to the 17% of the specific costs for the inputs of irrigated crops. The water from CBC and from non-CBC sources is assumed to be free of charge;

*3b.Input+*: similar to the above scenario, but we applied the 37% of the costs for the inputs;

*4a.Output*: the charge for the water consumption is calculated in average in terms of 8% of the outputs obtained from irrigated crops. No other charge for CBC and non-CBC water;

*4b.Output+*: similar to the above scenario, but we applied the 13% of the outputs obtained from irrigated crops;

*6a.Quota*: we assumed a regime with a constant water tariff of 0.09 Eur/$m^3$, but a rigid constraint to the water availability to each farm, equal to 2,050 $m^3$/ha;

*6b.Quota+*: similar to the above, but the quota is limited to 1,025 $m^3$/ha;

*6c.Quota++*: similar to the scenario 6.a, but the quota is limited to 820 $m^3$/ha;

*7a.Area*: we considered a fixed charge per hectare of irrigated land of 205 Eur/ha, regardless to the consumption of water;

*7b.Area+*: the charge per hectare of irrigated land is 308 Eur/ha.

In order to simulate the group of scenario CAP 2013, we considered that prices for the commodities that are target of the reform (sugarbeet and tomato) are lower, while the SFP is increased accordingly.

## 5. Results

5.1. Simulated effects of alternative water pricing methods

The first type of results consists on the most relevant outcomes of the optimal solutions found through the linear programming model. In Table 1 we list the basic production inputs (land, labour, capital, and the water resource), the most relevant outcomes, from the point of view of the decision makers, such as economic performances (value added, value added per member of the farming family), desirable environmental impacts (land cover by vegetable crops, water saving), and undesirable environmental impacts (potential contamination by pesticides and nitrates).

By comparing scenario *2a. Vol_tot* with the *1a.Baseline*, we notice that an ideal implementation of the volumetric method also to non-CBC water sources would not lead to a significantly different results. In one hand, the administrative costs for the implementation may not be worthwhile in comparison of the additional water charges. However, in the other hand, farmers would become conscious that water resources are not abundant, nor free of charge, since their use in agriculture imply a corresponding deprivation for other sectors, or for the environment. Furthermore, the enforcement of the WFD under the baseline hypothesis, is only possible to save CBC water (*1b.Baseline+*), while under the full volumetric method, the saving of non-CBC water is more straightforward (*2b.Vol_tot+*, *2c.Vol_tot++*).

The enforcement of the indirect water charge through the estimates of input or output values, seems to cause a dramatic abandonment of land, while from an economic point of view the impacts are not very evident (value-added and value-added per capita, of scenarios *3a.Input* and *4a.Output*). In this case, the enforcement of the WFD aimed at saving water (scenarios *3b.Input+* and *4b.Output+*), would lead to the abandonment of intensive crops, with a dramatic reduction of labour and economic performances.

Finally, an area based pricing method (*7a.Area*) seems to cause a significant reduction of economic performances, that is even more emphasized with the enforcement of the WFD (*7b.Area*).

The introduction of a system based on individual quotas (*6a.Quota*), that is relatively easy to enforce by policy makers and accepted by farmers, is also associated to good performances in terms of value added. However, in the case of the WDF enforcement, there would be benefits only for the CBC water, but non for other sources.

Under the *CAP 2013* hypothesis, it is evident a general reduction in term of water saving, in particular in the case of the indirect pricing on inputs and outputs. Probably, farms are more competitive towards the market, but also more aggressive towards natural resources. Obviously, the application of quotas confirm to achieve the objective of water saving.

Table 1 - Results of water pricing policy simulations

| | Input | | | | | Desired Outputs | | | | | Undesired Outputs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Simulations | Land | Labour | Capital | Water (M m3) | | VA | VA capita | Land cover | Water saving (M m3) | | Pesticides | Nitrates |
| *CAP 2006* | (M ha) | (M hours) | (M Eur) | CBC | Other | (M Eur[a]) | (1000 Eur[b]) | (M days[c]) | CBC | Other | (M kg[d]) | (M t[e]) |
| 1a. Baseline | 404 | 25 | 210 | 107 | 89 | 652 | 54 | 38 | 0 | 0 | 767 | 30 |
| 1b. Baseline+ | 391 | 22 | 198 | 50 | 89 | 593 | 50 | 36 | 57 | 0 | 649 | 29 |
| 2a. Vol_tot | 404 | 25 | 212 | 107 | 89 | 652 | 54 | 38 | 0 | 0 | 767 | 30 |
| 2b. Vol_tot+ | 388 | 22 | 199 | 107 | 12 | 576 | 51 | 36 | 0 | 77 | 615 | 28 |
| 2c. Vol_tot++ | 384 | 19 | 172 | 78 | 0 | 523 | 52 | 35 | 28 | 89 | 553 | 27 |
| 3a. Input | 380 | 25 | 180 | 107 | 89 | 648 | 59 | 38 | 0 | 0 | 591 | 27 |
| 3b. Input+ | 380 | 17 | 148 | 107 | 57 | 505 | 61 | 32 | 0 | 33 | 660 | 25 |
| 4a. Output | 380 | 23 | 171 | 107 | 89 | 631 | 57 | 43 | 0 | 0 | 731 | 26 |
| 4b. Output | 380 | 19 | 184 | 107 | 70 | 507 | 53 | 38 | 0 | 20 | 636 | 26 |
| 6a. Quota | 404 | 25 | 210 | 107 | 89 | 652 | 54 | 38 | 0 | 0 | 767 | 30 |
| 6b. Quota+ | 403 | 25 | 208 | 104 | 89 | 649 | 54 | 38 | 3 | 0 | 761 | 30 |
| 6c. Quota++ | 400 | 24 | 198 | 83 | 89 | 627 | 53 | 37 | 24 | 0 | 725 | 29 |
| 7a. Area | 412 | 23 | 203 | 107 | 89 | 627 | 55 | 37 | 0 | 0 | 820 | 30 |
| 7b. Area+ | 410 | 21 | 229 | 107 | 59 | 503 | 47 | 37 | 0 | 30 | 782 | 29 |
| *CAP 2013* | | | | | | | | | | | | |
| 1a. Baseline | 400 | 26 | 209 | 107 | 89 | 657 | 54 | 38 | 0 | 0 | 711 | 29 |
| 1b. Baseline+ | 399 | 21 | 195 | 59 | 89 | 589 | 52 | 36 | 47 | 0 | 668 | 28 |
| 2a. Vol_tot | 400 | 26 | 211 | 107 | 89 | 657 | 54 | 38 | 0 | 0 | 711 | 29 |
| 2b. Vol_tot+ | 394 | 20 | 190 | 107 | 12 | 562 | 53 | 36 | 0 | 77 | 615 | 28 |
| 2c. Vol_tot++ | 394 | 19 | 189 | 107 | 0 | 543 | 54 | 36 | 0 | 89 | 603 | 27 |
| 3a. Input | 394 | 22 | 175 | 107 | 89 | 617 | 57 | 36 | 0 | 0 | 649 | 27 |
| 3b. Input+ | 380 | 18 | 149 | 107 | 64 | 509 | 61 | 31 | 0 | 25 | 641 | 24 |
| 4a. Output | 394 | 24 | 188 | 107 | 89 | 631 | 54 | 41 | 0 | 0 | 759 | 27 |
| 4b. Output | 394 | 20 | 218 | 107 | 85 | 484 | 49 | 36 | 0 | 5 | 668 | 27 |
| 6a. Quota | 400 | 26 | 209 | 107 | 89 | 657 | 54 | 38 | 0 | 0 | 711 | 29 |
| 6b. Quota+ | 400 | 26 | 207 | 104 | 89 | 653 | 54 | 38 | 3 | 0 | 708 | 29 |
| 6c. Quota++ | 398 | 24 | 196 | 83 | 89 | 628 | 53 | 37 | 24 | 0 | 683 | 29 |
| 7a. Area | 412 | 23 | 200 | 107 | 89 | 626 | 55 | 37 | 0 | 0 | 785 | 29 |
| 7b. Area+ | 410 | 21 | 226 | 107 | 59 | 501 | 47 | 36 | 0 | 30 | 748 | 29 |

Notes: a) Value Added. b) Value Added per capita of the household employed in agriculture. c) Days of the year per ha of crops. d) Mass of biotic organism (rats) endangered with pesticides. e) Nitrate agronomic balance

5.2. Analysis of the efficiency

In Table 2 the results of the two steps of the DEA are shown. Although the volumetric pricing method is supposed to be the most efficient, the analysis reveals that it depends on the tariffs applied, and by the CAP scenario. In fact, under the CAP 2013 scenario, the volumetric method is more efficient, probably because farmers' strategies are more market oriented. The enforcement of the WFD (*2b.Vol_tot+*, and *2c.Vol_tot++*) are generally the most efficient.

The baseline performs in a similar to the volumetric method, showing that the pricing of non-CBC sources does not produce any significant improvement.

In the case of the indirect pricing method based on inputs, we find a good performance, that is confirmed also in case of the WFD implementation, either in the *CAP 2006* and *CAP 2013* hypothesis. Probably, this indirect pricing method is sufficient to internalize the externalities produced by the irrigation practice.

Table 2 – Analysis of the technical, ecological, and overall efficiency

| Simulations | Tech. Eff. | | Eco-Eff. | | Efficiency | |
|---|---|---|---|---|---|---|
| | *2006* | *2013* | *2006* | *2013* | *2006* | *2013* |
| 1a. Baseline | 0.976 | 1.000 | 0.900 | 0.987 | 0.976 | 1 |
| 1b. Baseline+ | 1 | 1 | 1 | 1 | 1 | 1 |
| 2a. Vol_tot | 0.976 | 1 | 0.900 | 0.987 | 0.976 | 1 |
| 2b. Vol_tot+ | 1 | 1 | 0.996 | 1 | 1 | 1 |
| 2c. Vol_tot++ | 1 | 1 | 1 | 1 | 1 | 1 |
| 3a. Input | 1 | 1 | 1 | 1 | 1 | 1 |
| 3b. Input+ | 1 | 1 | 1 | 1 | 1 | 1 |
| 4a. Output | 1 | 1 | 1 | 1 | 1 | 1 |
| 4b. Output | 0.940 | 0.863 | 0.985 | 0.959 | 0.985 | 0.959 |
| 6a. Quota | 0.976 | 1 | 0.900 | 0.987 | 0.976 | 1 |
| 6b. Quota+ | 0.977 | 1 | 0.906 | 0.989 | 0.977 | 1 |
| 6c. Quota++ | 0.983 | 1 | 0.948 | 1 | 0.983 | 1 |
| 7a. Area | 0.979 | 0.973 | 0.864 | 0.928 | 0.979 | 0.973 |
| 7b. Area+ | 0.855 | 0.853 | 0.822 | 0.873 | 0.855 | 0.873 |

In regards to the indirect pricing on outputs, it is efficient only with the actual situation, while with the WFD, there is a loss of efficiency.

The quota system is generally less efficient in the CAP 2006 hypothesis, while in the CAP 2013 hypothesis is is always efficent.

Finally, the fixed area pricing is the less efficient in every scenario, regardless to the WFD or the CAP reform.

Further details are shown in Table 3 and Table 3, in which for each scenario the determinant of the inefficiency for every scenario are analyzed.

Table 3 - Results of DEA analysis. Slacks in Step1

| Simulations | Tech. Efficiency | | Excess of Input | | | | | | | | | | Shortage Output (1000 Eur) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Land (M ha) | | Labour (M hrs) | | Capital (M Eur) | | Water CBC / Other (M m3) | | | | VA | | VA capita | |
| | *2006* | *2013* | *2006* | *2013* | *2006* | *2013* | *2006* | *2013* | *2006* | *2013* | *2006* | *2013* | *2006* | *2013* | *2007* | *2013* |
| 1a. Baseline | 0.976 | 1 | - | - | - | - | 20.8 | - | - | - | - | - | - | - | 5.2 | - |
| 1b. Baseline+ | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2a. Vol_tot | 0.976 | 1 | - | - | - | - | 23.0 | 2.2 | - | - | - | - | - | - | 5.2 | - |
| 2b. Vol_tot+ | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2c. Vol_tot++ | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3a. Input | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3b. Input+ | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4a. Output | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4b. Output | 0.940 | 0.863 | - | - | - | - | 27.7 | 33.1 | - | - | 4.0 | 42.1 | - | - | 3.3 | - |
| 6a. Quota | 0.976 | 1 | - | - | - | - | 20.8 | - | - | - | - | - | - | - | 5.2 | - |
| 6b. Quota+ | 0.977 | 1 | - | - | - | - | 18.8 | - | - | - | - | - | - | - | 4.7 | - |
| 6c. Quota++ | 0.983 | 1 | - | - | - | - | 5.4 | - | - | - | - | - | - | - | 2.0 | - |
| 7a. Area | 0.979 | 0.973 | - | - | - | - | 18.7 | 12.4 | - | - | 22.3 | - | - | - | 4.0 | 1.8 |
| 7b. Area+ | 0.855 | 0.853 | - | - | - | - | 47.0 | 27.7 | - | - | 3.9 | 23.9 | - | - | 5.7 | 1.4 |

Table 4 - Results of DEA analysis. Slacks in Step2

| Simulations | Eco-Efficiency | | Undesired Output | | | | Shortage of Output (M Eur) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Pest.(M kg) | | Nitr. (M t) | | VA (M Eur) | | VA cap.(1000 Eur) | | Land cover (M days) | | Water saving | | CBC / Other(M m3) | |
| | *2007* | *2013* | *2007* | *2013* | *2007* | *2013* | *2007* | *2013* | *2007* | *2013* | *2007* | *2013* | *2007* | *2013* | *2007* | *2013* |
| 1a. Baseline | 0.900 | 0.987 | - | - | - | - | - | - | 4.9 | 5.6 | 4.0 | 1.5 | - | - | - | - |
| 1b. Baseline+ | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2a. Vol_tot | 0.900 | 0.987 | - | - | - | - | - | - | 4.9 | 5.6 | 4.0 | 1.5 | - | - | - | - |
| 2b. Vol_tot+ | 0.996 | 1 | - | - | - | - | - | - | 5.7 | - | 3.0 | - | 24.4 | - | - | - |
| 2c. Vol_tot++ | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3a. Input | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3b. Input+ | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4a. Output | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4b. Output | 0.985 | 0.959 | - | - | - | - | 77.5 | 70.5 | 1.0 | 3.0 | - | - | 6.3 | - | - | 48.83 |
| 6a. Quota | 0.900 | 0.987 | - | - | - | - | - | - | 4.9 | 5.6 | 4.0 | 1.5 | - | - | - | - |
| 6b. Quota+ | 0.906 | 0.989 | - | - | - | - | - | - | 4.5 | 4.9 | 3.8 | 1.3 | - | - | - | - |
| 6c. Quota++ | 0.948 | 1 | - | - | - | - | - | - | 1.8 | - | 2.6 | - | - | - | - | - |
| 7a. Area | 0.864 | 0.928 | - | - | - | - | - | - | 1.3 | - | 4.4 | 2.4 | - | - | - | 0.8 |
| 7b. Area+ | 0.822 | 0.873 | 35.2 | 0.4 | - | - | 34.5 | 54.3 | 3.1 | 2.7 | - | - | 9.5 | - | - | - |

## 6. Concluding remarks

According to the experience reported in this paper, the application of the DEA technique to simulated scenarios of water pricing policies appears to provide useful informations to policy makers. In fact, the efficiency is one of the objective pursued either by the WFD, and by the CAP.

Our results have proved that the volumetric pricing methods are the most efficient. However, since indirect methods may be easier to be implemented, we proved that under some circumstances they might be preferable, without losses in terms of efficiency. In our experience, for example, we found that the pricing based on the value of inputs specific to irrigated crops performed with the maximum efficiency in any scenario. On the contrary, other indirect pricing methods were have shown some loss of efficiency.

In regards to the methodology, the disaggregation of the technical and ecological efficiency, may provide additional information to policy makers, in the case in which the achievement of environmental objectives have a priority, in respect to other objectives.

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